Eastern Mediterranean University

Department of Mechanical Engineering

The Capstone Team Project

MECT/MENG 411

Name of Project: *MULTI-CONTROLLED AUTONOMOUS WHEELCHAIR*

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ABSTRACT

Individuals with disabilities face limitations in their ability to carry out daily activities due to impairments in their body structure and function. To address these challenges, engineers have developed various assistive devices and technologies designed to support individuals with disabilities. These innovations range from prosthetics and mobility aids such as wheelchairs to assistive software and communication devices, that can greatly improve the quality of life for these individuals. The goal of this project is to design and develop a multi-controlled autonomous wheelchair for use by patients with mobility impairments. The multi-controlled wheelchair would be fully operational with voice command and there will also be an optional use of a joystick to control the wheelchair.

The main objective of this project is to provide solutions to people who are paraplegic or tetraplegic and hence cannot operate a regular wheelchair without the help of a third party. The project also aims to provide an easier and better alternative to regular wheelchair users. Various research papers and projects related to this topic were reviewed with respect to their mode of operation, terrain-ability, braking system, modularity as well as cost, in other to design new strategies and improve the efficiency of our project. Objectives such as design for cost, assembly, manufacturability, sustainability, environment, and end of life were all taken into consideration in the designing process. Also, the design was made to follow necessary standards available for a power wheelchair. During the project, there were several constraints: the most significant ones being, the availability of the materials in TRNC, time, and financial constraints. The steps and processes in the design and manufacturing of this project will be discussed in this report with necessary graphical models. Verification plans of objectives and standards and

failure mode analysis were developed for the proposed design. Lastly, recommendations and future works were discussed in the last chapter of the report.

TABLE OF CONTENTS

ABSTRACT iii

TABLE OF CONTENTS v

LIST OF FIGURES xii

LIST OF TABLES xvii

LIST OF SYMBOLS AND ABBREVIATION xix

CHAPTER 1 - INTRODUCTION 1

1.1 Detailed definition of the project 1

1.2 Significance of the project 2

1.3 Detailed project objectives 2

1.3.1 Design for cost 2

1.3.2 Design for manufacturability 3

1.3.3 Design for safety 3

1.3.4 Design for sustainability 3

1.3.5 Design for environment 4

1.3.6 Design for end of life 4

1.4 Detailed project constraints 4

1.4.1 Time 4

1.4.2 Cost 5

1.4.3 Availability of resources & materials 5

1.4.4 Manufacturability and Sustainability 5

1.5 Report Organization 5

CHAPTER 2 - LITERATURE REVIEW 7

2.1 Background information 7

2.2 Concurrent solutions 10

2.3 Comparisons of the concurrent solutions 18

2.4 Engineering standards of the concurrent solutions 19

CHAPTER 3 - DESIGN AND ANALYSIS 21

3.1 Quality Function Deployment (QFD) 21

3.2 Design criteria with selection matrices 22

3.2.1 Obstacle detection 23

3.2.2 Motor selection 24

3.2.3 Battery selection 24

3.2.4 Frame material selection 25

3.2.5 Speech control 26

3.2.6 Smartphone and controller connectivity 26

3.2.7 Motor driver selection 27

3.2.8 Controlling unit box material selection 28

3.2.9 Battery box selection 28

3.2.10 Arduino box selection 29

3.3 Different Design Configurations 29

3.3.1 Wheelchair Design A 29

3.3.2 Wheelchair Design B 31

3.3.3 Wheelchair design C 33
3.3.4 Wheelchair Design D 34
3.3.5 Wheelchair design E 36
3.3.6 Wheelchair design F 38
3.3.7 Design selection 39
3.4 Proposed/Selected design. 39
3.4.1 Mechanical subsystem 40
3.4.2 Electrical subsystem 53
3.5 System Breakdown Structure 67
3.6 Electrical connections 68
3.7 Engineering standards 70
3.7.1 Wheelchair standards 71
3.7.2 Electrical standards 72
3.7.3 Software standards 73
3.8 Design calculations 73
3.8.1 Mechanical Subsystem 73
3.8.2 Electrical Subsystem 82
3.9 Simulation 84
3.9.1 Description 84
3.9.2 Study Properties 84
3.9.3 Units 84
3.9.4 Material Properties 86

3.9.5 Loads & Fixtures ... 86

3.9.6 Interaction Information ... 87

3.9.7 Mesh Information ... 88

3.9.8 Resultant forces ... 88

3.9.9 Study Results ... 90

3.9.10 Conclusion ... 92

3.10 Cost analysis ... 92

3.11 Wheelchair control ... 95

3.11.1 Voice control ... 97

3.11.2 Joystick control ... 99

3.11.3 Smartphone control ... 101

3.11.4 Movement of the wheelchair ... 103

CHAPTER 4 - MANUFACTURING ... 104

4.1 Manufacturing process selection ... 104

4.1.1 Make or Buy decision for the Wheelchair Frame (1-1-1) ... 105

4.1.2 Tubes production ... 105

4.2 Detailed manufacturing process ... 106

4.2.1 Frame (1-1-1) ... 106

4.2.2 Rear wheels (1-1-1-1-1) ... 107

4.2.3 Caster (1-1-1-6) ... 108

4.2.4 Battery box (1-1-1-3) ... 110

4.2.5 Arduino box (1-1-1-2) ... 112

4.2.6 Controlling Unit box (1-1-1-4) 112

4.3 Mechanical Assembly 114

4.3.1 Rear wheels (1-1-1-1-1) 114

4.3.2 Casters 115

4.3.3 Motor holders 115

4.3.4 Battery box (1-1-1-3) 117

4.3.5 Arduino box (1-1-1-2) 117

4.3.6 Controlling Unit box (1-1-1-4) 120

4.3.7 Seat & back rest & arm rest 121

4.3.8 Ultrasonic sensor holders 123

4.3.9 Final assembly 124

4.4 Electrical assembly 125

4.5 Software and programming process 127

CHAPTER 5 - PRODUCT TESTING 130

5.1 Failure Modes and Effects Analysis (FMEA) 130

5.2 Verification of the objectives of the project 139

5.2.1 Design for cost 139

5.2.2 Design for manufacturability 139

5.2.3 Design for safety 140

5.2.4 Design for sustainability 140

5.2.5 Design for environment 140

5.2.6 Design for end of life 141

5.2.7 Speech control 141

5.2.8 Smartphone control 141

5.2.9 Joystick control 142

5.3 Verification of the applied engineering standards 142

5.3.1 Wheelchair static stability (ISO7176-1) 142

5.3.2 Wheelchair brake effectiveness (ISO 7176-3) 143

5.3.3 Dimensions Determination (ISO 7176-5) 143

5.3.4 The maximum speed, and acceleration, for electrical wheelchairs (ISO 7176-6) 144

5.3.5 Power and control systems for electrical wheelchairs (ISO 7176-14) 144

5.3.6 Welding and safety in welding 144

CHAPTER 6 - RESULTS AND DISCUSSIONS 145

6.1 The results 145

6.2 The engineering standards 149

6.2.1 Engineering standards that were followed 149

6.2.2 Engineering standards that were not followed 150

6.3 The constraints 153

CHAPTER 7 - CONCLUSIONS AND FUTURE WORKS 155

7.1 The conclusions 155

7.2 The future works 156

REFERENCES 158

APPENDIX A: Electronic Media 166

APPENDIX B: Standards 167

APPENDIX C: Constraints 185

APPENDIX D: Project Plan 188

APPENDIX E: Engineering Drawings 191

APPENDIX F: Electrical Schematic 207

APPENDIX G: Arduino Boards Specifications 210

APPENDIX H: Ashby Charts 211

APPENDIX I: Work Breakdown Structure 215

APPENDIX J: Arduino Codes 216

APPENDIX K: Error Analysis 217

APPENDIX L: User Manual 218

APPENDIX M: Data Sheets 222

LIST OF FIGURES

Figure 1: Manual wheelchair [4] 8

Figure 2: Electric powered wheelchair [7] 9

Figure 3: The system structure of the smart wheelchair (a) System module of the system. (b) Photograph of the smart wheelchair [15] 12

Figure 4: (a) The wheelchair before the sit to stand mechanism is deployed and (b) after the mechanism has been deployed. [23]... 14

Figure 5: The wheelchair before (a) and after (b) the horizontal transfer mechanism has been deployed. [23].. 15

Figure 6: Wheelchair performing stair-climbing [25, Fig. 14]... 16

Figure 7: Geeetech model Voice Recognition Module V.3 [28] 17

Figure 8: Voice control interface in Android [30, Fig. 5] 18

Figure 9: Quality Function Deployment 22

Figure 10: Wheelchair Design A.. 30

Figure 11: Wheelchair design B... 31

Figure 12: Back view of design B of the wheelchair 32

Figure 13: Wheelchair Design C.. 33

Figure 14: Wheelchair design D... 35

Figure 15: Back view of wheelchair design D 35

Figure 16: Wheelchair Design E 37

Figure 17: Wheelchair design F 38

Figure 18: Design configuration.. 40

Figure 19: Frame 41

Figure 20: Armrest 41

Figure 21. Motor Holder 42

Figure 22: Rear wheels 42

Figure 23: Arduino box 43

Figure 24: Battery box 44

Figure 25: Control unit holder 45

Figure 26: Control unit 45

Figure 27: Footrest 46

Figure 28: Caster fork 46

Figure 29: Caster spring 47

Figure 30: Front wheel 48

Figure 31: Wheelchair seat cushion 49

Figure 32: Handle grip 49

Figure 33: Folding mechanism 50

Figure 34: Maximum folding 51

Figure 35: Ultrasonic Sensor holders (a) rear holder; (b) front holders; (c) side holders 52

Figure 36: Motor selected for the design [32] 54

Figure 37: IBT-2 motor driver [33] 55

Figure 38: HC-SR04 Ultrasonic Sensor [34] 55

Figure 39: Battery 56

Figure 40: Battery Charger 57

Figure 41: IEC C13 connector (left) and XLR female connector (right) [35], [36] 58

Figure 42: LM2596 Buck converter [37] 58

Figure 43: HC-05 Bluetooth Module 59

Figure 44: Analog Joystick [38] 59

Figure 45: Active buzzer [39] 60

Figure 46: 5 mm LEDs [40] ... 61
Figure 47: Push buttons [41] ... 61
Figure 48: MAX30102 sensor ... 62
Figure 49: Three terminal rocker switch ... 63
Figure 50: Resistors [42] ... 63
Figure 51: 12 Volts DC Fan ... 64
Figure 52: Raspberry Pi 4 Model B [43] ... 65
Figure 53: Arduino Mega 2560 Rev3 [44] ... 66
Figure 54: System Breakdown Structure ... 67
Figure 55: Electrical connection of the electrical subsystem ... 68
Figure 56: Electric schematic for the Arduino box ... 69
Figure 57: Electrical schematic for the controlling box ... 70
Figure 58: NEC standards for DC power colour code [45] ... 72
Figure 59: Tipping angle of a wheelchair [48] ... 73
Figure 60: Freebody diagram of the wheelchair with assumptions ... 74
Figure 61: Shear force diagram ... 76
Figure 62: Bending moment diagram ... 76
Figure 63: Deflection of the beam ... 77
Figure 64: Plane stress element from the beam ... 78
Figure 65: Mohr’s circle of the stress element ... 79
Figure 66: Orientation of the stress element for maximum stresses ... 80
Figure 67: Center of mass (side view) ... 81
Figure 68: Centre of mass (back view) ... 82
Figure 69: Pie chart of the expenses ... 95
Figure 70: Overall system design ... 96

Figure 71:System Flowchart 96

Figure 72: Flowchart for voice control.. 98

Figure 73: Operating range of the joystick.. 99

Figure 74: Flowchart for joystick control.. 101

Figure 75: User interface of the SmartMobility Android application 102

Figure 76: Dismantled frame before rust removal 106

Figure 77: Wheelchair frame after painting 107

Figure 78: Machined connector fitted into wheels 108

Figure 79: Caster tubes during welding 109

Figure 80: Caster before welding and after welding the new tube.. 109

Figure 81: Caster fork before painting and after painting 110

Figure 82: Battery box before and after painting 111

Figure 83: Battery box machining.. 111

Figure 84: Arduino box machining 112

Figure 85: 3d printing of the controlling unit.. 113

Figure 86: Assembly Sequence 114

Figure 87: Wheels fastened to motor 114

Figure 88: Assembly of the caster.. 115

Figure 89: Motor holders... 116

Figure 90: Motor assembly.. 116

Figure 91: Battery box assembly.. 117

Figure 92: Box compartment and inner view 118

Figure 93: Motor drivers fixed in the Arduino box... 119

Figure 94: Electrical connection in the Arduino box 119

Figure 95: Control unit.. 121

Figure 96: Assembly of seat, back and arm rests 122

Figure 97: Ultrasonic sensor holders assembly 124

Figure 98: Smart Mobility Powered Wheelchair 124

Figure 99: Trunking system 125

Figure 100: Tagging of electrical cables. 126

Figure 101: Connectors used for electrical connections between the battery and the Arduino box. 126

Figure 102: Programming the wheelchair 129

Figure 103: Person moving the wheelchair on an ADA complaint ramp 143

LIST OF TABLES

Table 1: Comparisons of various research works. 18

Table 2: Comparison of different wheelchair controllers [9] 19

Table 3: Selection Matrix for proximity sensors 23

Table 4: Selection matrix for the motors 24

Table 5: Battery selection matrix 25

Table 6: Selection matrix for the frame of the wheelchair 25

Table 7: Selection matrix for available speech control methods 26

Table 8: Selection matrix for phone connectivity with the wheelchair 27

Table 9: Selection matrix for motor drivers 27

Table 10: Selection matrix for controlling unit box material. 28

Table 11: Selection matrix for battery box material 28

Table 12: Selection matrix for Arduino box material 29

Table 13: Design Selection decision matrix 39

Table 14: Mass & Quantity & Materials of the mechanical subsystem 53

Table 15: Technical specification of the motors 54

Table 16: I/O needed for the design 66

Table 17: Wheelchair standards 71

Table 18: Reactions and moment at specific points 75

Table 19: Maximum and minimum bending moment and shear force 76

Table 20: Deflection of different position on the beam 77

Table 21: Principal stresses on the beam 79

Table 22: Maximum current of the electrical components 83

Table 23: Study Properties for Simulation 84

Table 24: Simulation Units 85

Table 25: Material Properties 86

Table 26: Load and fixtures 86

Table 27: Interaction Information 87

Table 28: Mesh information 88

Table 29: Reaction Forces 88

Table 30: Reaction Moments 88

Table 31: Free Body Forces 89

Table 32: Free Body Moments 89

Table 33: Stress results 90

Table 34: Displacement results 90

Table 35: Strain Results 91

Table 36: Factor of safety results 91

Table 37: Bill of Materials 93

Table 38: Total Cost 94

Table 39: Failure Modes and Effects Analysis of the design 131

LIST OF SYMBOLS AND ABBREVIATION

API	Application Programming Interface
AW	Arc Welding
BCI	Brain Computer Interface
CG	Centre of Gravity
CNN	Convolutional Neural Networks
DC	Direct Current
ECG	Electrocardiogram
EEG	Electroencephalogram
EMG	Electromyography
EPW	Electric powered wheelchair
FMEA	Failure Modes and Effects Analysis
GPIO	General-Purpose Input/Output
GPS	Global Positioning System
GSM	Global System for Mobile Communications
I/O	Input/Output
IR	Infrared
ISWP	International Society of Wheelchair Professionals
LCD	Liquid Crystal Display
LED	Light-Emitting Diode
LIDAR	Light Detection and Ranging
LiPo	Lithium Polymer
MI	Motor Imagery
MIG	Metal Inert Gas

NEC	National Electrical Code
PID	Proportional Integral Derivative
PLA	Polylactic Acid
SMD	Surface Mount Device
SMS	Short Messaging Service
SW	Smart wheelchair
TIG	Tungsten Inert Gas
TTL	Transistor-Transistor Logic
UART	Universal Asynchronous Receiver Transmitter
YOLO	You Only Look Once

CHAPTER 1 - INTRODUCTION

1.1 Detailed definition of the project

The spontaneous growing gap between patients and caregivers necessitates numerous improvements in the types of wheelchairs currently in use. Therefore, the incorporation of smart systems into wheelchairs is called for to enable paraplegic and handicapped patients to move without the need for outside assistance. However, the costliness of several required improvements and upgrades explains the limited utilization of enhanced systems in smart wheelchairs today.

To tackle this issue, a proposal was made for a smart multi-controlled wheelchair. This wheelchair can be controlled through voice, joystick, and smartphone interfaces. The chosen microcontroller is an Arduino Mega 2560 Rev3. The speech control and navigational mechanisms operate by receiving user-defined keywords and subsequently guiding the wheelchair's movement based on the received instructions. Alongside speech control, a joystick can be employed as an input method, and the design incorporates proximity sensors to ensure the wheelchair's safe operation. The primary objective of this system is to facilitate patients' navigation in different spaces and reduce the costs associated with caregivers. To ensure the affordability of the proposed autonomous wheelchair system, a cost analysis will be conducted, comparing it to other available options. The system is estimated to be cheaper compared to the available options. In addition to being cost-effective, the proposed autonomous wheelchair system also incorporates various safety features and measures to ensure the safety of the user and any bystanders. The manufacturing and testing of the proposed autonomous wheelchair system will be carried out in accordance with published standards, and a testing plan will be thoroughly revised. The testing plan includes testing on numerous terrain and different conditions according to available standards of testing. Our goal is for the autonomous wheelchair to meet our expectations and effectively solve the problems discussed in this report.

1.2 Significance of the project

This project will be of great assistance to paraplegic and tetraplegic patients who are unable to utilize their hands for controlling a wheelchair. By incorporating various mechanisms and technological systems into the chair, patients' lifestyles will be significantly improved, promoting locomotion, mobility, and the prevention of pressure sores. The chair offers flexibility in control methods by enabling speech, joystick, and smartphone-based control options, providing individuals confined to wheelchairs with the freedom to choose their preferred mode of control.

Furthermore, the wheelchair design proposed in this project exhibits modularity, allowing for easy implementation of different control modes that were not included in this project, such as brain control, eye blink control, and sip and puff control. Future wheelchair prototypes can leverage the insights gained from this project to incorporate multifunctional features, including autonomous navigation driven by artificial intelligence.

1.3 Detailed project objectives

The objective of this project is to create a functional autonomous speech-controlled wheelchair that can be operated in various environments. The wheelchair is intended to be controllable using speech, a joystick, and a smartphone. To ensure timely completion and maintain a high standard of production, materials and parts were outsourced and constructed remotely. The design took into consideration the following objectives.

1.3.1 Design for cost

The final product of the wheelchair should be designed in a way that ensures inexpensive mass production of the chair. The amount budgeted for production, which is $800, should not be exceeded by the cost of production. A well-refined and cost-effective production process should be utilized for manufacturing the wheelchair parts. To cater to all markets successfully, the wheelchair should be made affordable to the average customer by the end of the production process.

1.3.2 Design for manufacturability

A manufacturing process will be designed to be robust and as efficient as possible to avoid material waste during production. The wheelchair design should also be kept as simple as possible while utilizing strong and easily alterable materials, aiming to reduce machining/manufacturing costs and save time. The outsourced parts should seamlessly integrate with locally manufactured parts without any additional issues, ensuring an inexpensive and manageable manufacturing process.

1.3.3 Design for safety

The design should be safe and should not pose any danger to the user. This includes ensuring that there are no sharp edges that could cause harm to the user, as well as properly insulating all electrical wires. To avoid uncontrollable actions while in motion, the wheelchair should have a stop/reset button. Proximity sensors should also be incorporated on the wheelchair to ensure the user's and passers-by's safety.

1.3.4 Design for sustainability

Another critical design consideration is ensuring that the final product has no negative impact on the natural world. Designing a project with a long-life cycle whilst reducing waste is a sustainable consideration. The design should be based on the Hannover principles, which assert human and natural rights to coexist in a supportive, healthy, diverse, and sustainable environment.

1.3.5 Design for environment

Ensuring a negligible carbon footprint for the product is of utmost importance. To prevent environmental pollution, minimal energy should be used by the wheelchair. The manufacturing processes should also aim to utilize less energy and avoid causing environmental pollution.

1.3.6 Design for end of life

This includes measures taken after the product has served its purpose and how its components can be recycled to create new products. This entails disassembling the system into individual components to recover the materials used. End-of-life design also includes designing for disassembly, designing products with a longer life span, using fewer different types of material, and labelling components for easy material identification. After disassembling, the parts can be reused in a variety of other projects. Furthermore, the material used in the chair's construction can be used for other industrial purposes.

1.4 Detailed project constraints

The conception and creation of a design are governed by constraints, which are limitations that vary depending on the design of the product. Product quality can be improved by identifying these constraints, as it helps in lowering costs and making the manufacturing process easier. The following constraints were faced during the project.

1.4.1 Time

The time constraint refers to the project's completion schedule, which includes deadlines for each step of the project as well as the date for the final prototype. Time is an important factor to consider in the design process because it determines how well the final product will perform. To ensure that the project is completed on time, proper planning, scheduling, monitoring, and control are required during the design process.

1.4.2 Cost

This is the most important constraint to consider in the project because all work is done on the designed budget. This influences the decision to make or buy. Because the essential materials required for the best performance of our prototype are expensive, less expensive alternatives can be used to achieve the project objectives. The cost will vary from the initial estimate as the design phase progresses.

1.4.3 Availability of resources & materials

Since the resources are limited, the design should be created in such a way that the available resources are utilized effectively. This will also save money on purchasing the necessary materials. This includes resources such as the electronic components and other hardware components such as the joystick. Some of the materials required for the design are difficult to obtain in the country, necessitating material outsourcing.

1.4.4 Manufacturability and Sustainability

A well-revised manufacturing plan can be used to ensure the high quality of the prototype. This also extends the prototype's life cycle while reducing waste. Since some of the machines needed for manufacturing are not available in the workshop, low-cost alternatives will be used.

Sustainability is important because it reduces the amount of energy consumed per cubic mm of material removed. Reduced energy waste also results in reduced energy consumption, making the manufacturing processes more environmentally friendly.

1.5 Report Organization

This report is divided into seven chapters. In Chapter 1, the significance, objectives, and constraints of the project are well described.

Chapter 2 includes the review of various publications and research papers. The solutions for achieving the project objectives and the engineering standards of the reviewed research papers are provided.

Chapter 3 contains the selected design, analysis of the selected design, standards of the selected design, and the system breakdown structure of the selected design. Alternate designs made during the design process are also included. Decision matrices were drawn to select the best components for the design. Additionally, a cost analysis and bill of materials were created for the components required for the selected design.

In Chapter 4, the manufacturing procedure used for the parts mentioned in Chapter 3 is discussed. The reasons for choosing each manufacturing process are also stated. The electrical layout of the wheelchair is also covered in this chapter.

Chapter 5 highlights the testing process used to meet the project objective under the given constraints. This chapter also includes the Failure Modes and Effect Analysis (FMEA) to demonstrate the detailed performance of the wheelchair during use. Furthermore, the different verification plans of engineering standards carried out on the wheelchair are discussed.

Chapter 6 reviews the results, engineering standards, and constraints of this project.

Finally, in Chapter 7, suggestions are made for future works and improvements on the performance and functionality of the wheelchair.

CHAPTER 2 - LITERATURE REVIEW

2.1 Background information

One of the most popular assistive devices to boost mobility and improve the quality of life for those who have trouble walking is the wheelchair. A wheelchair as the name implies is a chair with wheels on it, used when walking is difficult or impossible to perform due to illness, disability, or problems related to old age and injury. Some of the problems of people aided by a wheelchair are spinal cord injuries (paraplegia, hemiplegia, and quadriplegia), brain injury, cerebral palsy, osteogenesis imperfecta, motor neurone disease, multiple sclerosis, muscular dystrophy, and spina bifida [1], [2]. Since people that use wheelchairs have different problems and needs, it is impossible to cater for all their needs with a single wheelchair. The two main types of wheelchairs are manual and electric-powered wheelchairs.

Two big wheels at the back and two caster wheels at the front make up a manual wheelchair, along with a seat and footrest. A manual wheelchair is shown in Figure 1. Push handles are typically located at the top of the back of manual wheelchairs to provide manual propulsion by assisting individuals. People with lower limb disabilities are primarily reliant on manual wheelchairs. In a manual wheelchair that is driven by the user, the person with the disability controls and manoeuvres the wheelchair. However, compared to using your legs, hand activity is less productive and more taxing. It is not recommended to use manual wheelchairs regularly because doing so lowers the user's physical capability [3].

Figure 1: Manual wheelchair [4]

An electric-powered wheelchair (EPW), on the other hand, is any seating surface with wheels attached that is moved by a motor and a battery. Figure 2 shows a picture of an electric-powered wheelchair. EPW is useful for people who cannot propel themselves with a manual wheelchair. The most common control used in an electric wheelchair is a joystick. Since some people with disabilities cannot use a joystick for navigation, alternative control systems such as head joysticks, chin joysticks, sip and puff, and brain control is used [5], [6]. One of the advantages of EPW is that it maximizes the independence of the user without the need for much muscle work, energy, and effort. There are still people who lack motor skills, visual acuity and lack strength that cannot use electric-powered wheelchairs. These set of people rely on people to move them around. To solve this problem, several researchers have used technologies to develop a smart wheelchair [3].

Figure 2: Electric powered wheelchair [7]

A smart wheelchair (SW) typically consists of either a standard EPW base to which a computer and a collection of sensors have been added or a mobile robot base to which a seat has been attached [5]. Some of the technologies used in smart wheelchairs are proximity sensors such as LIDAR and ultrasonic sensors, infrared sensors, laser range finders and machine vision. These technologies aid in accident-free travel, autonomous driving, and even reduce the user's responsibility to drive the wheelchair [3].

Simpson et al. [8] conducted a study on how people will benefit from smart wheelchairs. They did a survey and found out that a huge number of wheelchair users find the operation of existing manual or powered wheelchairs difficult, and in some extreme cases, impossible to operate. It was estimated that 61 to 91 percent of wheelchair users will benefit from a smart wheelchair. This wheelchair could be brain, speech or joystick controlled. The different control methods used in smart wheelchairs will be discussed in the next session.

2.2 Concurrent solutions

One of the problems with conventional wheelchairs with a joystick is that they cannot be used by people with upper extremities disabilities. To solve this problem, Riman [9] worked on developing a multi-controlled wheelchair for people with upper extremities disabilities. The two ways to control this wheelchair are by eye blinks and sip-and-puff. A wheelchair that can be controlled by eye blinks and another wheelchair that can be controlled with sip-and-puff were developed. A wheelchair with both control systems was not developed by the researcher, but the paper gives an idea of the possibility of multi-control.

A wheelchair that has two control modes was developed by Shahin et al. [10]; automatic (using single-modal and multimodal approaches) and manual control. Signals such as EEG signals, head movements and facial expressions were collected using an Emotiv EPOC headset and used to control the wheelchair automatically. The single-modal approach uses only one signal while the multimodal approach uses more than one signal for control. In manual control mode, a four-button pad was designed to accept input from the user and control the wheelchair.

Mirza et al. [11] proposed a wheelchair that can be controlled using thoughts. A Neurosky MindWave headset was used to measure electroencephalography (EEG) readings from the brain and convert them to attention, meditation, and eye blinks. The readings were then translated to movement commands by the Arduino microcontroller, which in turn moved the wheelchair using the motors. In the proposed design, there is no use of proximity sensors to stop the wheelchair when there is an obstacle in its way.

Another brain-controlled wheelchair prototype was developed by Awais et al. [12]. The same system that [11] used for getting EEG readings was used in the prototype. In addition to brain control, a joystick and remote control through an Android application were included as secondary control in the prototype. A safety system that uses four ultrasonic sensors to detect obstacles was also implemented. This work shows that more than one control for a wheelchair is possible.

Most brain/mind-controlled wheelchairs rely on distracting external stimuli such as flashing lights and use expensive medical-grade EEG amplifiers. Xiong et al. [13] proposed a wheelchair prototype that uses consumer-grade EEG systems and electromyography (EMG) to collect hand motor imagery (MI) and jaw clench data. The data collected is passed through a logistic regression model to command the wheelchair to turn left, right and stop. Additionally, the wheelchair incorporated automated driving features, a location tracker, and a heart rate monitor to increase safety and usability.

Tang et al. [14] presented a brain-actuated smart wheelchair system that consists of an omnidirectional wheelchair, a lightweight robotic arm, a target recognition module, and an auto-control module (Figure 3). Auto-control mode is based on the you only look once (YOLO) algorithm. In the algorithm, the system recognises and locates targets in real-time, which is then confirmed using a P300-based BCI. An expert system plans a proper solution for the confirmed target. For example, the planned solution for a door is opening the door and then passing through it. The auto-control system then jointly controls the wheelchair and robotic arm to complete the operation. The system was achieved using modern technology equipment and the help of artificial intelligence. The wheelchair costs a lot, and it is not suitable to be a product in the future since the manufacturability and the assembly is very difficult as well as the programmability. Nevertheless, it is completely efficient.

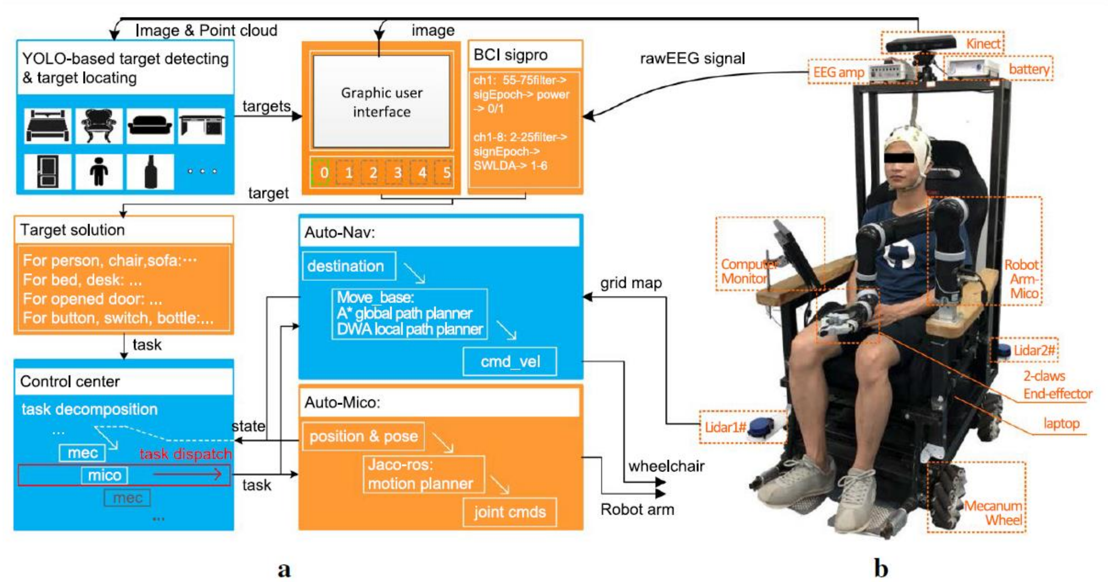


Figure 3: The system structure of the smart wheelchair (a) System module of the system. (b) Photograph of the smart wheelchair [15]

A wheelchair that can be controlled using a joystick and gestures was developed by Ahmed et al. [16]. Voice control was also implemented to assist people that have difficulty using a joystick. The voice control is meant to help the user to access different features of the wheelchair and it is not used to get commands for driving the wheelchair. A user interface was designed with the use of an LCD screen to cycle between different modes of the wheelchair. Voice training and accelerometer calibration are also one of the features of this wheelchair. Lastly, heart rate monitoring and an emergency response system with the use of a GPS module were integrated into the wheelchair. The wheelchair developed by Ahmed et al. does not have any safety features such as proximity sensors to prevent the wheelchair from hitting any obstacle. Also, the wheelchair cannot be used by people that are paralysed from the neck down since the methods of control are for people with hands.

A head-controlled semi-autonomous wheelchair designed by Kader et al. [17] uses head motion in four axes to help paraplegic patients achieve motion without the need for external aid. When a head movement is detected, a wireless 3-axis accelerometer sensor (AD XL345) transmits the information to two DC motors that operate the wheelchair. In case of an accident or fatal event, GSM is utilized to send information to any nearby help/emergency services through an SMS containing the location and information of the patient. The wheelchair also uses sonar sensors that identify impediments at the front and back of the wheelchair thus avoiding collisions. The head motion detection circuit and motor control circuit are all connected wirelessly due to the system's use of an HC-05 Bluetooth module, which also lowers the wiring harness. Mishra & Shrivastava [18] worked on controlling a wheelchair using head motion using an accelerometer. Other features such as obstacle detection, GPS tracking and pulse rate detection of the user were added to the wheelchair.

Jameel et al. [19] also designed a wheelchair that is controlled using head motion. A gyroscope sensor was used to get the angular velocity of the head, and the data is then used to control the wheelchair. The wheelchair control system had an overall performance of 98% which outperformed previous research findings. The wheelchair also had ultrasonic sensors to prevent collision with obstacles.

Different researchers have worked on developing a wheelchair that is controlled using a smartphone. An android mobile application was created with buttons for different directions and a stop button to control the wheelchair. Voice control is also implemented in the mobile application to control the wheelchair. Lastly, the wheelchair is kitted with an obstacle detection system which reduces the chances of collision [20], [21].

To improve navigation and achieve better performance in autonomous speech-controlled wheelchairs, Koložvari et al. [22] employed cloud-harvesting principles. The main concern of the study was aimed at solving the issues concerning word error rate and command error rate by proposing a better approach through engaging several cloud-based speech recognition systems such as Node, JS, and JavaScript that combined two cloud speech APIs namely IBM Watson, and Google Cloud Speech API. To do this, Node, JS, and JavaScript were used to develop a complete control system, PID algorithm and Fuzzy logic for navigation control. The results obtained showed significantly better results in the speech recognition accuracy and command error rate compared to when the speech recognition APIs were used in solitary.

D'Angelo et al. [23] devised two concepts for wheelchair mechanics with integrated transfer support features that would make it easier for caregivers to move patients onto wheelchairs or make it possible for the patients to stand without additional assistance. These concepts include seat-to-stand, which can help patients stand upright, and horizontal transfer, which facilitates patient transitions from bed to chair. To do this, wheelchair components are guided to move into the desired configurations using a four-bar and parallelogram linkage, as indicated in the figures below. The contributions of this paper include the choice of a passive actuator for weight compensation and simulation of the force it induces (static design), and the experimental assessment of the simulation using rapid prototyping functional models of the concepts. The outcome is two distinct design ideas, each of which results in easy transfer motion (Figure 4 and Figure 5).

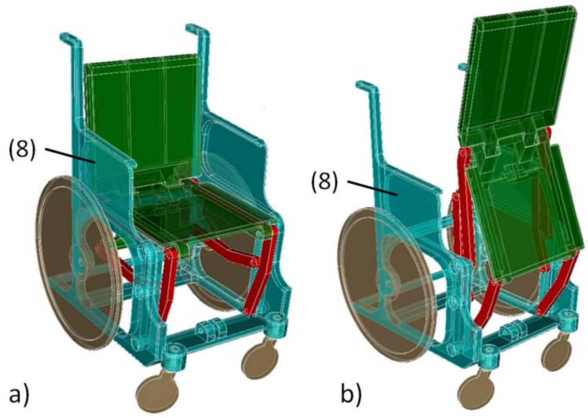


Figure 4: (a) The wheelchair before the sit to stand mechanism is deployed and (b) after the mechanism has been deployed. [23]

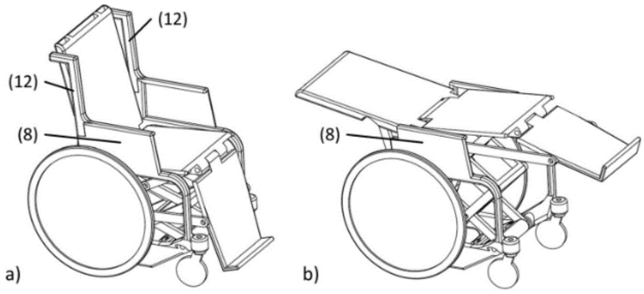


Figure 5: The wheelchair before (a) and after (b) the horizontal transfer mechanism has been deployed. [23]

Ruşanu et al. [24] proposed a system to provide training sessions for people with neuromotor disabilities so that they can use voluntarily eye blinks to control a mobile robot, which can be substituted for a wheelchair. National Instruments Virtual Instrument Software Architecture toolkit was then used to process the number of eye blinks and send the corresponding command to the microcontroller, which in turn moves the robot. This implementation is low-cost, portable, friendly, interactive, and convenient. The only disadvantage faced by the researchers is fluctuation in accurately detecting eye-blinking strength by the EEG device used.

A wheelchair that can operate in different terrains such as pedestrian areas, schools, hospitals, and workplaces and can also change sitting posture depending on the user's need was developed by Thai et al. [25]. This wheelchair was also made flexible to be able to climb staircases (Figure 6). A remote-control system that allows the user to control the wheelchair using a smartphone was also integrated into the wheelchair. Furthermore, a safety system that monitors the operating status of the wheelchair such as speed, temperature, tilt angle and the health status of the user such as heart rate was developed.


Figure 6: Wheelchair performing stair-climbing [25, Fig. 14]

Aktar et al. [26] developed a voice-controlled wheelchair that detects obstacles on its way and has location tracking. To achieve voice control, an inexpensive ElecHouse voice recognition module v3 is used. This module is trained on the user's voice and when input is given, it compares the received command to the trained commands. If it matches, the microcontroller moves the wheelchair in the specified direction or changes the speed. IR sensor is used for obstacle detection and a GPS module is used for location tracking. Lastly, a smartphone application was developed to enable the family members of the patients to know the location of the patient.

In most of the research papers reviewed before, turning the wheelchair left/right is achieved by stopping one of the rear motors and leaving the other motor to rotate. Umchid et al. [27] developed a wheelchair that is controlled using voice. Voice control was achieved with the use of Geeetech model Voice Recognition Module V.3 (Figure 7). An electric actuator was attached to both front wheels to turn the wheelchair in the left and right directions. Ultrasonic sensors were also utilised to prevent obstacle collisions.

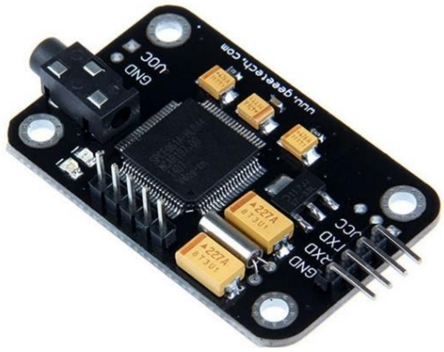


Figure 7: Geeetech model Voice Recognition Module V.3 [28]

A voice recognition system using Convolutional Neural Networks (CNN) was developed to steer a wheelchair by Bakouri et al. [29]. This system uses a mobile application to get the voice input of the user and sends the input to a Raspberry Pi which uses the neural network model to evaluate what was said by the user. The Raspberry Pi then controls the motors of the wheelchair to move in accordance with the specified user commands. Performance metrics were performed on the developed model and the results were high.

A smartphone can also be used to control a wheelchair using voice and gesture. The microphone of the smartphone will be used for voice input and the smartphone's gyroscope sensor is used for gesture control. For recognising the voice of the user, Google's Voice Search Engine can be utilised [30]. One of the problems with this implementation is network latency since Bluetooth is used for communication between the smartphone and the microcontroller. Figure 8 shows the interface of voice control in Android. The issue with this voice control interface is that the microphone icon must be tapped before the voice of the user is received by the application. This makes the interface unusable for people that cannot use their hands such as quadriplegics.

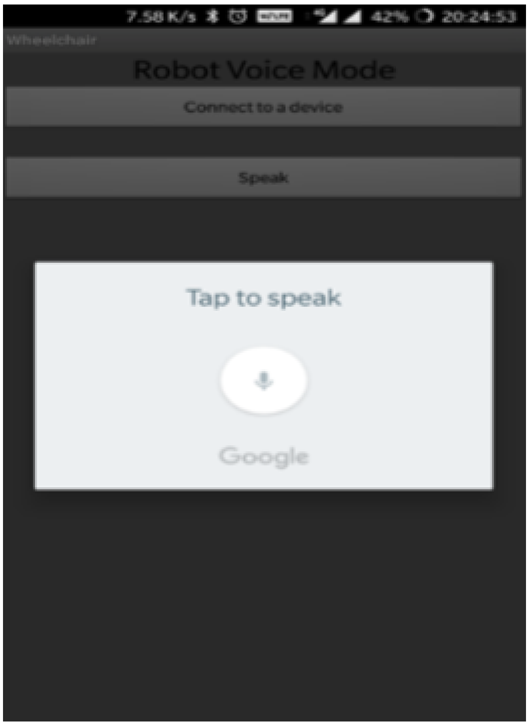


Figure 8: Voice control interface in Android [30, Fig. 5]

2.3 Comparisons of the concurrent solutions

Table 1 classifies different research work on wheelchair controls into control methods, sensors used and input methods, and the smart features incorporated in their designs.

Table 1: Comparisons of various research works.

Research Paper	Control methods	Sensors used and method of input	Smart features
[19]	Head movement	EMOTIV-based gyroscope, ultrasonic sensors	Obstacle detection
[18]	Head movement or hand gestures	ADXL335 accelerometer, ultrasonic sensor, heart rate sensor	Obstacle detection, heart rate monitoring
[10]	Facial expressions, head movements, EEG signals and a keypad	Emotiv EPOC headset	
[12]	Attention and eye blinking, joystick control and Android application	MindWave Mobile headset, ultrasonic sensors, smartphone, and a joystick	Obstacle detection
[17]	Head movement	ADXL345 accelerometer, ultrasonic sensors, SIM800 module	Obstacle detection. Location tracking and SMS notification.

[9]	Eye-blink and sip-and-puff	IR sensors, absolute air pressure sensor, chin push button	
[26]	Voice commands	Voice recognition module, IR sensors, GPS module	Obstacle detection. GPS tracking
[13]	Brain and jaw clenching	EEG, ECG, and EMG sensors, ultrasonic sensors	Wall following Fall prevention Obstacle detection GPS tracking and SMS notification
[27]	Voice commands	Voice recognition module, ultrasonic sensors	Obstacle detection
[29]	Voice commands	Android application and a CNN model	
[30]	Voice and gesture	Android application, ultrasonic sensors	Obstacle detection

Riman [9] compared different types of wheelchair controllers. The comparison is shown in Table 2.

Table 2: Comparison of different wheelchair controllers [9]

Type	Power use	CPU Speed	Causes user's fatigue	Used with upper limb disability	Added controller cost
Joystick	Low	Low	Heavy use	No	No
Eye-blink	Avg. (IR)	High	Heavy use	Yes	75 USD
Sip-and-puff	Avg.	High	Light use	Yes	140 USD
Voice	High	High	Light use	Yes	160 USD
Head motion	Avg.	High	Light use	Yes	150 USD
Chin	Low	Low	Light use	Yes	100 USD
Hand	Low	Low	Heavy use	No	No

2.4 Engineering standards of the concurrent solutions

The standards used were used in the research papers reviewed are the following:

- EN 12183: Manual wheelchairs
- EN 12184: Electrically powered wheelchairs, scooters and their chargers - Requirements and test methods
- ASME B16.3-2021: Malleable Iron Threaded Fittings: Classes 150 and 300

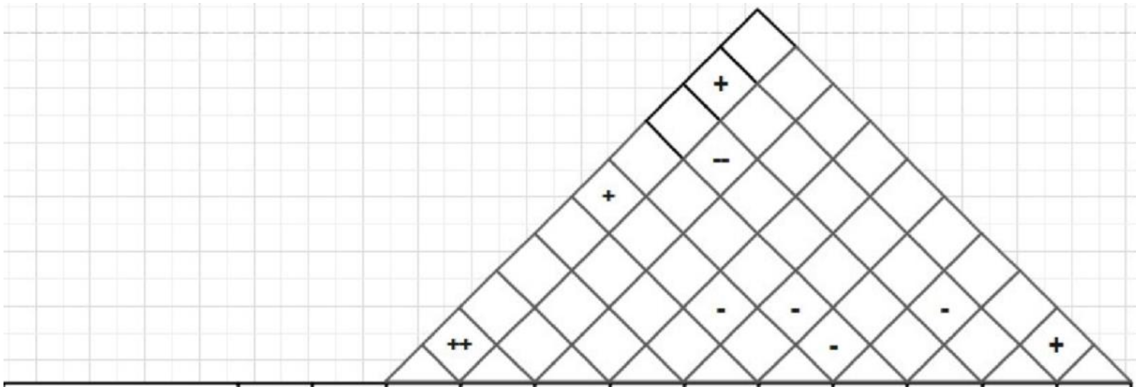
- EC 1907/2006: Regulation (EC) No 1907/2006 - Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)
- EU RoHS: Restriction of Hazardous Substances Directive
- EN50581:2012: Technical documentation for the assessment of electrical and electronic products with respect to the restriction of hazardous substances
- EN 62311:2008: Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0 Hz - 300 GHz)
- ISO/IEC Guide 37:2012: Instructions for use of products by consumers
- IEEE 802.15.1: IEEE Standard for Information technology-- Local and metropolitan area networks-- Specific requirements-- Part 15.1a: Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications for Wireless Personal Area Networks (WPAN)
- ISO 9001:2015: Quality management systems — Requirements
- IEC 61496-1: Safety of machinery - Electro-sensitive protective equipment - Part 1: General requirements and tests
- IEC 60034: Rotating electrical machines - Part 1: Rating and performance
- IEC 60086: Primary batteries - Part 1: General
- ISO 8373:2012: Robots and robotic devices — Vocabulary
- ISO 7176: Wheelchairs (all parts included)

CHAPTER 3 - DESIGN AND ANALYSIS

3.1 Quality Function Deployment (QFD)

An organized method for identifying client needs or requirements and converting them into detailed plans for producing goods that would satisfy those demands is known as quality function deployment (QFD) [31]. A QFD was drawn to relate the customers' requirements to engineering specifications. The QFD of the project is shown in Figure 9.

The target customers of this project are disabled people and hospitals. From Figure 9, it can be observed that the cost of production carries the highest weight. Thus, it is essential that the components used must be moderately cheap in other to increase the wheelchair's affordability. Other important weights include the use of a joystick, proximity sensors, and a voice recognition system. All these are necessary for the operation of the wheelchair. The joystick and voice recognition module both receive input from the user and send instructions to the wheelchair. The job of the proximity sensors is to detect obstacles and prevent the wheelchair from crashing. The features with the low scores are rechargeability, low power consumption and foldable design. Even though these features will be a great and advantageous addition to the project, they are simply not a priority. The low-scoring features will be worked on if all other important features are achieved and there are available resources.



	Importance	Relative weights	Cost of production	Strength to Weight ratio	Rechargeable	Use of Joystick	Voice control	Use of Proximity sensors	Low Power Consumption	Foldable design	Use of Bluetooth Module	Smartphone control
WHATs												
Cheap	5	9.8	◉	○	△	○	○	◉			○	
Low power consumption	3	5.9			○	△	△	○	◉		○	○
Durable	3	5.9	◉	◉						○		
Seat material	4	7.8	◉	○								
Armrest material	4	7.8	◉	○		△						
Seat dimension	3	5.9	◉									
Foldability	2	3.9	○	◉		○				◉		
Controllability	5	9.8	△		△	◉	◉	◉		△	◉	◉
Lightweight	2	3.9	◉	◉								
Voice controlled	5	9.8			△		◉	○	△			◉
Joystick controlled	4	7.8			△	◉			△			
Rechargeable batteries	3	5.9	△		◉							
Obstacle detection	4	7.8	△			△	△	◉	○			
Smartphone controlled	4	7.8						○	○		◉	◉
Important Weights	51		405.1	199.5	108	221	219.5	317.1	117.5	62.6	205.5	264.3
Relative Importance Weights			19.1	9.4	5.1	10.4	10.3	15.0	5.54	2.95	9.71	12.5

Figure 9: Quality Function Deployment

3.2 Design criteria with selection matrices

The requirements for the wheelchair are:

i. Obstacle detection

ii. Battery powered.

iii. Speech controlled.

iv. Joystick controlled.

v. Rechargeable

vi. Use of a lightweight and strong material

vii. Smartphone-controlled

There are a lot of options that can be selected to satisfy the requirements. To select the best material, method or module for the design, decision matrices was drawn for each feature.

3.2.1 Obstacle detection

An obstacle-detection feature is needed as a safety requirement for the wheelchair. Since the user of the speech-controlled wheelchair can command the wheelchair to move forward when there is a wall in front, the wheelchair should be able to stop and avoid crashing into the wall. There are different sensors available to achieve obstacle detection. These include ultrasonic, RADAR, LIDAR, and IR sensors. Different types of these sensors were compared using certain criteria and the highest-scoring sensor was selected. Table 3 shows the selection matrix for proximity sensors.

Table 3: Selection Matrix for proximity sensors

Selection Criteria	Weights	Ultrasonic sensor (HC-SR04)	Time of Flight Distance Sensor (VL53L0X)	TF Mini LIDAR sensor	IR proximity sensor SHARP GP2Y0A21YK
High range	2	6	4	10	7
Low cost	5	10	9	4	7
Low sensitivity to harsh environmental conditions	3	10	3	4	4
Total		92	62	52	61

Ultrasonic sensors were selected for obstacle detection since they outscored the other alternatives.

3.2.2 Motor selection

Motors are needed to move the wheelchair. There are different factors to consider when choosing a motor and there are different motors to choose from. To select the best motors for our design, a selection matrix was drawn. The selection matrix for motors is shown in Table 4.

Table 4: Selection matrix for the motors

Selection criteria	Weights	24 V brushed DC hybrid gearbox motor	24 V brushed DC worm gear motor	12 V brushed DC wiper motor	24 V DC brushless hub motor
Low cost	5	10	9	7	4
Low noise generated	4	5	4	3	10
High power	3	10	10	6	9
High availability	5	10	7	10	3
Good braking system	3	6	3	3	8
Total		168	135	124	117

24V brushed DC hybrid gearbox motors were chosen for the design since it has the highest total score in Table 4.

3.2.3 Battery selection

A battery will be used to power the wheelchair. There are two types of batteries. These are primary (non-rechargeable), and secondary (rechargeable).

Due to the requirement that the battery should be rechargeable, a secondary battery will be used for powering the electrical components of the wheelchair. Different secondary batteries were evaluated using different selection criteria and the highest scoring one was selected. Table 5 shows the selection matrix of the batteries.

Table 5: Battery selection matrix

Selection Criteria	Weights	Lead-Acid Batteries	Nickel-Cadmium Batteries	Nickel – Metal Hydride Batteries	Lithium – Ion Batteries	Lithium Polymer Batteries
Low cost	5	9	5	5	2	1
Low toxicity level	2	2	2	7	7	8
High power discharge	4	7	5	5	7	6
Cycle Life	3	4	7	5	9	8
Fast charge time	2	2	7	6	6	7
Total		91	84	86	91	83

From the matrix, lithium-ion and lead-acid batteries have the highest score. The battery that was selected in this project is the lead acid battery because the main priority is low cost.

3.2.4 Frame material selection

Different materials can be used for the frame of the wheelchair. To select the best material for the frame, a selection matrix will be drawn. Table 6 shows the selection matrix for the frame of the wheelchair.

Table 6: Selection matrix for the frame of the wheelchair

Criteria	Credit	Aluminium	Mild Steel	Titanium
Cost	5	7	8	4
Durability	4	6	7	8
Strength-to-weight ratio	5	9	7	10
Corrosion resistance	4	9	6	10
Availability	5	8	10	6
Machineability	5	10	9	3
Total		230	222	187

From the matrix, the best material to select for the frame is aluminium.

3.2.5 Speech control

There are a lot of ways that can be used to control the wheelchair with speech. These include the use of speech recognition modules, speech-to-text APIs provided by Google, Deepgram, AssemblyAI and libraries such as DeepSpeech, Kaldi and Wav2Letter. These available methods were compared using some criteria and the best one for the project was picked. Table 7 shows the selection matrix for speech control methods.

Table 7: Selection matrix for available speech control methods

Selection Criteria	Weights	Google API	DeepGram API	ELECHOUSE Voice recognition module
Low cost of implementation	5	7	3	10
High accuracy when there is ambient noise	4	10	10	4
Total		85	55	66

Google's API for speech recognition was chosen in this project since it has the highest score in Table 7.

3.2.6 Smartphone and controller connectivity

Bluetooth and Wi-Fi are the available options for wireless control of the wheelchair using a smartphone. Wi-Fi control means that the smartphone and the Wi-Fi module must be on the same Wi-Fi network, or they must be both connected to the internet. Bluetooth control on the other hand means that the module and the smartphone will be connected using Bluetooth. A decision matrix will be used to know which is the best option for the project. Table 8 shows the decision matrix for phone connectivity options.

Table 8: Selection matrix for phone connectivity with the wheelchair

Criteria	Weights	Bluetooth	Wi-Fi
High range	1	-1	+1
Low power consumption	5	+1	-1
Ease of use and comfortability of the user	4	+1	0
Cost	5	-1	+1
Total		3	1

Range has the lowest weight because there is no need for long-range since the user will stay in the wheelchair to operate it. From Table 8, it is better to connect the smartphone to the wheelchair controller using Bluetooth.

3.2.7 Motor driver selection

A motor driver is needed to control the motion of a motor. There are different kinds of motor drivers available in the market. Four motor drivers that have the capacity to drive a 24 volts motor will be evaluated and the best one will be selected using a decision matrix.

Table 9: Selection matrix for motor drivers

Criteria	Weights	IBT 2 BTS7960	Sabertooth 2x12	Sabertooth 2x25	SyRen 25A
Availability	5	10	3	3	3
Cost	5	10	4	2	4
Ability to supply a continuous current up to 12 A	2	4	8	10	10
Efficiency in heat dissipation	3	4	8	9	9
Total		120	75	72	82

Table 9 shows the decision matrix for a motor driver. The selected motor driver for the design is the IBT 2 motor driver.

3.2.8 Controlling unit box material selection

The controlling unit box unit box is the central hub or control module of an electric wheelchair. This box typically houses the components that are responsible for the operation and control of the wheelchair. It also features other components such as the heart sensor, buzzer, and the operation lights. Table 10 shows the selection matrix for the controlling unit box material.

Table 10: Selection matrix for controlling unit box material.

Criteria	Weights	Wood	Aluminium	PLA
Availability	4	10	7	8
Cost	5	8	5	8
Manufacturability	5	8	7	10
Corrosion resistance	4	8	8	10
Weight	3	9	8	9
Total		179	144	189

From Table 10, the selected material for the controlling unit box is PLA.

3.2.9 Battery box selection

This is a compartment or enclosure that houses the batteries used to power the wheelchair. The battery box is an essential component in electric wheelchairs, as it contains the electrical components that provides the necessary electrical energy for the wheelchair's operation. Table 11 shows the decision matrix for the battery box material.

Table 11: Selection matrix for battery box material

Criteria	Weights	Iron	wood	Mild steel
Cost	5	6	10	7
Availability	3	7	10	8
Manufacturability	4	6	9	6
Corrosion resistance	4	5	8	7
Heat management	5	6	5	6
Total		125	173	141

Wood was chosen as the material for the battery box.

3.2.10 Arduino box selection

An Arduino box refers to a physical enclosure or case used to protect and house an Arduino board and associated circuitry for the wheelchair project. This enclosure provides a way to neatly organize and protect the components while allowing access to necessary inputs, outputs, and connectors. Table 12 shows the selection matrix for the material of the Arduino box.

Table 12: Selection matrix for Arduino box material

Criteria	Weights	PLA	Mild steel	wood
Cost	5	8	6	10
Availability	4	8	7	9
Manufacturability	5	8	7	8
Corrosion resistance	3	10	6	8
Yield Strength	5	8	10	4
Total		182	161	170

The material selected for the Arduino box was PLA.

3.3 Different Design Configurations

In this project, a lot of designs were produced. Every design has some advantages and disadvantages. Therefore, all the design configurations will be discussed in this section and the most suitable one will be chosen by a decision matrix based on the availability, cost, manufacturability, assembly, time, durability, environmental footprint, safety, and end-of-life.

3.3.1 Wheelchair Design A

The design shown in Figure 10 is the first model drawn for the wheelchair. This design is a standard wheelchair design. The container at the bottom will be used to place the battery, microcontroller, motor drivers, wires, and any other electrical components. The tubes of the frame are 21.3 mm in diameter, the rear wheels are 24 inches in diameter and the front wheels are 8 inches in diameter. The material selected for the wheelchair is steel. The motor used is a DC brushed motor with a chain connected to the rear wheels.

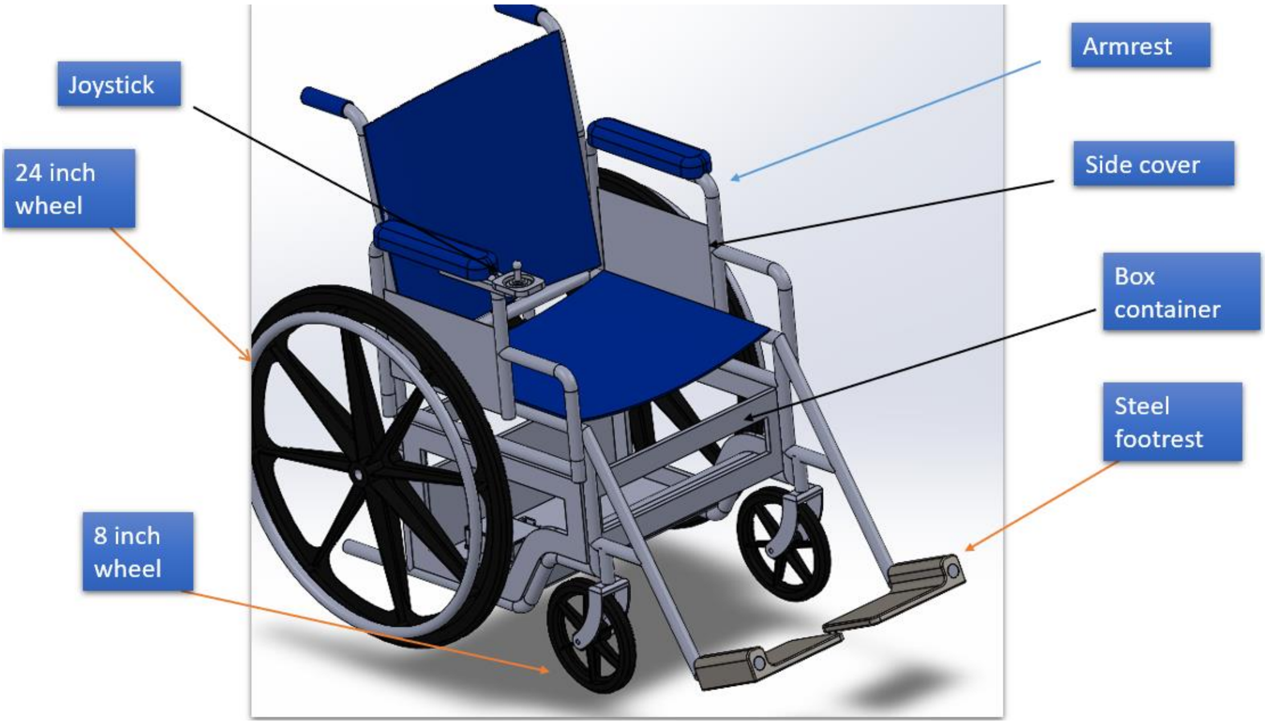


Figure 10: Wheelchair Design A

Advantages:

- It is very big.
- It is widely available.
- The wheelchair has enough space for the electrical components.

Disadvantages:

- The wheelchair is not foldable.
- There are so many unnecessary materials in the wheelchair.
- It is heavy.
- Lots of machining and welding are required.
- There is no damper or spring.
- It does not follow standards.

3.3.2 Wheelchair Design B

The design shown in Figure 11 is design B. This design is a standard manual wheelchair design. As shown in Figure 11, the wheelchair can be transformed into a powered wheelchair by placing the battery in the side of the chair and putting 2 motors connected with wheels in the sides of the frame. The microcontroller, the motor driver, other electrical connections, and the wires are to be arranged anywhere in the frame. The tubes of the frame are 21.3 mm in outer diameter. The wheelchair is foldable. The joystick used is the Arcade joystick. The material used is aluminium. The front wheel is 8-inch, and it does not contain a damper or a spring while the rear wheels are 12 inches in diameter. The motor is a brushless DC motor.

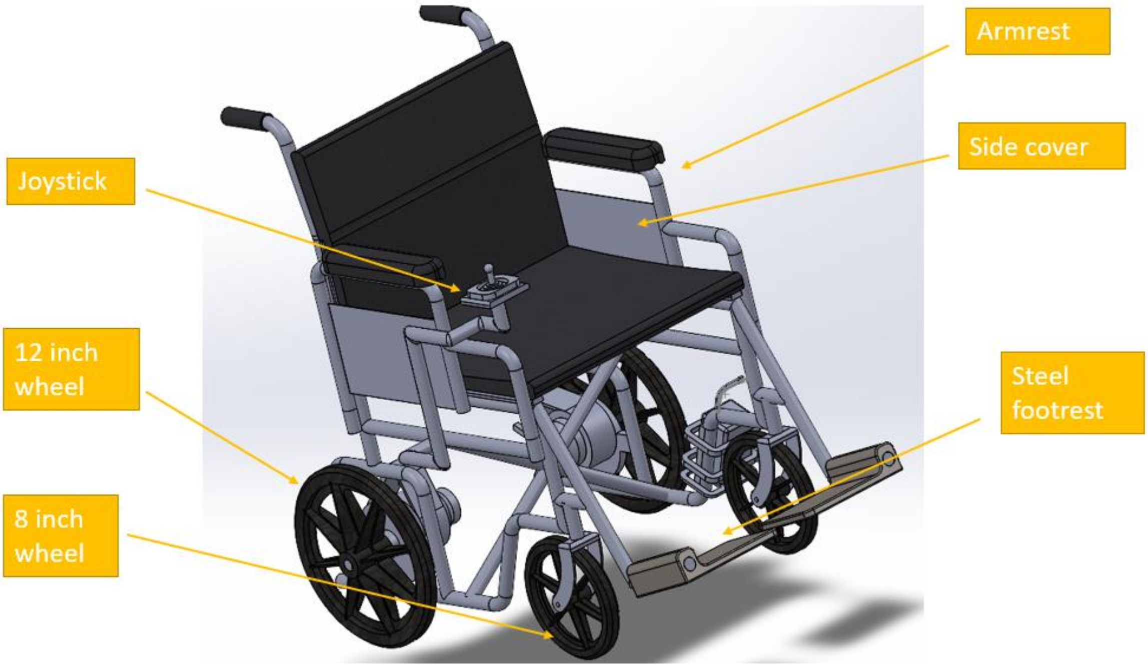


Figure 11: Wheelchair design B

Figure 11 shows design B of the wheelchair. The armrests, the side cover and the footrest are shown in this figure as well as the joystick and the wheels.

Figure 12: Back view of design B of the wheelchair

Figure 12 shows the back view of wheelchair design B. The electrical connections of the battery and motors are also shown in Figure 12.

Advantages:

- It is large.
- The motor used is better than the previous design's motors.
- The dimensions are acceptable.
- The wheelchair is foldable.
- It can be easily assembled and manufactured.

Disadvantages:

- There is no damper or a spring.
- The battery is not placed correctly.
- The wheelchair design is not following standards.
- The motors are not held in place well.

3.3.3 Wheelchair design C

The design shown in Figure 13 is design C of the wheelchair. This design is not a standard manual wheelchair design. It has been edited by minimizing the tubes, removing unnecessary materials, and increasing the outer diameter of the tube to 24 mm in diameter. As shown in Figure 13, the wheelchair is well-designed to be a powered wheelchair. The battery is placed on the right side of the chair and two brushless motors are connected to the wheels on the sides of the frame. The Arduino, motor drivers, and other electrical connections are to be arranged anywhere in the frame. The wheelchair is foldable. The controlling unit was designed using a small Arduino joystick and a few push buttons. The material used is aluminium. The front wheel is 8 inches in diameter, and it contains a spring while the rear wheel is 12 inches in diameter. The frame is very light compared to the previous designs (A and B).

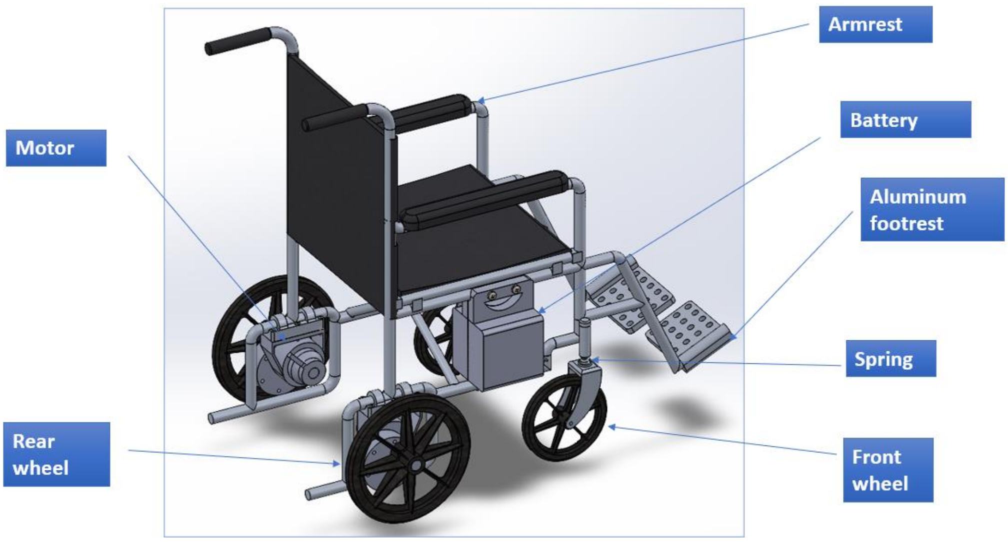


Figure 13: Wheelchair Design C

Figure 13 shows the design C of the wheelchair. The armrests, the side cover and the footrest are shown in this figure as well as the brushless motors and the wheels. Moreover, it shows the battery and the springs.

Advantages:

- It is large.
- It holds the motor well.
- The wheelchair dimensions are standardised.
- The rear wheels dimensions are suitable.
- The wheelchair design is foldable.
- It can be easily manufactured and assembled.
- It is lightweight.
- It contains a spring to reduce vibrations.
- Less machining and welding are required.
- It has a safe battery compartment.

Disadvantage:

- The motor has low availability.

3.3.4 Wheelchair Design D

The design shown in Figure 14 is design D. The battery is placed on the left side of the chair and two DC Hybrid Gearbox high torque motors are connected to the wheels in the sides of the frame. The Arduino, motor drivers, and the other electrical connections are arranged on the right side of the frame where the controlling unit is placed. The battery will be placed on the left side of the frame. The wheelchair is foldable. The controlling unit was designed using a small Arduino joystick and a few push buttons. The controlling unit is placed on the right side of the chair. The material used is aluminium. The front wheel is 8 inches in diameter, and it contains a spring while the rear wheel is 12 inches in diameter. Finally, the way of holding the motors was changed and anti-tipping tubes were added to avoid reversal issues and protect the user from possible tilting issues.

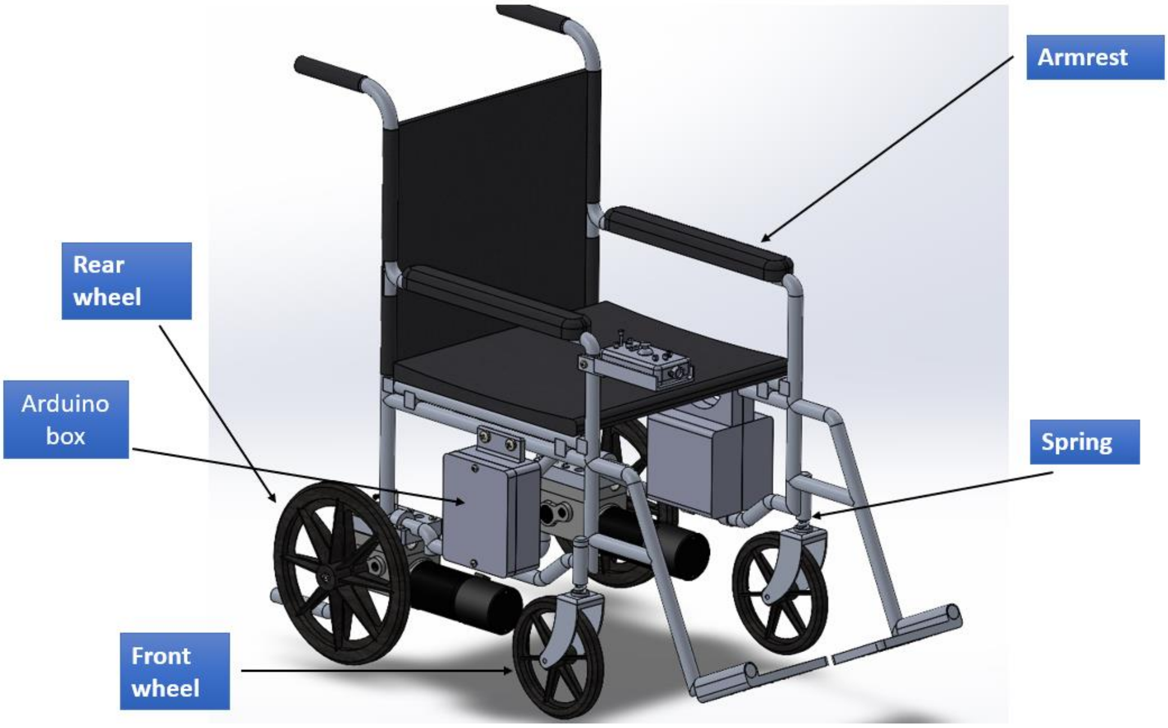


Figure 14: Wheelchair design D

Figure 14 shows the following parts of wheelchair design E. It shows the rear wheels, the Arduino box, the armrest, the springs, and the front wheels.

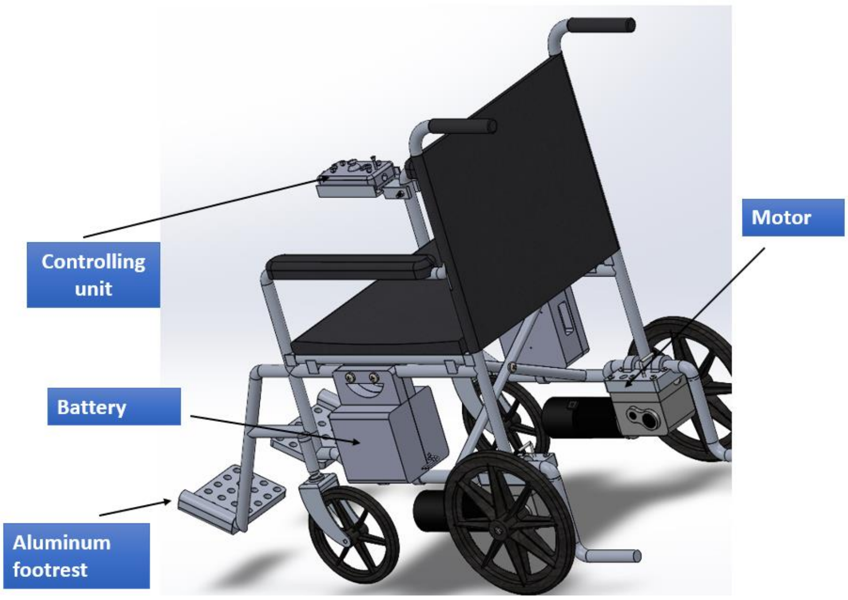


Figure 15: Back view of wheelchair design D

Figure 15 shows the controlling unit, the battery, the aluminium footrest, and the DC hybrid gearbox motors.

Advantages:

- The wheelchair design follows standard dimensions.
- It is foldable.
- It can be easily manufactured and assembled.
- It is lightweight.
- It contains a spring to reduce vibrations.
- The battery is placed in a safe spot.
- The motors are held perfectly.
- Easy wiring and simple connections arrangements.
- The design has an anti-tip mechanism.

Disadvantage:

- The motor selected is not as efficient as the one in design C.

3.3.5 Wheelchair design E

The design shown in Figure 16 is design F. This design is a modern wheelchair design. The main difference in this wheelchair is the container in the middle as well as the frame. Tubes were not used in this design. The container will contain the battery, microcontroller, motor drivers, and wires. The wheelchair is not foldable. The joystick used is an arcade joystick. The material used is aluminium. The motor is a brushed gearbox DC motor. The wheelchair is very heavy, and it needs a lot of machining.

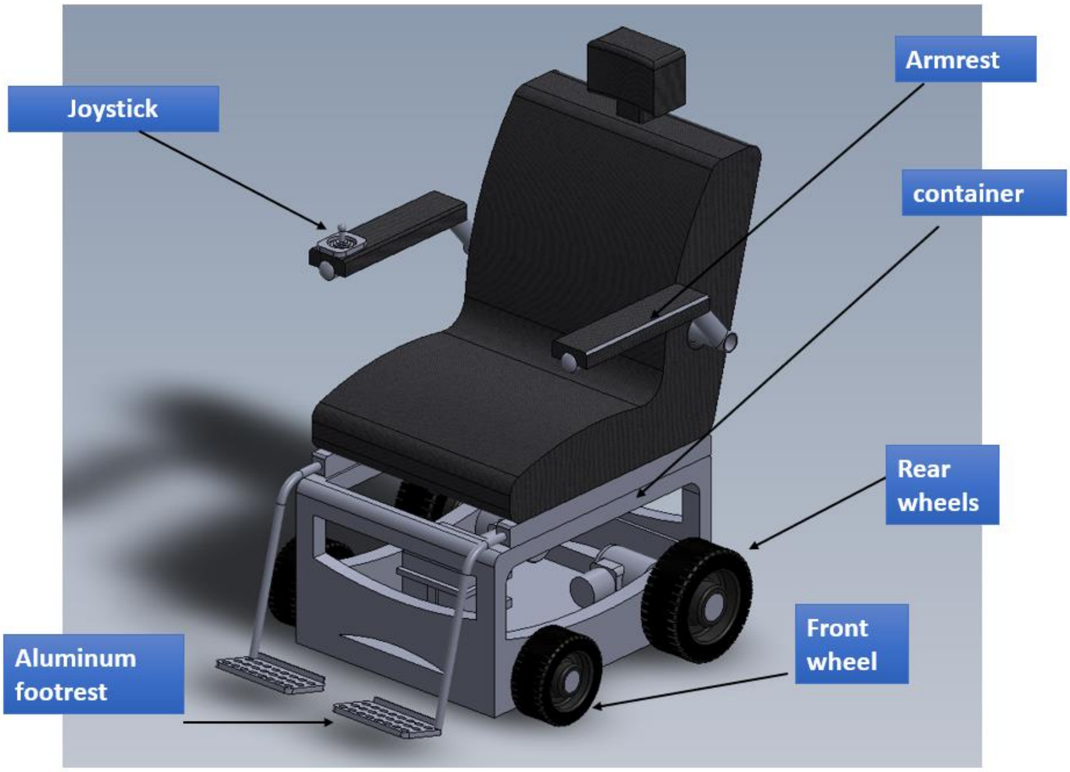


Figure 16: Wheelchair Design E

Figure 16 shows the following components of design E: the Aluminium footrest, the rear wheels, the front wheels, the container, the armrest, and the arcade joystick.

Advantages:

- It is large.
- It is very comfortable.
- The design has enough space for the electrical components.

Disadvantages:

- It is not foldable.
- The design has a lot of unnecessary materials.
- It is heavy and not durable.
- Lots of machining and welding are required.
- There is no damper or a spring.
- It does not follow any standards.

3.3.6 Wheelchair design F

This design is based on the prototype to be made. From the decision matrix in Table 13 below, the design was ranked to have a better durability, availability of materials, safety and more cost effective compared to other design configurations. It has the batteries placed on the base just below the seat of the wheelchair which reduces the centre of gravity of the wheelchair. Another feature of this design is the five ultrasonic sensors (two in front, one on each side and one at the back) used for obstacle detection. The frame is made with hollow aluminium tubes which reduces the overall weight of the wheelchair.

Figure 17: Wheelchair design F

Figure 17 above shows the design that closely resembles the prototype to be manufactured. It consists of batteries, sensors, joystick, motors, Arduino, motor drivers, fan, etc.

3.3.7 Design selection

A decision matrix that contains all the criteria required for selecting the design is shown in Table 13.

Table 13: Design Selection decision matrix

Criteria	Importance weight	Design A	Design B	Design C	Design D	Design E	Design F
Cost	9	10	5	8	8	2	9
Time	10	10	8	10	10	2	10
Availability	10	10	1	1	7	10	8
Manufacturability	10	10	7	9	9	5	9
Assembly	10	4	8	10	10	6	9
Environmental footprint (10 = best)	10	1	10	10	8	1	8
End of life	9	2	6	9	7	4	8
Safety	10	8	2	10	8	8	9
Durability	10	2	7	10	8	2	9
TOTAL		558	529	753	764	374	773

From the results above, the best design based on criteria specified in the report is design F.

3.4 Proposed/Selected design.

The proposed design will be divided into two subsystems: mechanical and electrical subsystems.

3.4.1 Mechanical subsystem

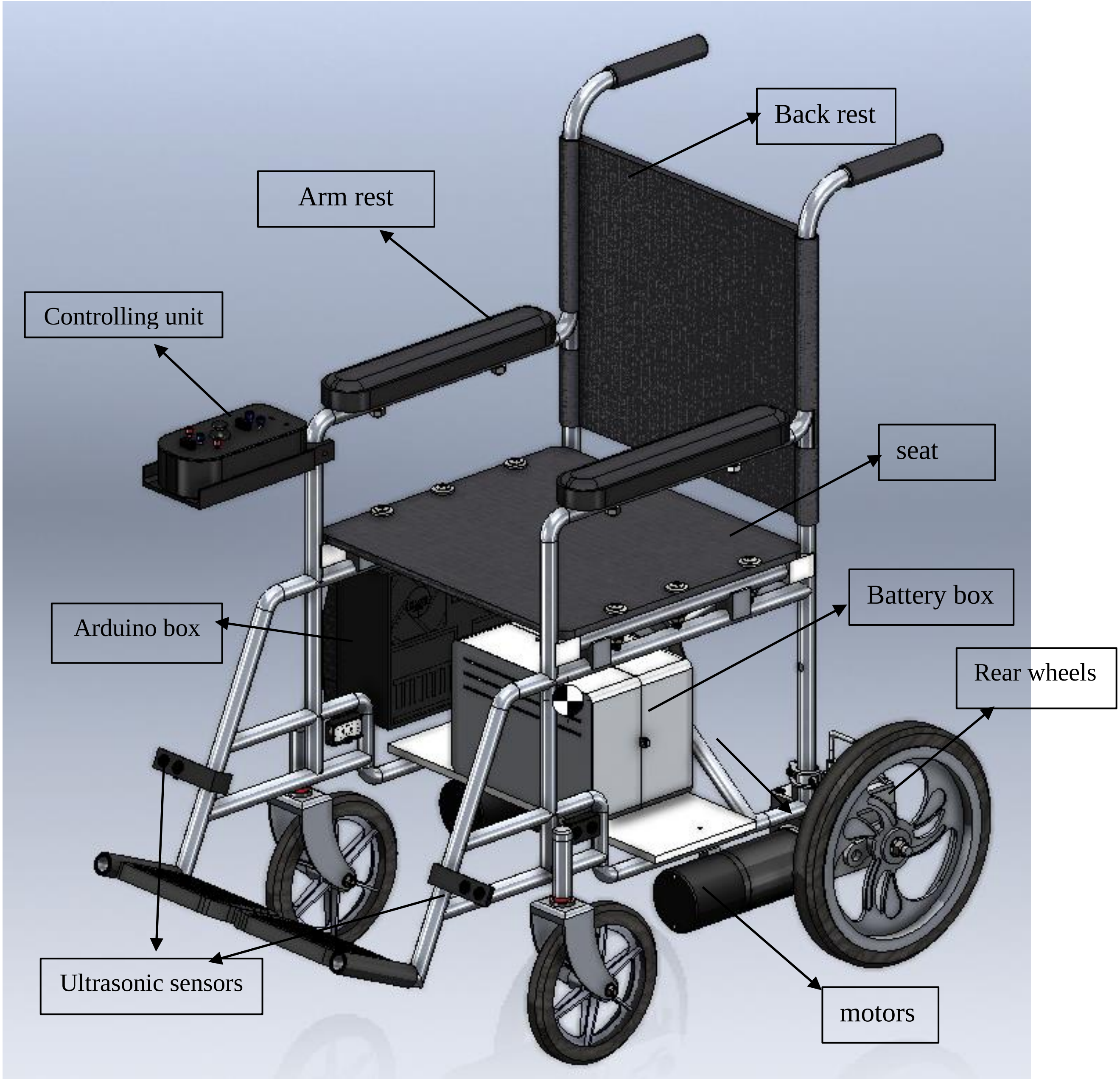


Figure 18: Design configuration

Figure 18 shows the following parts of wheelchair design F: rear wheels, the Arduino box, the armrest, ultrasonic sensors, motors, controlling unit.

3.4.1.2 Frame

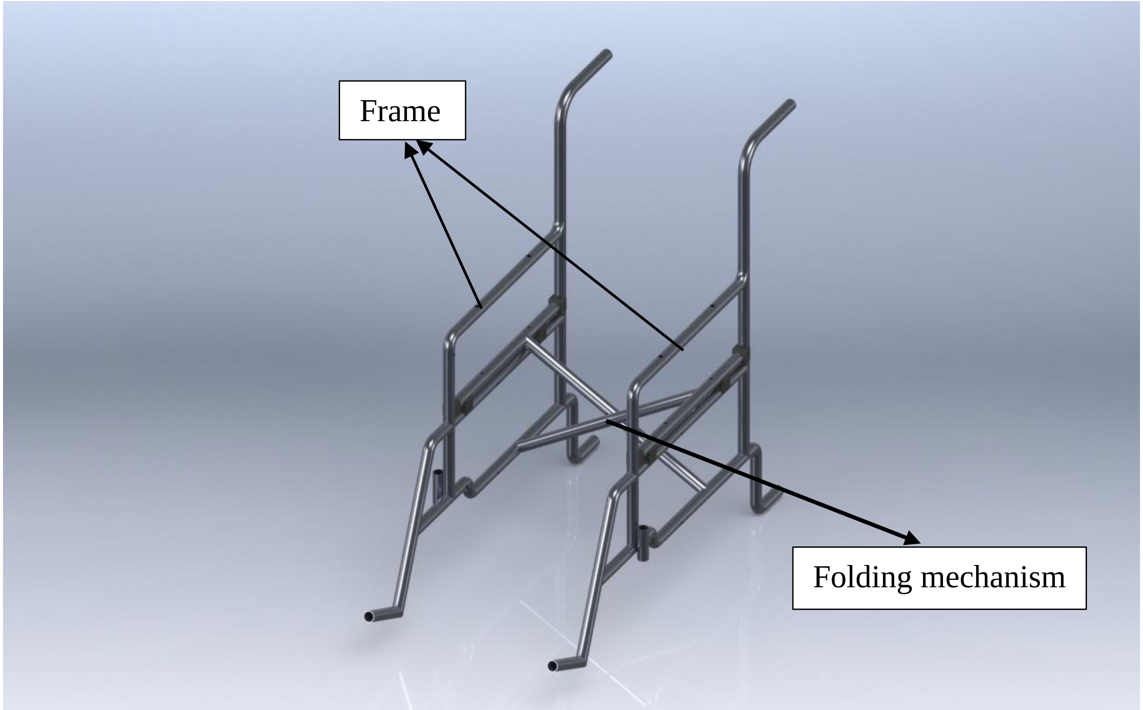


Figure 19: Frame

Figure 19 shows the frame and some of its subsystems connected to the folding mechanism. The frame is the first mechanical subsystem, and it is made of aluminium tubes. It was designed for safety, manufacturability, durability, cost, assembly, environment, and end of life.

3.4.1.3 Armrest pad

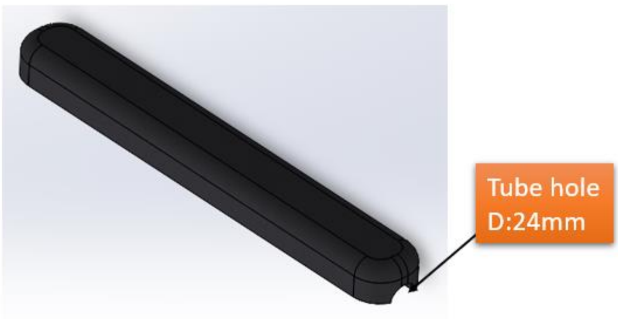


Figure 20: Armrest

Figure 20 shows the armrest pad. It is connected to the frame by placing it in the hole shown.

The armrest pad can be made of different materials like leather, nylon, and plastic. In this project, the plan is to buy the armrest based on the best cost, assembly, availability, and safety.

3.4.1.4 Motor holder

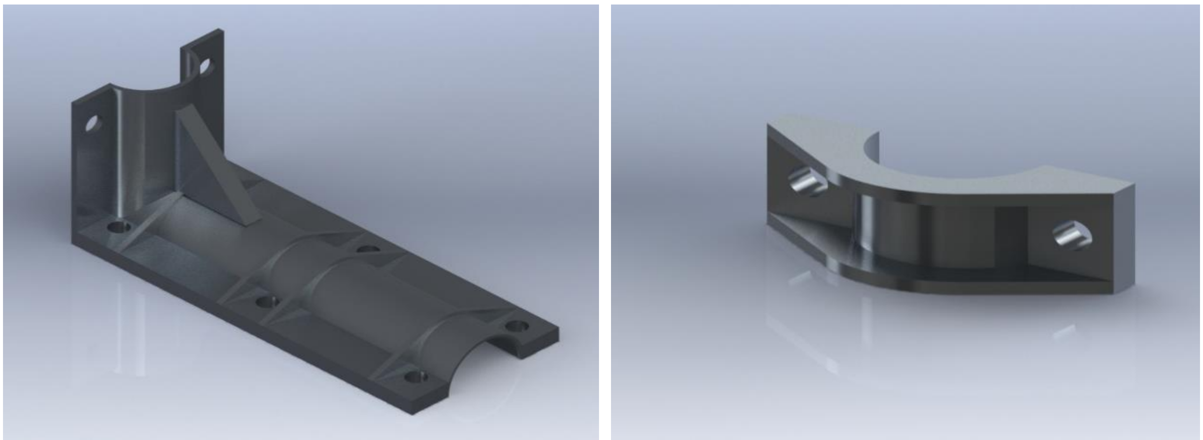


Figure 21. Motor Holder

Figure 21 shows two parts that are used to connect the motor to the frame. One is screwed to the motor and the other supports the main holder. The holes are 6mm in diameter.

3.4.1.5 Rear wheels

Figure 22: Rear wheels

Figure 22 shows the rear wheel used in the project. The place where the wheel will be connected to the motor is shown.

The wheel (which is a subsystem of the motor) is to be bought and not manufactured. The wheel is made from plastic and covered by airfield tire, while the connector is made of steel.

3.4.1.6 Arduino box

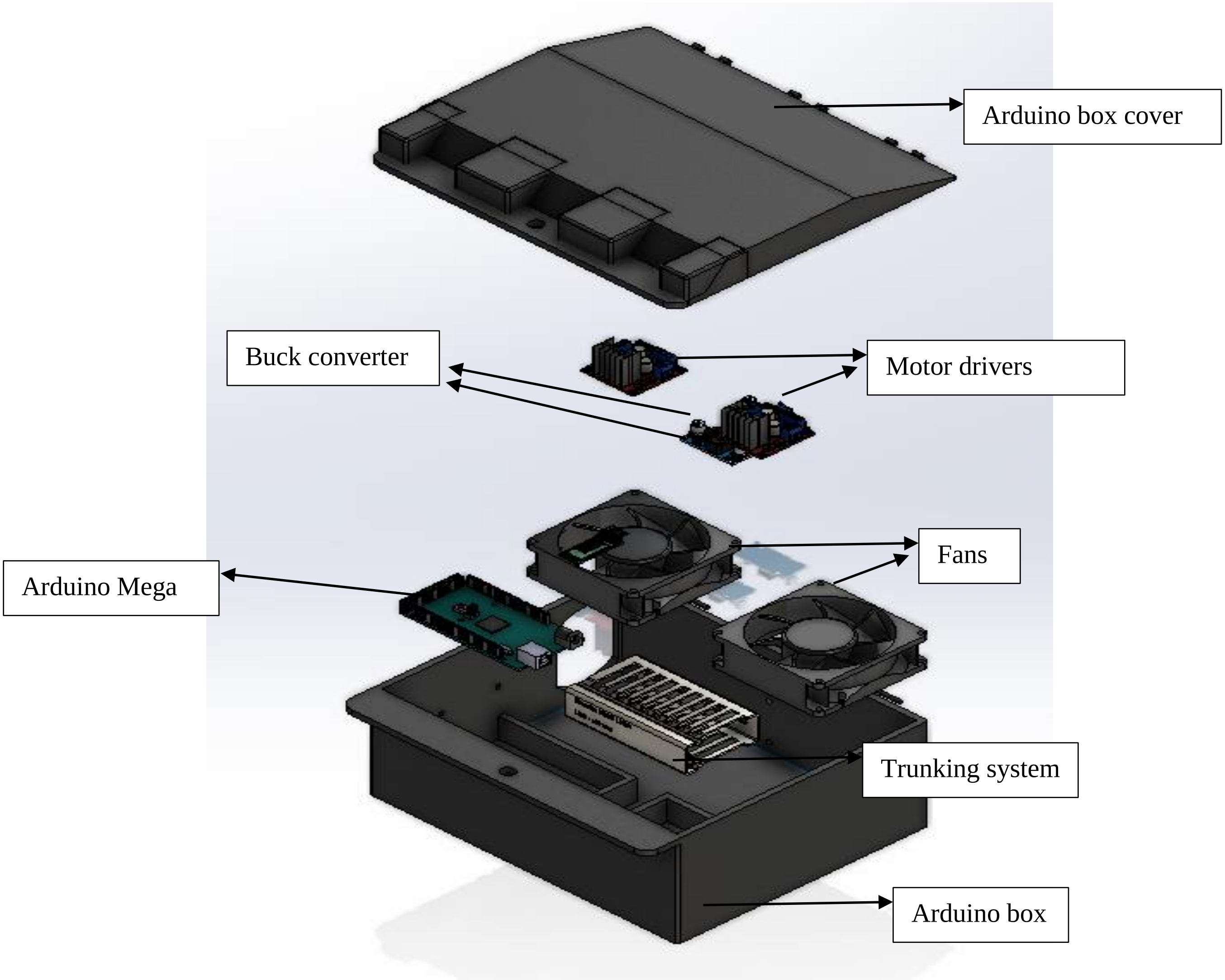


Figure 23: Arduino box

Figure 23 shows the Arduino box with some of the components that are going to be in the box as well as the exits of the wires.

Safety standards were followed when designing the Arduino box. The box is designed for assembly, cost, safety, and durability. The material used for manufacturing the box is PLA material and it should be 3D printed.

3.4.1.7 Battery box

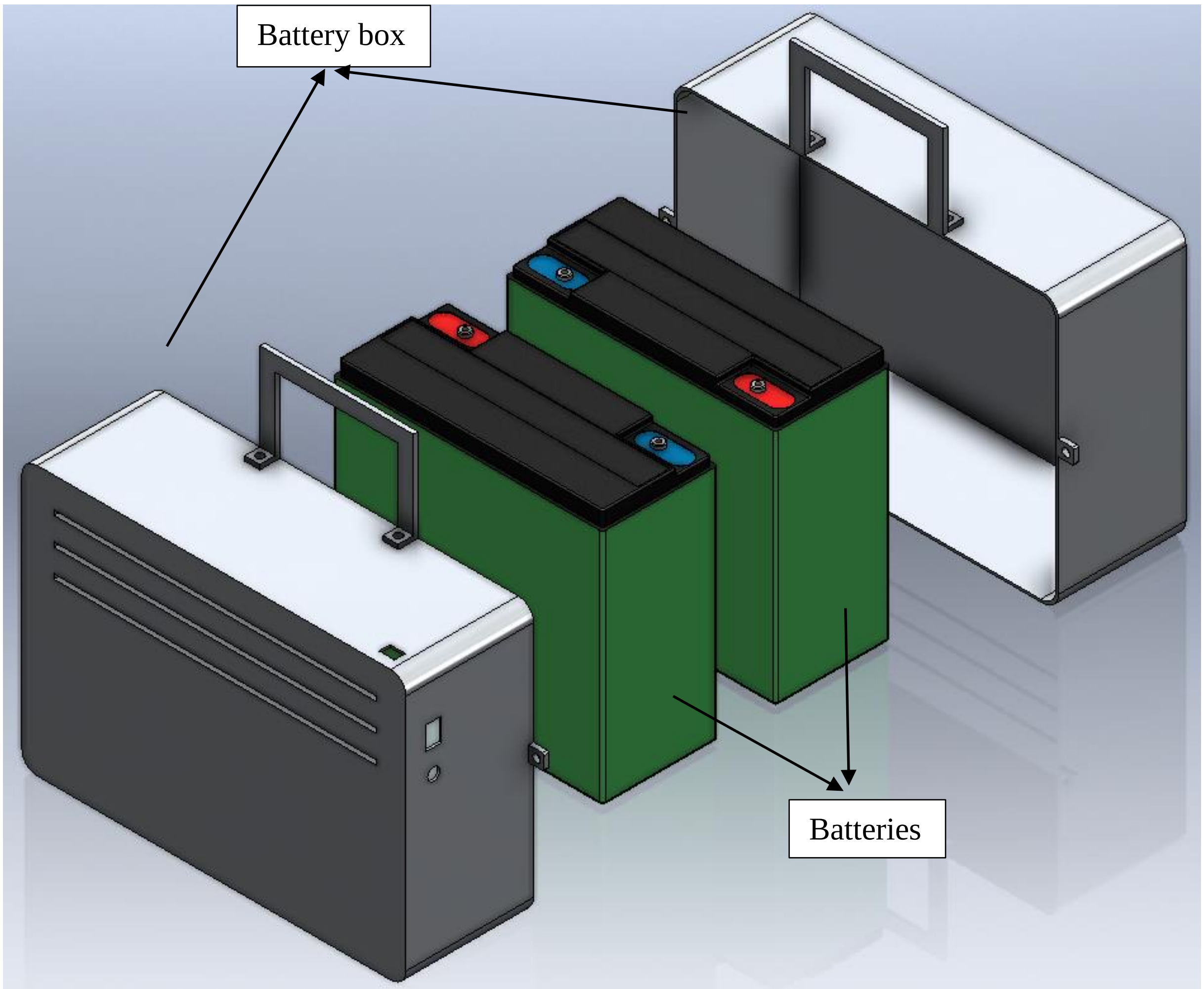


Figure 24: Battery box

Figure 24 shows the design of the battery container and the batteries used to power the wheelchair. The box has some space to allow for wires to be plugged to it.

3.4.1.8 Controlling unit holder

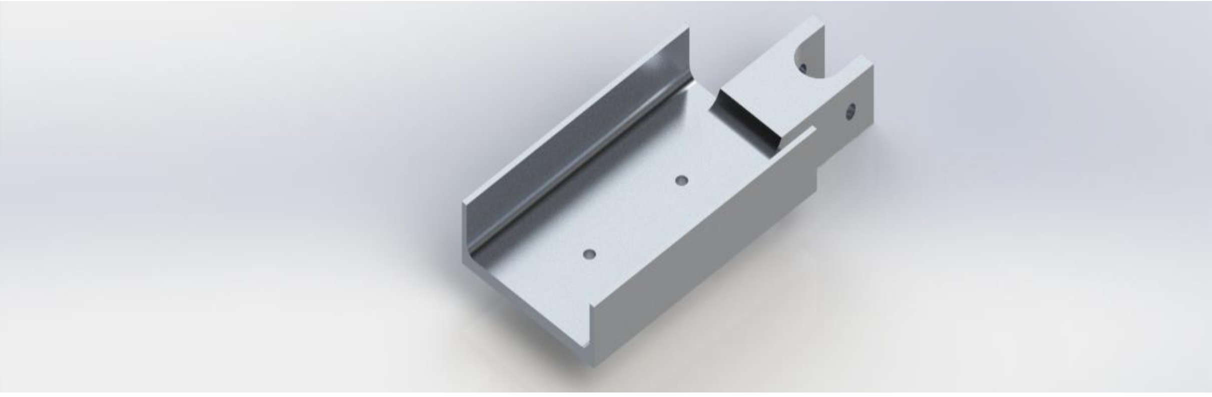


Figure 25: Control unit holder

Figure 25 shows the controlling unit holder which holds the controlling unit for joystick control movement. The controlling unit holder is movable, made from Aluminium, and is a subsystem of the frame. The function of this holder is to hold the controlling unit in a comfortable level for the user. It was designed based on durability, assembly, manufacturability, cost, and environmental footprint.

3.4.1.9 Controlling unit

Figure 26: Control unit

Figure 26 shows the controlling unit with its components which are the microphone, the push buttons, as well as the mode screen which is designed to show the current control mode of the user. It also shows the joystick used in the project.

The controlling unit (which is a subsystem of the controlling unit holder) was designed to provide full comfortable control for the user based on the required power safety standards and based on durability, assembly, manufacturability, cost, and environmental footprint. The controlling unit was manufactured using PLA material and 3D printing was the preferred manufacturing method.

3.4.1.10 Footrest

Figure 27: Footrest

Figure 27 shows the footrest design for the model. The footrest (which is a subsystem of the frame) is to be bought and not manufactured due to availability, cost, durability, and manufacturability.

3.4.1.11 Caster fork

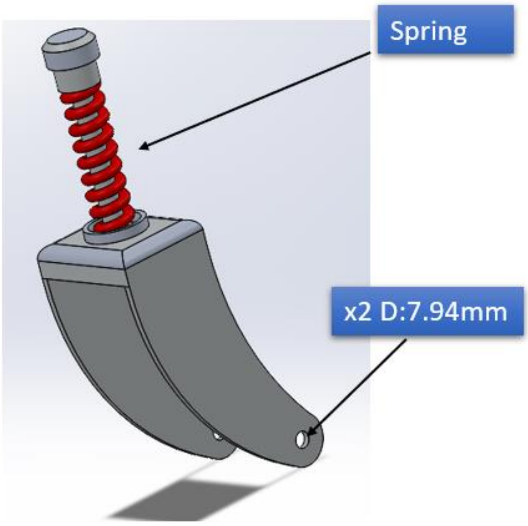


Figure 28: Caster fork

Figure 28 shows the caster fork. The assembly of the caster fork subsystems is shown with the dimensions of the holes that are used for the wheel connection.

The caster fork (which is a subsystem of the frame) was bought due to the availability, cost, durability, manufacturability, time, and environmental footprint. The caster fork is made from Aluminium material.

3.4.1.12 Spring

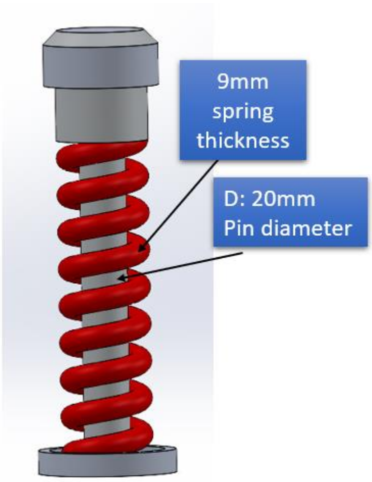


Figure 29: Caster spring

Figure 29 shows the spring used in the caster fork with some of its information. The spring (which is a subsystem of the caster fork) is used to decrease the vibration impact on the wheelchair to increase the safety and durability of the wheelchair, and to make the wheelchair more comfortable.

3.4.1.13 Front wheels

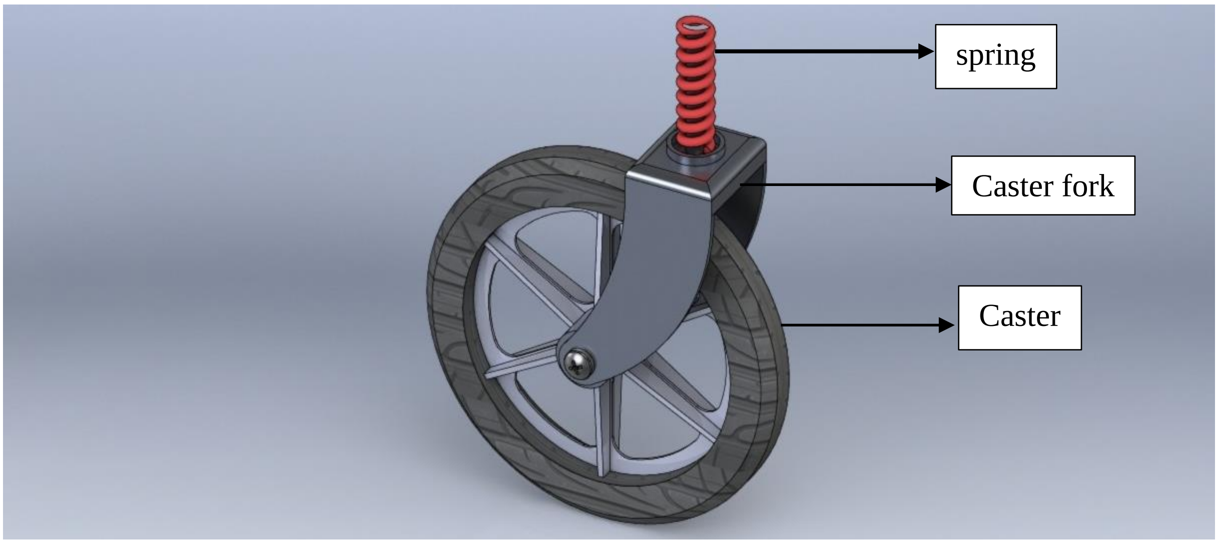


Figure 30: Front wheel

Figure 30 shows the front wheel(caster) connected to the caster fork used in the project. A screw is used to connect the wheel to the caster fork and locked in place with a nut on the other side. The wheel (which is a subsystem of the caster fork) is to be bought and not manufactured. The wheel is made from plastic and covered by airfield tire, while the connector is made of steel.

3.4.1.14 Seat

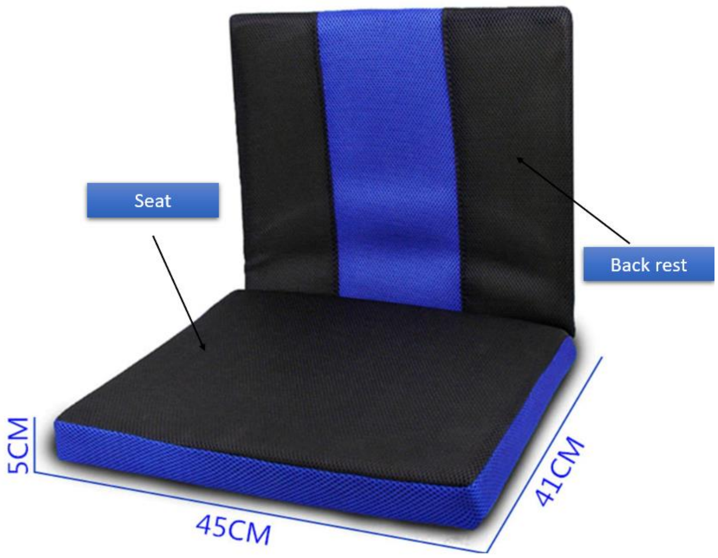


Figure 31: Wheelchair seat cushion

Figure 31 shows the seat used in the project with its specifications. This seat is made from nylon, and it is removable and comfortable. The seat will be placed above the default leather seat and then removed when folding the wheelchair. The seat is following the standard dimensions and it was chosen due to its availability, durability, sustainability, time, and cost.

3.4.1.15 Handle Grip

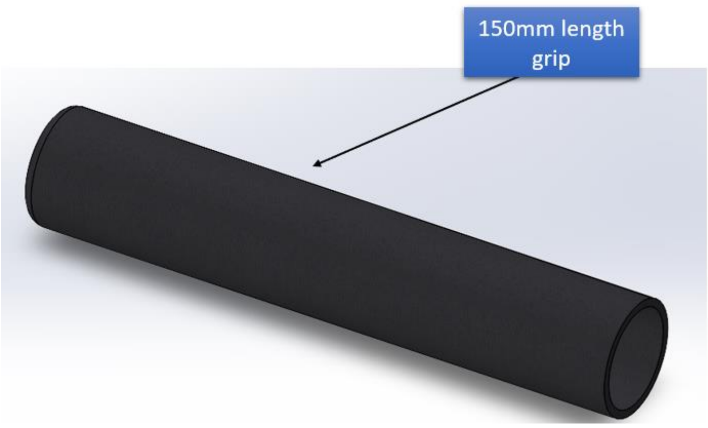


Figure 32: Handle grip

Figure 32 shows the grip that is used in the wheelchair handle grip. The grip is to be 3D printed using PLA material. The grip is comfortable and durable. It is easy to be assembled, cheap and safe.

3.4.1.16 Folding mechanism

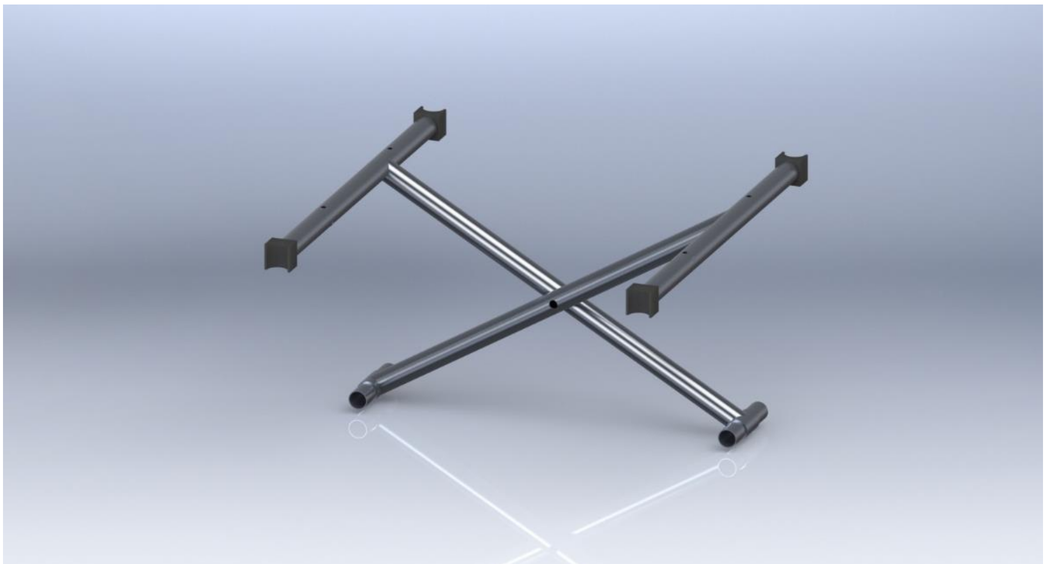


Figure 33: Folding mechanism

Figure 33 shows the folding mechanism of the wheelchair and its components (the frame attachments and the beams). It is made from Aluminium, and it has a special kind of screw called “thickened folding screw”. The black components that connect to the frame are made from rubber. The design allows the user to fold the wheelchair to a minimum width of 29 cm as shown above.

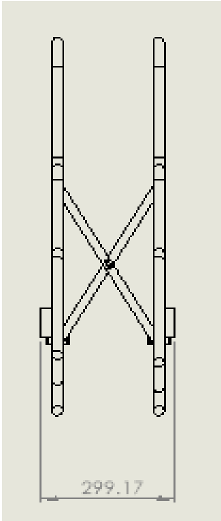


Figure 34: Maximum folding

Figure 34 shows the maximum folding distance from the most left to the most right.

3.4.1.17 Ultrasonic Sensor Holder

This component has three slightly varying configurations due to the location of the sensors on the wheelchair and how each holder connects to the frame. The front holders and the rear holder are similar, but the rear holder has more length. The holders on the sides are smaller and fits on the frame better than the other holders.

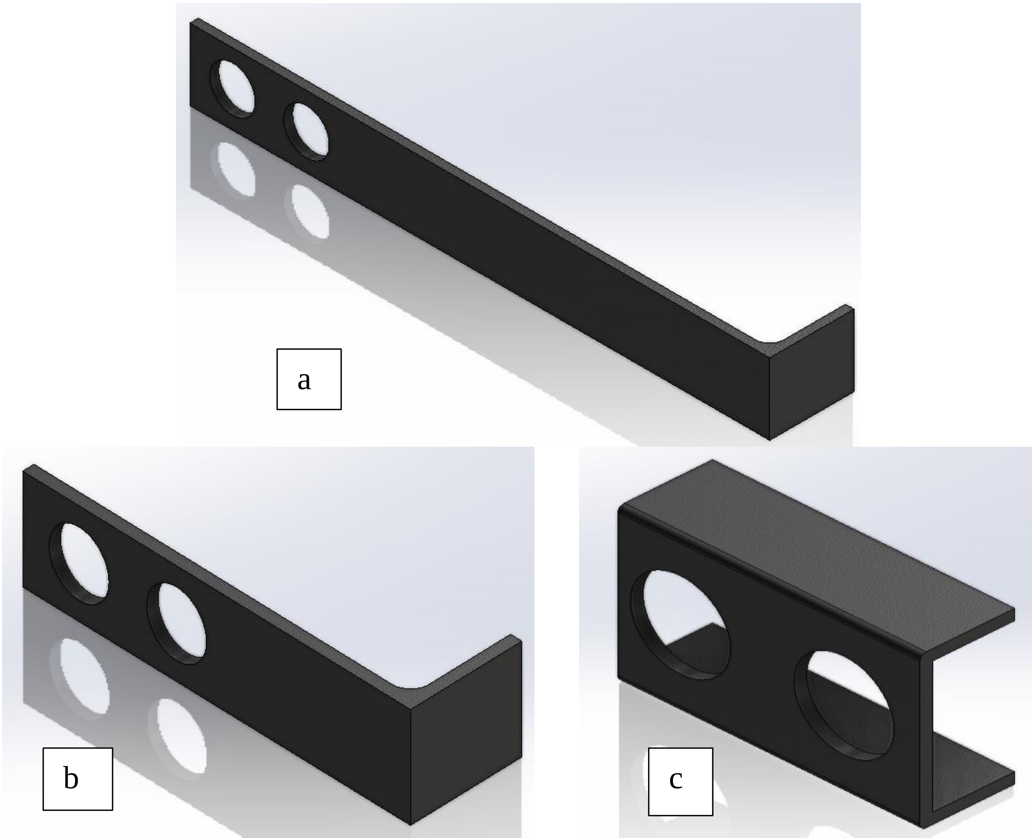


Figure 35: Ultrasonic Sensor holders (a) rear holder; (b) front holders; (c) side holders

Figure 35 above shows the different ultrasonic holders used to connect the ultrasonic holders to the frame. Five ultrasonic holders are used in total (two in front, two on each sides, & one at the back)

Table 14 below shows the mass of components as well as the quantity and materials of the parts. This is useful in estimating the overall weight of the wheelchair and number of parts used in the assembly. The mass values are based on the SolidWorks design.

Table 14: Mass & Quantity & Materials of the mechanical subsystem

Part no	Mechanical subsystem	Quantity	Total Mass	Material
1-1-1	Frame	2	2 Kg	Steel
1-1-1-8	Armrest pad	2	1 Kg	Leather & Plastic
1-1-1-1	Motor holder	2	0.086 Kg	Aluminium
1-1-1-1-1	Motor holder-frame connector	2	0.01 Kg	Aluminium
1-1-1-1-1	Rear wheels	2	3 Kg	(Plastic- rubber – aluminium)
1-1-1-2	Arduino box	1	0.8 Kg	Plastic
1-1-1-2-1	Arduino box cover	1	0.6 Kg	Plastic
1-1-1-3	Battery box	1	1.5 Kg	PLA
1-1-1-4	Controlling unit holder	1	0.2 Kg	Plastic
1-1-1-4-1	Controlling unit box	1	0.2 Kg	PLA
1-1-1-5	Foot plate	2	0.2 Kg	Rubber
1-1-1-6	Caster fork	2	0.27Kg	Aluminium
1-1-1-6-1	Spring	2	0.02 Kg	Steel
1-1-1-1-2	Front wheels	2	0.5 Kg	(Plastic- rubber – aluminium)
1-1-1-9	Seat	1	0.085 Kg	Foam
1-1-1-7	Handle Grip	2	0.036 Kg	Plastic
1-1-1-10	Back rest	1	0.03	Foam
1-1-2	Folding mechanism	1	0.475Kg	Aluminium

3.4.2 Electrical subsystem

3.4.2.1 Motors

The motor must be able to carry both the person and the wheelchair. The motors selected for the wheelchair design are a 24 V hybrid gearbox brushed DC motor with a braking torque of 3 Nm. A picture of the motor is shown in Figure 36. The specifications of the motors are shown in Table 15.

Figure 36: Motor selected for the design [32]

Table 15: Technical specification of the motors

Voltage (V)	24
No load speed (rpm)	138
Rated torque (Nm)	12
Rated speed (rpm)	130
Rated current (≤A)	14.5
Gear ratio	32:1
Braking torque (Nm)	3

3.4.2.2 Motor drivers

A motor driver is used to control the motion of a motor and its direction by feeding current accordingly. The voltage, continuous current and peak current required by the motor are parameters used when selecting a motor driver. Using the information shown in Table 15, the motor driver selected for the design is the IBT-2 (BTS7960B). This motor driver is shown in Figure 37. This driver uses two high current half bridge BTS 7960 chips for motor drive applications. Interfacing with a microcontroller is made easy using this driver which features current sensing, slew rate adjustment and protection against overrun temperature, overvoltage, under-run voltage, overrun current and short circuit. This small-sized driver provides a cost-optimized solution for protected high current PWM motor drives.

Figure 37: IBT-2 motor driver [33]

3.4.2.3 Ultrasonic sensors

Ultrasonic sensors use ultrasound for the detection of objects. Ultrasound is any sound wave with frequencies greater than 20 kHz. This sound wave is inaudible to humans since its' frequencies are higher than the audible range of human ears. HC-SR04 ultrasonic sensors were selected to serve as proximity sensors. A picture of HC-SR04 is shown in Figure 38.

Figure 38: HC-SR04 Ultrasonic Sensor [34]

The width of the received pulse directly correlates to the time taken to receive the waves and it can be used to calculate the distance between the sensor and the object. This can be done using Equation (1).

$$Distance\ between\ the\ sensor\ and\ object = Speed\ of\ Sound \times \frac{Time}{2} \quad (1)$$

Ultrasonic sensors will be placed at the front, back, left, and right of the wheelchair. These sensors will be used to detect obstacles along the path of the wheelchair.

3.4.2.4 Battery

From the conclusion of the interpretation of Table 5, the best battery type to be selected is the lead acid battery. Since the motors selected have a voltage of 24 V, the battery should supply a voltage of 24 V.

Figure 39: Battery

Figure 39 shows the battery selected for the design. Two of this battery will be connected in series to make a 24 V power supply. The rating of the batteries is 20 Ah.

3.4.2.5 Battery Charger

A battery charger is needed to charge the battery chosen for the design. This battery charger must fit the specification of the battery. A picture of the selected battery charger is shown in

Figure 40. The selected battery charger can supply up to a voltage of 30 V and can supply up to a current of 2 A.

Figure 40: Battery Charger

3.4.2.6 Charging Port

The wheelchair was equipped with two charging ports: XLR and IEC 13 female connectors. An XLR female connector was chosen as the charging port because it is the standard port used in wheelchairs and scooters. The wheelchair was also equipped with an IEC 13 female connector to give the user more freedom in choosing charging plugs for the wheelchair.

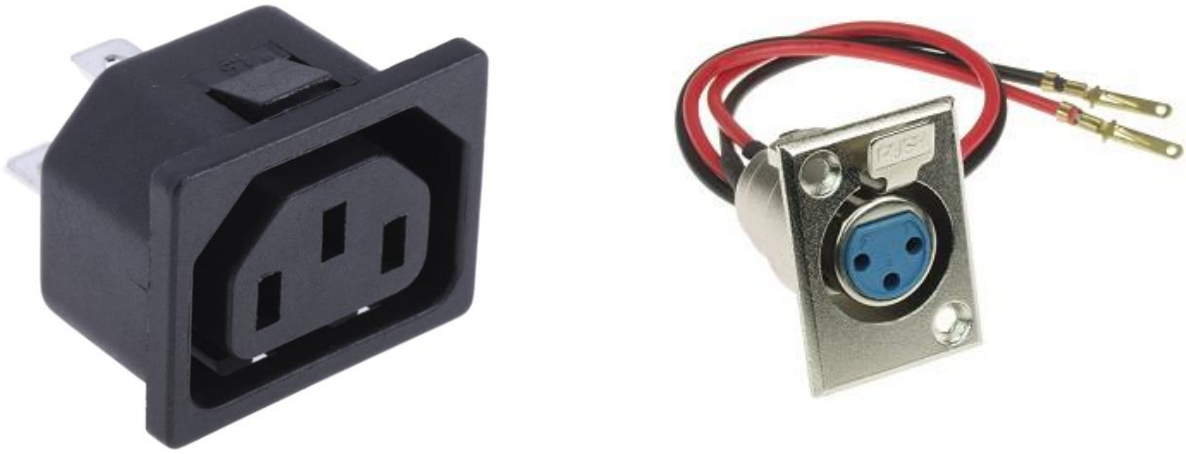


Figure 41: IEC C13 connector (left) and XLR female connector (right) [35], [36]

3.4.2.7 Buck Converter

A buck converter is used where the DC output voltage needs to be lower than the DC input voltage. This is useful for the components that need 5 V and 12 V power supply to function. The buck converter that was selected for the project is the LM2596 buck converter (Figure 42). Two buck converters were used to convert the 24 V supply to 5 V and 12 V.

Figure 42: LM2596 Buck converter [37]

3.4.2.8 Bluetooth Module

The module selected for Bluetooth connectivity is HC-05. It uses Bluetooth 2.0 protocol and can be used in a master or slave configuration. Figure 43 shows a picture of the HC-05 Bluetooth

Module. This module will be used for establishing wireless communication between a smartphone and the controller.

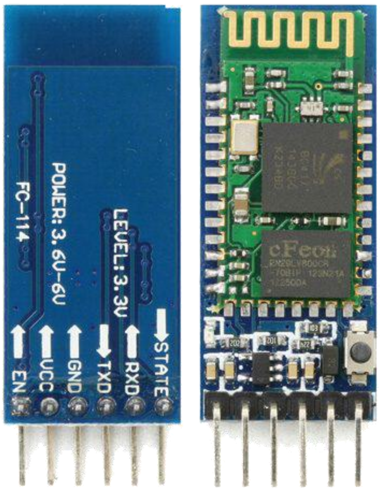


Figure 43: HC-05 Bluetooth Module

3.4.2.9 Joystick


Figure 44: Analog Joystick [38]

A joystick will also be used to control the wheelchair. Figure 44 shows the selected joystick for the design. Two potentiometers on the joystick are used to read user input. The analog output voltage for X-Direction movement is obtained using one potentiometer, while the analog output voltage for Y-Direction movement is obtained using the other potentiometer. The joystick also has one tactile switch.

3.4.2.10 Buzzer

A buzzer was integrated into the wheelchair design. This will help warn people around the operating area of the wheelchair to know that the wheelchair is going backwards. It can also be used by the user to alert passers-by obstructing his/her path. The buzzer selected for this design is an active buzzer. Figure 45 shows a picture of the active buzzer that is selected for the design. Active buzzers are called active because they can produce sound directly when connected to the battery. Most manufacturers' active buzzers can produce a single tone set to 2 kHz.

Figure 45: Active buzzer [39]

3.4.2.11 Indicator lights

The wheelchair has three modes and three speed levels, and indicator lights will help in showing which mode and speed level the wheelchair is in. Six 5 mm LEDs are used for the indicator lights. A picture of 5 mm LEDs is shown in Figure 46.

Figure 46: 5 mm LEDs [40]

3.4.2.12 Push buttons

A push button switch (Figure 47) is a mechanical device that uses manual pressure to activate an internal switching mechanism to regulate an electrical circuit. The push buttons will help to increase and decrease the speed of the wheelchair, change the input of the wheelchair, stop the wheelchair in an emergency, and activate the buzzer. Five push buttons were used in this design.

Figure 47: Push buttons [41]

3.4.2.13 Pulse oximeter and heart rate sensor (MAX30102)

The MAX30102 is an integrated pulse oximetry and heart rate monitor module. It includes internal LEDs, photodetectors, optical elements, and low-noise electronics with ambient light rejection. Behind the window on one side, the MAX30102 has two LEDs – a RED and an IR LED. On the other side is a very sensitive photodetector. The idea is that you shine a single

LED at a time, detecting the amount of light shining back at the detector, and based on the signature, you can measure blood oxygen level and heart rate.

This sensor is placed in the controlling unit and the user of the wheelchair can use it to measure his/her heart rate. A picture of the MAX30102 sensor is shown in Figure 48. This sensor did not work correctly at first due to voltage level incompatibility. One of the SMD resistor had to be removed for the sensor to work properly. The connection for this sensor can be found in the electrical schematic which is in the appendix of the report.

Figure 48: MAX30102 sensor

3.4.2.14 Switch

A switch is needed to turn on/off the wheelchair when it is to or not to be used. The switch that was chosen for the wheelchair is a three-terminal rocker switch. Figure 49 shows a picture of the three-terminal switch. The brass colour terminal is connected to the negative terminal of the battery. The middle pin is connected to the positive terminal of the battery and the last pin is connected to the load of the circuit.

Figure 49: Three terminal rocker switch

3.4.2.15 Resistors

Resistors are passive two-terminal electrical components that resist the flow of electric current. These are used with the LEDs to limit the current through them and the push buttons. 10 kilo ohms and 330 ohms resistors are connected to the pushbuttons and LEDs respectively. Three 3.7 kilo ohms resistors are also used with the MAX30102 sensor. Figure 50 shows a picture of different resistors.

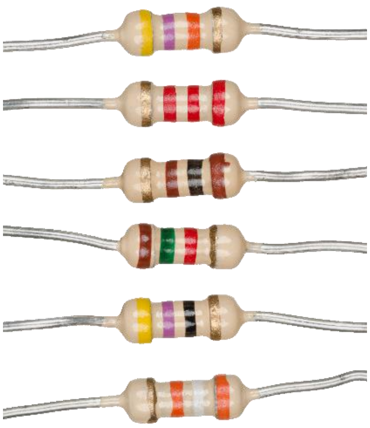


Figure 50: Resistors [42]

3.4.2.16 Fans

The motor drivers and other electrical components are positioned in a box. If there is little ventilation, overheating can occur. To prevent overheating from happening, two 12 volts fan are placed in the box. Figure 51 is a picture of the 12 V DC Fan. These fans are situated very close to the motor drivers because they have a higher chance of overheating.

Figure 51: 12 Volts DC Fan

3.4.2.17 Raspberry Pi 4

The Raspberry Pi is a relatively affordable Linux-powered computer that also features a set of GPIO (general purpose input/output) pins that let you explore the Internet of Things (IoT) and control electronic components for physical computing. To achieve voice control, a Raspberry Pi 4 Model B is used to accept and process the voice input from the user. Details on how each control method is achieved is explained in 3.9. A picture of the Raspberry Pi 4 is shown in Figure 52.

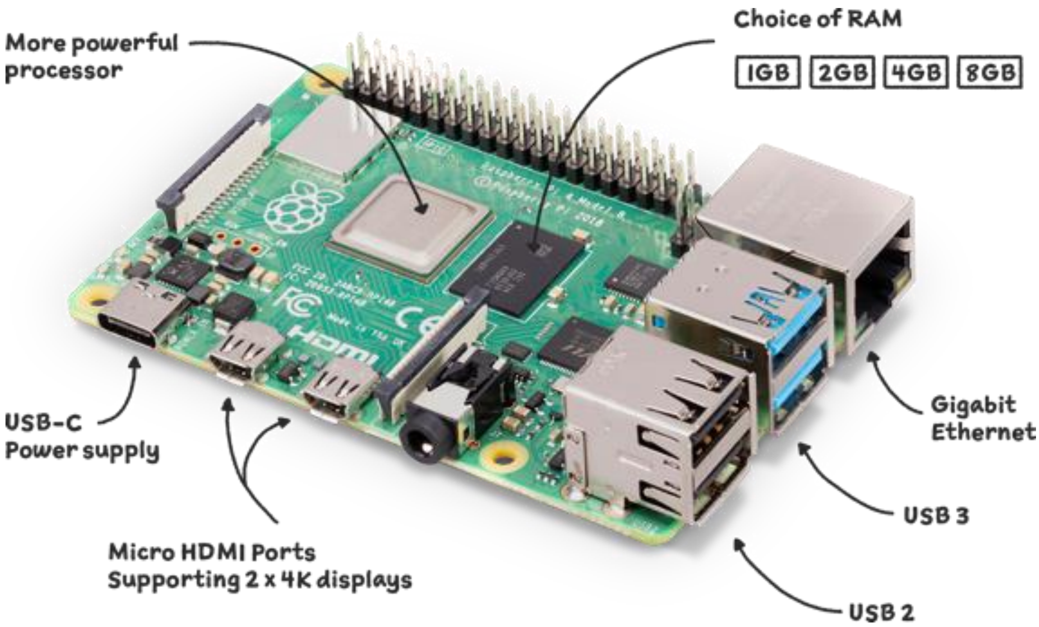


Figure 52: Raspberry Pi 4 Model B [43]

3.4.2.18 Microphone

A microphone is needed to receive voice commands/inputs from the user of the wheelchair. The microphone is connected to the Raspberry Pi 3 via a USB audio adapter.

3.4.2.19 USB audio adapter

A USB audio adapter is an audio adapter that interfaces with a computer via USB. This is connected to the Raspberry Pi 3 and microphone. This audio adapter acts as a sound card and provides the recorded audio to the Raspberry Pi in high quality for processing.

3.4.2.20 Controller

The amount of input and output pins must be considered when choosing a controller. Table 16 shows the electrical components of the proposed design and the number of I/O pins needed for each component.

Table 16: I/O needed for the design

Components	Units	Number of I/O pins for a unit	Total number of pins
HC-05	1	2 digital pins	2 digital pins
HC-SR04	5	2 digital pins	10 digital pins
Joystick	1	2 analog pins and 1 digital pin	2 analog pins and 1 digital pin
LED	5	1 digital pin	5 digital pins
Active buzzer	1	1 digital pin	1 digital pin
IBT-2 motor driver	2	2 digital pins (PWM)	4 digital pins
Push buttons	6	1 digital pin	6 digital pins
MAX30102	1	1 digital pin, SCL and SDA	1 digital pin and I2C pins
Total			30 digital pins, 2 analog pins and I2C pins

The total I/O pins needed for the design are 30 digital, 2 analog, and I2C pins. The specifications of the available Arduino controllers are shown in APPENDIX G: Arduino Boards Specifications. From the specifications, Arduino Mega 2560 Rev3 will be chosen as the controller for this design. A picture of the controller is shown in Figure 53. This controller has 54 I/O pins (of which 15 can be used as PWM outputs), 16 analog inputs, and 4 UARTs.

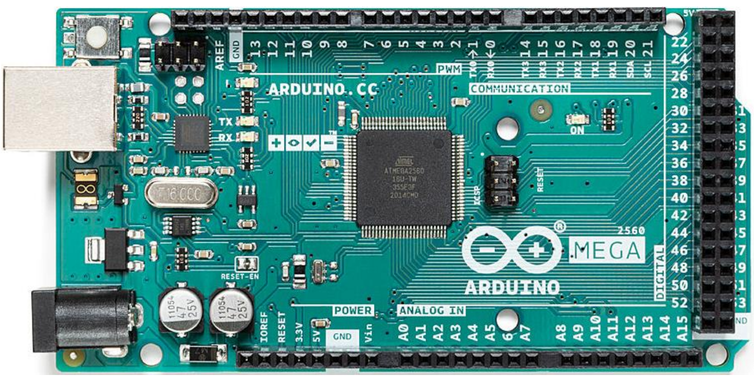


Figure 53: Arduino Mega 2560 Rev3 [44]

3.5 System Breakdown Structure

Figure 54 shows the system breakdown structure of the proposed wheelchair design.

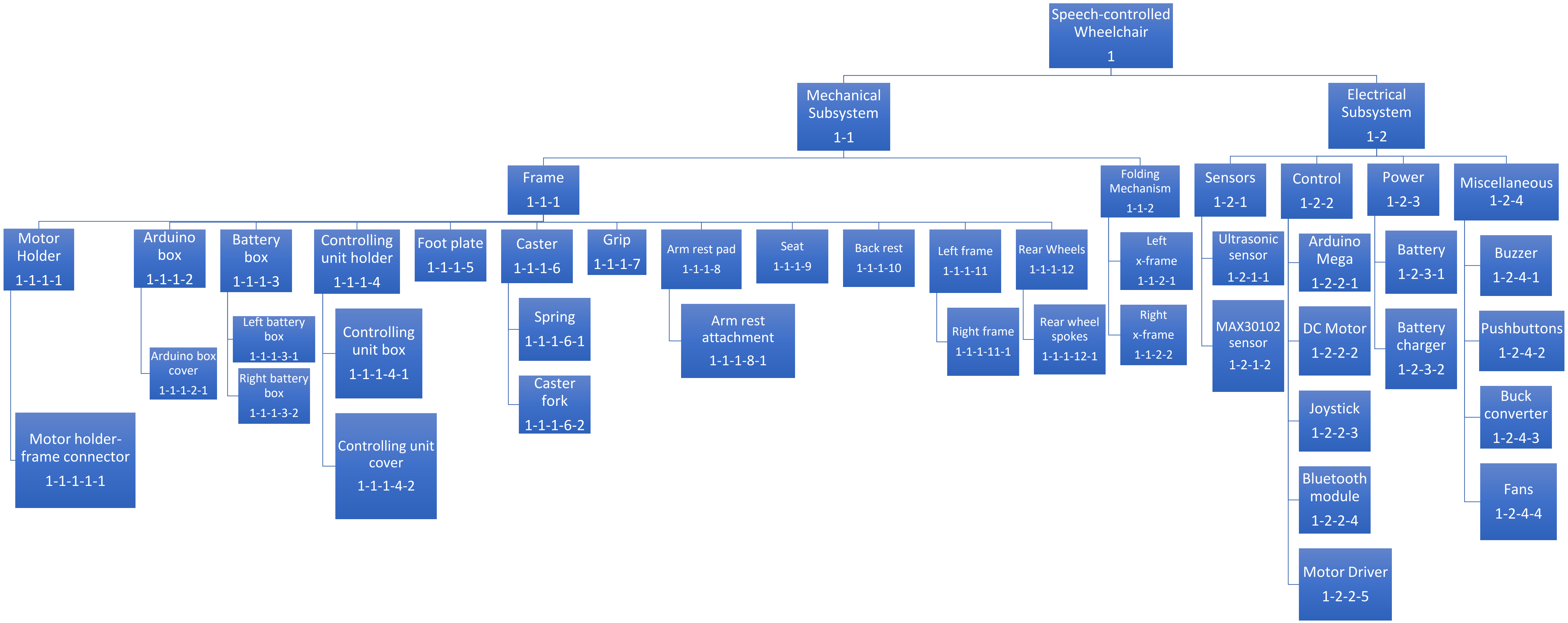


Figure 54: System Breakdown Structure

3.6 Electrical connections

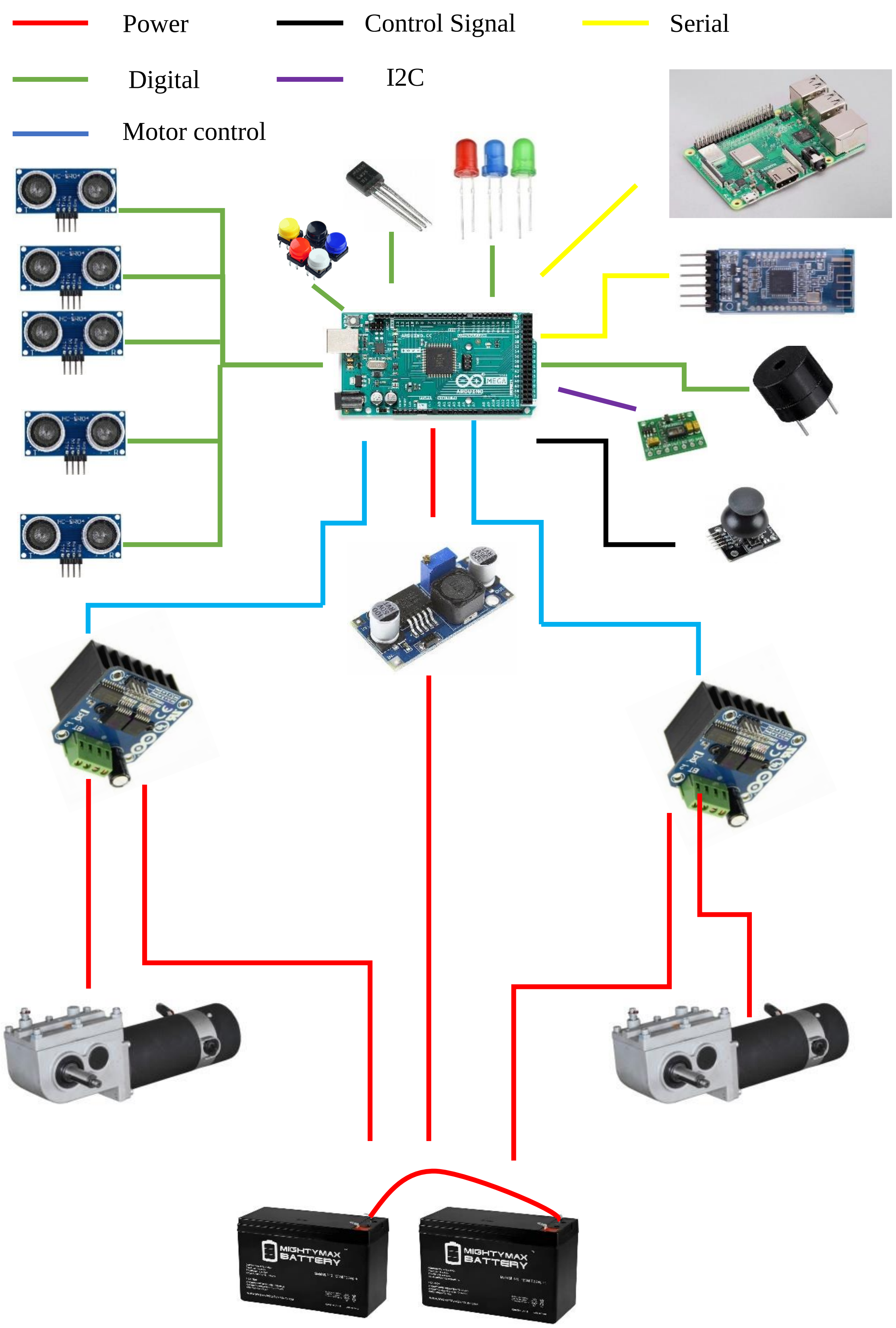


Figure 55: Electrical connection of the electrical subsystem

Figure 55 shows a simplified version of the electrical connections in the wheelchair. 5 V will be supplied by the buck converter and the Arduino to the electrical components that require it for power.

The electrical connections in the Arduino box are shown in Figure 56.

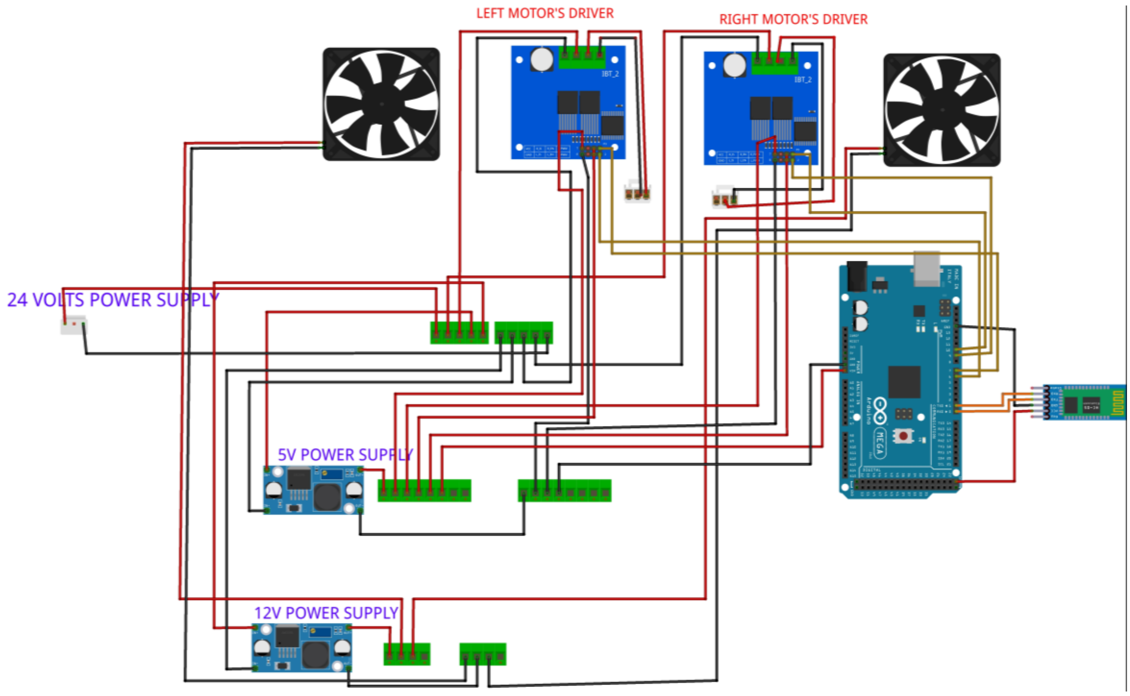


Figure 56: Electric schematic for the Arduino box

Figure 57 shows the electrical connections in the controlling box.

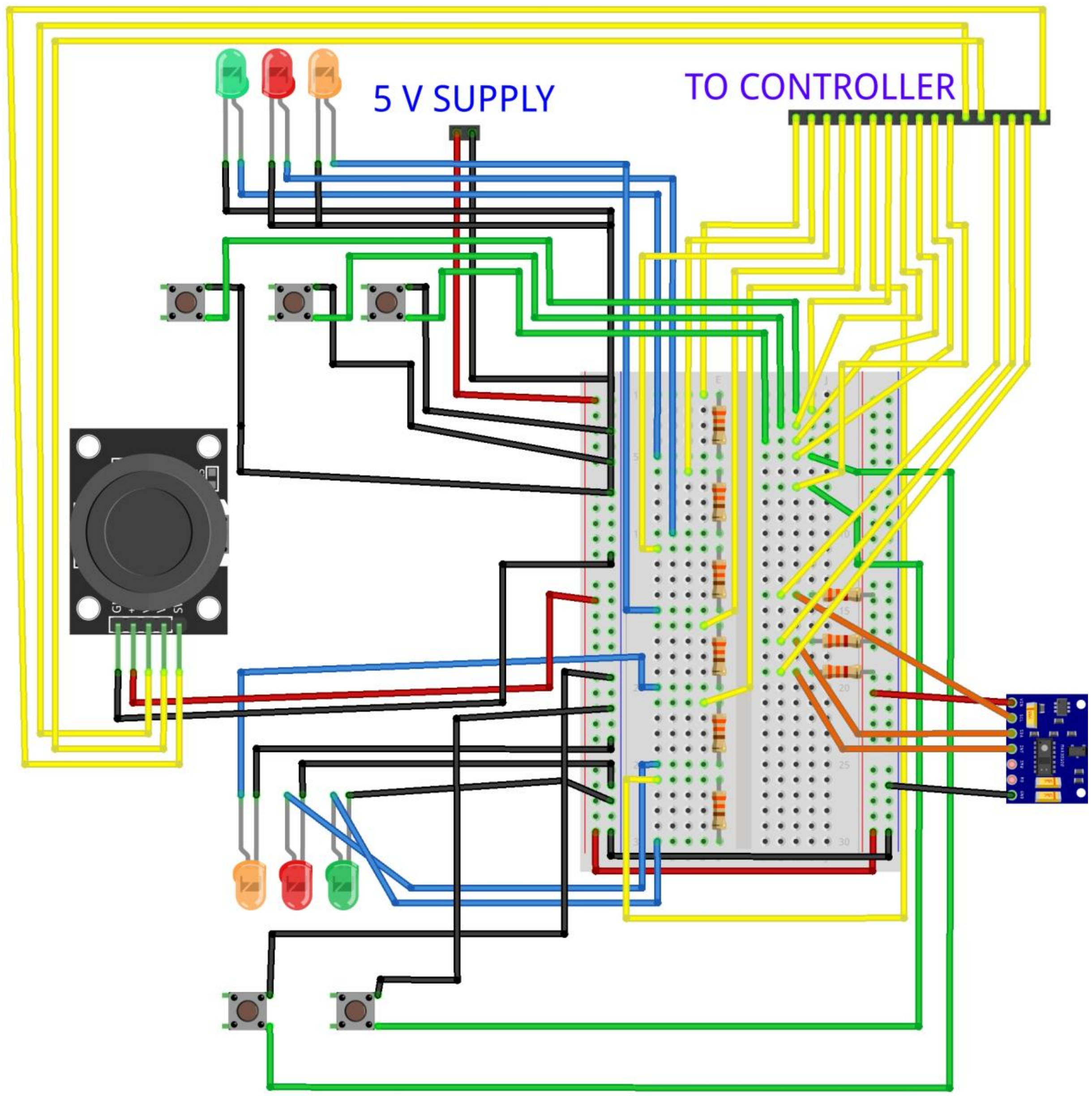


Figure 57: Electrical schematic for the controlling box

3.7 Engineering standards

One of the objectives of this project is that the design should follow standards to prove the efficiency of the product. The design follows the World Human Organization (WHO) standards, the quality management systems standards (ISO 9001) and the environmental management standards (ISO 14001). In the following sections, the standards that could be followed for each subsystem are stated a table. More explanation about the standards in APPENDIX B.

3.7.1 Wheelchair standards

The applied and unapplied standards for each component of the wheelchair is shown in Table 17.

Table 17: Wheelchair standards

SUBSYSTEM	COMPONENT	APPLIED STANDARDS	UNAPPLIED STANDARDS
1-1-1	Frame	ISO 7176-1 ISO 7176-5	ISO 7176-2 ISO 7176-8
1-1-1-1	Motor Holder	ISO 7176-1 ISO 7176-5	ISO 7176-2 ISO 7176-8
1-1-1-2	Arduino box	ISO 7176-5 ISO 7176-14	ISO 7176-8
1-1-1-3	Battery box	ISO 7176-5 ISO 7176-14	ISO 7176-8
1-1-1-4-1	Controlling unit	ISO 7176-5 ISO 7176-14	ISO 7176-8
1-1-1-5	Foot plate	ISO 7176-5	ISO 7176-8
1-1-1-6	Caster	ISO 7176-1 ISO 7176-5	ISO 7176-2 ISO 7176-8
1-1-1-7	Grip	ISO 7176-5	ISO 7176-8
1-1-1-8	Arm rest	ISO 7176-5	ISO 7176-8
1-1-1-9	Seat	ISO 7176-5	ISO 7176-8
1-1-1-10	Back rest	ISO 7176-5	ISO 7176-8
1-1-1-12	Rear wheels	ISO 7176-1 ISO 7176-5	ISO 7176-2 ISO 7176-8
1-1-2	Folding mechanism	ISO 7176-1 ISO 7176-5	ISO 7176-2 ISO 7176-8
1-2-2-1	Arduino Mega 2560 Rev3	ISO 7176-4 ISO 7176-14 EU RoHS EC 1907/2006 EN50581:2012 ISO/IEC Guide 37:2012 I2C UKCA FCC SPI UART	
1-2-1-1	Ultrasonic sensor	ISO 7176-4 ISO 18436 EN 62311:2008	

1-2-2-2	DC Motor	ISO 14001 ISO 45001 IEC 60034 ISO 9001 ISO 7176-14 EC 1907 EU 2015/863 RoHS UKCA CE ISO 7176-1 ISO 7176-3 ISO 7176-6 ISO 7176-10	ISO 7176-2 ISO 7176-4 ISO 7176-13
1-2-2-4	Bluetooth module	ISO 7176-4 IEEE 802.15.1	
1-2-3-1	Battery	ISO 7176-4 ISO 7176-14	
1-2-3-2	Battery charger	ISO 7176-4	
1-2-4-3	Buck converter	JEDEC JEP 155	

3.7.2 Electrical standards

The NEC standards for wiring colour codes of DC power are used for the electrical connection of the components in the wheelchair. The colour codes are shown in Figure 58. Red and black wires indicate positive and negative wires respectively.

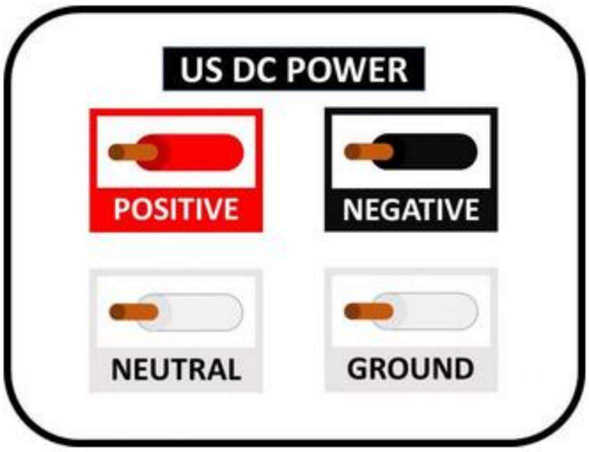


Figure 58: NEC standards for DC power colour code [45]

3.7.3 Software standards

It is necessary to follow a standard style in code writing. This makes the code more robust and reliable. It also makes it easy for developer to debug and contribute to the project if it is made open source. The coding style followed is the Arduino Coding Style Guide published by Carnegie Mellon University and the one published by Arduino [46], [47].

3.8 Design calculations

3.8.1 Mechanical Subsystem

3.8.1.1 Tipping angle

When the forces and moments acting on the wheelchair becomes unbalanced, the wheelchair will tip over. Tipping angle (θ_{tip}) is the angle that the wheelchair makes with the ground that can make it to tip over. Figure 59 shows where the tipping angle is located.

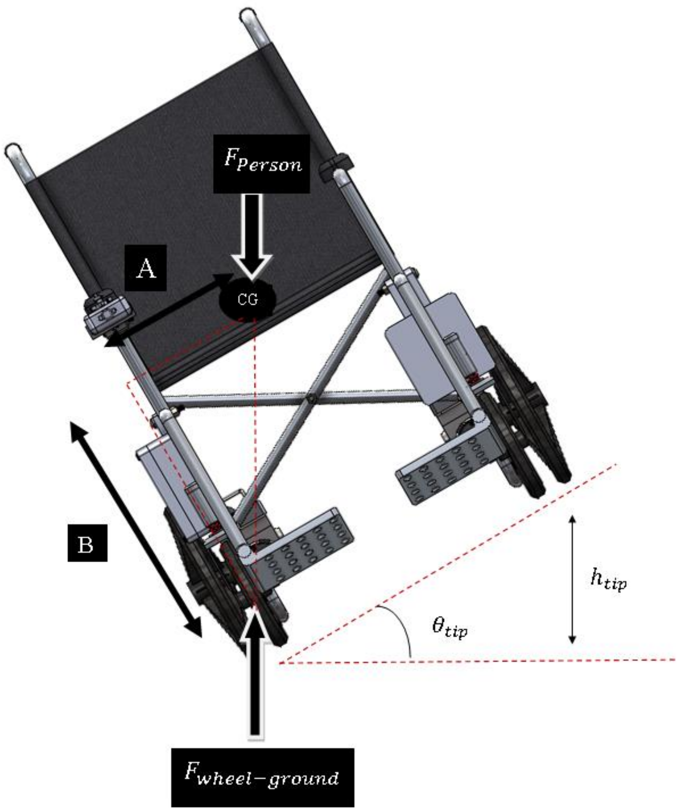


Figure 59: Tipping angle of a wheelchair [48]

Tipping angle of the wheelchair can be calculated using Equation (2).

$$\theta_{tip} = tan^{-1}\frac{A}{B} \tag{2}$$

where A = horizontal length from the centre of gravity to the tires

B = vertical length from the tires to the centre of gravity

$$\theta_{tip} = \tan^{-1}\frac{220}{351.43} = 32.04°$$

3.8.1.2 Maximum allowable mass

It is assumed that the seat where the person sits is a simply supported circular hollow beam with the weight of the person distributed along the beam as shown in Figure 60.

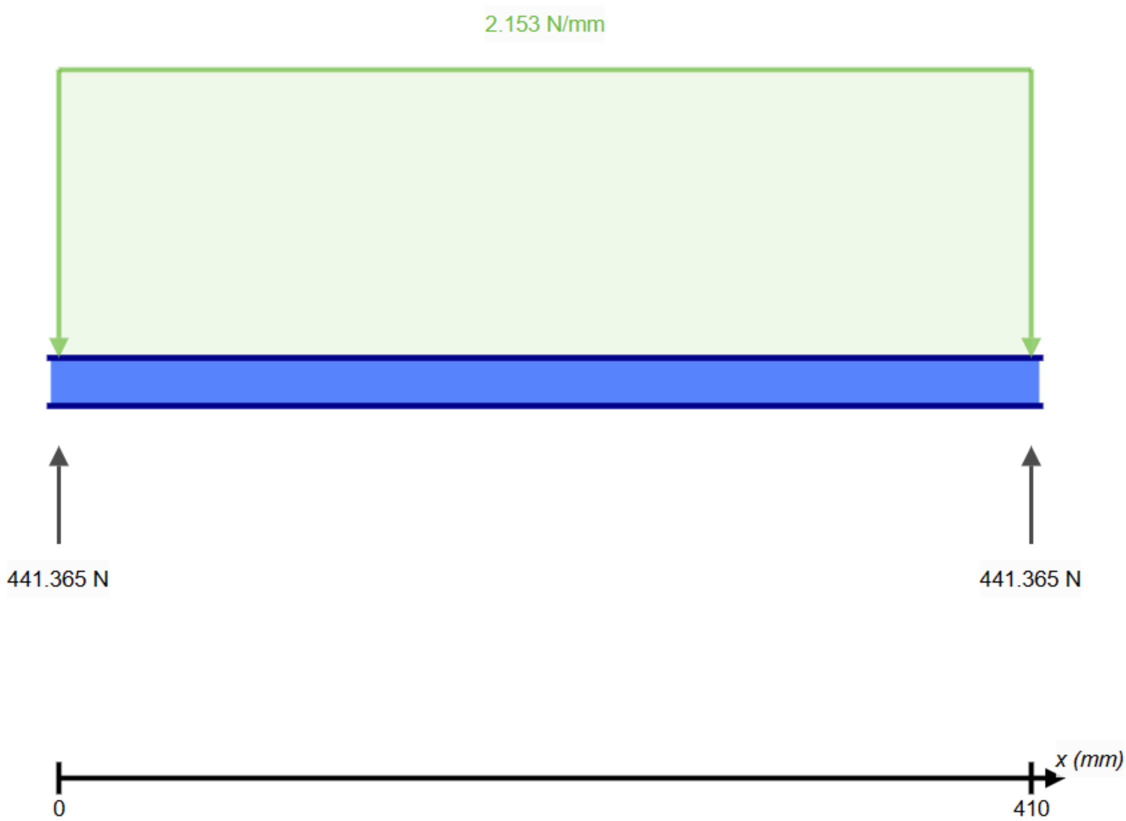


Figure 60: Freebody diagram of the wheelchair with assumptions

It was assumed that a 90 kg person is seated on the seat of the wheelchair. The seat will be under distributed loading. The distributed load will be converted to a point load acting in the middle of the bar. The force on the bar would be $(9.81 \times 90)\ N = 882.9$ N.

$\text{Length of the beam} = 410\text{mm}$

Table 18 shows the reactions and moment at specific location on the beam.

Table 18: Reactions and moment at specific points

Support at (mm)	X (N)	Y (N)	Mx (Nm)
0	0	441.365	0
410	0	441.365	0

The bending moment and shear force diagrams are shown in Figure 61 and Figure 62. The maximum and minimum values of the shear force and bending moment were extracted from the figures and can be seen in Table 19.

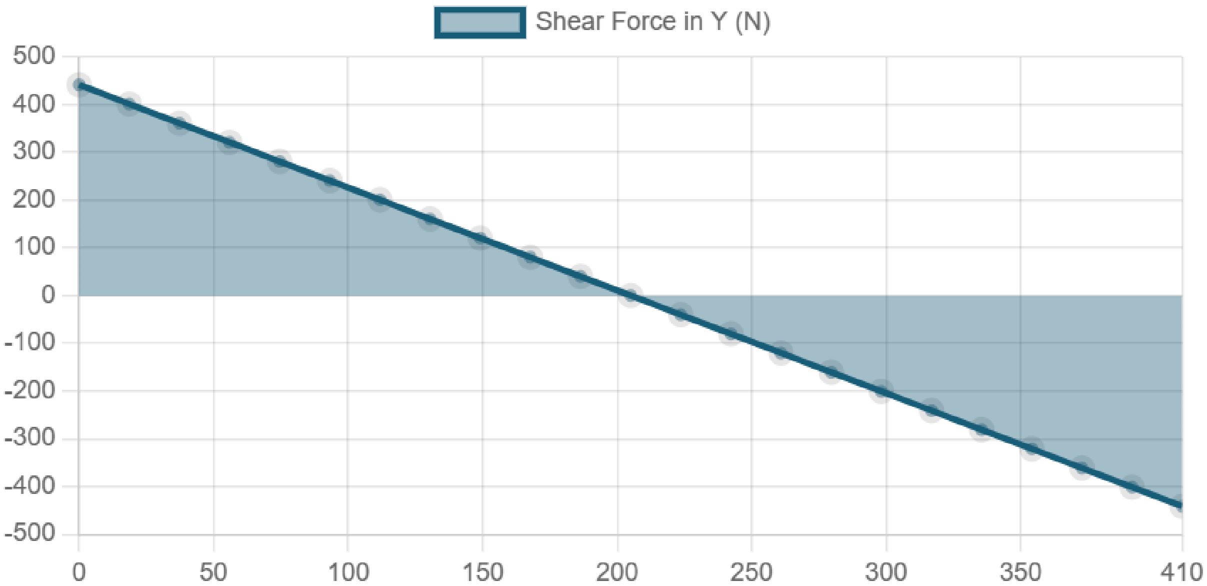


Figure 61: Shear force diagram

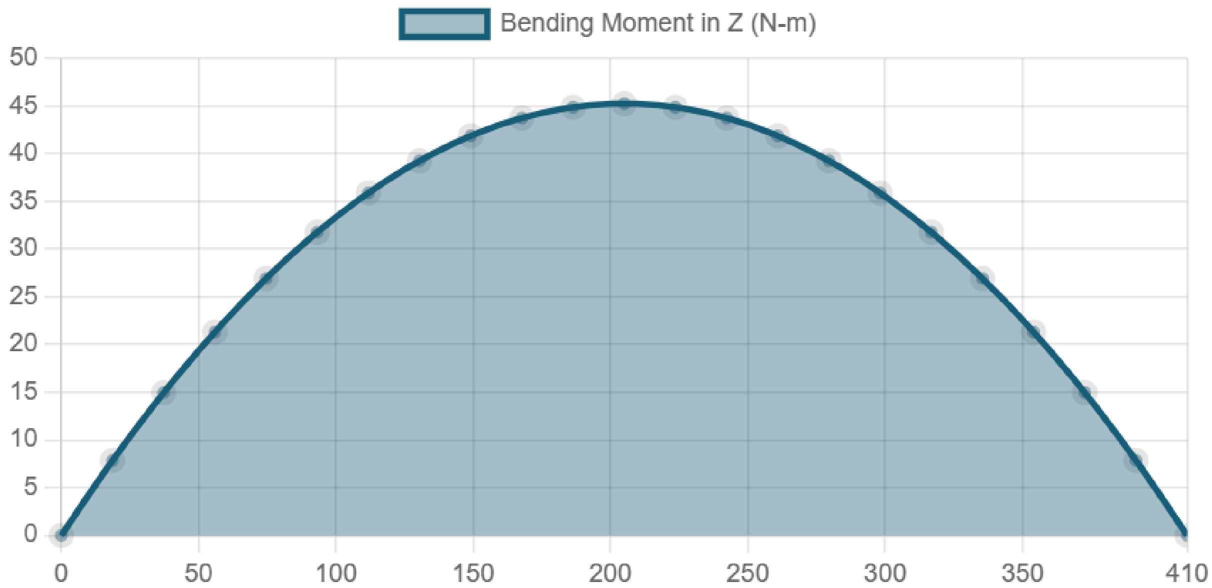


Figure 62: Bending moment diagram

Table 19: Maximum and minimum bending moment and shear force

Result	Max	Min
Bending Moment	45.24 Nm	0
Shear	441.365 N	-441.365 N

Modulus of elasticity of mild steel, E = 210,000 N/mm²

Moment of inertia $I = {}^{\pi}/_{64}\,(22^4 - 19^4) = 5101.897\ \text{mm}^4$

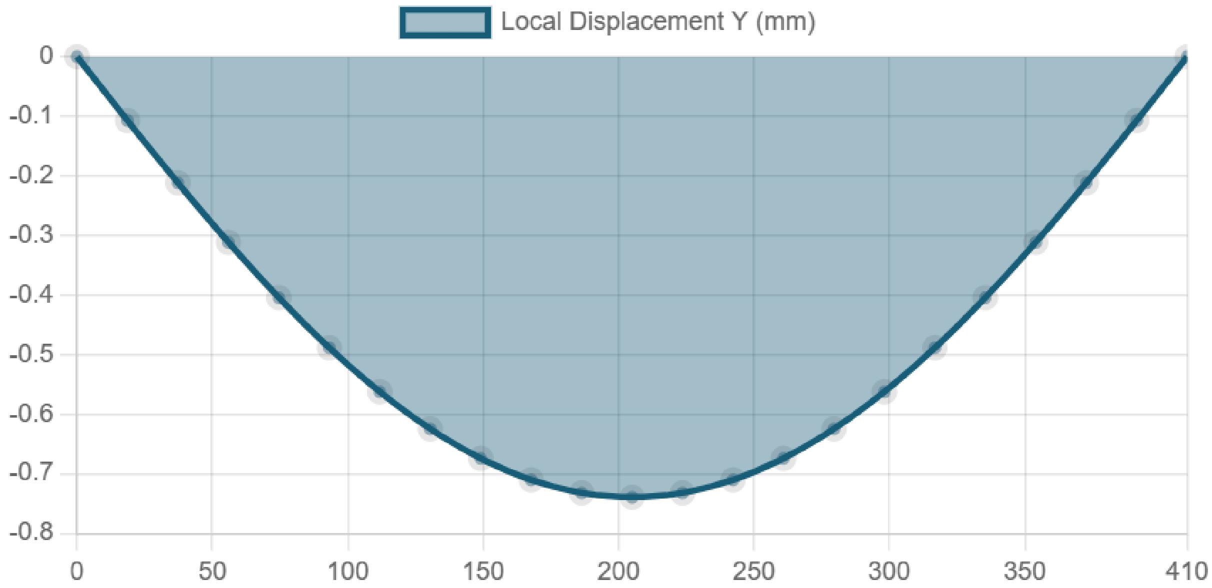


Figure 63: Deflection of the beam

Table 20: Deflection of different position on the beam

Location (mm)	Total deflection (mm)
0	0
205	0.739
410	0

Figure 63 shows the deflection of the beam with a force of 882.9 N. Table 20 shows the location of the maximum and minimum deflection of the beam when a force of 882.9 N is applied.

Outer diameter = 22 mm

Inner diameter = 19 mm

Bending stress (σ) $= \frac{Mc}{I} = \frac{45240 \text{ Nmm} \times 11\text{mm}}{5101.897 \text{ mm}^4} = 97.54 \text{ MPa}$

$\text{Q} = {}^2\!/_3\,(11^2 - 9.5^2)(11 - 9.5)\; mm^3 = 30.75 \text{ mm}^3$

Thickness (t) $= 11 - 9.5 = 1.5$ mm

Shearing stress(τ) $= \frac{VQ}{I*(2t)} = \frac{441.365 \text{ N}\times 30.75 \text{ mm}^3}{5101.897 \text{ mm}^4 \times 3 \text{ mm}} = 0.89 \text{ MPa} \approx 1 \text{ MPa}$

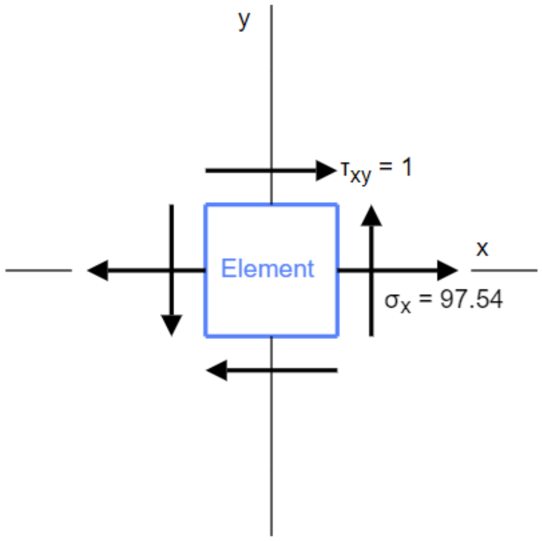


Figure 64: Plane stress element from the beam

Figure 64 shows the picture of a stress element under the maximum bending and shearing stress. The Mohr's circle for the stress element is shown in Figure 65 and the principal stresses are shown in Table 21.

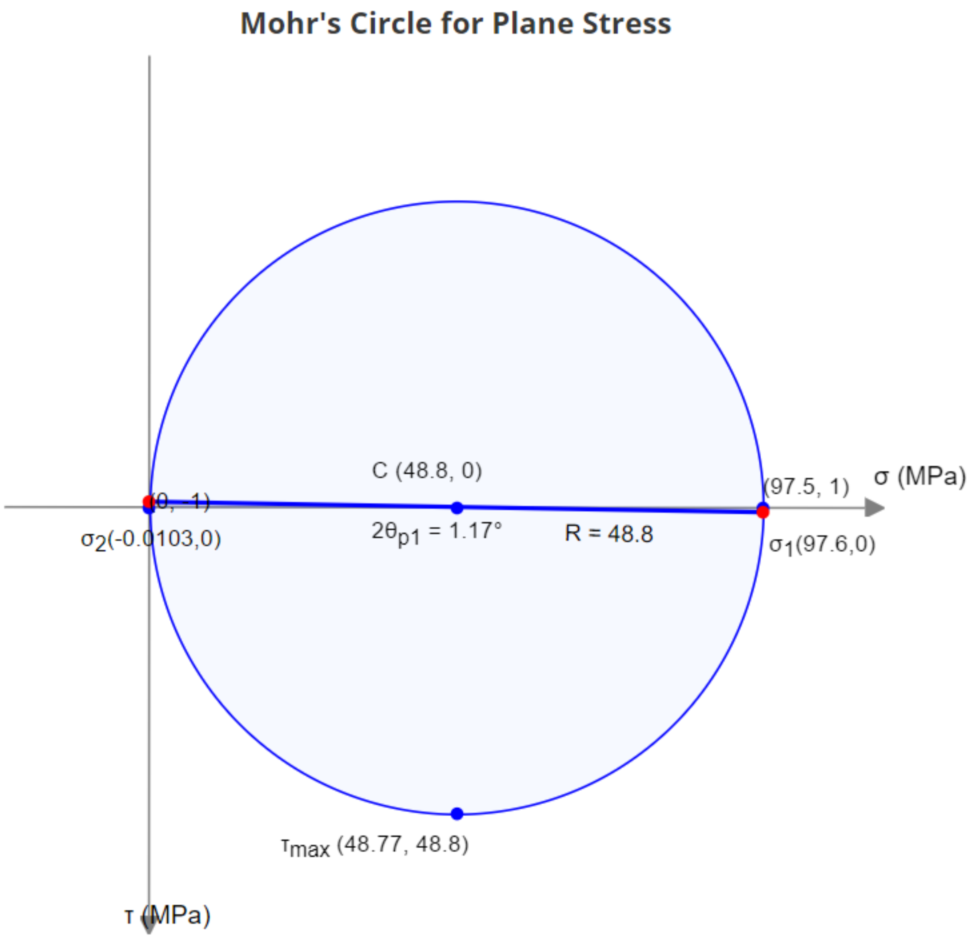


Figure 65: Mohr's circle of the stress element

Table 21: Principal stresses on the beam

Max principal stress	97.55 MPa
Min principal stress	-0.010251 MPa
Von Misses stress	97.56 MPa
Mean Normal stress σ_{av}	48.77 MPa

Figure 66 shows the orientation of the stress element. One of the angles for the principal plane is 0.59° and the plane for maximum shear stress at angle 45.59°

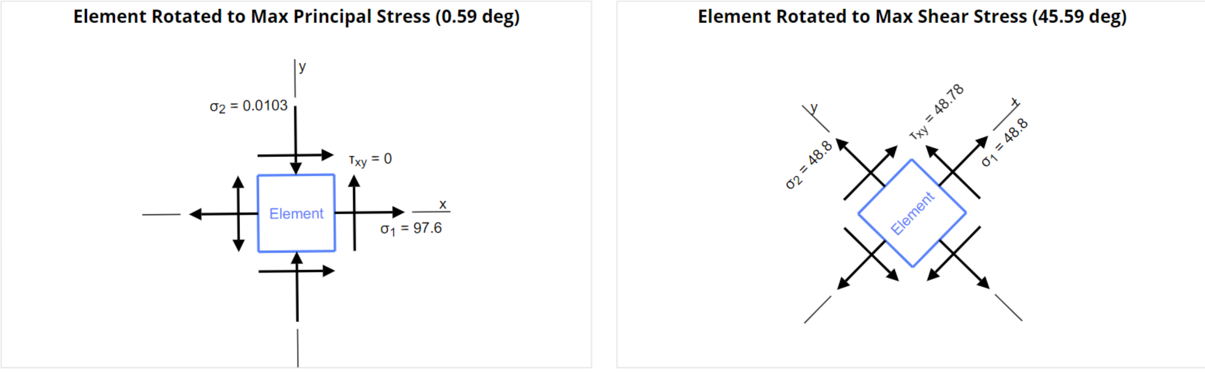


Figure 66: Orientation of the stress element for maximum stresses

Factor of safety:

$$F.S. = \frac{370}{97.55} = 3.8$$

Upon conducting a stress analysis, it was determined that the maximum principal stress experienced by the wheelchair is 97.55 MPa. It is crucial to note that this stress value is significantly lower than the yield strength of mild steel, which is known to be 370 MPa. This indicates that the wheelchair's structure is well within its safe operating limits, with an ample safety margin. So, in this case, the stress experienced by the wheelchair falls well below the yield strength, ensuring a safe and reliable performance. Based on the analysis done, it was implemented a factor of safety of 3.8. This means that the maximum stress value of 97.55 MPa is only a fraction of the stress level that could potentially cause deformation or failure of the structure. With this level of safety, the team was confident in confirming that the wheelchair has been designed and engineered to safely accommodate individuals weighing up to 90 kg.

3.8.1.3 Centre of mass

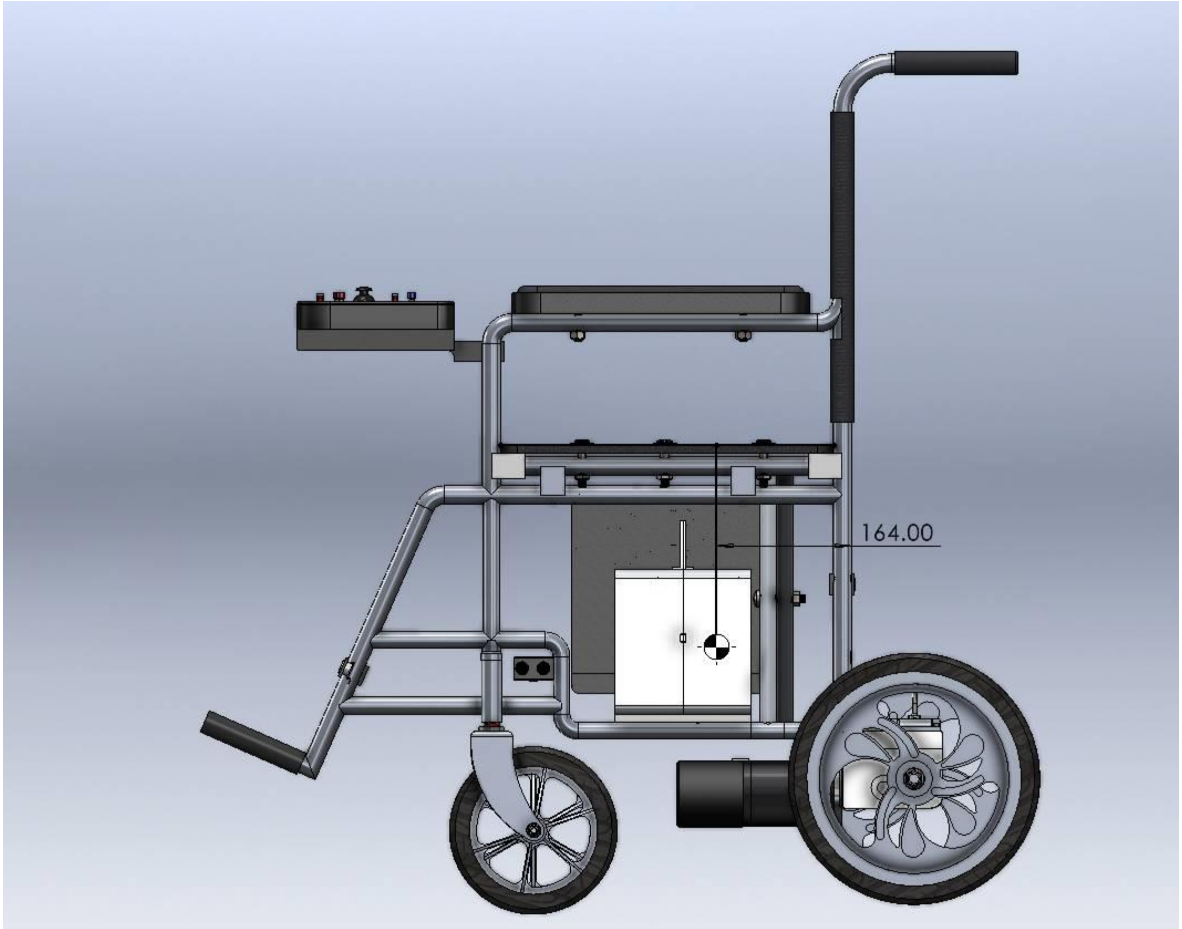


Figure 67: Center of mass (side view)

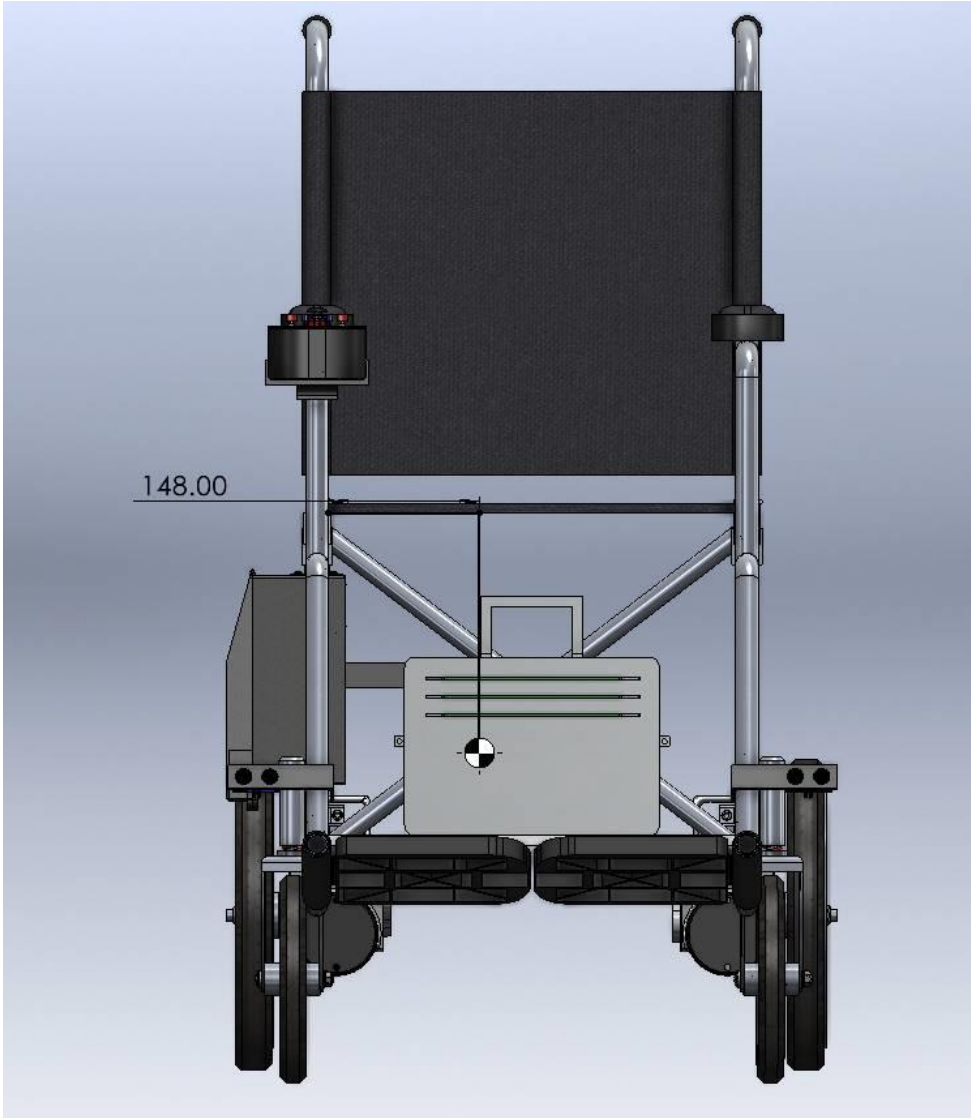


Figure 68: Centre of mass (back view)

The centre of mass of the wheelchair was gotten from SolidWorks and it is shown in Figure 67 and Figure 68. The dimensions in the pictures are in centimetres.

3.8.2 Electrical Subsystem

In this section, parameters such as maximum current needed by the electrical components and run time of the battery will be calculated.

3.8.2.1 Maximum current

The current needed for powering all the electrical components will be calculated in this section.

Table 22: Maximum current of the electrical components

Components	Units	Maximum current for each unit (A)	Maximum current (A)
Motors	2	14.2	28.4
Ultrasonic sensors	4	0.015	0.06
Bluetooth module	1	0.04	0.04
Buzzer	1	0.032	0.032
5mm LEDs	6	0.02	0.12
Arduino Mega 2560 Rev3	1	1	1
Raspberry Pi 4	1	3	3
Total			32.652

Table 22 shows that the maximum total current needed by the components is 32.652 A. This means that the battery chosen must be able to supply a continuous current of around 33 A.

3.8.2.2 Minimum battery run time.

The batteries selected for the design are two 12 V lead-acid deep-cycle batteries. These batteries will be connected in series to have 24 V. It is recommended that only 50% of the capacity should be discharged.

$$Minimum\ run\ time = Battery\ Capacity \times \frac{\%Discharge}{Maximum\ Current\ Drawn} \tag{3}$$

Equation (3) shows the formula for calculating the minimum run time of the battery.

$$Minimum\ run\ time = 20 \times \frac{50\%}{32.652} \times 60\ min = 18.4\ min$$

The minimum run time of the batteries selected is 18.4 minutes. It should be noted that this is the worst-case scenario, and the battery will last more than 18 minutes for normal usage of the wheelchair.

3.9 Simulation

3.9.1 Description

The Smart Mobility wheelchair is an innovative and advanced mobility device that uses speech recognition technology to allow users to control the chair using voice commands. This cutting-edge technology makes it easier for individuals with physical disabilities, who may have limited mobility, to move around independently.

3.9.2 Study Properties

The study properties of the simulation carried out on SOLIDWORKS are shown in Table 23.

Table 23: Study Properties for Simulation

Study name	SM Multi-controlled Autonomous wheelchair static simulation
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	Automatic
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off

3.9.3 Units

The units used in this simulation study are shown in Table 24.

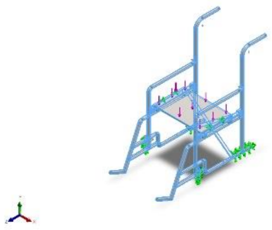
Table 24: Simulation Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

3.9.4 Material Properties

Table 25 shows the properties of the material used for designing the wheelchair.

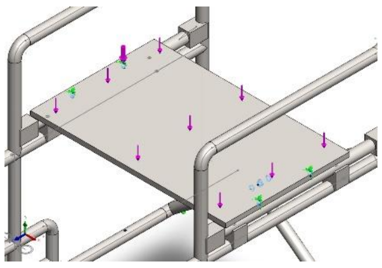
Table 25: Material Properties

Model Reference	Properties	
	Name:	**Plain Carbon Steel**
	Model type:	**Linear Elastic Isotropic**
	Default failure criterion:	**Max von Mises Stress**
	Yield strength:	**2.20594e+08 N/m^2**
	Tensile strength:	**3.99826e+08 N/m^2**
	Elastic modulus:	**2.1e+11 N/m^2**
	Poisson's ratio:	**0.28**
	Mass density:	**7,800 kg/m^3**
	Shear modulus:	**7.9e+10 N/m^2**
	Thermal expansion coefficient:	**1.3e-05 /Kelvin**

3.9.5 Loads & Fixtures

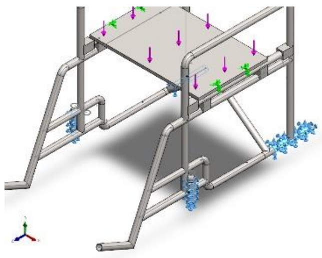
Table 26 contains the details of the load and fixtures used for the simulation study.

Table 26: Load and fixtures

Fixture name	Fixture Image	Fixture Details
Fixed Hinge-1		**Entities:** **12 face(s)** **Type:** **Fixed Hinge**

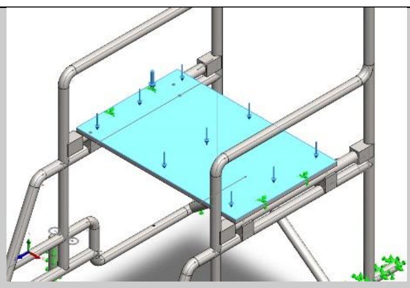
Resultant Forces

Components	**X**	**Y**	**Z**	**Resultant**
Reaction force(N)	**2.81886**	**755.437**	**0.122633**	**755.443**
Reaction Moment (N.m)	**0**	**0**	**0**	**0**

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** **4 face(s)** **Type:** **Fixed Geometry**

Resultant Forces

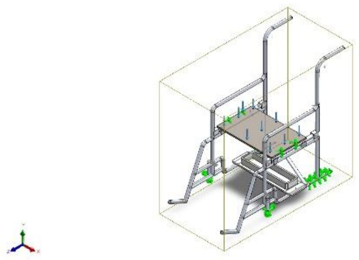
Components	**X**	**Y**	**Z**	**Resultant**
Reaction force(N)	**-2.8289**	**29.0613**	**-0.130615**	**29.199**
Reaction Moment (N.m)	**0**	**0**	**0**	**0**

Load name	Load Image	Load Details	
Force-1		**Entities:**	**1 face(s)**
		Type:	**Apply normal force**
		Value:	**784.5 N**

3.9.6 Interaction Information

Information of the interaction used in the simulation is shown in Table 27.

Table 27: Interaction Information

Interaction	Interaction Image	Interaction Properties	
Global Interaction		Type:	**Bonded**
		Components:	**1 component(s)**
		Options:	**Independent mesh**

3.9.7 Mesh Information

Table 28 contains information on the type of mesh used for the simulation.

Table 28: Mesh information

Mesh type	Solid Mesh
Mesher Used:	Blended curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	45 mm
Minimum element size	2.25 mm
Mesh Quality	High
Remesh failed parts independently	Off
Total Nodes	167344
Total Elements	84882
Maximum Aspect Ratio	193.5
% of elements with Aspect Ratio < 3	22.6
Percentage of elements with Aspect Ratio > 10	4.91
Percentage of distorted elements	0
Time to complete mesh(hh;mm;ss):	00:00:46

3.9.8 Resultant forces

The reaction forces, reaction moments, free body forces, and free body moments for the entire model are shown in Table 29, Table 30, Table 31, and Table 32 respectively.

Table 29: Reaction Forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-0.00999928	784.498	-0.00799751	784.498

Table 30: Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Table 31: Free Body Forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0.748212	-0.822183	0.149287	1.12165

Table 32: Free Body Moments

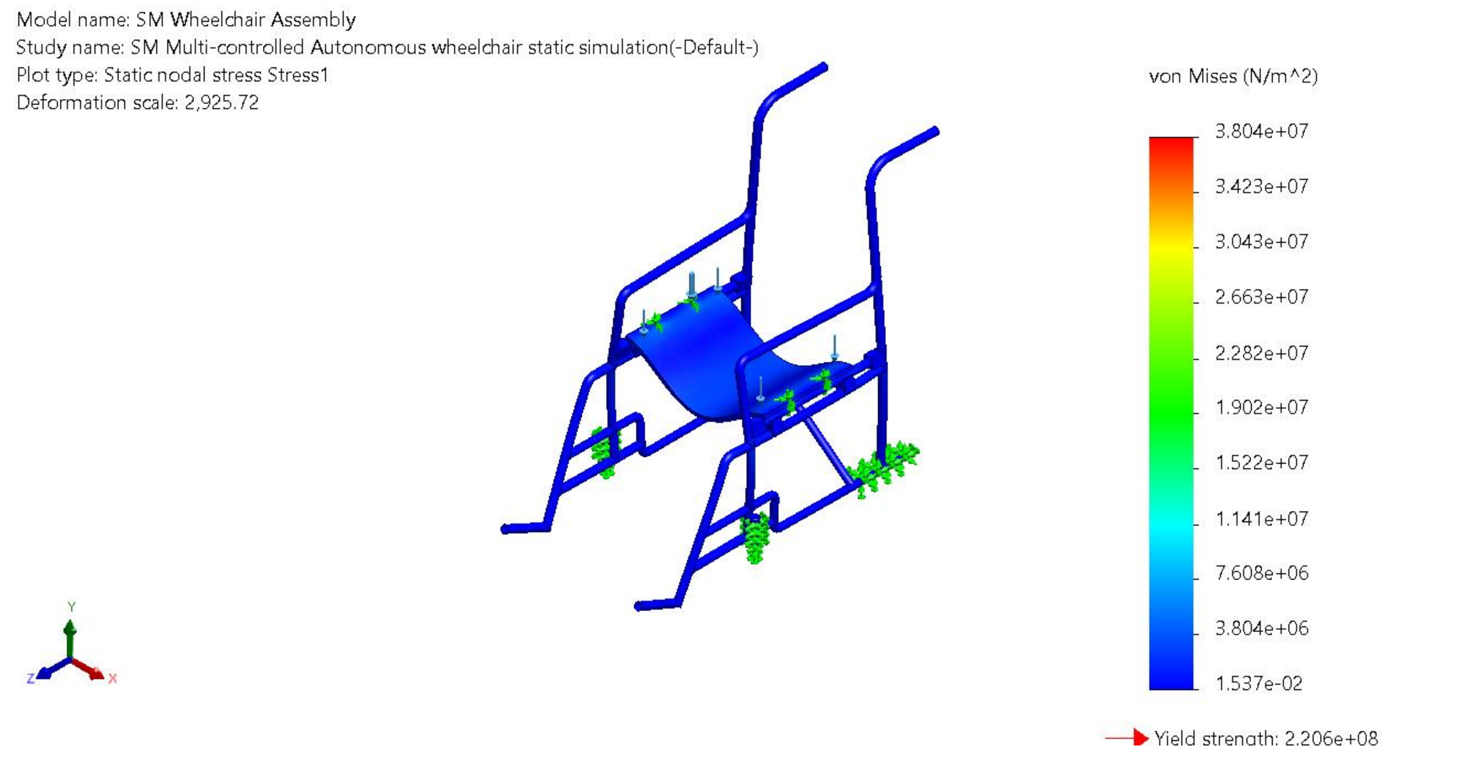
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	1e-33

3.9.9 Study Results

Table 33, Table 34, Table 35, and Table 36 shows the stress, displacement, strain, and factor of safety results of the wheelchair respectively.

Table 33: Stress results

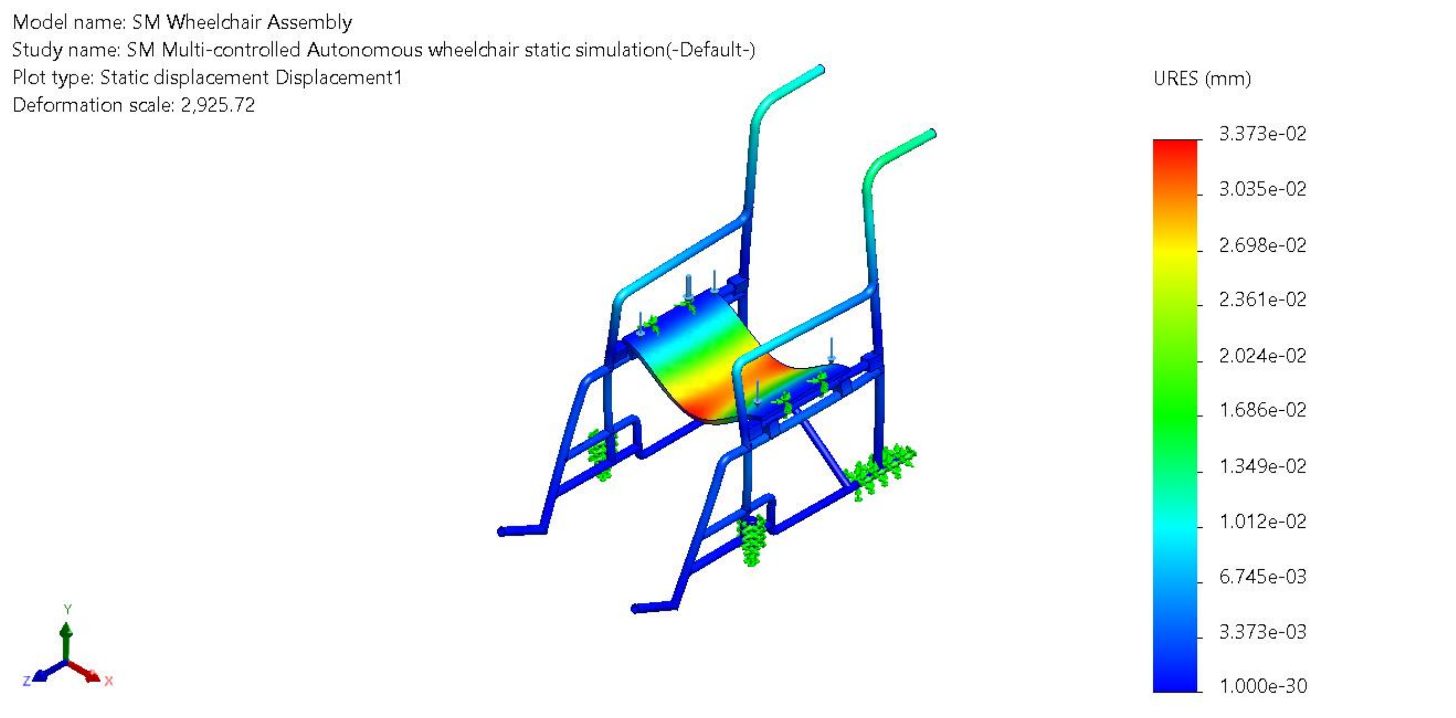
Name	Type	Min	Max
Stress1	VON: von Mises Stress	1.537e-02N/m^2 Node: 34487	3.804e+07N/m^2 Node: 133872



SM Wheelchair Assembly-SM Multi-controlled Autonomous wheelchair static simulation-Stress-Stress1

Table 34: Displacement results

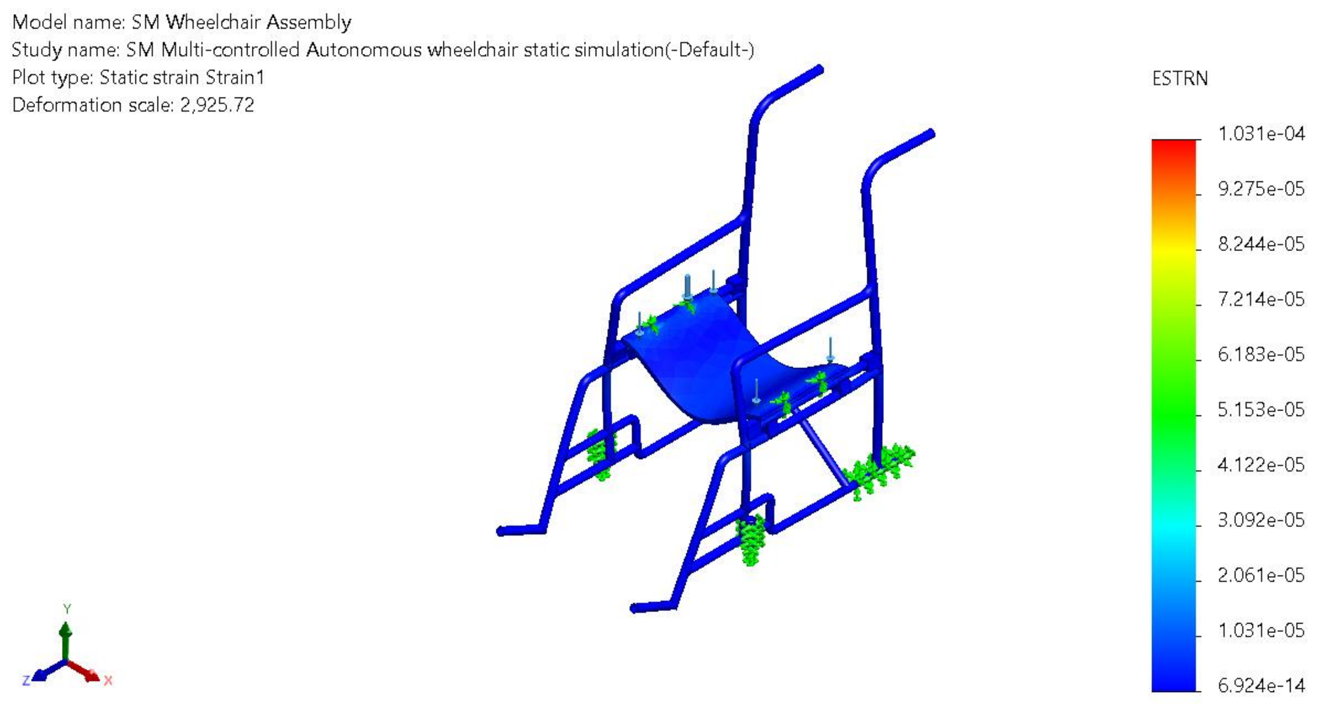
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 16936	3.373e-02mm Node: 16233



SM Wheelchair Assembly-SM Multi-controlled Autonomous wheelchair static simulation-Displacement-Displacement1

Table 35: Strain Results

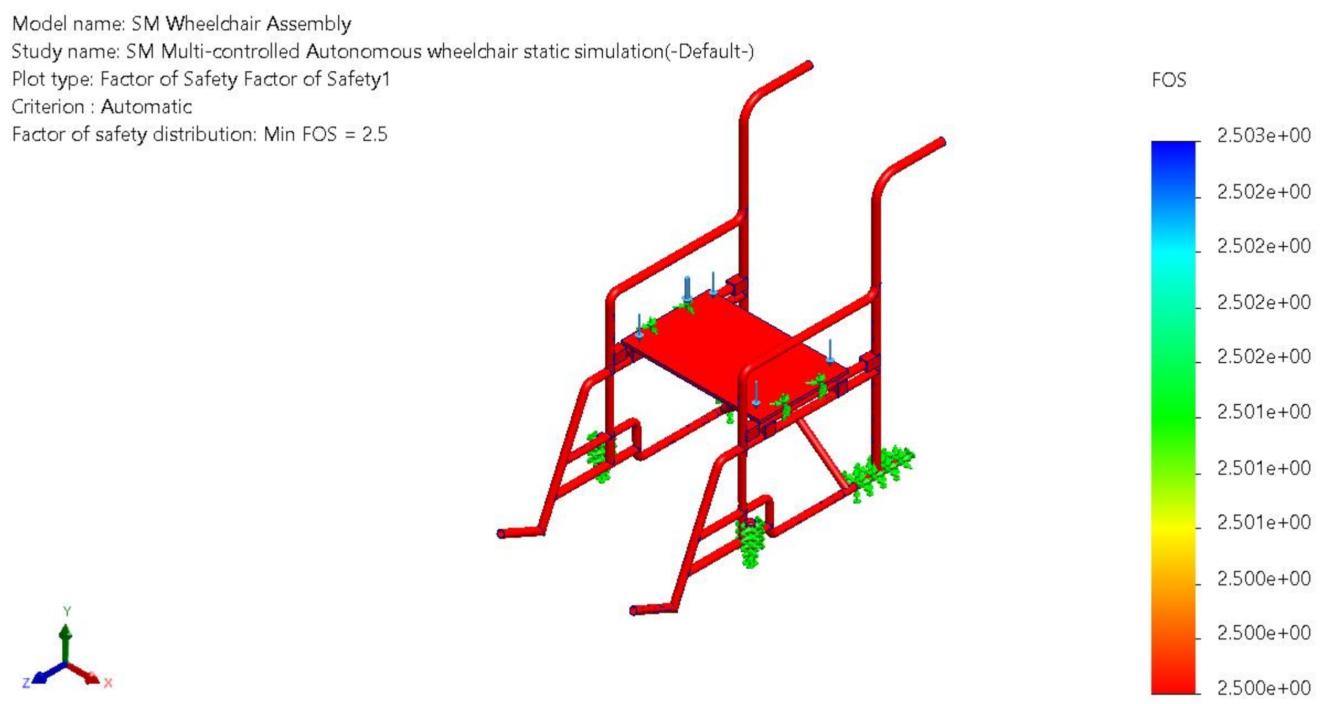
Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	6.924e-14 Element: 60023	1.031e-04 Element: 79671



SM Wheelchair Assembly-SM Multi-controlled Autonomous wheelchair static simulation-Strain-Strain1

Table 36: Factor of safety results

Name	Type	Min	Max
Factor of Safety1	Automatic	2.500e+00 Node: 1	2.500e+00 Node: 1



SM Wheelchair Assembly-SM Multi-controlled Autonomous wheelchair static simulation-Factor of Safety-Factor of Safety

3.9.10 Conclusion

In conclusion, the static analysis performed on the system yielded valuable insights regarding its structural integrity. The Factor of Safety, calculated to be 2.5 indicates that the system is capable of withstanding loads well above the applied forces, providing a margin of safety. The analysis of strain revealed minimal strain levels, with a minimum strain of 6.924×10^{-14} and a maximum strain of 1.031×10^{-4}. These results indicate that the system is experiencing negligible deformation under the given load conditions, highlighting its stability and robustness. Furthermore, the maximum displacement observed in the system was measured to be 3.373×10^{-2} mm. This displacement value suggests that the system maintains its structural integrity and remains within acceptable limits during operation. The assessment of stress using the von Mises criterion revealed a range of stress values. The minimum von Mises stress was calculated to be $1.537 \times 10^{-2}\ \mathrm{Nm}^{-2}$, indicating relatively low stress levels. The maximum von Mises stress was determined to be $3.804 \times 10^{7}\ \mathrm{Nm}^{-2}$, signifying the highest stress experienced by the system. Overall, the static analysis results indicate that the system is well-designed and capable of withstanding the applied loads without compromising its structural integrity. These findings provide confidence in the system's performance and validate its suitability for the intended application. However, it is important to consider other factors such as dynamic loads, long-term durability, and material properties to ensure a comprehensive understanding of the system's behaviour and performance in real-world scenarios.

3.10 Cost analysis

During the design of the speech-controlled wheelchair, some materials will be purchased. The details of the project expenses are shown in Table 37.

Table 37: Bill of Materials

S/N	Part no.	Part Name	Description	Vendor	Quantity	Price/unit	Total USD
1	1-2-2-1	Arduino Mega	2560 Rev3	Robotistan	1	20.5	20.5
2	1-2-2-2	DC Motor	24V hybrid brushed motor	Keskinler	2	196.25	392.5
3	1-2-1-1	Ultrasonic sensor	HC-SR04	Aliexpress	4	1.5	6
4	1-2-3-1	Battery	12V lead acid	AYSE KOSE	2	39	78
5	1-2-3-2	Battery charger	24V charger	EMU Computer centre	1	10	10
6	1-2-4-1	Buzzer	Active buzzer	Robotistan	1	0.5	0.5
7	1-2-2-3	Joystick	Arduino joystick	Robotistan	1	0.8	0.8
8	1-2-4-2	Push buttons		Robotistan	6	0.5	3
9	1-2-2-4	Bluetooth Module	CC2541 HM-10	Robotistan	1	5	5
10	1-2-2-5	Motor Driver	IBT-2 (BTS7960B)	Robotistan	2	8	16
11	1-2-4-3	Buck converter	3A step down	Robotistan	3	2.5	7.5
12	1-2-2-6	Voice recognition module	Elechouse Voice Recognition Module V3	n11	1	50	50
13	1-2-2-7	Microphone	USB microphone	n11	1	5	5
14	1-2-1-2	Temperature Sensor	LM35DZ	Robotistan	1	1.5	1.5
15		Resistors	330ohm-4.7Kohm - 59Kohm-10Kohm	n11	4	0.8	2.25
16		Veroboard			1	1.5	1.5
17		Cables	Multiple cables + jumpers	Robotistan & Izmir electric	------	-------	5.25
18		Filament	PLA	Robotistan	1	12	12
19		Cables connectors		Izmir Electric	4	1.9	7.5
20	1-2-4-4	Fan	12V	EMU Computer centre	2	2.5	5
21	1-1-1-9	Seat	Nylon seat	Yummy bite restaurant	1	5	5

Table 38: Total Cost

Cost Breakdown	
Cost of components	$525
Cost of Shipping	$41
Transportation	$8
Tax 18%	$ 103
Total	$ 677

The cost of the DC motors is the highest in comparison with the cost of other electronic components. It is estimated that the electrical components will make up 89% of the overall cost incurred while working on the speech-controlled wheelchair. Some of the goods will be procured locally and the rest internationally, so the prices are both based on the local and international markets. Prices of goods that will be procured locally are converted to its equivalent in USD, the prices of some product may fluctuate depending on the time of purchase and current exchange rate.

Table 38 shows the total cost breakdown of the project. The pie chart of the total cost can also be seen in Figure 69. After a thorough comparison of the price of automated/smart wheelchairs in the current market and the overall price that was spent on the project, the team found out that ours is cheaper, the average price of similar wheelchairs in the current market is $985, and the total amount spent on the project is around $700. This indicate that the resources and components used by the group were effectively allocated.

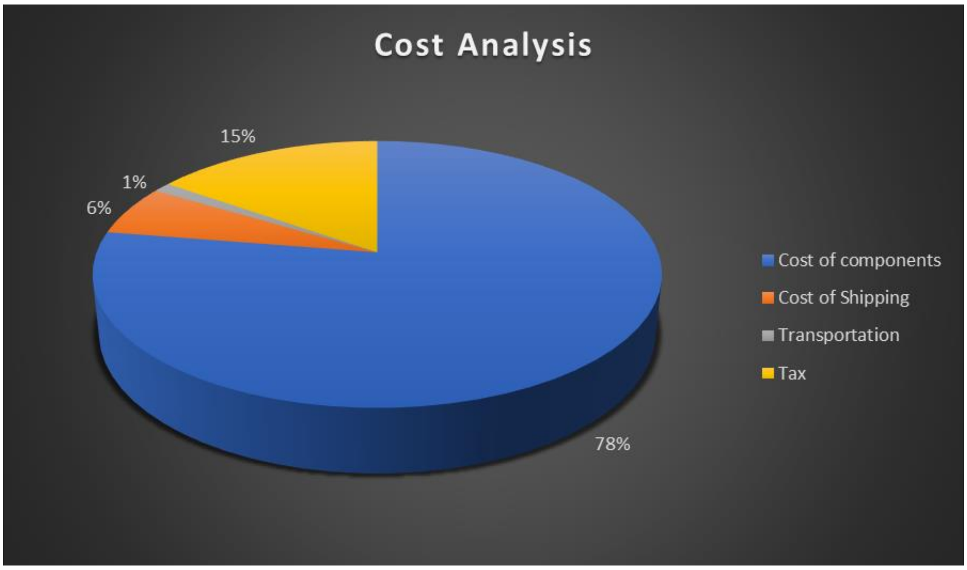


Figure 69: Pie chart of the expenses

3.11 Wheelchair control

The wheelchair has three control methods: voice, joystick, and smartphone. In this section, all the control methods of the wheelchair will be discussed. When the wheelchair is turned on, the default control is voice control. This is to ensure that tetraplegic patients can use the wheelchair once it is turned on. Other class of users can change the control to his/her preferred control by pressing the change mode button. The system flowchart is shown in Figure 71. Three LED lights on the controlling box are used to indicate the current mode of the wheelchair.

Figure 70 shows the overall system design of the wheelchair. The Raspberry Pi is used to accept and process the voice commands. HC 05 Bluetooth module is used to connect the controller to the Android phone of the user for control. The controller uses the inputs from the ultrasonic sensors to decide on the next action to take. If there is an obstacle in front of the wheelchair and the user commands the wheelchair to go forward, the controller will not send any drive signals to the motor drivers. So, the wheelchair will not move forward. The same thing happens when there is an obstacle behind or at the sides of the wheelchair.

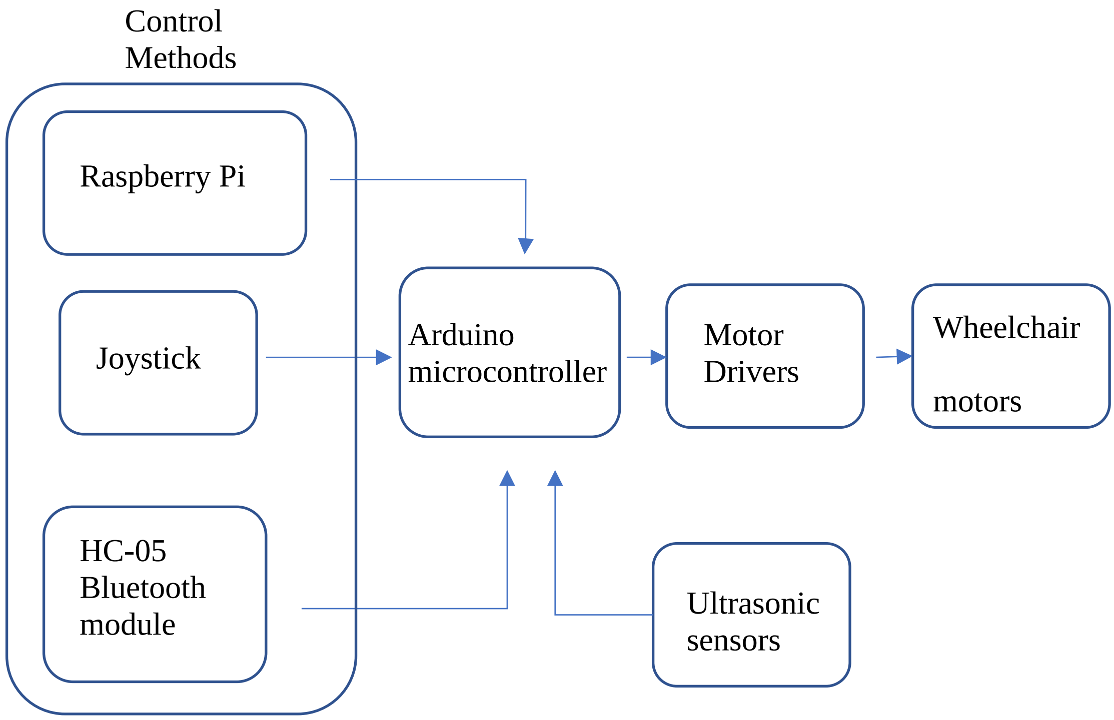


Figure 70: Overall system design

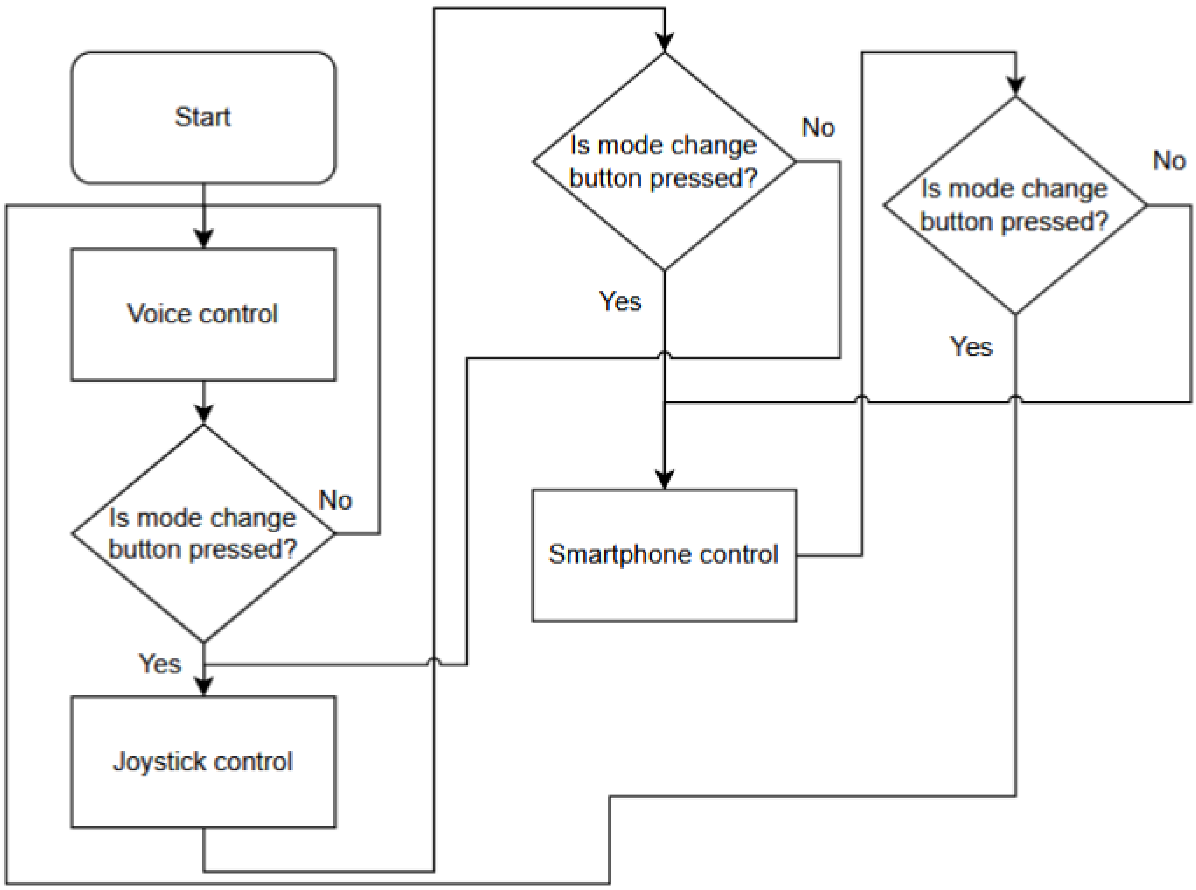


Figure 71:System Flowchart

3.11.1 Voice control

A microphone is connected to a Raspberry Pi for voice control. A Python script is used to record the voice of the user and send it to Google's speech-to-text API. The response gotten from the API contains the user's command in text. Keywords such as “forward”, “reverse”, ‘left’, “right”, and “stop” are looked for in the response.

If the user says “forward”, the Python script running on the Raspberry Pi recognises it and sends a command to the Arduino microcontroller through serial to move the wheelchair forward. If the user says “left”, a command to move the wheelchair to the left is sent to the microcontroller. The same process is done for “right”, “stop”, “reverse”, and “stop”.

When the microcontroller receives any command from the Raspberry Pi, it checks if there is any obstacle along the specified movement direction. If there is no obstacle, the microcontroller sends commands to the motor drivers to move the wheelchair accordingly. If there is an obstacle along the specified direction, the wheelchair stops.

If there is no input from the user, the microcontroller uses the last input received as the current input. This means that if the user says “forward”, the wheelchair moves forward. If there are no more commands from the user, the wheelchair keeps going forward till it reaches an obstacle.

Figure 72 shows the flowchart for voice control.

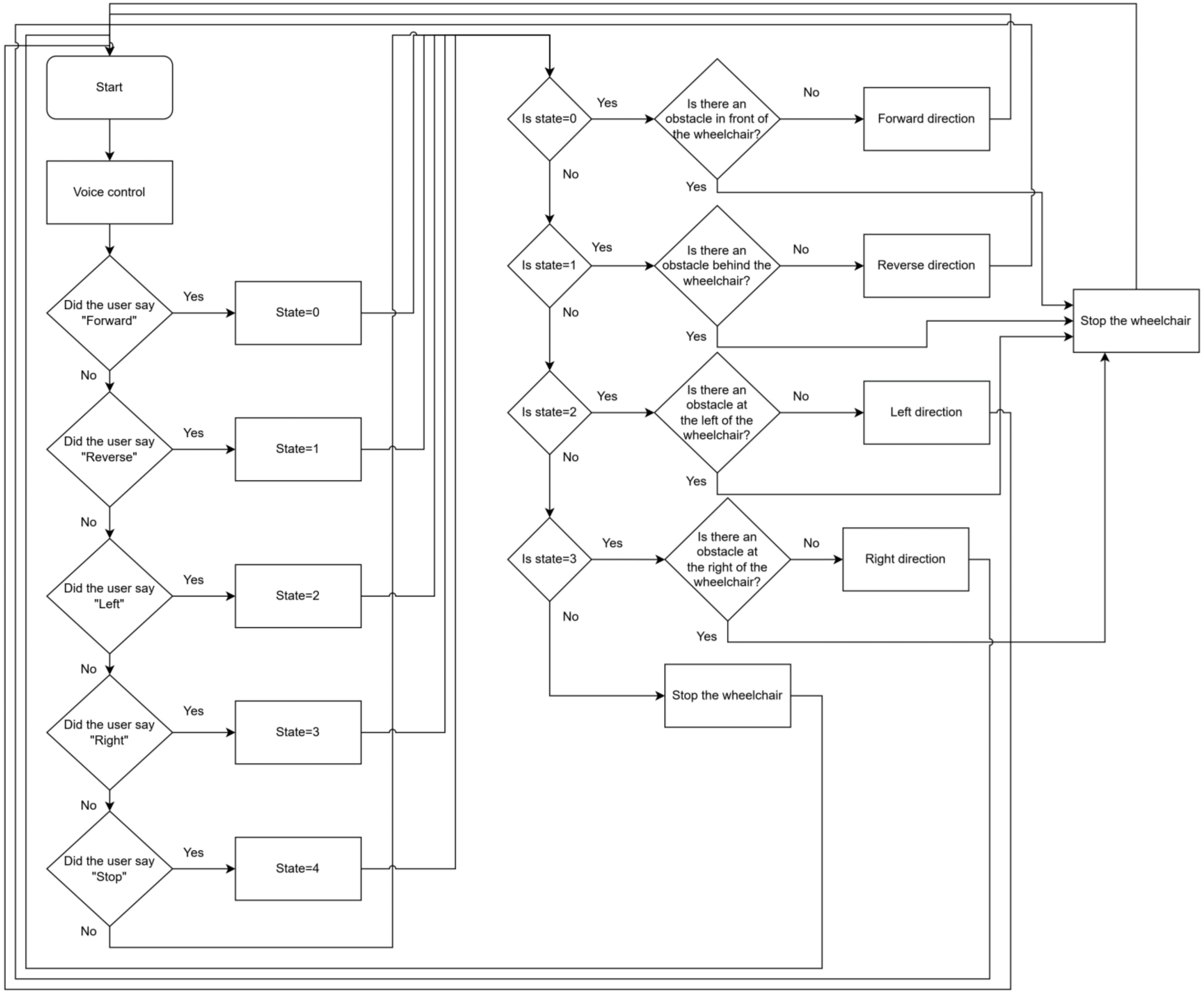


Figure 72: Flowchart for voice control

3.11.2 Joystick control

The joystick module sends analog values (x and y) that represents the position of the joystick to the controller. These analog values range from 0 to 1023. Figure 73 shows the operating range of the joystick on the wheelchair.

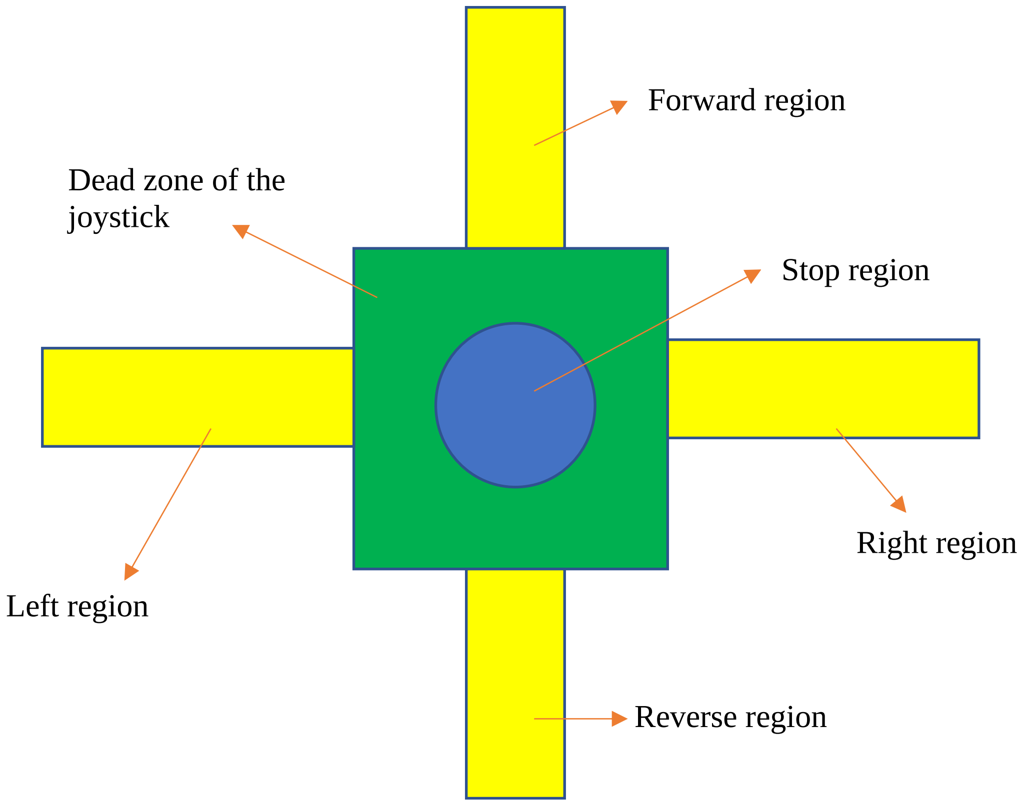


Figure 73: Operating range of the joystick

The blue area in Figure 73 represents the joystick when it is at rest. If the joystick is in this area, the wheelchair stops.

If the joystick is pushed to the forward region and there is no obstacle in front of the wheelchair, the wheelchair moves forward. The speed of the wheelchair in forward motion is dependent on the distance of the joystick from the centre. If the joystick is at the maximum point in the forward region, the wheelchair will move at the maximum set speed.

The wheelchair moves to the right when the joystick is moved to the right region and there is no obstacle at the right of the wheelchair. The speed of turning is also dependent on the distance of the joystick from the rest position. The wheelchair moves to the left when the joystick is moved to the left region and there is no obstacle at the left of the wheelchair. The wheelchair's turning speed depends on the distance of the joystick from the rest position.

The wheelchair moves in reverse when the joystick is moved to the right region and there is no obstacle behind the wheelchair. The speed of the wheelchair when reversing is set to a fixed value.

The wheelchair will stop if the joystick is placed at any position that is not in the fixed regions. The wheelchair does not move if the joystick is placed within its dead zone. This is to prevent the wheelchair from moving when the joystick is accidentally moved. The wheelchair also stops when there is an obstacle where it wants to move to. So, if the user moves the joystick to the forward region and there is an obstacle in front of the wheelchair, the wheelchair will stop. The same thing goes for all the regions of the joystick.

The flowchart for joystick control is shown in Figure 74.

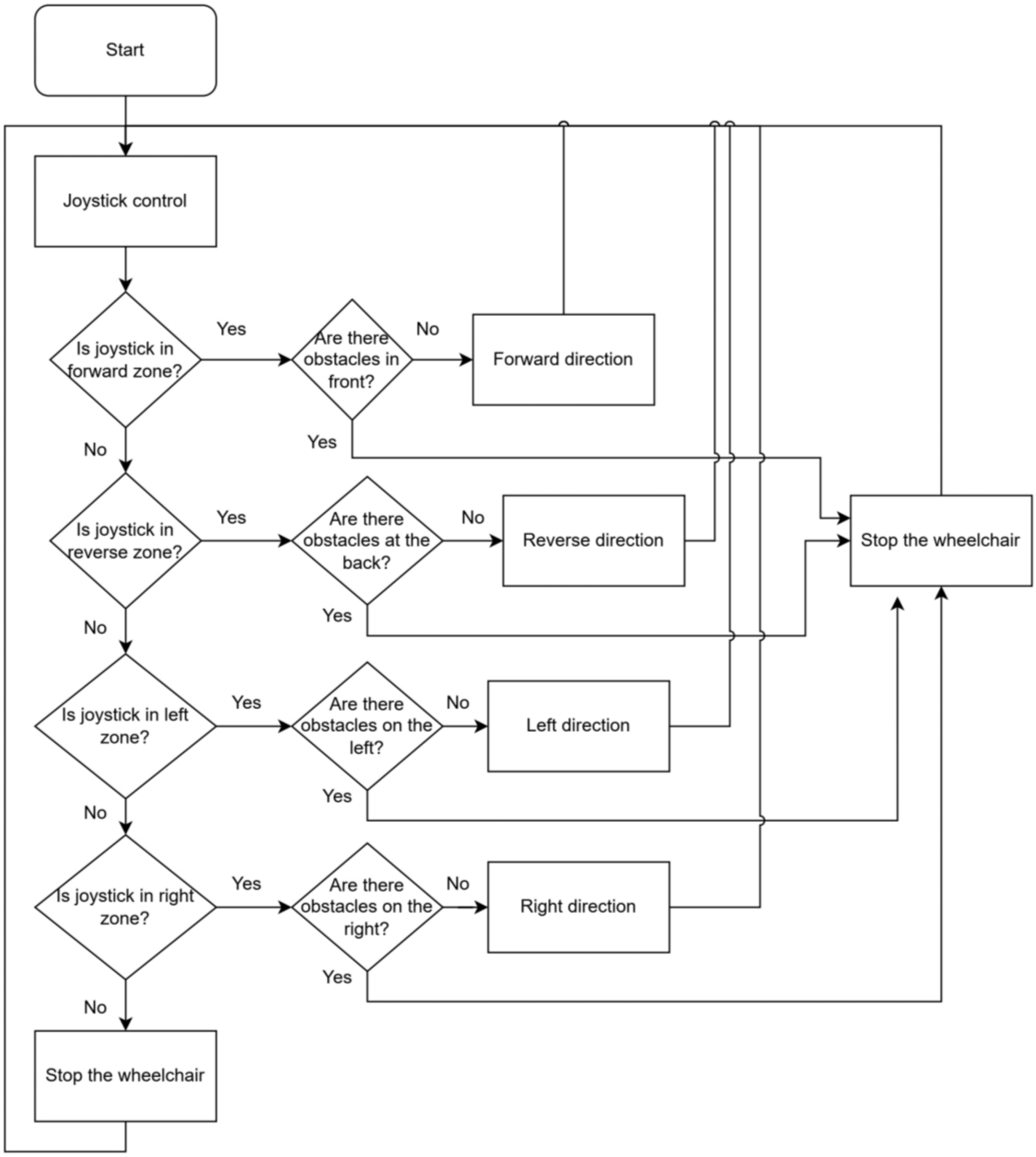


Figure 74: Flowchart for joystick control

3.11.3 Smartphone control

When the wheelchair is in smartphone control mode, it uses commands received from a smartphone to control the wheelchair. An Android app was made specifically for controlling the wheelchair. Figure 75 shows the home screen of the SMobility application.

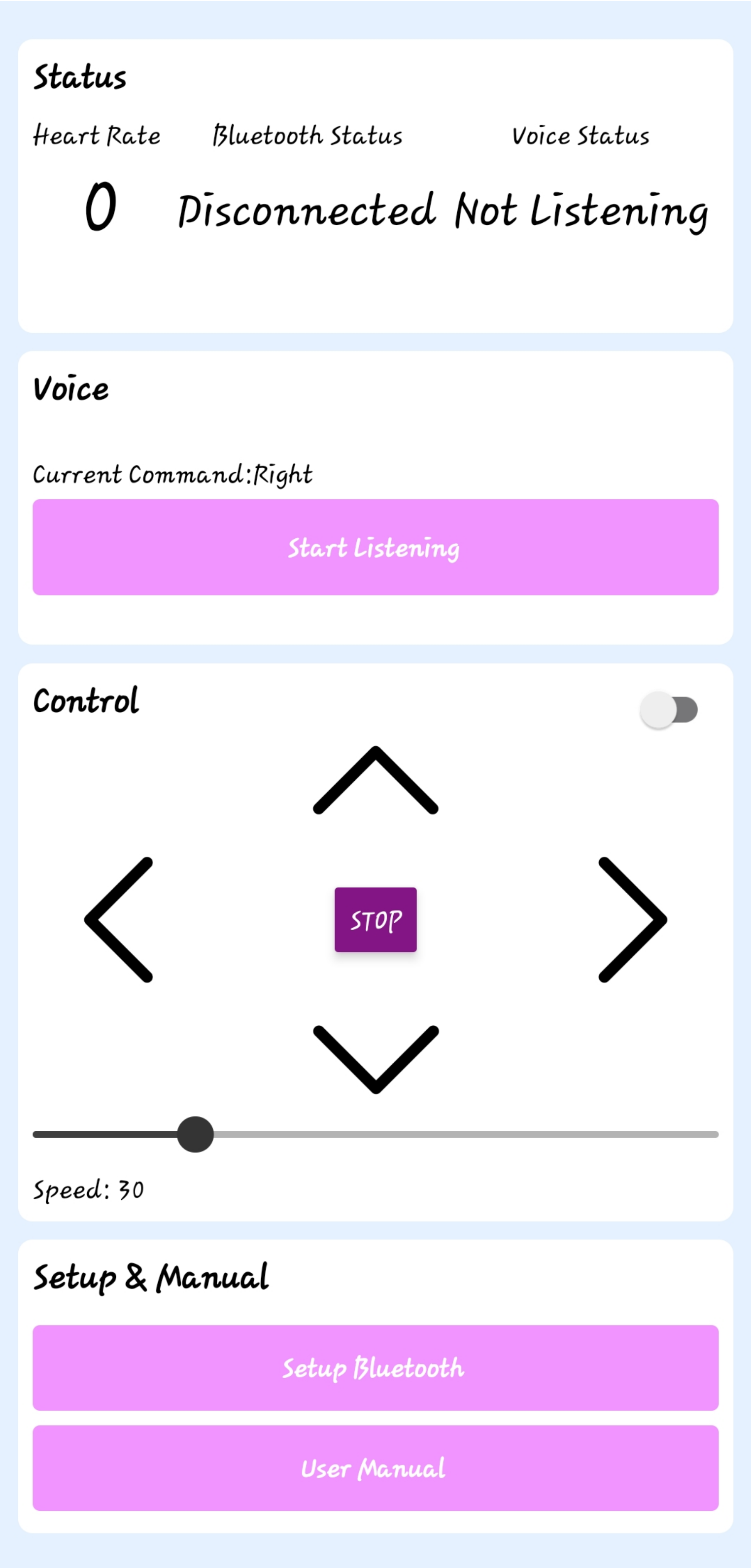


Figure 75: User interface of the SmartMobility Android application

The user of the application can control the wheelchair using buttons or voice. The user can also check his/her heart rate and change the speed of the wheelchair from the application.

The application constantly listens for command if voice control is activated on the application. The mode of operation is like the voice control made using Raspberry Pi. The flowchart is shown in Figure 72.

If the user decides to use the buttons for controlling the wheelchair, he/she can click on the desired direction and wheelchair will move accordingly provided there is no obstacle along its path. If any of the directional button is long-pressed, the wheelchair will move in the specified direction. The wheelchair will continue to move in that direction even if the user stops clicking on the button. To stop the wheelchair, the user must press the stop button in the application.

3.11.4 Movement of the wheelchair

The wheelchair moves forward when the microcontroller sends commands to the two motor drivers to move the motors forward (clockwise). The speed of the wheelchair is determined by the user. Three levels of speed are available for the user to choose from.

The wheelchair moves backwards when the microcontroller sends commands to the two motor drivers to move the motors in reverse (counterclockwise). The speed of the wheelchair when it is going in reverse is fixed to a small value. This is to ensure the safety of the user. When the wheelchair moves in reverse, a buzzer sounds to alert passers-by.

The wheelchair moves to the left by increasing the speed of the right motor and reducing the speed of the left motor (close to 0).

The wheelchair moves to the right by reducing the speed of the right motor and increasing the speed of the left motor.

CHAPTER 4 - MANUFACTURING

4.1 Manufacturing process selection

The necessary components for the manufacturing of the multi-controlled smart wheelchair project were vetted based on the following criteria: material compatibility, design complexity, and cost effectiveness, during the selection process of the materials & components.

Material compatibility: The materials selected for the project were evaluated in contrast to other viable options in other to ensure the chosen manufacturing process would be suitable for those materials. Since the frame of the wheelchair was composed of metal, it was important to selected processes that works effectively with metal. After careful considerations it was determined that welding and machining were the most suitable options for the wheelchair frame. Welding was selected as it allowed us join metal components together firmly while ensuring durability and strength. Machining process such as milling or turning enable us to shape and refine the metal parts precisely while ensuring dimension accuracy and smooth surface finish. Be selecting the right materials & process for the frame, the structural integrity of the wheelchair was ensured.

Design complexity: Due to the complexity of the wheelchair, it was critical to select process considering the precise and intricate designs needed in some components of the wheelchair. To achieve this, manufacturing processes that can handle the design complexity efficiently was chosen. 3D printing proved invaluable in creating complex geometries with high precision. This process was used in printing the controlling unit and joystick controller of the wheelchair. The team was able to put our creative design concepts into practice by using these procedures, creating a wheelchair that combines functionality with an appealing appearance.

Cost effectiveness: The cost effectiveness was a very significant criteria in the manufacturing process as resources were limited. It was aimed to maximize the value that was derived from the allocated budget. It was carefully evaluated different manufacturing processes and compared their cost, including equipment, shipping fees, production expenses etc. Balancing cost and quality, processes like 3D printing were very effective for small scaled production.

4.1.1 Make or Buy decision for the Wheelchair Frame (1-1-1)

The decision to compare the pros and cons of making the wheelchair frame versus buying one was made by the team. During the research, it was discovered that purchasing the frame from external suppliers was found to be more cost effective and time efficient than making one. Another added advantage was that the time spent making a new frame could be utilized to focus on other critical aspects of the project. After carefully evaluating the options, the decision was made by the team to buy a frame.

4.1.2 Tubes production

In this section, the manufacturing process that should be done if the frame is to be manufactured is explained. To get the desired tubes, a large trustable company that manufactures a wide range of tube dimensions is to be contacted. The dimensions which were mentioned in the design are to be sent to the company to make the tubes. The company should meet the ISO9001 and ISO14001 standards.

After being received from the manufacturer, the tubes will be cut into the desired dimensions. Subsequently, the tubes will be cleaned and taken to the bending machine, where they will be bent to the desired radius and ground to prepare them for welding. Nowadays, there are many different bending machines available. In this project, the chosen bending method is compression tube bending, which will be executed using the compression bending machine.

The welding process that should be used is TIG welding or MIG. The welding should be done carefully by the trained members of the team under the guidance of an expert welding mechanic. Finally, the wheelchair can be assembled.

4.2 Detailed manufacturing process

4.2.1 Frame (1-1-1)

To kick off the multi-controlled smart wheelchair project, our team obtained a scrap wheelchair with the aim of refurbishing it. The first step was to dismantle the frame, after which it was carefully sanded away any rust using sandpaper. Figure 76 shows the picture of the frame before rust removal. Once the frames were free of rust, a coat of paint was applied to protect the metal from further corrosion. Figure 77 shows the wheelchair frame after the painting process was complete.

Figure 76: Dismantled frame before rust removal

Figure 77: Wheelchair frame after painting

4.2.2 Rear wheels (1-1-1-1-1)

The motor and wheels of the multi-controlled smart wheelchair underwent a series of manufacturing processes to ensure optimal performance. Prior to fitting the wheels onto the motor, a section of the wheels was machined, and a step-down shaft adapter was created to fit the wheels onto the motor's shaft. To create the wheel connectors, an automatic power hacksaw machine to cut a round bar to precise measurements was used. Then, circular holes into both connectors using a horizontal turning machine were drilled. To complete the process, a keyway was drilled into both connectors using a lathe machine. These meticulous manufacturing steps ensured that the wheels can properly fit to the motor. Figure 78 shows the connector fitted into the wheels.

Figure 78: Machined connector fitted into wheels

4.2.3 Caster (1-1-1-6)

After the rear part of the wheelchair was addressed, the team shifted their attention to the castor wheels. The first task involved cleaning the frame for the castor wheels using sandpaper, followed by the careful attachment of the wheels to the frame. However, it was observed that the castor wheels did not establish proper contact with the ground surface, potentially impacting the wheelchair's stability and manoeuvrability in a negative manner. To address this issue, it was decided to weld the castor wheel holder into a new position, making it lower. After completing the welding process, the castor wheels were re-fitted and it was ensured they made proper contact with the ground. This careful adjustment allowed us to improve the overall stability and manoeuvrability of the wheelchair, resulting in a more comfortable and safe user experience. Figure 79, Figure 80, and Figure 81 shows the manufacturing process taken for the caster tubes.


Figure 79: Caster tubes during welding


Figure 80: Caster before welding and after welding the new tube

Figure 81: Caster fork before painting and after painting

4.2.4 Battery box (1-1-1-3)

As part of the wheelchair design, a wooden compartment was constructed to serve as a dedicated and secure housing for the two 12V batteries. The purpose of this compartment was to provide a protective enclosure, ensuring that the batteries were securely held in place and protected from potential damage. To facilitate maintenance and easy access to the batteries, hinges were installed on the battery box. These hinges allowed the box to be opened and closed, providing convenient access to the batteries whenever necessary.

As part of the machining process, specific features were incorporated into the battery box. A keyway was machined to accommodate the battery charging adapter, allowing for easy and secure connection during the charging process. Additionally, a pathway was created for the wire that powers the Arduino box, ensuring a neat and organized arrangement of the electrical components. Furthermore, a switch was installed to control the power supply to the wheelchair, and a suitable space was machined to accommodate it. Once the machining process was completed, the battery box underwent a finishing touch by being painted black. This painting not only added an aesthetic appeal but also provided an additional layer of protection against moisture and environmental factors. Figure 82 and Figure 83 shows the manufacturing process carried out on the battery box.

Figure 82: Battery box before and after painting

Figure 83: Battery box machining

4.2.5 Arduino box (1-1-1-2)

A box compartment was acquired to house most of the electrical components along with two fans. To facilitate cooling, holes and gaps were drilled into the box compartment, allowing for the dissipation of heat. Furthermore, a power port hole was drilled into the box to provide a convenient access point for power connections. The advantage of using this box is organizing the wires and protecting the sensitive sensors and parts. ISO 7176-14 was followed when making this box. Figure 84 shows the machining process of the Arduino box.

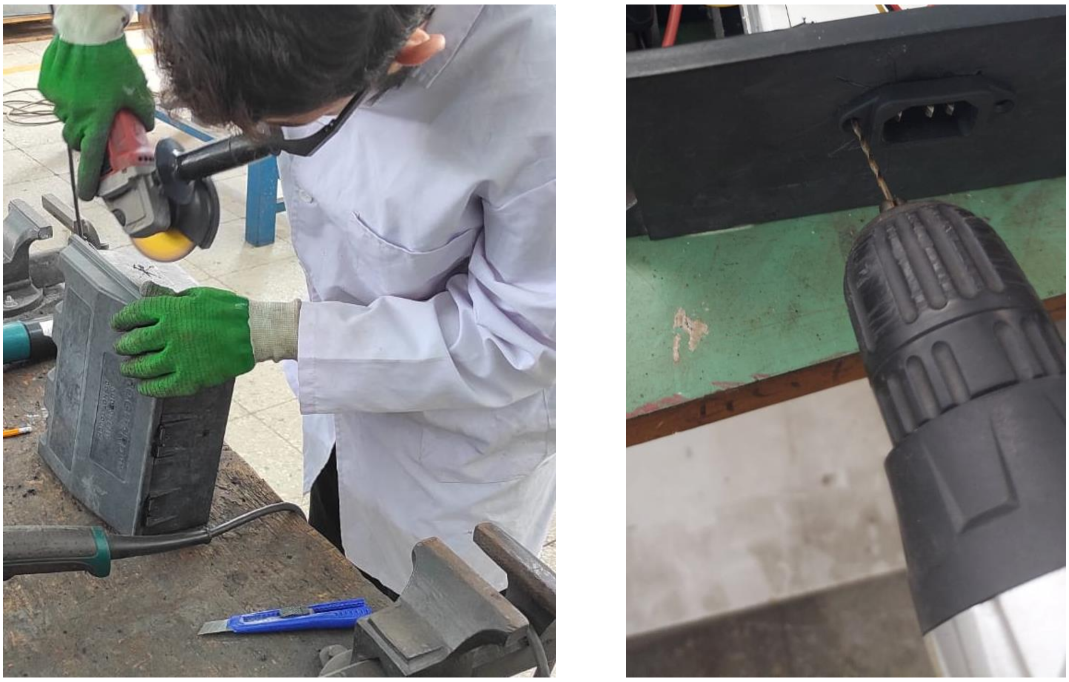


Figure 84: Arduino box machining

4.2.6 Controlling Unit box (1-1-1-4)

As a criterion for developing a multi-controlled smart wheelchair as the main objective of the project, it was decided to incorporate an additional control method to enhance the user experience. This additional control unit is a physical device positioned next to the right arm of the wheelchair. The control unit allows the user to have optimal control over the wheelchair's speed and features a joystick for manual control. Additionally, the unit displays the battery level of the wheelchair and enables the selection of different control modes.

The control unit consists of pushbuttons, a joystick, and an integrated circuit (IC) connected to an LED for the battery level display. To create the control unit, our team utilized 3D printing technology instead of conventional manufacturing methods. PLA was used throughout the 3D printing process. This choice was driven by the advantages of 3D printing, including its cost-effectiveness, accuracy, and speed in producing customized components. By leveraging 3D printing, the team was able to create a functional and ergonomic control unit that seamlessly integrates with the wheelchair, providing users with a versatile and user-friendly control interface. To follow standards of wheelchair controllers, an 8cm joystick was 3D printed, this ensures easy access and comfortability while controlling the wheelchair. Figure 85 shows the manufacturing of the controlling unit in progress.

Figure 85: 3d printing of the controlling unit

4.3 Mechanical Assembly

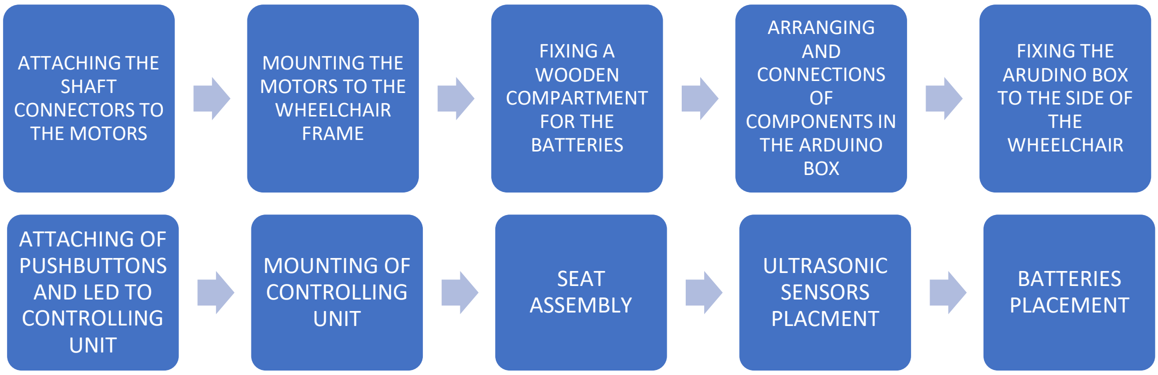


Figure 86: Assembly Sequence

The steps taken to assemble the wheelchair is shown in Figure 86.

4.3.1 Rear wheels (1-1-1-1-1)

To ensure proper functionality of the wheelchair, we took great care in ensuring that the shaft adapter could fit perfectly with the key on the motor shaft. After the connector was machined to fit into the wheels, the wheels were securely fastened onto the motor. This meticulous process ensured the precise alignment of the motor and wheels.

Figure 87: Wheels fastened to motor

Figure 87 shows the wheels being fastened on the motor.

4.3.2 Casters

After welding the new tube and then machining and grinding the welded part, the caster was painted and then assembled with the caster screws. Figure 88 shows the assembly of the caster to the wheelchair frame.

Figure 88: Assembly of the caster

4.3.3 Motor holders

Following the shaft adapter and motor connection process, our team proceeded to fit the motors onto the frame. To achieve this, four motor holders were utilized, with two holders being used for each of the right and left motors. These holders were carefully designed to fit the motors snugly onto the wheelchair frame, ensuring that they would remain firmly in place during operation. The specific motor holders which used to secure the motors onto the frame are illustrated below. The motor holders are part of the components gotten after buying the motors.

Figure 89 shows the motor holders and Figure 90 shows the motor holders being used to assemble the motors.

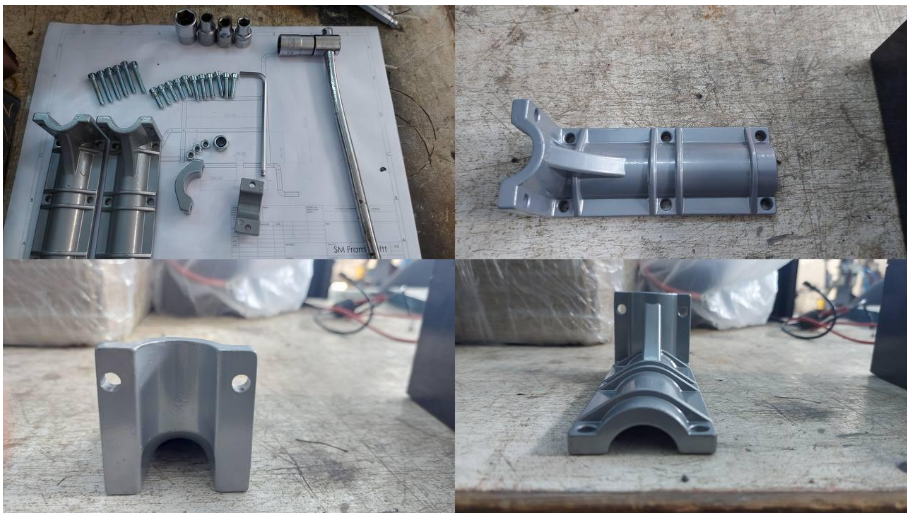


Figure 89: Motor holders

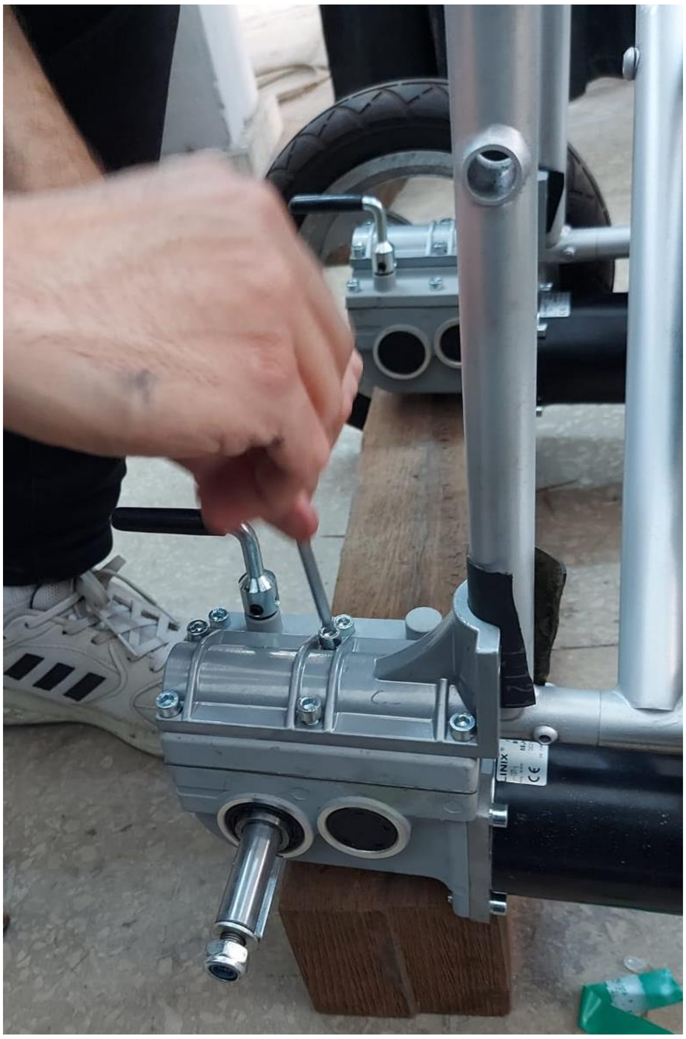


Figure 90: Motor assembly

4.3.4 Battery box (1-1-1-3)

The battery box was placed underneath the wheelchair. A wooden compartment was used to support the edges of the battery box. The purpose of the battery box was to provide a secure and convenient location to hold the batteries, keeping them protected from external elements and preventing any accidental damage during use. The wooden compartment served as a reliable enclosure to hold and secure the edges of the battery box. By fitting the battery box into the wooden compartment, the team ensured that the batteries would remain in place, minimizing the risk of shifting or displacement during wheelchair operation. Figure 91 shows the battery box assembly on the frame of the wheelchair.

Figure 91: Battery box assembly

4.3.5 Arduino box (1-1-1-2)

In order to safeguard the electronics from potential hazards such as water spills, a dedicated box compartment was created. This compartment serves as a protective enclosure for the electronic components. Within the box compartment, a fan was installed with the purpose of cooling the motor drivers and preventing overheating of other electrical components. One significant advantage of utilizing this compartment is that it allows for a reduced number of wire connections, resulting in a more organized and tidier electrical setup. The box compartment accommodates the power system, two regulators, two fans, a motor driver, and an Arduino Mega, providing a centralized and secure location for these crucial components.

Figure 92 shows the outer and inner view of the Arduino box. Figure 93 shows the motor drivers placed in the Arduino box using zip ties. Figure 94 shows the electrical connections in the Arduino box.

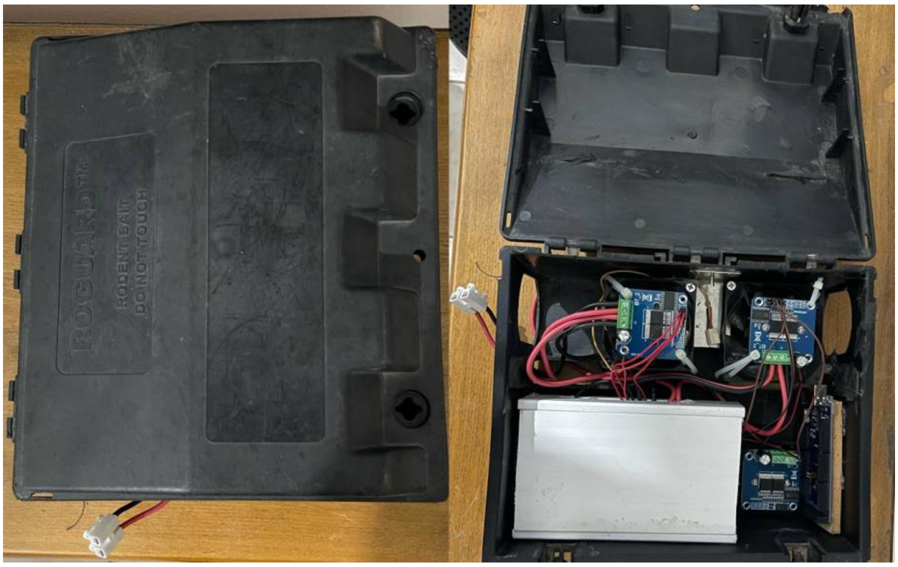


Figure 92: Box compartment and inner view

Figure 93: Motor drivers fixed in the Arduino box

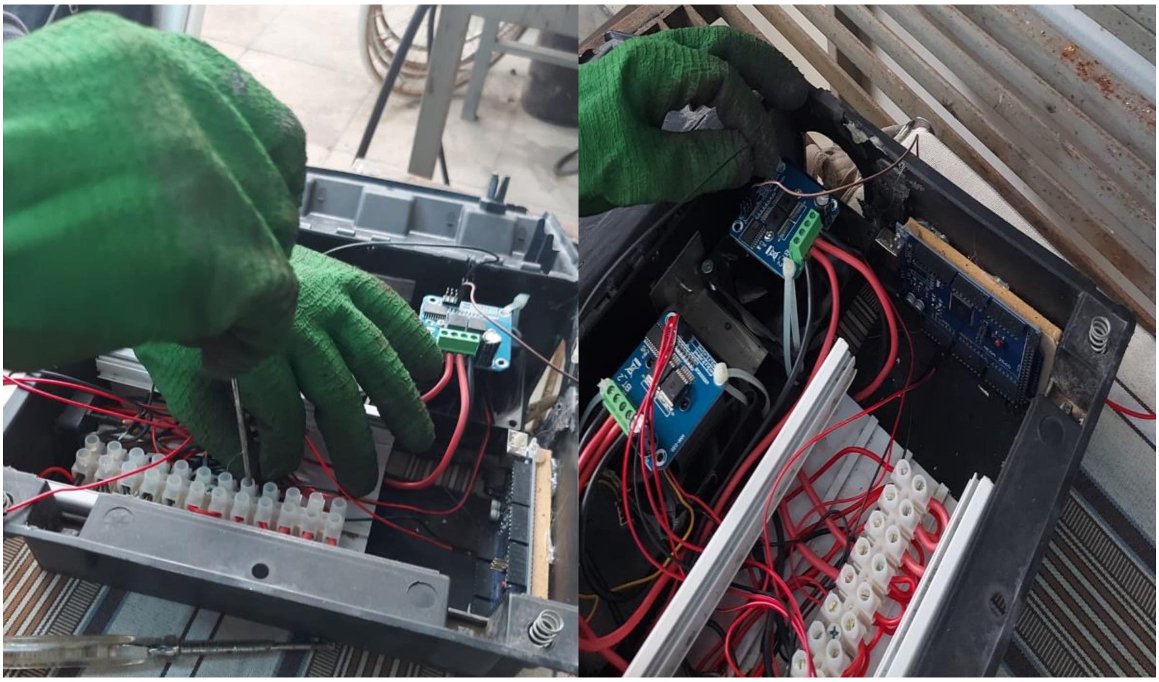


Figure 94: Electrical connection in the Arduino box

4.3.6 Controlling Unit box (1-1-1-4)

The controlling unit for the speech-controlled wheelchair project consisted of various components that were assembled to provide a user-friendly interface. This unit was strategically positioned on the upper right arm of the wheelchair frame for easy accessibility. The assembly of the controlling unit involved integrating five pushbuttons, an LED, ICs (Integrated Circuits), and a joystick. These components were carefully selected to enable different functionalities and control options for the wheelchair. To securely attach the controlling unit to the wheelchair frame, a specially designed holder was employed. This holder served as a mounting mechanism that facilitated the firm and stable attachment of the controlling unit. It ensured that the unit remained securely in place during wheelchair operation and provided a comfortable reach for the user.

The controlling unit was mounted on the upper right arm of the wheelchair frame, providing convenient access for the user to interact with the controls and features. The ergonomic placement of the controlling unit was intended to enhance the user experience and facilitate ease of operation. Figure 95 shows the controlling unit mounted on the frame of the wheelchair.

Figure 95: Control unit

4.3.7 Seat & back rest & arm rest

To provide comfort and support, the team mounted a seat onto the wheelchair frame and placed a backrest for added ergonomic benefit. The seat was positioned directly above two belts that were strategically placed at both ends of the frame to ensure stability and proper weight distribution.

To secure the seat onto the wheelchair frame, four holes were drilled into the frame. These holes served as attachment points for fastening the seat to the belts and the frame using bolts. By securely fastening the seat to the frame, the team ensured a safe and stable seating arrangement for the user. The seat material chosen for the project was fabric. This material selection was based on its comfort, durability, and suitability for extended periods of sitting. The back rest and the arm rest were chosen based on comfort, durability, and suitability for extended periods of sitting as well. Figure 96 shows the assembly of the seat, backrest and arm rests.

Figure 96: Assembly of seat, back and arm rests

4.3.8 Ultrasonic sensor holders

To enhance the wheelchair's navigational capabilities and obstacle detection system, the team incorporated five ultrasonic sensors into the project. These sensors played a crucial role in detecting objects and obstacles. The placement of the ultrasonic sensors was strategically determined to provide comprehensive coverage. Two sensors were positioned in the front to detect obstacles directly ahead, while one sensor was placed on each side of the wheelchair to detect objects in the right and left directions. The fifth sensor was positioned at the rear of the wheelchair to detect objects behind it.

To secure and protect each ultrasonic sensor, a mini compartment was created. The team designed compartments specifically tailored to accommodate the sensors and ensure their stability and protection. Holes were drilled into these compartments to provide openings for the ultrasonic sensors to emit and receive signals. To secure the ultrasonic sensors within their respective compartments, zip ties were utilized. These zip ties were fastened around the sensors and securely attached to the compartments. This fastening mechanism ensured that the sensors remained firmly in place. Figure 97 shows the assembly of the ultrasonic sensor holders.

Figure 97: Ultrasonic sensor holders assembly

4.3.9 Final assembly

A picture of the finished product is shown in Figure 98.

Figure 98: Smart Mobility Powered Wheelchair

4.4 Electrical assembly

To achieve all the desired functionalities many electrical connections were done in this project. For the design of assembly, the connections had to be as short as possible. And for design for safety, the trunking system was used to hide the cables and protect them from being damaged or burned. Trunking system can be seen in Figure 99.

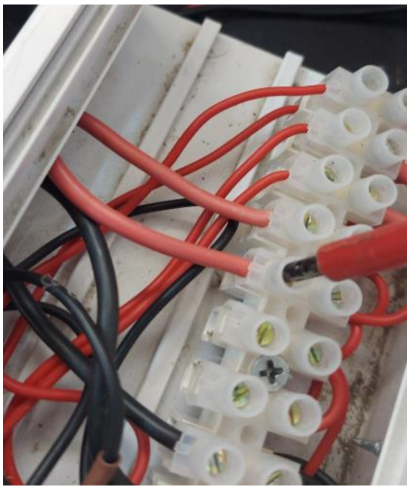


Figure 99: Trunking system

Furthermore, all the cables were tagged based on the schematic drawing of the connections done. This is shown in Figure 100.

Moreover, standard connecter was used to supply the power from the battery to the control system and the sensors to ensure the safety and the ease of assembly and disassembly. This can be seen in Figure 101.

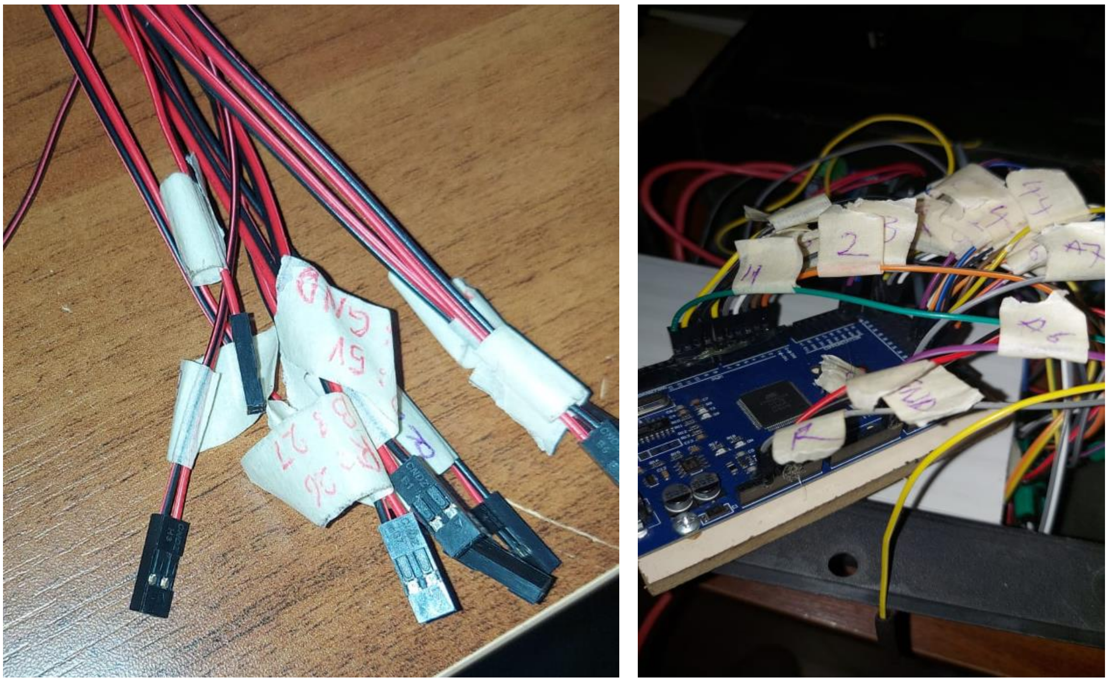


Figure 100: Tagging of electrical cables.

Figure 101: Connectors used for electrical connections between the battery and the Arduino box.

To ensure proper insulation and protection of the wires used in the wheelchair project, shrink tubes were employed. These tubes are designed to shrink when heat is applied, creating a tight seal around the wires, and offering insulation from external elements, such as moisture and dust. This insulation serves to prevent short circuits, electrical interference, and potential damage to the wires.

Given the extensive use of wires throughout the project, a connector was utilized to streamline the wiring connections and enhance efficiency. Connectors provide a convenient and reliable means of joining multiple wires together, reducing the complexity of the wiring system and facilitating easier maintenance and troubleshooting. By employing connectors, the team simplified the process of connecting and disconnecting various wires, enabling efficient assembly and disassembly of components.

4.5 Software and programming process

In this project, the programming section holds great sensitivity and significance as it involves controlling multiple components. The programming language chosen for this project is C++ since the Arduino Mega 2560 microcontroller was selected. The microcontroller, which is a compact integrated circuit designed for specific operations, governs the functionality of various components. During the programming process, the following components were controlled and programmed as described below.

Voice control was achieved through the utilization of an Android application. The available instructions were limited to 'forward', 'backwards', 'right', 'left', and 'stop'. When any of these instructions were spoken by the user, the voice recognition sensor recognized and converted them into input for the microcontroller. Subsequently, the microcontroller sent the instructions to the relevant components to act accordingly.

The motors were programmed to move using a motor driver based on the user's choice provided via the voice recognition module for speed and direction. When selecting the right direction, the right motor would cease movement while the left motor moved. The opposite was true for moving in the left direction. Both motors would move simultaneously when choosing forward or backward. In the absence of instructions or when a stop instruction was given, the motor would enter a braking mode, preventing rotation. A motor with a built-in braking system was selected for this purpose.

The ultrasonic sensors were programmed to perform the following function: when the sensor detected an object near the wheelchair, it sent signals to the microcontroller to deactivate or stop the motor. This action caused the wheelchair to come to a halt. To ensure accurate results and efficient performance, five ultrasonic sensors were utilized on each side of the wheelchair.

A joystick was chosen as an interface for receiving user commands. When the user moved the joystick in any direction, signals were transmitted to the microcontroller. Subsequently, the microcontroller sent instructions to the motor driver based on the specified direction from the user.

Additionally, there were push buttons and an LED light located on the front side of the wheelchair. Programming these components was straightforward. When the push buttons were pressed, the predefined instructions stored in the code were executed. The first push button was used to increase the speed, while the second button decreased the speed. The third button changed the operation mode of the wheelchair, and the fourth button served as an emergency stop. The last push button activated the wheelchair's buzzer.

In summary, the programming section of this project played a crucial role in controlling various components. The C++ programming language was utilized, as it was compatible with the Arduino Mega 2560 microcontroller. The components, including voice control, motors, ultrasonic sensors, joystick, push buttons, and LED light, were programmed to ensure seamless operation and effective user control of the smart wheelchair.

Figure 102 shows the wheelchair being programmed using the Arduino IDE.

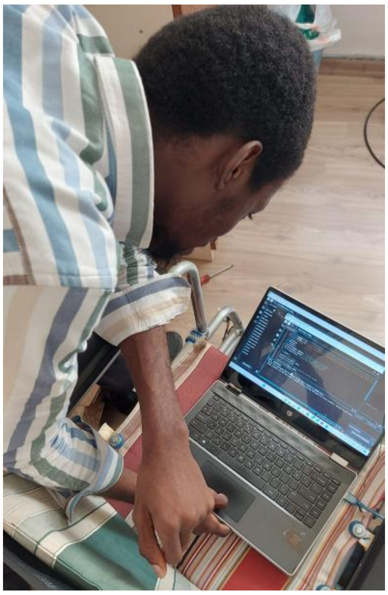


Figure 102: Programming the wheelchair

CHAPTER 5 - PRODUCT TESTING

5.1 Failure Modes and Effects Analysis (FMEA)

The final design of the wheelchair should be tested after manufacturing to ensure its safety and quality. All parts should be tested to make sure they work as intended. FMEA is used to assess processes for potential failures and to prevent them by making proactive process corrections as opposed to responding to unfavourable occurrences after failures have already happened. Table 39 shows the FMEA of the wheelchair design.

Table 39: Failure Modes and Effects Analysis of the design

Failure Mode and Effects Analysis
(Design FMEA)

Design Product: Multi controlled Autonomous Wheelchair

													Action Results				
Item No.	Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls (Prevention)	Current Design Controls (Detection)	Det	RPN	Recommended Action(s)	Actions Taken	New Sev	New Occ	New Det	New RPN
	Motors	Bearing failure	Increased friction and heat generation	8	Inadequate lubrication or lubricant contamination. Excessive loading or overloading of the motor	3	Using favourable lubrication and regular maintenance	Monitor for excessive noise	6	144	Regular maintenance and using long lasting well graded lubrication	Regular maintenance and lubrication	7	2	6	84
		Mechanical unbalance, Shaft deformation and rotor deflection	Increased Vibration and discomfort	8	Improper matching of motor to applied load. Vibration/mechanical looseness	4	Using motors that can withstand the applied loads	Monitor for excessive noise and vibration	2	64	Using increased torque and high-quality motors	Update the motors used	6	2	2	24
	Motor Drivers	Overheating	Thermal shutdown, Reduced motor driver efficiency, Complete failure	8	Inadequate heat sinking or poor thermal design. Insufficient airflow or ventilation around the motor driver	9	Adequate heat sinking and thermal management	Implementation of thermal protection circuits	1	72	Ensure proper heat sinking and thermal management	Improve ventilation and airflow around the motor driver	6	6	1	36

		Overcurrent/overlo ad	Risk of damage to the motor	8	Excessive current flow exceeding the motor driver's rated capacity. Overloading	9	Conducting thorough testing	Integration of current sensing circuits	4	28 8	Verify proper motor sizing and selection	proper motor sizing and selection	6	6	2	72
	Brakes	Excessive wear	Noticeable noises when operating the brakes, Poor braking characteristics	1 0	Deficient maintenance, Extreme braking, Increased mechanical vibration	4	Use of high-quality brakes and braking systems	Monitor for bad braking and increased noise when braking	4	16 0	Use of numerous types of braking systems.	Implementa tion of different braking systems	4	4	1	16
		Corrosion of the contact surface	Noise, Faulty braking	1 0	Insufficient cleaning of the contact surface on the wheel hub, accumulation of dirt and foreign material.	4	Use of high-quality brakes and braking systems	Check for damages on the brakes	2	80	Use high quality material brakes	Paint coating the brakes	5	3	1	15
	Ultrasonic sensors	Physical Damage	compromised system reliability	6	Improper Handling	3	Quality Control	Check for lack of sensitivity	2	36	protective enclosure	proper mounting and installation	5	3	2	30
		Connection Failure	Inability to transmit data to the control system	3	Loose Connections, Interference	7	Shielding and Filtering	Check for lack of sensitivity	2	42	Calibration and Testing	proper mounting and installation	3	5	2	30
	Microphon e	Noise and interference	Bad interpretation thus wrong instruction execution	6	Noisy surroundings.	8	Ensuring the mic is closer to the user	No movement from the wheelchair	1	48	Maintaining a high signal to noise ratio, use different movement alternatives	Avoid noisy surrounding s	6	6	1	36

		Multi path interference	The mic will receive the instructions late increasing response time.	6	Mic dropouts and dead spots due to sound waves being received at different times/twice.	10	Use of high-quality microphones	Double execution of the instruction.	1	60	Using numerous mics and antenna	Avoid noisy surroundings	6	4	1	24
	Microcontroller	Memory stack overflow	Firmware producing a random hardware failure	6	Limited RAM/memory storage options	5	Numerous tests	Error messages or no function from the wheelchair	8	240	Place guard bands around the stack	No actions taken	3	4	7	84
		Overload	Damage to other electrical components	9	Connecting numerous components beyond capacity	3	Using numerous controllers whilst avoiding many connections to each controller	Monitor for burning odour and burnt components	8	216	Using numerous microcontrollers	Using numerous microcontrollers	8	2	7	112
	Bluetooth module	Communication Failure	Data Loss or Corruption, Inability to Pair or Connect, Unreliable or Intermittent Connection	3	Interference, Software Bugs or Incompatibility, Hardware Failure, Power Supply Issues	8	Frequency Hopping, Signal Strength Optimization, Compatibility Testing	Connection Status Monitoring, No actions when in operation, Error Checking and Handling	4	96	User Education and Troubleshooting Resources, Firmware and Software Updates, Interference Mitigation	proper placement of the Bluetooth module, rigorous testing	3	6	3	54

	Back Wheels	fractured wheels and spokes/forks	Damage to the frame, Discomfort, poor navigation	9	Excessive loads, Damaged tyres, excessive speeds.	3	Using high strength wheels	Monitor for broken forks/spokes.	2	54	Use wheels that do not contain spokes or using spoke covers.	No actions taken	4	2	1	8
		Damaged/ worn-out tyres	Poor navigation, Damage to the wheel and spokes, Discomfort	9	Moving in harsh terrain, Excessive loads, Extreme braking	3	Avoid driving on rough terrain	Broken rubber wheels	2	54	Use of high-quality rubber wheels	No actions taken	9	3	1	27
		Eccentricity	High noise, Deteriorated driving comfort	9	Carrying weights beyond accepted tolerance.	4	Avoid heavy loads beyond capacity	Monitor for noise when using the wheelchair	1	36	Use of high strength wheels	No actions taken	9	3	1	27
	Front wheels	Damaged joints	No locomotion, Increased vibration	8	vibration, loose bolts, and connections	3	Ensuring tight connections of the wheel components	Excessive Noise and discomfort	1	24	using permanent wheel hubs to lock the front wheels	No actions taken	8	3	1	24
	Battery	Overcharging/Overheating	accelerated plate corrosion, electrolyte loss, battery rupture or explosion.	5	Electrolyte reduction, solid product formation, Overcharge of the battery or short circuit	3	Avoid temperature extremes both high and low	Reduction in battery capacity	1	15	Use battery covers to control temperatures	Proper battery placement	5	3	1	15

		Chemical corrosion reaction at the cathode	Increased resistance, reduction of power, reduction of current density	5	Overcharging of the battery	3	avoid overcharging the battery	Monitor for corrosion at the terminals	4	60	Use trickle chargers	No actions taken	5	3	4	60
	Frames	Buckling	Discomfort, Inoperable wheelchair, Difficulty in movement	10	Excessive loads/weights beyond capacity.	5	Avoid applying high loads that recommended	Detect for changes in shape	2	100	Use of high strength frames	adding extra supports to the frame	8	3	1	24
		Rusting	Damaged frame, Increased friction, and poor appearance	9	Inadequate maintenance, Increased maintenance using water or oxidation materials	5	Painting/coating the wheelchair.	Monitor for changes in colour	1	45	Use stainless steel	Coating of the frames with coating layer of paint	8	1	1	8
		Bending	Cracks and creases, Damage in appearance	10	Excessive loads/weights beyond capacity.	5	Avoid applying high loads that recommended	Detect for changes in shape	1	50	Use of high strength frames, adding extra supports to the frame	adding extra supports to the frame	8	2	1	16
	Joystick	Mechanical Wear and Tear, Contact or Button Failure.	Inaccurate Input, Reduced Durability, Unresponsive Controls	4	Continuous Use, Environmental Factors, Poor Manufacturing Quality, Physical Impact	6	Robust Materials and Construction, Ergonomic Design,	Monitor for increased noise and vibration	1	24	Use of high-quality joystick with numerous degrees of freedom	Design the joystick with replaceable components that can be easily swapped	4	6	1	24

							Quality Assurance									
	Seat	Loose straps/harnesses	Discomfort	8	Excessive loads/weight beyond the capacity	6	Using straps of stronger material	Loose harnesses, discomfort	1	48	Use of high strength harnesses	No actions taken	8	6	1	48
		Seat material damage	Unattractive appearance, Discomfort	8	Cuts from sharp objects, huge loads on the seat	6	Using stronger materials for the seat	Unattractive appearance, cuts on the seat	1	48	Using stronger materials for the seat	No actions taken	8	6	1	48
	Voice recognition	Wrong interpretation	No locomotion, wrong instruction execution	6	Accent and language misinterpretation, Noise	9	Use of better/robust voice recognition software	Misinterpretation of instructions	1	54	Coding the software to recognize multiple accents	No actions taken	6	9	1	54
	Lightbulbs	No light emitted	No response.	3	Damaged bulb components, faulty connections	5	Regular maintenance	No emitted light	1	15	Ensure the connections are properly connected	No actions taken	3	5	1	15

	Heart rate sensor	Inaccurate readings	Misinterpretation of heart rate data	3	sensor malfunction, poor contact with the skin, or interference from external factors such as motion or ambient light	2	Quality assurance and testing	Implement error detection algorithms to identify inconsistent or erroneous heart rate readings	7	42	ensure proper sensor placement and contact	contact the manufacturer's support	3	2	7	42
		Signal interference	Intermittent or complete loss of heart rate signal	3	External factors such as electromagnetic interference from other electronic devices	2	Incorporate shielding or isolation mechanisms	Incorporate signal quality monitoring mechanisms.	8	48	minimize potential sources of interference	keeping the heart rate sensor away from other electronic devices	3	2	7	42
	Battery gauge.	Delayed or slow response	difficulties in obtaining real-time information	5	hardware limitations, processing delays, or inefficient software algorithms	3	Advanced algorithms and optimized software	notification or alert the user	4	60	reaching out to the manufacturer's support or service centre	Corrective measures	5	3	4	60
		Incorrect low battery indication	Battery depletion	5	improper voltage thresholds	3	Extensive testing and validation processes	voltage monitoring mechanisms	4	60	troubleshooting or possible recalibration	Quality control improvements	4	3	4	48
	Buck converters	Overheating	Component damage or degradation	7	Inadequate heat dissipation or poor thermal design	4	Adequate heat sinking and thermal management techniques	Temperature sensors or thermistors	1	28	heatsinks, thermal pads, or fans.	Adding fans to aid with cooling	4	4	3	48

		Component failure	Short circuits or overload	8	Component aging, degradation, or wear-out	3	Selecting components from reputable manufacturers	fault detection and isolation techniques	4	96	components from reputable manufacturers	components from reputable manufacturers	8	4	3	96
	Switch Button	Mechanical Wear and Tear, Contact or Button Failure.	Unresponsive Controls, Safety Concerns	6	Continuous Use, Physical Impact	2	Robust Materials and Construction	User Feedback, Built-in Diagnostics	1	12	Robust Materials and Construction	Quality Assurance	5	2	1	10
	Battery charger	Short Circuit	Charger Malfunction, Safety Risks	8	Poor Manufacturing Quality, Component Aging or Wear, Electrical Overload	3	Robust Design and Construction	Diagnostic Features	2	48	Use Genuine and Approved Chargers, User Education on Safe Usage	Compliance with Standards	6	3	2	36
		Voltage Instability, Poor Charging Algorithm	Incomplete or Insufficient Charging, Overcharging	8	Insufficient Heat Dissipation, Environmental Factors	3	Heat Management, Accurate Charging Algorithms	Indicator Lights or Displays	8	192	Ensure Proper Electrical Infrastructure	Heat Management	6	3	5	90
	Buzzer	Mechanical Failure	No Sound Output, Weak or Distorted Sound	2	Continuous Use, Connector or Wiring Issues, Aging and Degradation	2	Voltage Regulation and Protection, Environmental Protection	Functional Testing	1	4	Environmental Protection	Modify the housing design or incorporate additional seals	2	2	1	4

5.2 Verification of the objectives of the project

The main objective of this study is to achieve autonomy by incorporating different modes of control such as speech control, joystick control and smartphone control into a wheelchair. In this section, the objectives that were accomplished will be verified.

5.2.1 Design for cost

To ensure optimal economic margins, cost management was a priority within the planned estimates. Material selection was carefully optimized, favouring the combination of affordability and good quality for this project. The cost analysis demonstrates that the overall expenditure for this project is comparatively lower than that of other powered wheelchairs. The design was simplified to reduce costs, and standard parts were predominantly chosen to minimize manufacturing expenses and streamline assembly. Re-evaluation of the current cost analysis was conducted, exploring more affordable and easily accessible materials without compromising quality or meeting necessary standards. This process aimed to eliminate excessive spending while ensuring that the selected materials are of high quality and meet the required standards.

5.2.2 Design for manufacturability

For an efficient manufacturing plan, parts that require expensive and complicated manufacturing processes were replaced with more affordable, simpler, and less complicated solutions. As shown in the engineering drawings, the parts were designed with appropriate tolerance to reduce the risk of manufacturing errors which might lead to repeat the manufacturing process. The designers considered to design parts that are respecting the capabilities of the operators. The design was also be improved and refined to make manufacturing simpler by eliminating parts that are expensive to produce.

5.2.3 Design for safety

It was especially important to make the wheelchair extremely safe. To achieve the safety for the wheelchair the following was done:

It was considered to place the arm rest and the footrests in a suitable place that doesn't absorb the vibration acting on the wheelchair which makes the user more comfortable. Moreover, it was considered to choose a comfortable standard material for the seat which is Nylon.

To increase the safety of the wheelchair, it was considered following the stability standards to make the wheelchair as stable as possible and to minimize tipping over. Not to mention that ultrasonic sensors were integrated to detect obstacles and prevent collisions.

Furthermore, emergency systems such as emergency pushbutton, and power switch were added to the wheelchair. Also, the cables are well insulated, and the sensors are kept in standard boxes.

Finally, to ensure the safety, it was considered to put limitations on the speed to be between 1km/h to 5km/h.

5.2.4 Design for sustainability

Sustainable materials were utilized in the wheelchair's fabrication for a longer lifespan. To maintain resource efficiency, production with low waste was at the centre of the manufacturing operations. To increase the sustainability, it was considered to use 40% of the motor power to maintain the life of the battery longer. The ability to use solar energy panels to charge the batteries was provided in this project. It was considered in the parts designed to be manufactured with minimal impact. Emissions were almost non-existent during the manufacturing.

5.2.5 Design for environment

The wheelchair has an extremely low carbon footprint during manufacturing. Eco-friendly materials and components that have a lower environmental impact were used in this project. The wheelchair should function without harming the environment, so harmful parts will be replaced with environmentally friendly ones. Since it was considered to use 40% of the motor power to maintain the life of the battery longer the power consumption was reduced which directly reduced all kinds of impacts. It was considered designing for ease of recycling so that the parts can be recycled without any harmful footprint.

5.2.6 Design for end of life

Recyclable parts were utilized in the design so that pieces can be reused after the wheelchair's life. The parts can be reused in a variety of other projects after being disassembled. Furthermore, the material utilized to make the chair can be used for various industrial purposes. Standardized connectors and interfaces like the power port and the cables connectors were used for easy replacement of parts in the future. The product can be refurbishment or upgradeability when desired.

5.2.7 Speech control

Testing the movement of the wheelchair by speech control through a predetermined distance was done. The wheelchair responds to the voice commands with a latency that is less than one second. The instructions were delivered to the microcontroller without any errors and the response was correct. So, when saying right, it goes right. When saying left, it goes left and same with forward and backward and stop. The wheelchair was tested with speech control carrying a person with 75 kg on an inclined surfaces with 5 degrees as required in the standard ADA for ramps. The wheelchair was responding to the instructions and stopping smoothly in 2 seconds.

5.2.8 Smartphone control

Mobile application proved its efficiency strongly. You could control the wheelchair from a very far distance. The application is user friendly. You may use your hands to open the application and operate the wheelchair and you may use the wheelchair with only voice. After testing the application, the wheelchair responded to voice and button instructions almost immediately. The application is amazingly simple and tidy. The wheelchair was tested in an incline just like the previous control and everything was working well. The mobile application is also good as a human machine interface. Someone can control the wheelchair from a very far distance and someone else can be in the wheelchair.

5.2.9 Joystick control

Joystick also proved its efficiency. The response of the joystick was the fastest. When moving the joystick forward it goes forward immediately and the same for the other directions. Moreover, good feature in this control is that when choosing the speed of the wheelchair for example speed number 2 which indicates maximum of speed 60 you can go within the range between 0-60 using the joystick by pushing the angle of the joystick. When pushing the joystick 50% of its maximum angle it gives you speed of 30 instead of 60. The joystick was also tested in the incline of 5 degrees, and it was having a better and a faster response than the other controls.

5.3 Verification of the applied engineering standards

5.3.1 Wheelchair static stability (ISO7176-1)

As mentioned in chapter 3 after preparing the frame, the motors, and the folding mechanism, calculations and force detection were done on the wheelchair to verify the stability of the wheelchair numerically. After that, to verify achieving the standard, test methods were applied for the wheelchair on an inclined test plane at a 5° angle to the horizontal. As shown in Figure 103, the wheelchair was able to move up and down an ADA complaint slope. Moreover, the wheelchair was able to stop in the middle of the incline. With a high-speed travel, vibrations affecting the wheelchair was detected. Driving the wheelchair is wonderfully, comfortable, and safe.

Figure 103: Person moving the wheelchair on an ADA complaint ramp

5.3.2 Wheelchair brake effectiveness (ISO 7176-3)

Calculations and specifications of the motor have already proved the ability of the wheelchair to stop safely on level ground and on an incline, as well as its capacity to stay stationary while parked on a slope or an incline. Nevertheless, test methods were applied with speed more than 5 km/hr considering more than 75 kg on an incline with angle more than 5 degrees. As shown in Figure 103, the wheelchair was able to carry a person with constant speed on the incline, and then stop without any sliding errors. Moreover, the wheelchair was able to carry the person and speed up after braking in the middle of the incline.

5.3.3 Dimensions Determination (ISO 7176-5)

As mentioned in this standard, the maximum width allowable is 65 cm, the maximum length allowable is 80 cm, and the maximum hight is 95 cm from the ground to the grip. Since the wheelchair frame was taken from the industry based on the standard dimensions. As shown in the engineering drawing, the specified dimensions were achieved. Measurements were taken manually using all the required measurement instruments to test the dimensions by the Quality Control engineer.

5.3.4 The maximum speed, and acceleration, for electrical wheelchairs (ISO 7176-6)

It is mentioned in the standard that the maximum speed should not exceed 15 km/hr. It was chosen in this project to have a 5 km/hr maximum speed to keep the wheelchair stable and safe. The specifications of the motor proved that the wheelchair could speed up to 9 km/hr. Test methods on the road were applied to prove the standard. By choosing a 1 km road and measuring the time of driving while using 40% of the motor power the following results were gotten.

The speed of the wheelchair when nobody is sitting on it is 2.16 km/hr.

The speed when 68 kg person sitting on the wheelchair is 1.8 km/hr.

To improve the results or increase the speed, a better motor driver should be used.

5.3.5 Power and control systems for electrical wheelchairs (ISO 7176-14)

The cables were insulated and well organized as mentioned in the standard. Moreover, a system for the power was done with a standard charging port and a standard case. Furthermore, a system was done for the control systems like the microcontroller and the motor driver and their cable distribution with a standard case with a power port. The case or the boxes of those systems are removable. A 24 V charger was bought for charging the wheelchair. Not to mention that a controlling unit or a remote control was manufactured with a well-organized cable connection and with standard dimensions.

5.3.6 Welding and safety in welding

In this project, the wheelchair frame which has 99% of the welding operation was done by a wheelchair industry that follow standards. Therefore, the standard welding technique for the fame tubes which is MIG welding was done by the industry by considering all the safety requirements.

CHAPTER 6 - RESULTS AND DISCUSSIONS

6.1 The results

The culmination of our intensive research and development efforts in creating a ground-breaking wheelchair system that redefines the standards of mobility assistance is presented in this results summary. With unwavering dedication to excellence, several mechanisms have been incorporated while also designing a wheelchair that operates robustly in a variety of environments. The focus was on reliability, cost-effectiveness, power consumption, future expandability, size, and adaptability to commercial wheelchair chassis. The obtained results revealed a prototype that effectively met the mobility requirements of individuals in need of a wheelchair. Initially, assistance from another person was required for the setup of the new wheelchair system. However, once the setup was complete, efficient functionality in both indoor and outdoor spaces was demonstrated by the system. The wheelchair was designed to incorporate multiple control options, including speech control, joystick control, and control through a mobile device. Rigorous testing was conducted on each control option to ensure its effectiveness in various situations.

Successful results were achieved with the wheelchair's joystick control option, allowing users to intuitively manoeuvre the wheelchair by manipulating the joystick in different directions. The integration of the joystick module provided precise control over the wheelchair's movements. Furthermore, speed control was implemented based on the amount of pressure applied to the joystick. The system adjusted the wheelchair's speed accordingly by measuring force or displacement. This feature enhanced the user experience and provided greater control during manoeuvring. Accurate and reliable performance was consistently demonstrated by the joystick module through extensive testing. Smooth and precise navigation of the wheelchair across various environments was ensured. User comfort and accessibility were prioritized with its ergonomic design, catering to individuals with limited mobility.

When deploying these methods, high latency, inaccurate results, and high dependency on the internet speed were faced using OpenAI’s tiny model of Whisper and the Python Speech Recognition package on a Raspberry Pi 4 Model B. This is why the decision was made to use an Android phone for voice recognition.

Significant enhancement was achieved with the incorporation of mobile phone control through our in-house application for our multi-controlled, autonomous wheelchair. This feature allowed the wheelchair to be conveniently operated using mobile devices by the users. An intuitive and user-friendly interface was provided by our dedicated application, expanding the options available for controlling the wheelchair and catering to individual preferences and needs. With mobile phone control, enhanced mobility and increased convenience were provided to the users, further improving their overall experience and control over the movements of the wheelchair. The wheelchair can be controlled using buttons or voice through an Android phone.

Seamless performance was achieved with voice control using an Android phone. The user's command was provided in text format by the API's response, which was then compared to the keywords such as "forward," "reverse," "left," "right," and "stop." The instruction that has the closest degree of similarity is chosen if it passes a certain threshold. User commands were successfully executed by the microcontroller after checking for obstacles in the specified movement direction during testing. However, challenges were encountered with users speaking with non-clear accents, requiring them to repeat their commands for accurate recognition. Additionally, voice commands were responded to by the wheelchair with a delay of close to 3 seconds. This means that voice control needs improvement.

The ultrasonic sensor system was designed to be robust and reliable, capable of operating effectively in various environmental conditions. The sensors were able to detect a wide range of objects, including both static and moving obstacles. This allowed the wheelchair to navigate through complex environments, such as crowded hallways or outdoor pathways, with improved precision and obstacle avoidance capabilities. To ensure optimal performance, extensive testing was conducted to fine-tune the parameters and algorithms of the sensor system. The wheelchair was programmed to track objects within a range of 60 cm for its front and back ultrasonic sensors and 40 cm for its left and right ultrasonic sensors. The position of detected obstacles relative to the wheelchair was quickly interpreted by the system's intelligent algorithms, which analysed the sensor data in real-time.

In situations where an obstacle was detected at the front, causing the wheelchair to come to a stop, the presence of the obstacle was continuously monitored by the system. Once the obstacle was no longer detected within the designated range, the movement of the wheelchair was resumed, allowing for seamless navigation and efficient manoeuvring. This automatic stopping and resuming functionality provided a safe and user-friendly experience, preventing potential collisions and ensuring smooth operation in dynamic environments. The integration of the ultrasonic sensor system in our wheelchair design aimed to enhance user confidence and independence by providing reliable obstacle detection and avoidance capabilities. The unidirectional ultrasonic sensors used were not capable of detecting obstacles outside their narrow field of view.

During the testing phase, challenges were encountered related to the wheelchair's ability to maintain a straight trajectory when moving forward. This issue primarily stemmed from misalignment of the wheels, resulting from manufacturing tolerances. In addition, variations in tire pressures among the wheels contributed to the problem, causing inconsistent rolling resistance and unequal traction. To address these issues, the importance of regular maintenance and wheel alignment adjustments was recognized. Improved manoeuvrability and reduced deviations from the intended path were achieved by ensuring proper alignment, parallelism, and perpendicularity of the wheels. Monitoring and equalizing tire pressures also played a vital role in maintaining consistent rolling resistance.

During the testing phase, challenges were also faced with the motor drivers purchased from Robotistan, as they frequently malfunctioned and were unable to drive the motors effectively. This issue arose due to compatibility and performance limitations, resulting in the constant breakdown of the motor drivers. Unfortunately, there was no alternative but to continue using them since acquiring replacement motor drivers was not possible due to availability constraints. The constant malfunctions were suspected to be primarily caused by the motor drivers' inability to handle the power requirements and load demands of the wheelchair motors, leading to overheating and eventual failure.

On a positive note, impressive battery life was exhibited by the wheelchair during the testing phase. Over an hour of continuous operation was achieved with a fully charged battery. This extended battery life ensured prolonged mobility for users, reducing the frequency of recharging, and enhancing the usability of the wheelchair. Prolonged battery life was contributed by the efficient power management system implemented in the wheelchair, optimizing energy consumption, and allowing users to engage in longer periods of activity without interruption.

In addition to mobility assistance, heart rate monitoring functionality was also incorporated into the wheelchair. The user's heart rate could be measured in real-time through non-invasive sensors integrated into the joystick box. This feature provided valuable health monitoring capabilities, allowing individuals with specific medical conditions, or monitoring needs to track their heart rate while using the wheelchair. The heart rate data is wirelessly transmitted to a connected mobile device for further analysis and monitoring. The integration of heart rate monitoring aimed to enhance user safety, allowing for prompt response and intervention in case of any abnormal heart rate readings.

It is firmly believed that the potential to significantly enhance the lives of individuals with limited mobility is possessed by this revolutionary wheelchair system. By combining technological innovation, user-centric design, and a commitment to excellence, the foundation for a new era of mobility assistance has been laid.

6.2 The engineering standards

6.2.1 Engineering standards that were followed

- Wheelchair Stability (ISO 7176-1)

When the wheelchair was standing on a slope, the parking brake(s) were engaged, and static stability was measured. The centre of the area where the wheelchair wheels and other components contact the ground was adjusted, and the force points on the chair were detected through manual calculations and software simulation. Based on the results, appropriate actions were taken. In this project, obtaining a high-torque motor with safe and effective braking capability was considered. As a result, the wheelchair was capable of safely carrying a person weighing 75 kg without requiring excessive torque and power. Additionally, the wheelchair demonstrated the ability to remain stable when stopping in the middle of an incline. The driving experience of the wheelchair was characterized by remarkable comfort and safety.

- Wheelchair brakes effectiveness (ISO 7176-3)

The purpose of this section of ISO 7176-3 is to ensure that the wheelchair can safely stop on both level ground and inclines, as well as remain stationary when parked on a slope. The selection of an appropriate electrical motor with a high braking torque was based on calculations. As a result, the wheelchair could carry the person smoothly at a constant speed on the incline and coming to a stop without experiencing any sliding errors. Furthermore, the wheelchair was able to resume carrying the person and accelerate after braking in the middle of the incline.

- Dimensions Determination (ISO 7176-5)

This standard mentioned the caster fork, front wheels, rear wheels, seat width, seat length, seat height, total wheelchair width, total wheelchair length, and height from the ground to the seat. The wheelchair frame, sourced from the industry, was based on these standard dimensions.

- The maximum speed, and acceleration, for electrical wheelchairs (ISO 7176-6)

Since design for safety is one of the project objectives, the maximum speed of the wheelchair is best to be 5 km/hr. ISO 7176-6 standard states that the maximum speed of an electrical wheelchair should not exceed 15 km/h due to safety and stability and it provides methods to adjust the acceleration that is suitable based on the speed provided by the producer.

- Power and control systems for electrical wheelchairs (ISO 7176-14)

To ensure safety and reliability, it was necessary to have a well-distributed and organized power system that could be effectively controlled. The power and control systems were managed by utilizing a box to contain the Arduino and other electrical connection systems. The motor drivers were properly connected above cooling fans and adjusted within the Arduino control system box. Furthermore, to prevent power consumption issues and undesired speed behaviour, the wheelchair's speed was designed to be adjustable in three levels (2 km/hr, 3.5 km/hr, 5 km/hr). A standard removable box was used to house the batteries, which featured a switch and standard charging ports for safe battery charging. The cables were organized and insulated according to the mentioned standards. Additionally, a standardized charging port and case were implemented for the power system, while a standardized case with a power port was utilized for the control systems, including the microcontroller and motor driver, along with their cable distribution. The cases or boxes for these systems could be easily removed when needed.

6.2.2 Engineering standards that were not followed

- Power consumption (ISO 7176-4)

Factors such as temperature, age, charging history, and discharging history also exert an influence on the state of the battery. This standard can be utilized as a benchmark for comparing different wheelchairs under identical testing conditions. The wheelchair's range capability is highly dependent on its operational usage. Therefore, relying solely on a single theoretical range estimate may not suffice to fully comprehend its performance. In accordance with this standard, a motor with low power consumption was selected. The power consumption of the electronics was disregarded. The battery was chosen to withstand the impact of the wheelchair's surrounding temperature. During the testing of the wheelchair on various road conditions, the power consumption was measured. The wheelchair was able to operate for over an hour and 30 minutes. However, additional testing methods needed to be carried out to obtain accurate and precise results. Due to time constraints, the monitoring of power consumption was not conducted.

6.2.2.1 Strength of materials and fatigue strength (ISO 7176-8)

For the safety of the wheelchair, it was very important to notice the strength of the frame and the maximum stress that leads to failure. The standard ISO 7176-8 outlines test procedures and establishes minimum standards for the wheelchair as a whole and each individually stressed component's static, impact, and fatigue strength. There are more requirements in this standard which are not mentioned. To achieve and follow this standard, a special testing machine was needed. Due to unavailability of the testing machines, cost, and time, this standard was not followed. Nevertheless, calculations and simulation were done for the fatigue and the failure of the parts therefore, the risk was solved.

6.2.2.2 Electric wheelchair climate tests (ISO7176-9)

The wheelchairs can be adversely affected by the environment in which they are used or stored. Factors such as rain or traversing wet streets, as well as exposure to sunlight, can have negative consequences. The ISO7176-9 standard serves the purpose of considering these factors. It specifies requirements and test procedures to evaluate the impact of weather conditions, including rain, dust, condensation, and temperature fluctuations, on the essential functionality of electrically driven wheelchairs. However, due to considerations such as cost, availability, manufacturability, and time constraints, the adherence to this standard was not implemented. Although measures such as well-covered wires, waterproof motors, and protective covering for the battery were taken, the full requirements of this standard were not met.

6.2.2.3 Friction acting on the wheelchair (ISO 7176-13)

Defining the friction acting on the wheelchair from any road condition is critical therefore, in this project, a high friction coefficient was assumed in the calculations. Unfortunately, this is not enough to follow any standard. The standard ISO 7176-13 outlines a test procedure for figuring out a test surface's coefficient of friction that has a rough texture, such as unfinished concrete. If the test technique is used on polished or flat surfaces, caution should be taken to ensure that the coefficient of friction is measured as being constant over the whole test surface. This standard requires using many testing apparatuses which are not available for us and not affordable. Therefore, due to the availability, the cost, and the time the team could not follow this standard.

6.2.2.4 ISO 7176-2 Dynamic Stability

This standard outlines the testing procedures for evaluating the dynamic stability of wheelchairs with electrical propulsion. The wheelchair is put through a series of driving tests that simulate using one, and its motions are monitored for the occurrence of a variety of specified unstable circumstances. rigid, flat, horizontal test plane that is big enough to conduct the tests and has a coefficient of friction larger than 0,6. The surface of the test plane must be between two hypothetical horizontal planes spaced 20 mm apart and have a maximum slope or cross slope change of 0.5° during the test. The wheelchair must be able to go at its highest speed and stop within the specified inclination on a rigid, flat, inclined surface with a run up and run down. It was proved as mentioned in the previous chapter that the wheelchair can do this job. Nevertheless, there are testing methods were not done due to the cost and the time constrains.

6.3 The constraints

Several constraints were encountered during the design and development of the autonomous wheelchair for our graduation project. These constraints played a crucial role in shaping the project and effectively meeting the objectives.

Time:

The time constraint was a critical factor in the project. A project schedule was established with deadlines for each step, including the completion of the final prototype. The project's progress was carefully planned, scheduled, monitored, and controlled to ensure timely completion.

Cost:

The cost constraint was a significant consideration throughout the project. Working within a limited budget of $700, careful consideration was given to the cost implications of design choices. Cost-effective alternatives were explored to achieve the project objectives without compromising quality.

Availability of resources & materials:

The project was designed to make the best use of available resources and materials. This approach helped in saving money on purchasing necessary materials. However, challenges were faced in obtaining some materials locally, necessitating outsourcing from various online retailers such as Robotistan.

Manufacturability and sustainability:

Emphasis was placed on ensuring the manufacturability and sustainability of the prototype. A well-revised manufacturing plan was developed to ensure high-quality production. By reducing waste and optimizing energy consumption, the aim was to extend the prototype's lifecycle and make the manufacturing process more environmentally friendly.

Speech recognition accuracy:

To enhance the accuracy of the speech recognition system, extensive training and testing were conducted using diverse speech data. This allowed the system to correctly understand user commands, accommodating various speech patterns, accents, and languages. Overcoming the challenge of achieving a voice control system that functions well even in the presence of ambient noise was a priority.

Real-time responsiveness:

Real-time responsiveness was given priority in the design of the wheelchair. Low latency was crucial to ensure smooth navigation. The processing capabilities of the speech recognition system were optimized, and efficient communication and coordination with the control system were implemented to minimize delays and provide prompt responses.

CHAPTER 7 - CONCLUSIONS AND FUTURE WORKS

7.1 The conclusions

The mobility of paraplegic individuals has always been aided by wheelchairs. In this capstone project, the focus was on constructing a smart wheelchair with multiple controlling systems to enhance mobility and independence while ensuring comfort for individuals with limited physical abilities. Throughout the project, various stages of manufacturing, including machining, welding, and assembly, were undertaken.

The wheelchair comprises three main systems: electrical, mechanical, and control systems. All three systems were designed to work harmoniously. Signals are transmitted from the control systems to the electrical units, which then execute the user's desired commands. The mechanical aspects involve machining, 3D printing, and other processes. Careful calculations were made to ensure the structural integrity of the wheelchair, and soft ergonomic components were installed in the control systems to enhance comfort. These measures were taken to provide multiple functionalities in the wheelchair.

The integration of a physical control unit introduced a manual control option alongside the speech recognition system. This unit allows for speed adjustment, directional control, and various controlling modes, empowering the wheelchair user further.

Safety and convenience were also prioritized by incorporating a battery compartment with adequate protection and ventilation. This helped prevent hazards and facilitated the cooling of motor drivers and other electrical components, ensuring optimal performance and longevity. By combining in-house manufacturing with externally sourced components, the project achieved a balance between cost-effectiveness, quality assurance, and time efficiency.

Overall, the successful completion of the capstone project demonstrates the team's dedication, technical proficiency, and innovative problem-solving skills. The multi-controlled smart wheelchair serves as a testament to the potential of technology to enhance the lives of individuals with mobility limitations, offering them newfound independence and an improved quality of life.

7.2 The future works

In the future, the integration of brain control is likely to be seen as a new method of controlling wheelchairs, complementing existing control mechanisms. This innovative approach will involve the utilization of an EEG (Electroencephalography) device to capture and interpret the user's brain waves while employing a sophisticated classifying algorithm to discern specific commands. By leveraging brain-computer interfaces, individuals will have the ability to control their wheelchairs intuitively and seamlessly.

Additionally, the transformation of wheelchairs into self-driving vehicles is an exciting development. The ability for users to input their desired destination will enable the wheelchair to autonomously plan a suitable route. Factors such as traffic conditions and moving obstacles along the wheelchair's path will be considered by the autonomous navigation system. To achieve this, a LIDAR sensor can be employed to accurately map the surrounding environment, providing crucial data for safe and efficient navigation.

To ensure precise movement and accurate navigation, the integration of PID (Proportional-Integral-Derivative) control and encoders into the wheelchair's control system is essential. This incorporation will promote stability and manoeuvrability, allowing the wheelchair to move in a straight line when required to move forward.

Furthermore, the enhancement of wheelchair performance entails upgrading various components. These improvements include the implementation of superior motor drivers, the adoption of brushless motors for improved efficiency and durability, the replacement of lead-acid batteries with lithium-ion batteries for greater energy density and longer operating times, and the utilization of an aluminium frame to enhance structural integrity while maintaining a lightweight design.

Addressing the challenges posed by traversing stairs can be achieved through the implementation of a stair detection system in the multi-controlled autonomous wheelchair. One potential system that could be utilized is a combination of depth-sensing cameras and machine learning algorithms. These cameras would capture depth information and analyse it using advanced algorithms to accurately identify staircases. By integrating this system into the wheelchair's navigation capabilities, the wheelchair can detect and avoid stairs, ensuring the safety and autonomy of the user.

Additionally, improving the charging rate is a crucial aspect in advancing wheelchair technology. Innovative charging solutions can be implemented, leveraging rapid charging technologies such as fast-charging stations or wireless charging pads. These advancements would significantly reduce the charging time for the wheelchair's batteries, allowing users to spend less time waiting for a recharge and more time utilizing their mobility device. Improved charging rates would enhance the overall experience and convenience of wheelchair users, providing extended periods of uninterrupted usage.

Overall, the functionality and performance of wheelchairs will be revolutionized by the integration of brain control, autonomous navigation, PID control, and upgraded components. By incorporating innovative technologies and systems, individuals will be empowered with enhanced mobility and independence in their daily lives.

REFERENCES

[1] "Role of the Wheelchair - Physiopedia." https://www.physio-pedia.com/Role_of_the_Wheelchair#cite_note-:0-1 (accessed Oct. 27, 2022).

[2] "Wheelchair - Wikipedia." https://en.wikipedia.org/wiki/Wheelchair (accessed Oct. 27, 2022).

[3] S. Desai, S. S. Mantha, and V. M. Phalle, "Advances in smart wheelchair technology," *2017 International Conference on Nascent Technologies in Engineering, ICNTE 2017 - Proceedings*, Jun. 2017, doi: 10.1109/ICNTE.2017.7947914.

[4] "Wheelchair definition and meaning | Collins English Dictionary." https://www.collinsdictionary.com/dictionary/english/wheelchair (accessed Nov. 03, 2022).

[5] J. Leaman and H. M. La, "A Comprehensive Review of Smart Wheelchairs: Past, Present, and Future," *IEEE Transactions on Human-Machine Systems*, vol. 47, no. 4, pp. 486–489, Aug. 2017, doi: 10.1109/THMS.2017.2706727.

[6] C. P. DiGiovine, "electric wheelchair." https://www.britannica.com/technology/electric-wheelchair (accessed Oct. 27, 2022).

[7] "Invacare Storm 4 power wheelchair - Invacare UK." https://www.invacare.co.uk/power-wheelchairs-mobility-scootersalber/outdoorindoor-wheelchairs/invacare-storm-4-power-wheelchair (accessed Nov. 03, 2022).

[8] R. Simpson, E. LoPresti, and R. Cooper, "How many people would benefit from a smart wheelchair?," *rehab.research.va.gov*, vol. 45, no. 1, pp. 53–72, 2008, doi: 10.1682/JRRD.2007.01.0015.

[9] C. F. Riman, "Multi-Controlled Wheelchair for Upper Extremities Disability," *Journal of Mechatronics and Robotics*, vol. 2, no. 1, pp. 121–131, Dec. 2018, doi: 10.3844/JMRSP.2018.121.131.

[10] M. K. Shahin, A. Tharwat, T. Gaber, and A. E. Hassanien, "A Wheelchair Control System Using Human-Machine Interaction: Single-Modal and Multimodal Approaches," *Journal of Intelligent Systems*, vol. 28, no. 1, pp. 115–132, Jan. 2019, doi: 10.1515/JISYS-2017-0085/ASSET/GRAPHIC/J_JISYS-2017-0085_FIG_012.JPG.

[11] I. A. Mirza *et al.*, "Mind-controlled wheelchair using an EEG headset and arduino microcontroller," *Proceedings - International Conference on Technologies for Sustainable Development, ICTSD 2015*, Apr. 2015, doi: 10.1109/ICTSD.2015.7095887.

[12] M. A. Awais, M. Z. Yusoff, N. Yahya, S. Z. Ahmed, and M. U. Qamar, "Brain Controlled Wheelchair: A Smart Prototype," *Journal of Physics: Conference Series*, vol. 1529, no. 4, p. 042075, Apr. 2020, doi: 10.1088/1742-6596/1529/4/042075.

[13] M. Xiong *et al.*, "A low-cost, semi-autonomous wheelchair controlled by motor imagery and jaw muscle activation," *Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics*, vol. 2019-October, pp. 2180–2185, Oct. 2019, doi: 10.1109/SMC.2019.8914544.

[14] J. Tang, Y. Liu, D. Hu, and Z. T. Zhou, “Towards BCI-actuated smart wheelchair system,” *BioMedical Engineering Online*, vol. 17, no. 1, pp. 1–22, Aug. 2018, doi: 10.1186/S12938-018-0545-X/TABLES/6.

[15] J. Tang, Y. Liu, D. Hu, and Z. T. Zhou, “Towards BCI-actuated smart wheelchair system,” *Biomed Eng Online*, vol. 17, no. 1, Aug. 2018, doi: 10.1186/s12938-018-0545-x.

[16] F. Ahmed, R. Paul, M. M. Ahmad, A. Ahammad, and S. Singha, “Design and Development of a Smart Wheelchair for the Disabled People,” *2021 International Conference on Information and Communication Technology for Sustainable Development, ICICT4SD 2021 - Proceedings*, pp. 45–49, Feb. 2021, doi: 10.1109/ICICT4SD50815.2021.9397034.

[17] M. A. Kader, M. E. Alam, N. Jahan, M. A. B. Bhuiyan, M. S. Alam, and Z. Sultana, “Design and implementation of a head motion-controlled semi-autonomous wheelchair for quadriplegic patients based on 3-axis accelerometer,” *2019 22nd International Conference on Computer and Information Technology, ICCIT 2019*, Dec. 2019, doi: 10.1109/ICCIT48885.2019.9038512.

[18] P. Mishra and S. Shrivastava, “IoT based automated Wheel Chair for Physically Challenged,” *Materials Today: Proceedings*, vol. 56, pp. 533–541, Jan. 2022, doi: 10.1016/J.MATPR.2022.02.183.

[19] H. F. Jameel, S. K. Gharghan, and S. L. Mohammed, “Wheelchair control system for the disabled based on EMOTIV sensor gyroscope,” *Microprocessors and Microsystems*, vol. 94, p. 104686, Oct. 2022, doi: 10.1016/J.MICPRO.2022.104686.

[20] P. Rai, S. Bagade, and V. Bankar, “Smart Wheelchair,” *International Journal of Research Publication and Reviews*, vol. 3, no. 5, pp. 223–225, May 2022,

Accessed: Oct. 28, 2022. [Online]. Available: https://ijrpr.com/uploads/V3ISSUE6/IJRPR4685.pdf

[21] M. S. Amin, S. T. H. Rizvi, S. Malik, Z. Bin Faheem, and A. Liaqat, "Smart Wheelchair-An Implementation of Voice and Android Controlled System," *2021 International Conference on Digital Futures and Transformative Technologies, ICoDT2 2021*, May 2021, doi: 10.1109/ICODT252288.2021.9441532.

[22] A. Koložvari *et al.*, "Speech-recognition cloud harvesting for improving the navigation of cyber-physical wheelchairs for disabled persons," *Microprocessors and Microsystems*, vol. 69, pp. 179–187, Sep. 2019, doi: 10.1016/J.MICPRO.2019.06.006.

[23] L. T. D'Angelo, K. Abdul-Sater, F. Pfluegl, and T. C. Lueth, "Wheelchair models with integrated transfer support mechanisms and passive actuation," *Journal of Medical Devices, Transactions of the ASME*, vol. 9, no. 1, Mar. 2015, doi: 10.1115/1.4029507/376775.

[24] O. A. Ruşanu, L. Cristea, and M. C. Luculescu, "Arduino based mobile robot controlled by voluntary eye-blinks using LabVIEW GUI & NeuroSky Mindwave Mobile Headset," *IOP Conference Series: Materials Science and Engineering*, vol. 997, no. 1, p. 012059, Dec. 2020, doi: 10.1088/1757-899X/997/1/012059.

[25] P. Q. Thai, V. C. Tai, and L. M. Tien, "Design and implementation of an electric wheelchair operating in different terrains," *International Journal of Mechanical Engineering and Robotics Research*, vol. 9, no. 6, pp. 797–802, Jun. 2020, doi: 10.18178/IJMERR.9.6.797-802.

[26] N. Aktar, I. Jaharr, and B. Lala, "Voice Recognition based intelligent Wheelchair and GPS Tracking System," *2nd International Conference on Electrical,*

Computer and Communication Engineering, ECCE 2019, Apr. 2019, doi: 10.1109/ECACE.2019.8679163.

[27] S. Umchid, P. Limhaprasert, S. Chumsoongnern, T. Petthong, and T. Leeudomwong, “Voice Controlled Automatic Wheelchair,” *BMEiCON 2018 - 11th Biomedical Engineering International Conference*, Jan. 2019, doi: 10.1109/BMEICON.2018.8609955.

[28] “Arduino Voice Recognition Module - Geeetech Wiki.” https://www.geeetech.com/wiki/index.php/Arduino_Voice_Recognition_Module (accessed Nov. 04, 2022).

[29] M. Bakouri *et al.*, “Steering a Robotic Wheelchair Based on Voice Recognition System Using Convolutional Neural Networks,” *Electronics 2022, Vol. 11, Page 168*, vol. 11, no. 1, p. 168, Jan. 2022, doi: 10.3390/ELECTRONICS11010168.

[30] C. Joseph, S. Aswin, and J. Sanjeev Prasad, “Voice and gesture controlled wheelchair,” *Proceedings of the 3rd International Conference on Computing Methodologies and Communication, ICCMC 2019*, pp. 29–34, Mar. 2019, doi: 10.1109/ICCMC.2019.8819662.

[31] D. R. Kiran, “Quality Function Deployment,” *Total Quality Management*, pp. 425–437, Jan. 2017, doi: 10.1016/B978-0-12-811035-5.00030-1.

[32] “Linix High Torque Electric Wheelchair Motor 88mm 24v 340w Brush Dc Motor With Gear Reduction 32:1 For Electric Wheelchair Motor - Buy Electric Wheelchair Motor,Brush Dc Motor With Gear Reduction,Motor Dc 24v With Encoder Product on Alibaba.com.” https://www.alibaba.com/product-detail/Linix-high-torque-electric-wheelchair-motor_1600353906012.html (accessed Dec. 16, 2022).

[33] "IBT-2 H-Bridge with Arduino – Dr Rainer Hessmer." http://www.hessmer.org/blog/2013/12/28/ibt-2-h-bridge-with-arduino/ (accessed Dec. 17, 2022).

[34] "ULTRASONIC SENSOR HC-SR04 : 9 Steps - Instructables." https://www.instructables.com/ULTRASONIC-SENSOR-HC-SR04/ (accessed Dec. 07, 2022).

[35] "EVO-PORT.jpg (JPEG Image, 300 × 203 pixels)." https://electricscooterparts.com/images7/EVO-PORT.jpg (accessed May 17, 2023).

[36] "RS PRO C13 Snap-In IEC Connector Socket, 15A, 250 V | RS." https://befr.rs-online.com/web/p/iec-connectors/7769138 (accessed May 17, 2023).

[37] "PCB Circuit Board 24V 12V to 5V 10A 50W DC DC Step Down Buck Converter for Taxi Bus Car LED Display Power Supply Module| | - AliExpress." https://www.aliexpress.com/item/1005005014985107.html?spm=a2g0o.productlist.main.3.641ffb1bUNZzAx&algo_pvid=53446691-be76-446e-906b-ba7f4260fed6&algo_exp_id=53446691-be76-446e-906b-ba7f4260fed6-1&pdp_ext_f=%7B%22sku_id%22%3A%2212000031350174105%22%7D&pdp_npi=2%40dis%21TRY%21238.12%21238.12%21%21%21%21%21%40212243c016713629894017076d0776%2112000031350174105%21sea&curPageLogUid=g3l8B9pNdsLP (accessed Dec. 18, 2022).

[38] "Analog Joystick | Sensors & Modules." https://www.electronicwings.com/sensors-modules/analog-joystick (accessed Dec. 10, 2022).

[39] “Active Buzzer 5V – EcoRobotics.” https://www.ecorobotics.com.na/products/active-buzzer-5v (accessed Dec. 16, 2022).

[40] “LED Specifications, Power Requirement and Application Notes.” https://www.make-it.ca/led-specifications/ (accessed Dec. 16, 2022).

[41] “Momentary Push Button Switches - 12mm Square 6 colors.” https://www.gravitech.us/mopubusw12sq.html (accessed Dec. 30, 2022).

[42] “Resistor - Wikipedia.” https://en.wikipedia.org/wiki/Resistor (accessed May 23, 2023).

[43] “Buy a Raspberry Pi 4 Model B – Raspberry Pi.” https://www.raspberrypi.com/products/raspberry-pi-4-model-b/ (accessed May 26, 2023).

[44] “Arduino Mega 2560 Rev3 — Arduino Official Store.” https://store.arduino.cc/products/arduino-mega-2560-rev3 (accessed Dec. 17, 2022).

[45] “Easy Chart Electrical Wire Color Codes - Infographic – Wira Electrical.” https://wiraelectrical.com/wire-color-codes/ (accessed May 26, 2023).

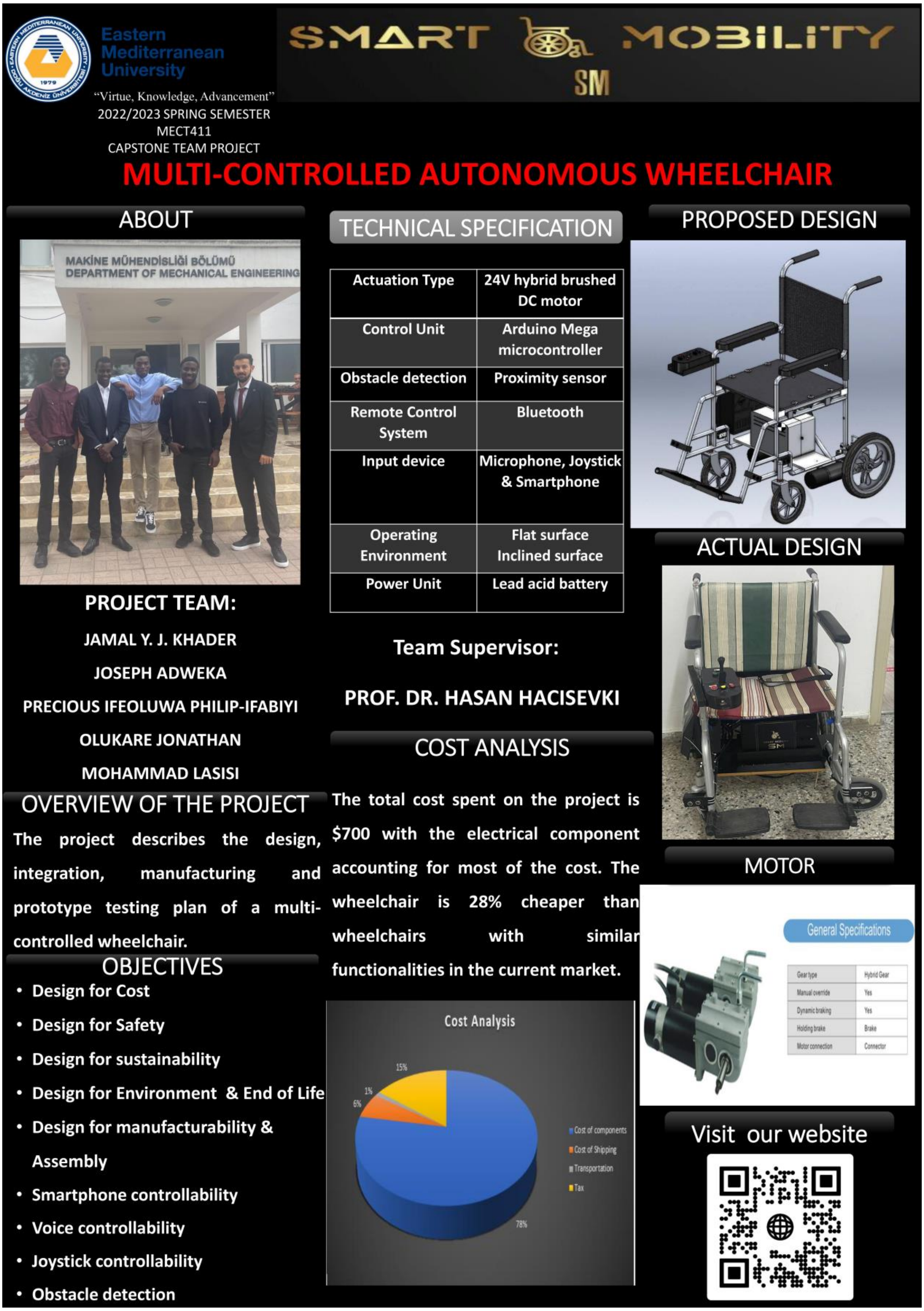
[46] “5.12. Arduino Coding Style Guide — 16-223 Introduction to Physical Computing.” https://courses.ideate.cmu.edu/16-223/f2016/text/resrc/coding-style-guide.html (accessed May 26, 2023).

[47] “Arduino Style Guide for Writing Content | Arduino Documentation.” https://docs.arduino.cc/learn/contributions/arduino-writing-style-guide (accessed May 26, 2023).

[48] A. Winter and R. Hotchkiss, “Mechanical principles of wheelchair design,” *mit.edu,* 2010, Accessed: Dec. 31, 2022. [Online]. Available:

http://web.mit.edu/Sp.784/www/DOCUMENTS/Wheelchair%20Manual-Final.pdf

APPENDIX A: ELECTRONIC MEDIA



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APPENDIX B: STANDARDS

Wheelchair Stability (ISO 7176-1)

In this project, we aim to make the wheelchair as stable as possible to increase its safety. The test procedures for establishing the static stability of wheelchairs are described in this section. When the wheelchair is standing on a slope, the parking brake(s) are engaged, and static stability is measured. Tests are also conducted with the wheels unlocked, replicating scenarios such as the wheelchair standing on a slope with the wheels up against obstacles, the wheelchair user reaching for an object on a level surface while the wheels are unlocked, or instability while moving. Additionally, tests are performed to assess the wheelchair's static stability while it is being kept from toppling over by a forward- and/or backward anti-tip device, as well as the efficiency of those anti-tip devices should the wheelchair tip in that direction.

- The frame (1-1-1)

To achieve a frame that follows the static stability standards, the centre of the area where the wheelchair wheels and other components make contact with the ground were adjusted and the force points on the chair were detect by manual calculations and software simulation and actions were taken based on the results. By making the static analysis on the frame theoretically and numerically using simulation programs, the forces were detected hence, the frame was improved. Moreover, the centre of mass was adjusted in which the gravitational force line from the centre of mass is contained within the area on the ground that is delimited by the contour of its wheels' contact points. Considering the tipping angle was not required by the standard. So, it was ignored due to the time and the cost constraints. Because it is also required to apply the testing methods on the wheelchair to prove the static stability. Testing of the frame stability is applied. Details are in section 5.

- Folding Mechanism (1-1-2)

To achieve a stable folding mechanism, static analysis on the frame numerically using simulation programs was done to detect the forces acting on the folding mechanism hence, it was improved. Moreover, suitable folding screws were used for this application. The results of the simulation (shown in 3.9) are satisfying and perfect. It is required to apply the testing methods to prove it. Testing methods details in chapter 5.

- DC Motor (1-2-2-2)

It was mentioned in the standard requirements that it is necessary to have a wheel that can be locked up and has a parking brake or one whose motion is stopped by the means of propulsion. It was considered in this project to get a high torque motor that has a safe and high torque braking. In this project, the motor used has a 3 Nm braking torque. Moreover, calculations were done to ensure that the brake can work perfectly in an incline with 6 degrees angle.

Wheelchair brakes effectiveness (ISO 7176-3)

The wheelchair's brakes are important because they affect safety. The purpose of this section of ISO 7176-3 is to adjust the wheelchair's capacity to stop safely on level ground and on an incline. It also includes its capacity to stay stationary while parked on a slope or an incline. There are no numerical requirements in this standard. The following was considered during the design.

DC Motor (1-2-2-2)

Calculations were made to confirm that the wheelchair can move easily on an incline with an angle of 5 degrees. Based on the calculations, a suitable electrical motor with a high braking torque was chosen.

Power consumption (ISO 7176-4)

Electric use and battery health have an impact on an electrically driven wheelchair's range of travel. The ambient temperature, the overall weight and weight distribution of the occupants, and the tires all have an impact on energy usage. Factors including temperature, age, charging history, and discharging history also have an impact on the battery state. This standard may be used as a benchmark for comparing various wheelchairs under identical test circumstances. A wheelchair's ability to go a distance depends heavily on how it is operated. Therefore, a single theoretical range estimate might not be enough to comprehend how well it works. The requirements were as follows:

Arduino Mega (1-2-2-1)

Arduino Mega 2560 is the brain of the wheelchair. It will consume power as long as the wheelchair is working.

DC Motor (1-2-2-2)

The motor has the highest power consumption in this project. It is obvious that whenever the driver speeds up, the motors will consume more power. Moreover, a suitable motor with low power consumption was chosen to follow this standard.

Battery (1-2-3-1)

A suitable battery that provides a 32 km driving range with max speed of 5 km/hr. was chosen. The buttery was chosen to be able to resist the effect of the temperature around the wheelchair.

Battery charger (1-2-3-2)

Original charger that follows the international standards was chosen to avoid the current leakage, overloading during charging which might affect the battery, and slow charging.

Dimensions Determination (ISO 7176-5)

The objective of this standard (ISO 7176-5) is to provide technical definitions along with suitable measurement techniques for determining the key masses and dimensions of manual wheelchairs and electrically powered wheelchairs, to determine their suitability for a particular environment. In this standard, a lot of requirements were provided, which made the design very difficult to achieve. The caster fork, the front wheels, the rear wheels, the seat width and length and height, the total wheelchair width and length, and the height from the ground to the seat were mentioned in this standard.

Frame (1-1-1)

To design a perfect frame, it was necessary to follow this standard. By designing the length, the width, and the height as required and considering the maximum length and width and height, and considering the total mass that is going to sit on the wheelchair, this frame was designed. All the dimensions are mentioned in the engineering drawings.

Arduino box (1-1-1-2), battery box (1-1-1-3) and controlling unit box (1-1-1-4-1)

These boxes were designed by considering where it is going to be placed in order to see its effect on the overall width and height. Moreover, we selected light materials to avoid high wheelchair mass.

Caster fork (1-1-1-6)

Caster fork is a very important and critical component in the wheelchair. It affects many criteria in the wheelchair. It was necessary to consider all the requirements for the caster fork like the separation between the castor wheel's ground contact point and the location where the castor stem axis touches the surface.

Seat (1-1-1-9)

The maximum and minimum dimensions of the seat are the most significant terms in the wheelchair as it affects most of the other dimensions. A seat dimension that does not affect the maximum and minimum height, length, and width of the wheelchair was chosen.

Folding Mechanism (1-1-2)

The dimensions of opening the folding mechanism and closing it are one of the most significant dimensions of the wheelchair due to its effect on the maximum and minimum width and height. By looking at the maximum opening and closing dimensions and comparing it with the dimensions of the available seats, the dimensions of the folding mechanism should be within the range mentioned in the standard.

The maximum speed, and acceleration, for electrical wheelchairs (ISO 7176-6)

Maximum speed can play a significant role in determining which wheelchair is best for a certain person. Depending on local laws, maximum speed may affect whether electrically driven mobility equipment may be used on or off pavements, or both. While some people may be more concerned with moving as quickly as they can, others may be nervous about moving at faster speeds. Since design for safety is one of the project objectives, the maximum speed of the wheelchair is best to be 5 km/hr. ISO 7176-6 standard states that the maximum speed of an electrical wheelchair should not exceed 15 km/h due to safety and stability and it provides methods to adjust the acceleration that is suitable based on the speed provided by the producer.

DC Motor (1-2-2-2)

In this project, by following the steps of this standard and based on the maximum speed provided, we used the methods to calculate and provide the suitable acceleration and deacceleration and suitable motor and battery were chosen for this purpose.

Additional information

To ensure achieving this standard, the calculations were performed for the maximum mass that can be carried by the motor.

Climbing ability for the wheelchair (ISO 7176-10)

It is very important to consider that the user will be in a situation where he/she needs to go up using an incline. The purpose of ISO 7176-10 standard is to define the test procedures to be used to determine the wheelchairs' capabilities to climb and descend obstacles.

DC motor (1-2-2-2)

A suitable motor and a suitable battery were used to achieve the required torque and power. The maximum mass that can be carried by the selected motor of the wheelchair for an incline was calculated in this report. We applied the test methods and the details of the test methods in chapter 5.

Power and control systems for electrical wheelchairs (ISO 7176-14)

In the wheelchair, high power is used. The power must be well distributed and organized to be well controlled due to safety and reliability. The standard ISO 7176-14 outlines specifications for the power and control systems of electrically powered wheelchairs, along with related test procedures. It establishes performance and safety standards that are applicable during regular operation as well as under various abuse and failure scenarios. Additionally, it establishes limitations on the forces required for activities and specifies measuring techniques for the forces required to operate controls.

Arduino Mega (1-2-2-1)

Arduino Mega 2560 is the brain of the wheelchair. Using a box to contain the Arduino and the other electrical connections system, the power and control systems are managed. To organize the control of the wheelchair and to avoid overlapping, all the commands will be from the Arduino. The power is well distributed in the box and the wires are well insulated.

DC Motor (1-2-2-2)

The motor needs to be controlled in this project. It is obvious that whenever the driver speeds up, more power consumption will be faced therefore, more heat will be generated on the motor drivers. Therefore, the motor drivers are well connected above cooling fans and well-adjusted in the Arduino control system box. Moreover, to avoid the unwanted speed misbehaving, speed of the wheelchair was designed to be in 3 levels (2 km/hr, 3.5 km/hr, 5 km/hr.) to avoid the power consumption. Furthermore, by using motor drivers, the power distribution will be controlled in the motor.

Battery (1-2-3-1)

It is important to choose a battery that will provide a suitable power and current for the electrical components. The battery selected in this project should be able to resist the effect of the temperature around the wheelchair. Moreover, the batteries were kept in a standard removable box. The box has a switch and standard charging ports to be able to charge the batteries safely. There is a wire from the battery taken out to the Arduino control box to power the electronics.

Table 1: Engineering standards followed

Standard code	Title	Scope & Instructions	The subsystem
ISO 7176-1	Wheelchair stability	The description test procedures for establishing the static stability of wheelchairs. Specific speed and amount of weight is required.	The frame (1-1-1) Caster fork (1-1-1-6) Folding Mechanism (1-1-2) DC Motor (1-2-2-2)
ISO 7176-3	Wheelchair break	adjust the wheelchair's capacity to stop safely on level ground and on an incline, as well as its capacity to stay stationary while parked on a slope or an incline. There are no numerical requirements in this standard.	The frame (1-1-1) Folding Mechanism (1-1-2) DC Motor (1-2-2-2)
ISO 7176-4	Power Consumption	predict a range accurately for a specific wheelchair and occupant. However, it may be used as a benchmark for comparing various wheelchairs under identical test circumstances. A wheelchair's ability to go a distance depends heavily on how it is operated, therefore a single theoretical range estimate might not be enough to comprehend how well it works. calculating the nominal energy capacity of the wheelchair's battery system and the energy used during driving	Sensors (1-2-1) Control units (1-2-2) Arduino Mega (1-2-2-1) DC Motor (1-2-2-2) Battery (1-2-3-1) Battery charger (1-2-3-2)
ISO 7176-5	Wheelchair Dimensions	provide technical definitions along with suitable measurement techniques for determining the key masses and dimensions of manual wheelchairs and electrically powered wheelchairs, including scooters, in order to determine their suitability for a particular environment	Frame (1-1-1) Motor Holder (1-1-1-1) Arduino box (1-1-1-2) Battery box (1-1-1-3) Controlling unit holder (1-1-1-4) Controlling unit box (1-1-1-4-1) Foot plate (1-1-1-5) Caster fork (1-1-1-6) Seat (1-1-1-9)

			Folding Mechanism (1-1-2)
ISO 7176-6	Maximum speed & Acceleration	states that the maximum speed of an electrical wheelchair should not exceed 15 km/h due to safety and stability and it provides methods to adjust the acceleration that is suitable based on the speed provided by the producer.	DC Motor (1-2-2-2)
ISO 7176-10	Wheelchair climbing ability	define the test procedures to be used to determine the wheelchairs' capabilities to climb and descend obstacles.	DC Motor (1-2-2-2)
ISO 7176-14	Power and control systems	outlines specifications for the power and control systems of electrically powered wheelchairs, along with related test procedures. It establishes performance and safety standards that are applicable during regular operation as well as under various abuse and failure scenarios. Additionally, it establishes limitations on the forces required for particular activities and specifies measuring techniques for the forces required to operate controls.	Sensors (1-2-1) Control units (1-2-2) Arduino Mega (1-2-2-1) DC Motor (1-2-2-2) Battery (1-2-3-1)
ISO 6848	TIG Welding Electrodes	categorization of non-consumable tungsten electrodes for inert gas-shielded arc welding, plasma welding, cutting, and thermal spraying. specifications required for the categorization of non-consumable tungsten electrodes for thermal spraying, plasma welding, and arc welding with inert gas shielding.	Frame (1-1-1)
ISO 15611	Welding experience	the qualification of welding techniques based on prior welding experience	Frame (1-1-1)
ISO/TR 18786	Safety in welding	For the examination of the health and safety aspects of welding metallic materials, including on-site and maintenance operations offers recommendations.	Frame (1-1-1)

Table 2: Engineering standards that should be followed but not followed

Standard code	Title	Instruction & Requirements	The subsystems
ISO 7176-8	Strength of material and fatigue	outlines test procedures and establishes minimum standards for the wheelchair as a whole and each individually stressed component's static, impact, and fatigue strength. the number of test cycles for both two-drum and drop tests, as well as the speed and size of the slat on the two-drum test machine, are needed for testing and confirmation of the fatigue testing components. There are more requirements in this standard which are not mentioned.	Frame (1-1-1) Motor Holder (1-1-1-1) Arduino box (1-1-1-2) Battery box (1-1-1-3) Controlling unit holder 1-1-1-4 Foot plate (1-1-1-5) Caster fork 1-1-1-6 Folding Mechanism 1-1-2
ISO 7176-9	Climate tests	outlines specifications and test procedures to establish how weather conditions, including rain, dust, condensation, and temperature fluctuations, affect the fundamental functionality of electrically driven wheelchairs	The wheelchair in general
ISO 7176-13	Friction force	outlines a test procedure for figuring out a test surface's coefficient of friction that has a rough texture, such as unfinished concrete. If the test technique is used on polished or flat surfaces, caution should be taken to ensure that the coefficient of friction is measured as being constant over the whole test surface.	DC Motor

ISO 7176-1 (Static Stability)

Designed to provide mobility for one disabled person whose mass is in the range mentioned in ISO 7176-11. Also, it outlines techniques for measuring the tipping angles. The following terms are required in this Standard:

-contact point: the centre of the area where a wheelchair wheel or other component makes contact with the ground.

-Force detection point: location where the force beneath an upward pointing wheel is measured.

-A wheel that can be locked up is one that has a parking brake or one whose motion is stopped by the means of propulsion (e.g. by hands, levers, motors)

-parked state: a standstill posture that enables passenger entry or exit from the seat.

-Wheel that typically rolls on the ground when the wheelchair is moving along at a steady speed on a flat surface is referred to as a "running wheel."

-wheelchair tipping angle: The angle of the test platform with respect to the horizontal at which the vertical projection of the centre of mass goes outside of a polygon formed by the contact points of all the running wheels is known as the wheelchair tipping angle (to be assessed by empirical measure).

A weighted wheelchair is theoretically statically stable as long as the gravitational force line from the centre of mass is contained within the area on the ground that is delimited by the contour of its wheels' contact points. The stability of a wheelchair improves as the angle between the axis of the chair's tip and the plane containing its centre of mass grows. When tilted past this specified angle about the axis of tip, a wheelchair will tip.

ISO 7176-2 Dynamic Stability

This standard outlines the testing procedures for evaluating the dynamic stability of wheelchairs with electrical propulsion. The wheelchair is put through a series of driving tests that simulate using one, and its motions are monitored for the occurrence of a variety of specified unstable circumstances. rigid, flat, horizontal test plane that is big enough to conduct the tests and has a coefficient of friction larger than 0,6. The surface of the test plane must be between two hypothetical horizontal planes spaced 20 mm apart and have a maximum slope or cross slope change of 0.5° during the test. The wheelchair must be able to go at its highest speed and stop within the specified inclination on a rigid, flat, inclined surface with a run up and run down. The ramp's test area must be long enough for the wheelchair to halt within the specified inclination range, which must be within a tolerance of 1°.

The surface of the testing ramp area must be situated between two fictitious parallel planes spaced 50 mm apart.

Through a transition having a radius of no more than 25 mm, the test area must extend directly from the horizontal test plane.

Steps taller than 5 mm and loose debris must be absent from the surface being crossed.

Step heights of 15 mm, 25 mm, 50 mm, and multiples of 25 mm above that, if the manufacturer claims it Rigid vertical step transition, Test subject. And more tests about the rearward dynamic stability.

ISO 7176-3 Brakes effectiveness

This standard outlines the testing procedures for evaluating the performance of the brakes on manual and electrically powered wheelchairs. The definition and the requirements can be specified like tipping and sliding. The reflexes of the wheelchair are measured and monitored as a result of various wheelchair braking procedures. Test dummies, rigid flat test ramps, rigid flat inclined test ramps, rigid flat horizontal test planes, and rigid flat adjustable test planes additional weights, Instruments for measuring force, braking distance, and inclinometer are required to be available during the test.

ISO 7176-4 Energy consumption

This standard describes techniques for calculating the theoretical range of electrically powered wheelchairs, including scooters, based on measurements of energy used during operation and the nominal energy capacity of the wheelchair's battery set. It applies to wheelchairs that are electrically propelled and have a maximum nominal speed of no more than 15 km/h. Continuous driving and manoeuvring are the two modes of driving for which energy consumption is assessed. The wheelchair is driven continuously around a test track 10 times clockwise and ten times counterclockwise. and the amount of energy used is calculated. The wheelchair is driven through a circuit for maneuvering. halting and turning 10 times in either direction outside of two markers spaced five meters apart, while the Consumed energy is monitored. Values within the theoretical range are derived from the energy spent, the both the battery's capacity and the theoretical distance traveled. There are many requirements for this standard. Test track: a line drawn on a level, horizontal, hard surface away from drafts, when the temperature is between 18 and 25 degrees Celsius. The test track's centerline must be between 50 and 100 meters long. Each long side, L, must be long enough for the wheelchair to go at its top speed. Each short side, W, must be long enough to allow the wheelchair to turn without pausing. Two markers must be placed on one side of the test track, both parallel to the centerline and spaced 5,00 m 0,01 m apart. It must also have a center marker that is round and has a diameter of 0.13 m 0.03 m. A device for measuring energy consumption that can measure the electrical energy, expressed in watt hours, supplied by the wheelchair's battery terminals with an accuracy of 2% and that uses no more than 5% of the energy supplied. A positive measurement will reflect the energy that the battery set supplies to the wheelchair, and a negative measurement will represent the energy that the wheelchair returns to the battery set. When acquiring discrete samples, the device' sampling duration must not be longer than what is required to deliver the appropriate precision. Device for measuring distances that can measure the length of the test track's centerline with an accuracy of 100 mm.

ISO 7176-5 Determination of dimensions, mass

The objective of this standard (ISO 7176-5) is to provide technical definitions along with suitable measurement techniques for determining the key masses and dimensions of manual wheelchairs and electrically powered wheelchairs, including scooters, in order to determine their suitability for a particular environment. The caster fork, the front wheels, the rear wheels, the seat width and length and height, the total wheelchair width and length, and the height from the ground to the seat were mentioned in this standard. There are many requirements in this standard. Total mass, Loading the wheelchair, Castor wheel misalignment is the lateral separation between the castor wheel's ground contact point and the location where the castor stem axis touches the surface.

A fixed wheel is one whose axial direction with respect to the wheelchair cannot vary while the wheelchair is moving.

Front wheel track is the separation between the front wheels' points of contact with the ground.

Full occupied length is the measurement between the wheelchair's farthest forward and furthest back points, including the lower leg support assemblies and a reference occupant.

Full overall length is the distance between the wheelchair's farthest forward and furthest back points when it is fully constructed, ready for use, and equipped with any leg supports, foot supports, and anti-tipping devices.

ground clearance: The distance needed between the wheelchair's seat and the ground.

Midpoint of the region where the wheel hits the ground is known as the ground contact point.

wheelchair handgrip height is the vertical distance between the wheelchair's handgrip reference points and the ground.

reference point for the handgrip: the outermost lateral point halfway down the handgrip.

The term "lateral handrim deviation" refers to the handrim's departure from a flat plane perpendicular to the axle.

Departure of the wheel rim from a flat plane that is perpendicular to the wheel axle is known as lateral wheel deviation.

Mass of the heaviest component: The weight of the wheelchair's heaviest component (or component assembly) when it is disassembled for storage or transportation.

occupied height is the vertical distance from the test plane to the top of a reference occupant's head.

occupied width is the wheelchair's overall width, including the reference occupant.

pivot width: The smallest space necessary for a wheelchair with complete differential steering to turn through 180 degrees between two vertical, parallel walls.

rear wheel track: the separation of the rear wheel's ground contact points.

When opening an 800 mm wide door that is 600 mm from the side wall, there must be at least that much space between the wall housing the door and the wheelchair's furthest point.

ISO 7176-6 Determination of maximum speed

This standard includes test methods for determining the maximum speed of electrically powered wheelchairs, intended to carry one person with a maximum nominal speed not exceeding 15 km/h on a level surface. The apparatus for this standard includes:

Instrumentation: that may need to be added to the test dummy, in which case its mass should not exceed 5 % of the total dummy mass.

Horizontal test plane: made up of a rigid, flat, horizontal surface of sufficient size to conduct the tests and with a coefficient of friction that meets the requirements of ISO 7176-13.

Speed measurement device: To measure and record speed up to 5 m/s with an accuracy of ± 0.1 m/s and a sample rate of at least 60 Hz.

Test dummy: as specified in ISO 7176-11, or a human test occupant according to ISO 7176-22.

Supplementary weight: shall be added to a human test driver to give the mass distribution equivalent to the relevant dummy.

ISO 7176-8 Static, impact and fatigue strengths

The criteria for the static, impact, and fatigue strength of wheelchairs are laid forth in this standard. The test procedures for establishing if the requirements have been satisfied are specified. It also outlines the specifications for test results dissemination. The standard applies to wheelchairs for the disabled that are used indoors and outdoors, both manually and electrically driven. The standard establishes minimal specifications for both the wheelchair and its individual parts.

The requirements include:

No component may be readjusted, retightened, or have apparent fractures on the surface that do not extend to the structural substance. No component may be broken or have been detached. No externally visible electrical cable shall be cut, abraded, or crushed. No externally visible electrical connector shall be crushed or disconnected.

All moving, rotating, detachable, foldable, or adjustable elements must function as the manufacturer has specified. All power-operated systems shall operate as described by the manufacturer.

c.) Handgrips must remain in place.

d.) No part or assembly of components may show obvious plastic deformation, free play, or loss of adjustment that impairs the wheelchair's ability to function.

e.) The brake mechanism must remain in its predetermined locations.

- ISO 7176-9 Climatic tests

This standard outlines the conditions and procedures for testing how electrically powered wheelchairs will perform when it rains and condenses and when the temperature changes. Nevertheless, the standard does not mention any requirements for resistance to corrosion. There are instructions mentioned like the user should have a control device that allows them to steer the wheelchair in the direction they want it to go or at the pace they choose. Additionally, the ambient temperature of (20 5) °C and relative humidity of (60 20 %) should be taken into account. The wheelchair electrical system might be exposed to liquids, including salt water and since the effects of saltwater contamination are difficult to evaluate, the immunity of the system is assessed on the basis of exposure to a fresh water spray. trial run, a test subject or a test subject who has additional weights added to make their mass distribution comparable to the appropriate dummy, A human test driver or a remote control may be used to test drive a wheelchair. a thermometer that measures air temperature accurately to one degree Celsius, a timer that can accurately measure time to the nearest second, 2% accurate relative humidity measurement with a humidity measurement equipment, Cold test environment to expose a wheelchair to ambient temperatures between 25 and roughly 40 degrees Celsius, a hot test setting where a wheelchair would be exposed to temperatures between around 50 and 65 degrees, Test setting in which a wheelchair is exposed to typical environmental conditions (3.2), Water jets to spray water are all required in this standard.

ISO 7176-10 climbing ability

This standard defines the procedures for testing the capacity of one-person, electrically driven wheelchairs with a maximum nominal speed of 15 km/h to climb obstacles. Some of the required equipment are:

Test plane, a flat, hard plane with a friction coefficient as described in ISO 7176-13, with its whole surface enclosed between two imaginary, horizontal parallel planes spaced 5 mm apart and horizontal within 0,5°.

Test obstacle, an obstacle similar to that in Figure 1, with a relative tolerance of 5% or a tolerance of 2 mm, whichever is larger, and a height that can be changed in 5 mm increments up to a height of 200 mm. The test laboratory and the wheelchair provider must agree on any multiple of 5 mm for the nominal beginning height, which must be 10 mm.

ISO 7176-13 Coefficient of friction

This standard describes a test procedure for figuring out a test surface's coefficient of friction when it has a rough texture, such unfinished concrete. If the test technique is used on polished or flat surfaces, caution should be taken to ensure that the coefficient of friction is measured as being constant over the whole test surface. The characteristics of the wheelchair tires and the test surface determine the coefficient of friction between the two surfaces. This test technique was established in order to define the test surface in terms of the coefficient of friction using a standard approach that is independent of the wheelchair being tested since it is desired to compare the test results of various wheelchairs on comparable test surfaces. The technique entails dragging a certain block over the test surface at a predetermined speed with a conventional rubber interface. In accordance with this standard, test blocks, test rubber, and force gauges are necessary apparatus. When measured using the test technique described in this standard on each of the three typical surfaces, the test surface must be deemed acceptable if its coefficient of friction is between 0.75 and 1.

ISO 7176-14 Power and control systems

This standard outlines the specifications for the electrically powered wheelchairs' power and control systems, including battery chargers and related test procedures. It outlines certain circumstances for abuse and failure as well as the very minimum needs for safeguarding the wheelchair user while in regular usage. Additionally, it establishes limitations on the forces required for particular activities and provides measuring techniques for the forces required to operate the controls. This standard discusses many terms. The terms watchdog, command signal, controller, controller, nominal voltage of the battery, battery pack, battery charger, and battery set are all discussed in this standard. In addition, The following apparatus are discussed:

In order to complete the tests mentioned in 6.13.3, 6.15.3, and 6.17.3, an inclined test plane must be placed at a 5° angle to the horizontal, be large enough, and have a surface with enough friction to prevent significant wheel slippage. The minimum size that is advised is 5 m by 1.5 m.

a horizontal test plane large enough to accommodate the 6.11.3, 6.12.3, 6.16.3, and 7.3 tests, and having the same high-friction surface as the inclined test plane (4.1).

Speedometer or other device that can accurately measure the speed of a wheelchair within a range of 0 to 15 km/h.

wheelchair braking distance measurement tools with an accuracy of 100 mm.

A battery set with a voltage that is 1,25 times the nominal voltage of the battery set in the wheelchair that will be put through its paces—0 + 2 V—and a capacity that is at least equal to that of the battery set in the wheelchair will serve as the direct current source.

standard test finger with joints

Standard test finger without joints

Instrument for measuring forces with an accuracy of 1% of the rated capacity, measuring forces in the range of 0 N to 100 N in increments of 1 N

With an accuracy of 1% of the stated capacity, this force measuring instrument for control devices can measure forces in the range of 0 N to 10 N in 0,1 N increments.

ISO 7200: Technical drawings — Title blocks

Lays down appropriate rules and recommendations for the execution and practical use in the identification, administration and understanding of technical drawings and associated documents. It applies to all fields of engineering (mechanical, electrical, civil, etc.) and facilitates the exchange of documents by defining field names, their contents and their length (number of characters), ensuring compatibility with each other. It specifies the data fields used in the title blocks and headers of technical product documents.

APPENDIX C: CONSTRAINTS

In this project, we encountered several constraints that shaped the design and development of the autonomous wheelchair. These constraints played a crucial role in ensuring the success of the project and meeting the objectives effectively.

- Time:

Proper time management proved crucial in ensuring the completion of the multi -controlled autonomous wheelchair project within the scheduled timeframe, with defined deadlines for each step and a final prototype date. However, the lack of enough operating hours at the mechanical workshop significantly impacted on the available time to work on the wheelchair, requiring us to carefully allocate our time and prioritize tasks. This constraint hampered productivity and extended the overall project timeline. Furthermore, importing the necessary parts to TRNC took a chunk of time, as delays in customs clearance caused significant setbacks. Despite these challenges, we adapted our time management approach, optimizing our workflow within the limited workshop hours, and leveraging non-workshop hours to focus on other project aspects. Through these adjustments, we successfully completed the project, demonstrating the resilience of our time management strategies and project management plan.

- Cost:

The cost constraint was a significant consideration throughout our project. As we worked within a limited budget of $800, we carefully considered the cost implications of design choices. We purchased parts that met our quality requirements while ensuring they remained within budget. In some instances, we opted to fabricate certain components ourselves to reduce costs further. By making these strategic decisions, we successfully balanced quality and affordability, effectively managing the project's financial limitations.

- Availability of resources & materials:

We designed the project to make the best use of available resources and materials, which helped us save money on purchasing necessary materials. However, we encountered challenges in obtaining some materials locally, which led us to create certain resources in-house and import others. Through thorough market research, we identified the required resources and their availability. For the resources we couldn't find locally, we sourced them online from various retailers, such as Robotistan, ensuring that we obtained all the necessary components for the project. This comprehensive approach allowed us to efficiently manage our resources, both by utilizing in-house capabilities and conducting diligent procurement, ultimately ensuring the successful completion of the project.

- Manufacturability and sustainability:

Throughout the project, we prioritized the manufacturability and sustainability of the prototype, which led us to improvise new designs that still met the required standards. Despite encountering various manufacturing constraints, we leveraged our expertise and creative thinking to devise innovative solutions. By carefully analysing the constraints and requirements, we developed improvised designs for specific components such as the joystick, Arduino box etc., considering factors such as functionality, safety, and cost-effectiveness. Through iterative design processes and rigorous testing, we ensured that these improvised designs not only met the standards but also performed reliably and efficiently.

- Voice recognition accuracy:

To enhance the voice recognition system's accuracy, we subjected it to extensive training and testing using diverse voice inputs. We initially bought an ElecHouse voice recognition module, but the accuracy of the module was low in a normal operating environment of the wheelchair. This made us try different alternatives for voice recognition. After several testing, we ended up using the speech recognition library in Python and Google’s speech-to-text API.

Constraint	Yes	No
Time	X	
Cost	X	
Availability of resources and materials	X	
Manufacturability and sustainability	X	
Safety	X	

APPENDIX D: PROJECT PLAN

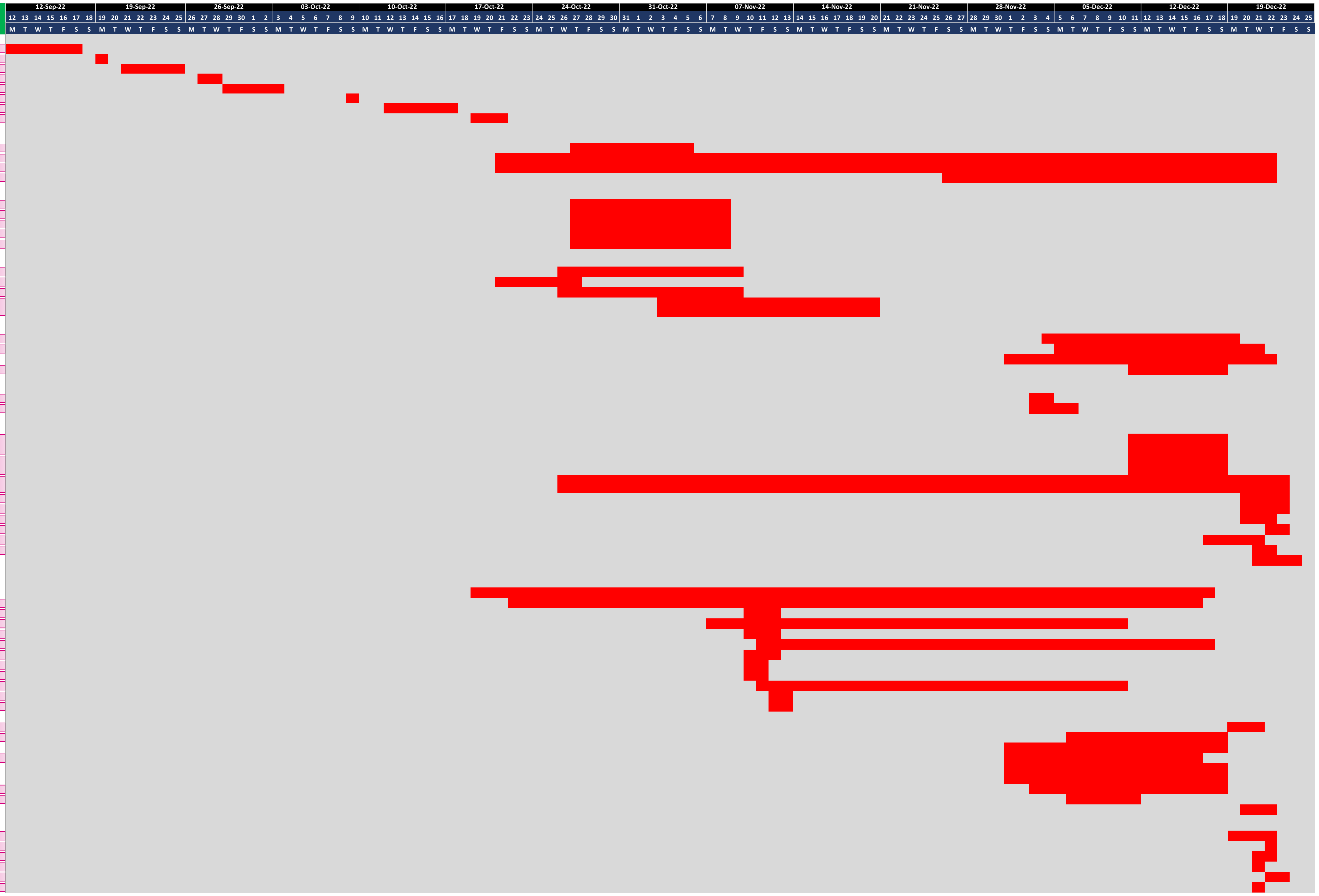
The Gantt charts for Capstone 1 and Capstone 2 are shown in the next two pages.

Gantt Chart **Smart Mobility**

Project Details	
Project Title	Speech Controlled WHEELCHAIR
Project supervisor	PROF. HASAN HACISEVKI
Project Maneger	PRECIOUS PHILIP-IFABIYI
Project Leader	JAMAL KHADER
Expected deadline	30-Dec-22

Project Team			
NAME	ROLE	MEMBER CODE	Phone Number
JAMAL	Designer	JM	5338403811
PRECIOUS	Programmer	PP	
JOSEPH	Failure Calculation	JC	
JONATHAN	Components assembling	JA	
MOHAMMED LASISI	Designer	MD	

Task Number	Task Discription	Team Member	Work Days	Start Date	End Date	Progress%
	Project proposal					
1	Project Title List	ALL	6	12-Sep	17-Sep	100%
2	CAE Feedback	ALL	1	19-Sep	19-Sep	100%
3	Project choosing	ALL	5	21-Sep	25-Sep	100%
4	Discussing the Objectives and the constrair	ALL	2	27-Sep	28-Sep	100%
5	Proposal report	ALL	5	29-Sep	03-Oct	100%
6	Roles Distribution	ALL	1	09-Oct	09-Oct	100%
7	Market Research	ALL	6	12-Oct	17-Oct	100%
8	Bill of materials	ALL	3	19-Oct	21-Oct	100%
	Project Report					
9	ABSTRACT	JA	10	27-Oct	05-Nov	100%
10	LIST OF FIGURES	ALL	63	21-Oct	22-Dec	100%
11	LIST OF TABLES	ALL	63	21-Oct	22-Dec	100%
12	LIST OF SYMBOLS and ABBREVIATIONS	ALL	27	26-Nov	22-Dec	100%
	CHAPTER 1 - INTRODUCTION					
13	1.1. Detailed definition of the project	JC	13	27-Oct	08-Nov	100%
14	1.2. Significance of the project	JC	13	27-Oct	08-Nov	100%
15	1.3. Detailed project objectives	JC	13	27-Oct	08-Nov	100%
16	1.4. Detailed project constraints	JC	13	27-Oct	08-Nov	100%
17	1.5. Report Organization	JC	13	27-Oct	08-Nov	100%
	CHAPTER 2 - LITERATURE REVIEW					
18	2.1. Background information	PP	15	26-Oct	09-Nov	100%
19	2.2. Concurrent solutions	ALL	7	21-Oct	27-Oct	100%
20	2.3. Comparisons of the concurrent solutio	PP	15	26-Oct	09-Nov	100%
21	2.4. Engineering standards of the concurrent solutions	PP & JM	18	03-Nov	20-Nov	100%
	CHAPTER 3 -DESIGN and ANALYSIS					
22	3.1. Proposed/Selected design	JM	16	04-Dec	19-Dec	100%
23	3.2. Engineering standards	JM	17	05-Dec	21-Dec	100%
24	3.3. Design calculations	JC&PP&JM	22	01-Dec	22-Dec	90%
25	3.4. Cost analysis	JA	8	11-Dec	18-Dec	100%
	CHAPTER 4 – MANUFACTURING PLAN					
26	4.1. Manufacturing process selection	JM	2	03-Dec	04-Dec	100%
27	4.2. Detailed manufacturing process	JM	4	03-Dec	06-Dec	100%
	CHAPTER 5 - PRODUCT TESTING PLAN					
28	5.1. Verification plan of the objectives of the project	JC	8	11-Dec	18-Dec	100%
29	5.2. Verification plan of the applied engineering standards	JC	8	11-Dec	18-Dec	100%
30	REFERENCES	PP	59	26-Oct	23-Dec	100%
31	APPENDIX A: Electronic Media	JA	4	20-Dec	23-Dec	100%
32	APPENDIX B: Standards	JM	4	20-Dec	23-Dec	100%
33	APPENDIX C: Constraints	JC	3	20-Dec	22-Dec	100%
34	APPENDIX D: Project Plan	JM	2	22-Dec	23-Dec	100%
35	APPENDIX E: Engineering Drawings	MD	5	17-Dec	21-Dec	100%
36	APPENDIX F: Ashby Charts (material selecti	MD	2	21-Dec	22-Dec	100%
37	APPENDIX G: DATA SHEETS	PP	4	21-Dec	24-Dec	10%
					###############	0%
	Project Work					
38	Buying components	PP & JM	60	19-Oct	17-Dec	50%
39	Mechanical & Electrical Design	JM & MD	56	22-Oct	16-Dec	100%
40	Material selection	MD	3	10-Nov	12-Nov	100%
41	Quality Function Deployment (QFD)	JA	34	07-Nov	10-Dec	100%
42	Design Criteria & Objectives & Constrains	ALL	3	10-Nov	12-Nov	100%
43	System breakdown structure	JA	37	11-Nov	17-Dec	100%
44	Mechanisim selection	JM	3	10-Nov	12-Nov	100%
45	Motor Selection	PP&JM&MD	2	10-Nov	11-Nov	100%
46	controller selection	PP&JM&MD	2	10-Nov	11-Nov	100%
47	FMEA	JC	30	11-Nov	10-Dec	100%
48	Joystick selection	PP	2	12-Nov	13-Nov	100%
49	Battery selection	JM	2	12-Nov	13-Nov	100%
50	Programming the Arduino	PP	1	20-Jan	20-Jan	0%
51	Editing Chp.1 and Abstract	JC	3	19-Dec	21-Dec	100%
52	Bill of materials	JA	13	06-Dec	18-Dec	100%
53	static analysis using SOLIDWORKS	JC	18	01-Dec	18-Dec	60%
54	failure calculations	JC	16	01-Dec	16-Dec	100%
55	Mechanical vibration Analysis using ANSYS or SOLIDWORKS	JC	18	01-Dec	18-Dec	40%
56	Control system using MATLAB	JA	18	01-Dec	18-Dec	0%
57	Motor and battery calculations	PP	16	03-Dec	18-Dec	100%
58	Electrical components cover design	JM	6	06-Dec	11-Dec	100%
59	Work breakdown structure	JM	3	20-Dec	22-Dec	0%
60	Portfolio	JM			###############	
61	Editing the report format	PP	4	19-Dec	22-Dec	100%
62	Edit motor selection and calculation	PP&JM	1	22-Dec	22-Dec	100%
63	Chp.2 format editing	PP	2	21-Dec	22-Dec	100%
64	Edit 3.4	JM	1	21-Dec	21-Dec	100%
65	Chp.4 Photos	JM	2	22-Dec	23-Dec	100%
66	Design Editing	JM	1	21-Dec	21-Dec	100%



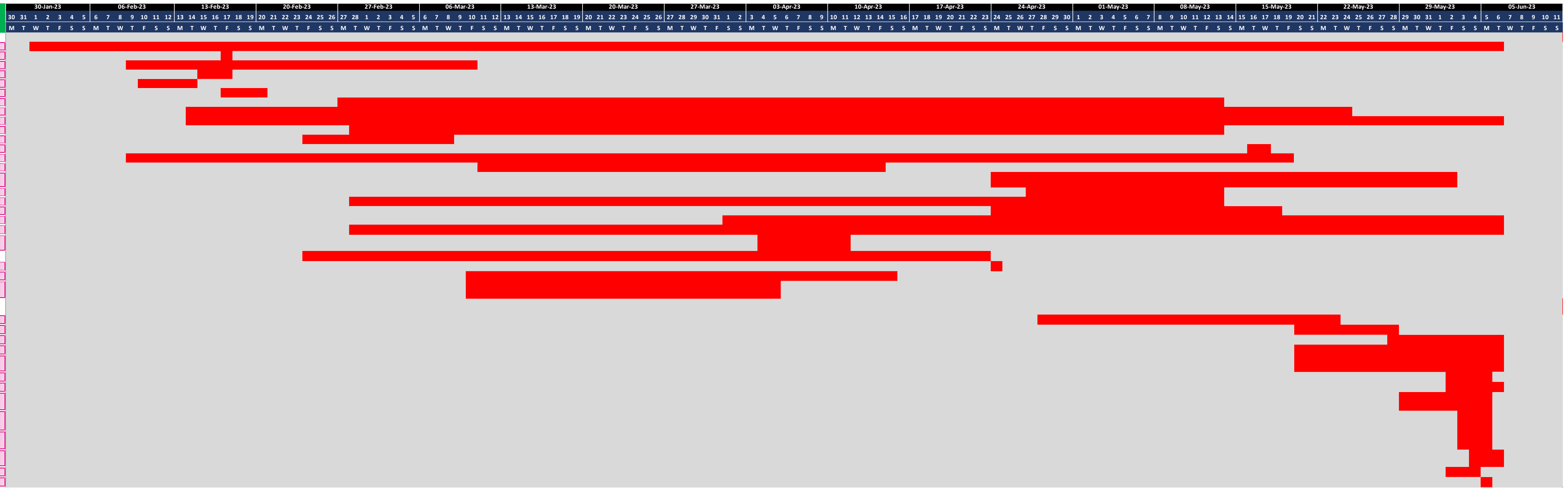
Gantt Chart Smart Mobility

Project Details	
Project Title	Speech Controoled WHEELCHAIR
Project supervisor	HASAN HASICEVKI
Project Maneger	PRECIOUS FILIP
Project Leader	JAMAL KHADER
Expected deadline	02-Jun-23

Project Team

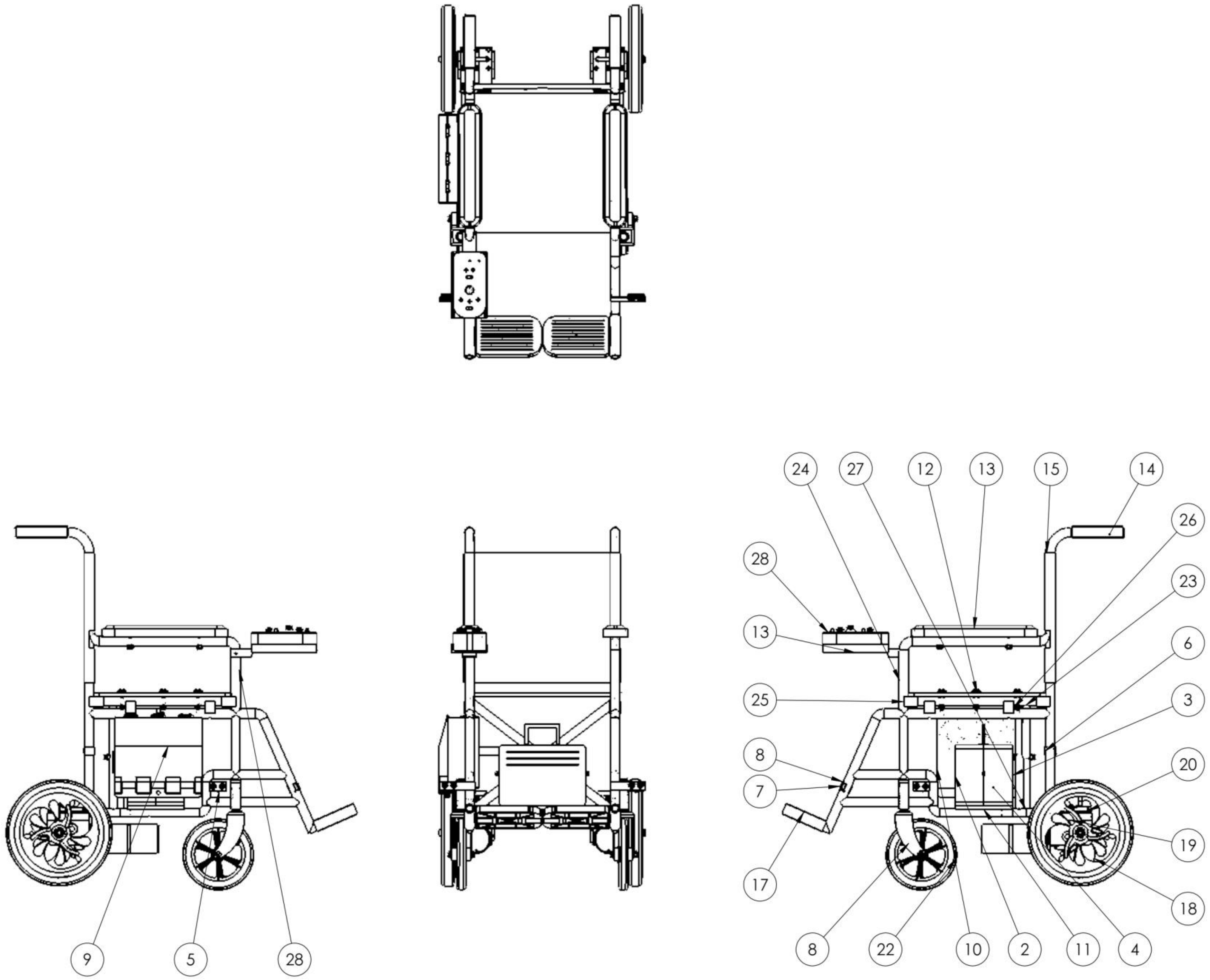
NAME	ROLE	MEMBER CODE	Phone Number
JAMAL	Designer	JM	5338403811
PRECIOUS	Programmer	PP	5338473405
JOSEPH	Failure Calculation	JC	
JPNATHAN	Components assembling	JA	
MOHAMMED LASISI	Designer	MD	

Task Number	Task Discription	Team Member	Work Days	Start Date	End Date	Progress%
	Project works (CAPSTON2)					
76	Portfolio 2		126	01-Feb	06-Jun	100%
77	Removing the bearings		1	17-Feb	17-Feb	100%
78	Edit the Design		30	09-Feb	10-Mar	100%
79	Engineering drawings & manufacturing plan		3	15-Feb	17-Feb	100%
80	Removing the rust from the frame tubes		5	10-Feb	14-Feb	100%
81	Wheels machining		4	17-Feb	20-Feb	100%
82	Assembly, manufacturing operation & documen		76	27-Feb	13-May	100%
83	ANSYS simulation		100	14-Feb	24-May	100%
84	Edit Calculations		113	14-Feb	06-Jun	100%
85	Blender simulation		75	28-Feb	13-May	100%
86	Edit the SOLIDWORKS simulation		13	24-Feb	08-Mar	100%
87	Product business Plan		2	16-May	17-May	100%
88	Electrical & Electronic connections		100	09-Feb	19-May	100%
89	Redesign the controlling unit		35	11-Mar	14-Apr	100%
90	Edit chapter 3		40	24-Apr	02-Jun	100%
91	3D Printing		17	27-Apr	13-May	100%
92	Programming the Arduino		75	28-Feb	13-May	100%
93	Edit chapter 2		25	24-Apr	18-May	100%
94	Build the Application		67	01-Apr	06-Jun	100%
95	Edit chapter 4		99	28-Feb	06-Jun	100%
96	Seat making		8	04-Apr	11-Apr	100%
97	Control system using MATLAB		59	24-Feb	23-Apr	0%
98	Edit chapter 1		1	24-Apr	24-Apr	100%
99	Prototype design		37	10-Mar	15-Apr	100%
100	Prototype battery base design		27	10-Mar	05-Apr	100%
101						
102	Engineering drawings		26	28-Apr	23-May	100%
103	Edit assembly drawing		9	20-May	28-May	100%
104	Edit the Poster		10	28-May	06-Jun	100%
105	Conclusion & future works		18	20-May	06-Jun	100%
106	Results and Discussion		18	20-May	06-Jun	100%
107	Video		4	02-Jun	05-Jun	100%
108	Presentation		5	02-Jun	06-Jun	100%
109	Insulate cables & use tranking system		8	29-May	05-Jun	100%
110	Edit the code		3	03-Jun	05-Jun	100%
111	edit the cables		3	03-Jun	05-Jun	100%
112	edit rspberry pi voice recognition		3	04-Jun	06-Jun	100%
113	finalizing the battery box and the controlling un		3	02-Jun	04-Jun	100%
114	Putting the seat belt		1	05-Jun	05-Jun	100%



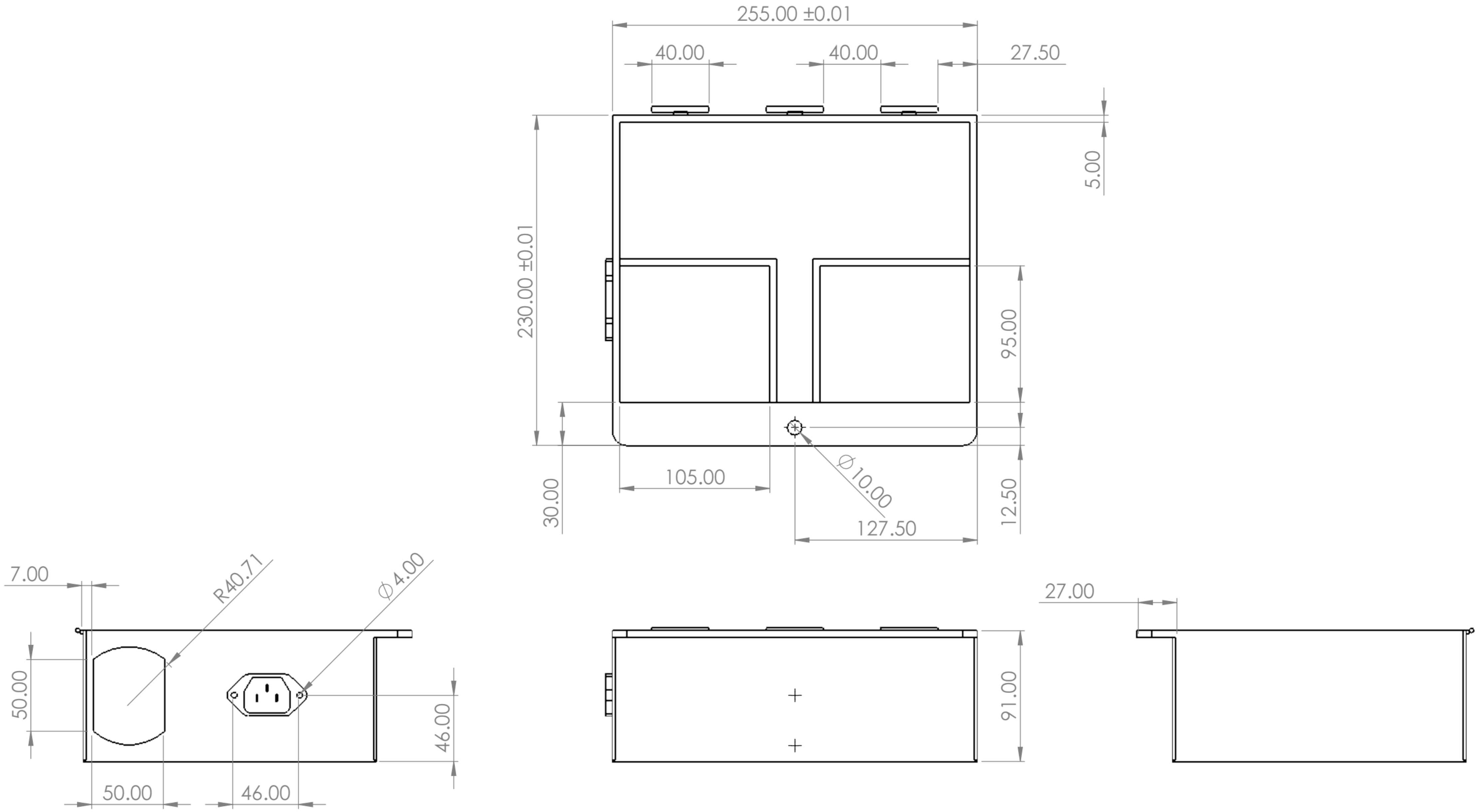
APPENDIX E: ENGINEERING DRAWINGS

Assembly and detailed drawings are shown from the next page.



ITEM NO.	PART NAME	QTY.
28	SM Frame right	1
27	Left x-frame	1
26	Frame Attach connector	4
25	Folding to frame connector	4
24	SM Frame leftt	1
23	Right x-frame	1
22	caster	2
21	Caster fork	2
20	motor_holder	2
19	motor	2
18	new spokes	2
17	foot_rest	2
16	Arm rest	2
15	back rest	1
14	grip	2
13	controlling unit_holder_	1
12	seat	1
11	base	1
10	arduino box	1
9	arduino box cover	1
8	front Ultrasonic sensor holder	2
7	Ultra Sonic Sensor	5
6	rear Ultra sonic sensor holder	1
5	side ultrasonic sensor holder	2
4	Lead Acid 20Ah Battery	2
3	Battery sheet box	1
2	Battery sheet box 2	1
1	controlling unit	1

	TOLERANCE: 180-9001			EASTERN MEDITERRANEAN UNIVERSITY MECHANICAL ENG. DEPT.
	NAME	SIGN.	DATE	
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	21/10/22	TITLE Multi-controlled Smart Wheelchair
CHECKED BY	JURY		08/06/23	PART NO. 1
MATERIAL:		SCALE:	1:10	



DIMENSIONS ARE IN MILLIMETERS & DEGREES

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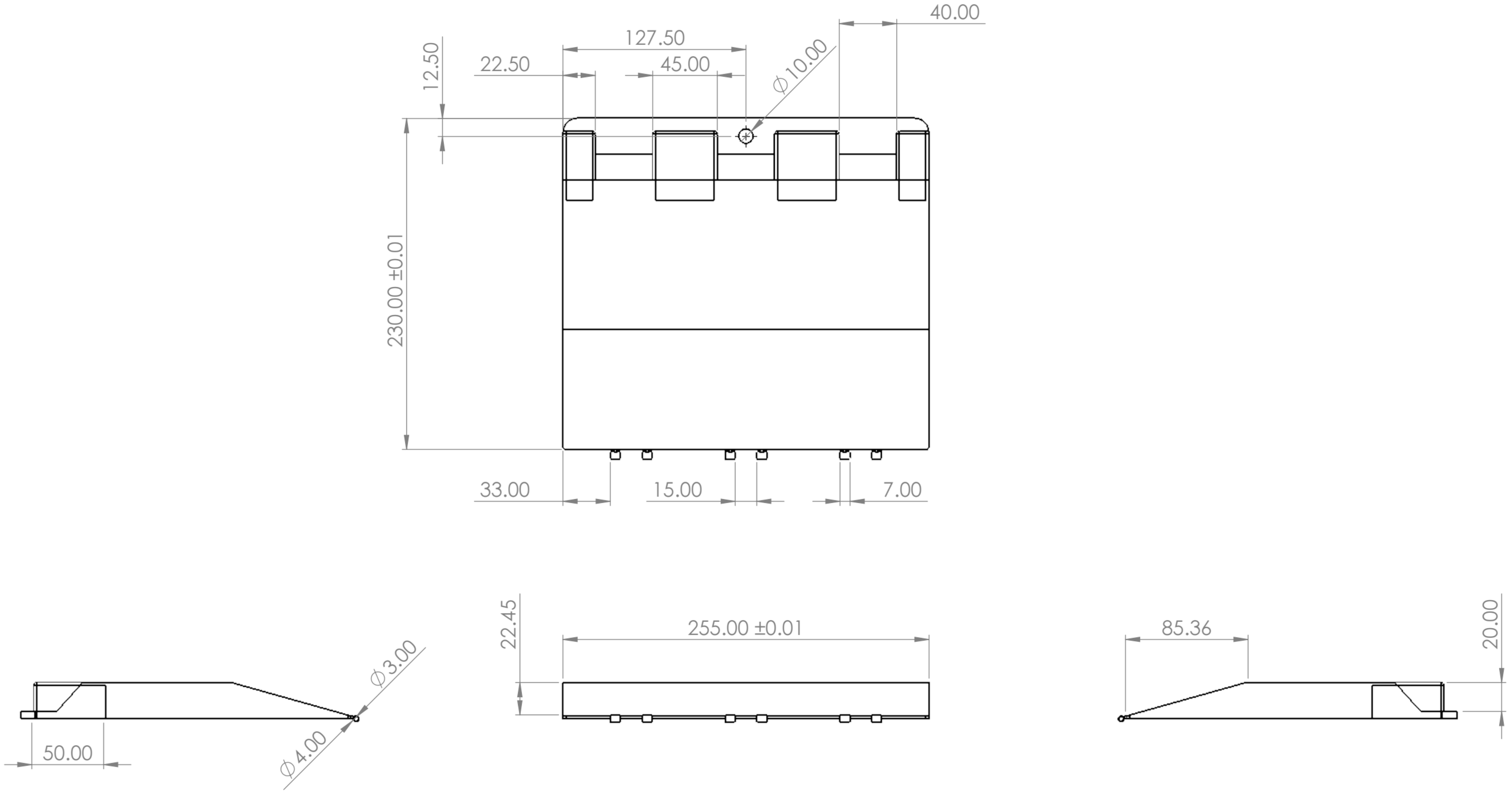
	NAME	SIGN.	DATE	
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	21/10/22	TITLE ARDUINO BOX
CHECKED BY	JURY		08/06/23	
MATERIAL:	PLASTIC	SCALE:	1:3	PART NO. 1-1-1-2



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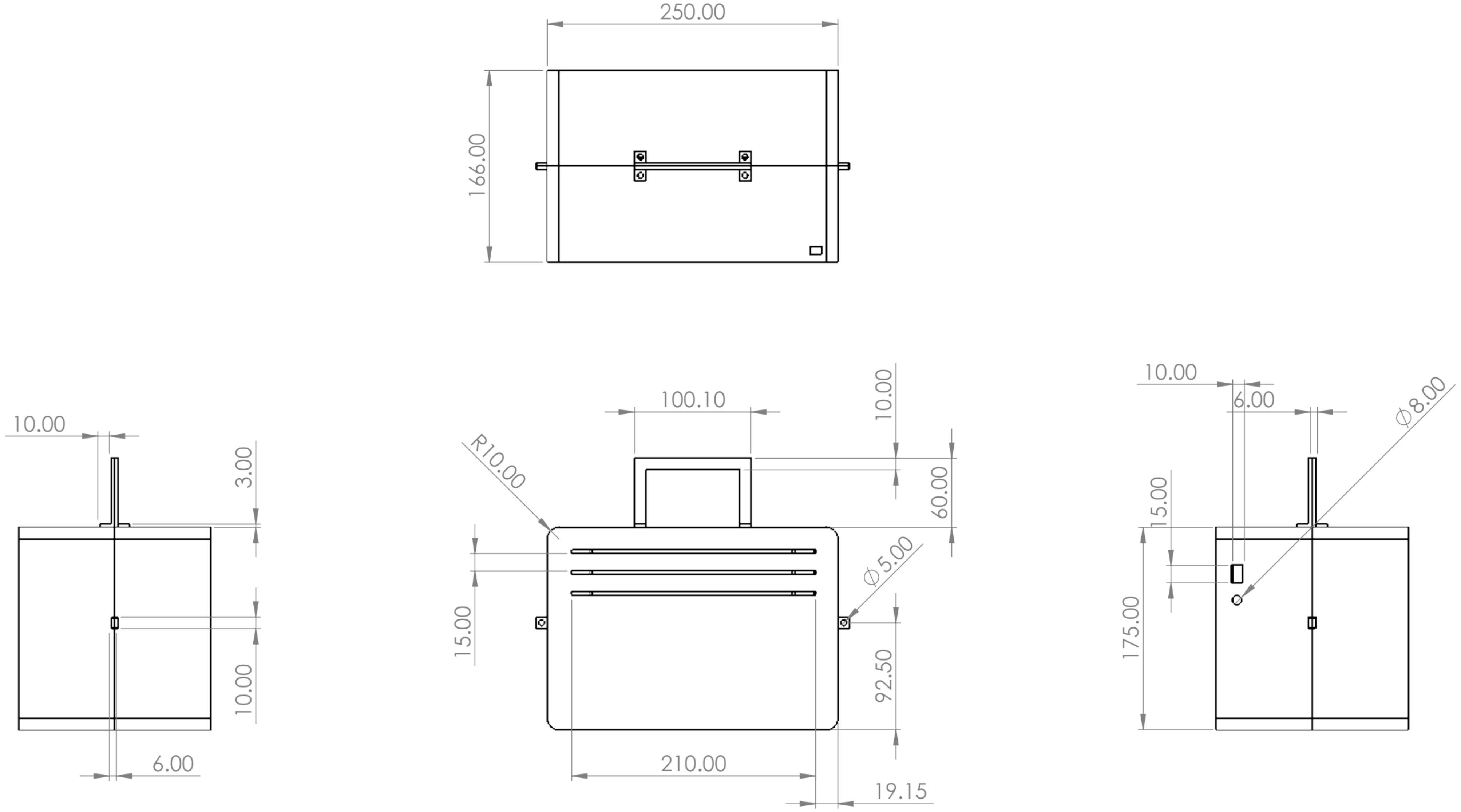
	NAME	SIGN.	DATE	
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	21/10/22	TITLE ARDUINO BOX COVER
CHECKED BY	JURY		08/06/23	
MATERIAL:	PLASTIC	SCALE:	1:3	PART NO. 1-1-1-2-1



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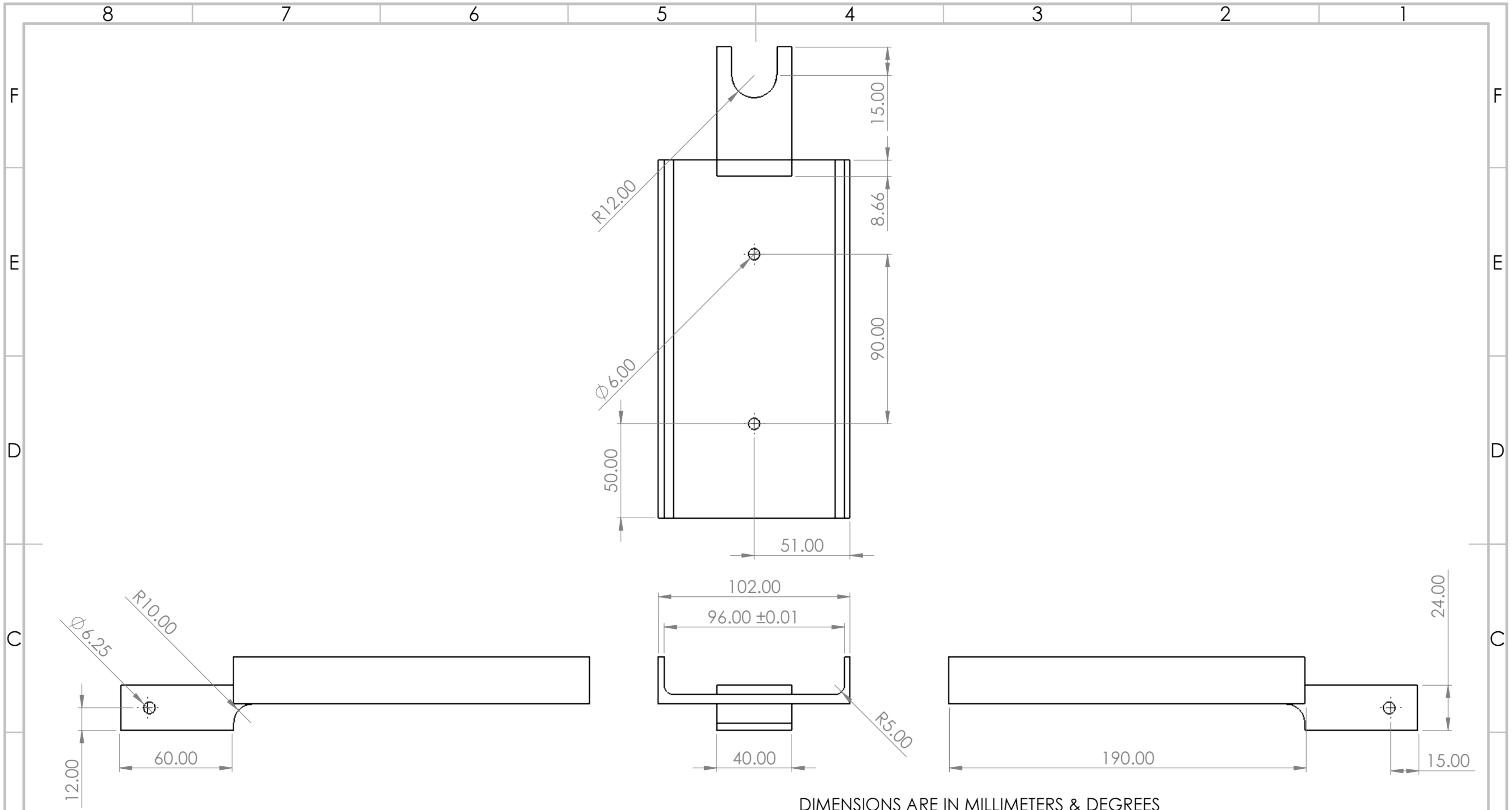
	NAME	SIGN.	DATE	
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	21/10/22	TITLE BATTERY BOX
CHECKED BY	JURY		08/06/23	
MATERIAL:	WOOD	SCALE:	1:4	PART NO. 1-1-1-3



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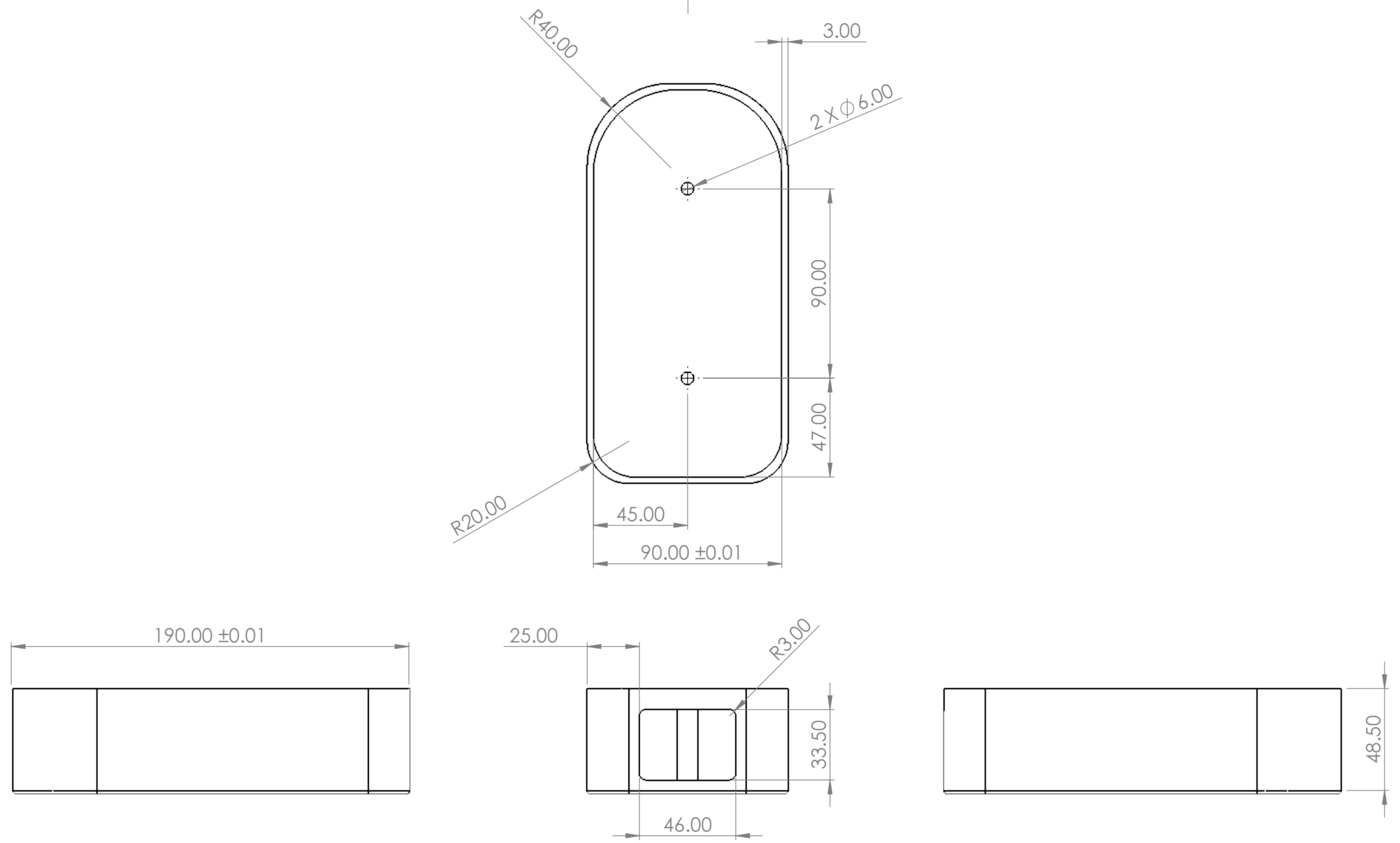
	NAME	SIGN.	DATE	
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	21/10/22	TITLE CONTROLLING UNIT HOLDER
CHECKED BY	JURY		08/06/23	PART NO. 1-1-1-4
MATERIAL:	PLASTIC	SCALE:	1:2	



DIMENSIONS ARE IN MILLIMETERS & DEGREES

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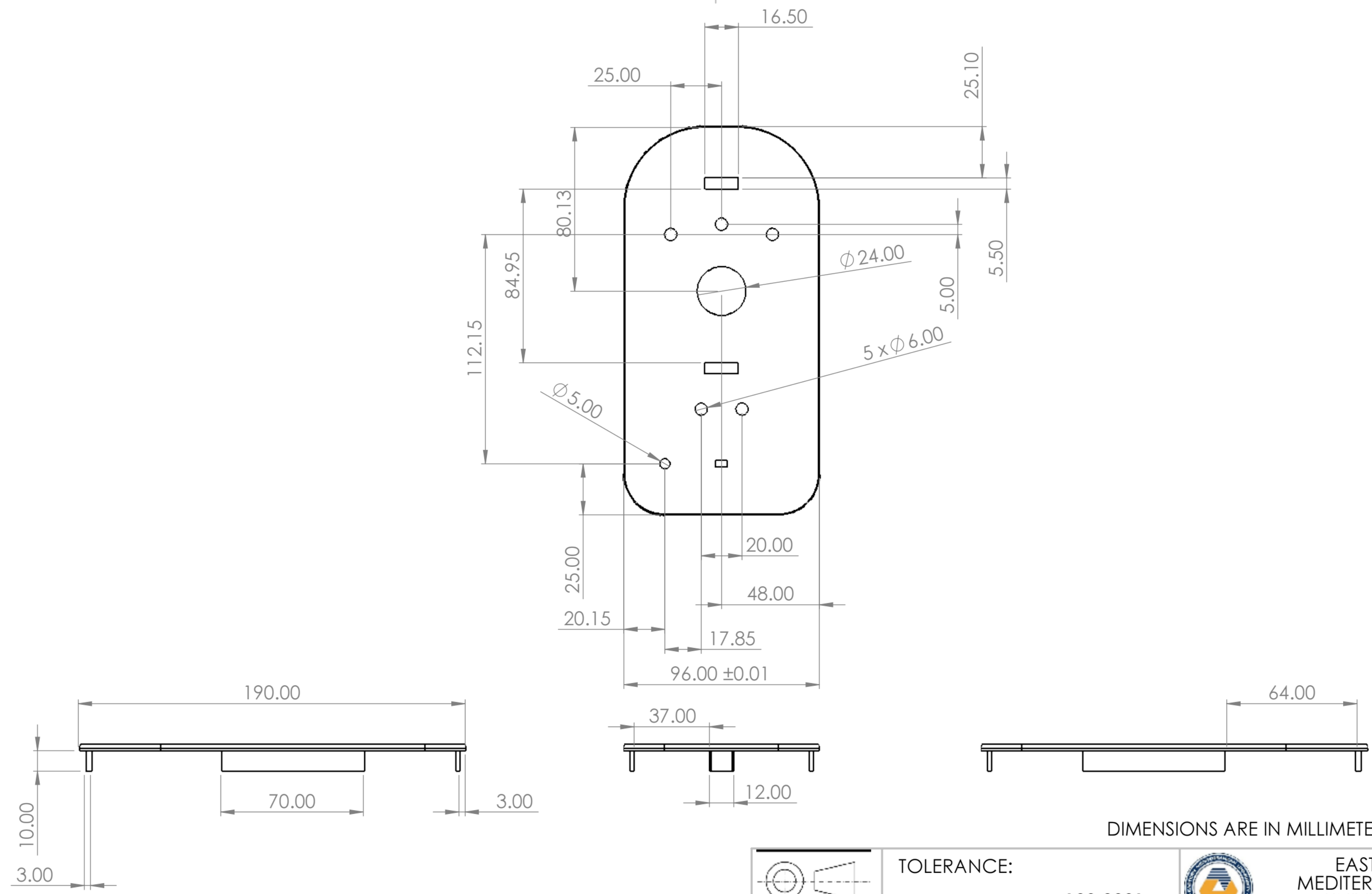
	NAME	SIGN.	DATE
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	21/10/22
CHECKED BY	JURY		08/06/23
MATERIAL:	PLASTIC	SCALE:	1:2

TITLE: CONTROLLING UNIT BOX

PART NO. 1-1-1-4-1



DIMENSIONS ARE IN MILLIMETERS & DEGREES

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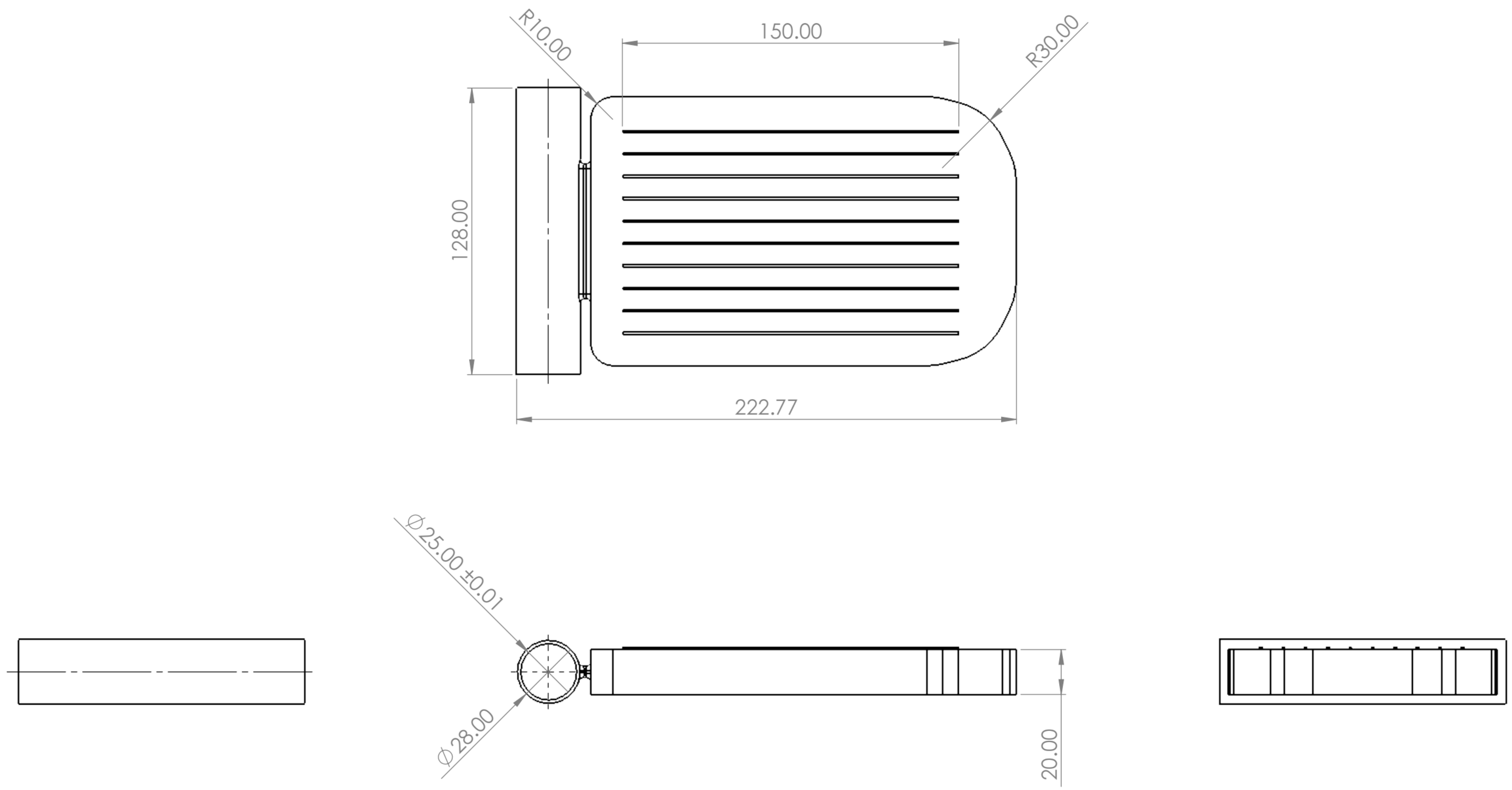
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	21/10/22	TITLE CONTROLLING UNIT COVER
CHECKED BY	JURY		08/06/23	
MATERIAL:	PLASTIC	SCALE:	1:2	PART NO. 1-1-1-4-2



DIMENSIONS ARE IN MILLIMETERS & DEGREES

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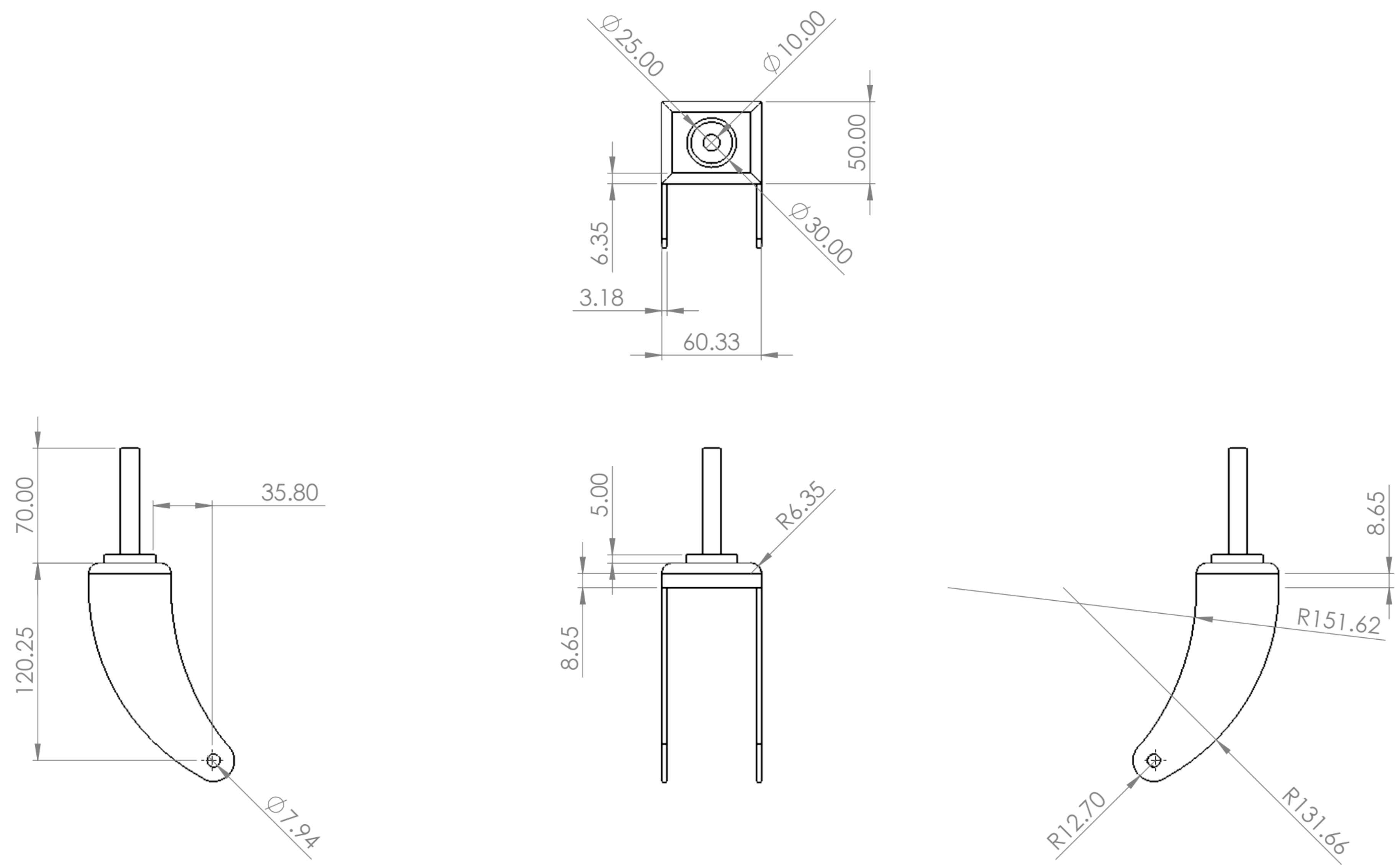
	NAME	SIGN.	DATE	
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	21/10/22	TITLE FOOT REST
CHECKED BY	JURY		08/06/23	PART NO. 1-1-1-5
MATERIAL:	PLASTIC	SCALE:	1:2	



DIMENSIONS ARE IN MILLIMETERS & DEGREES

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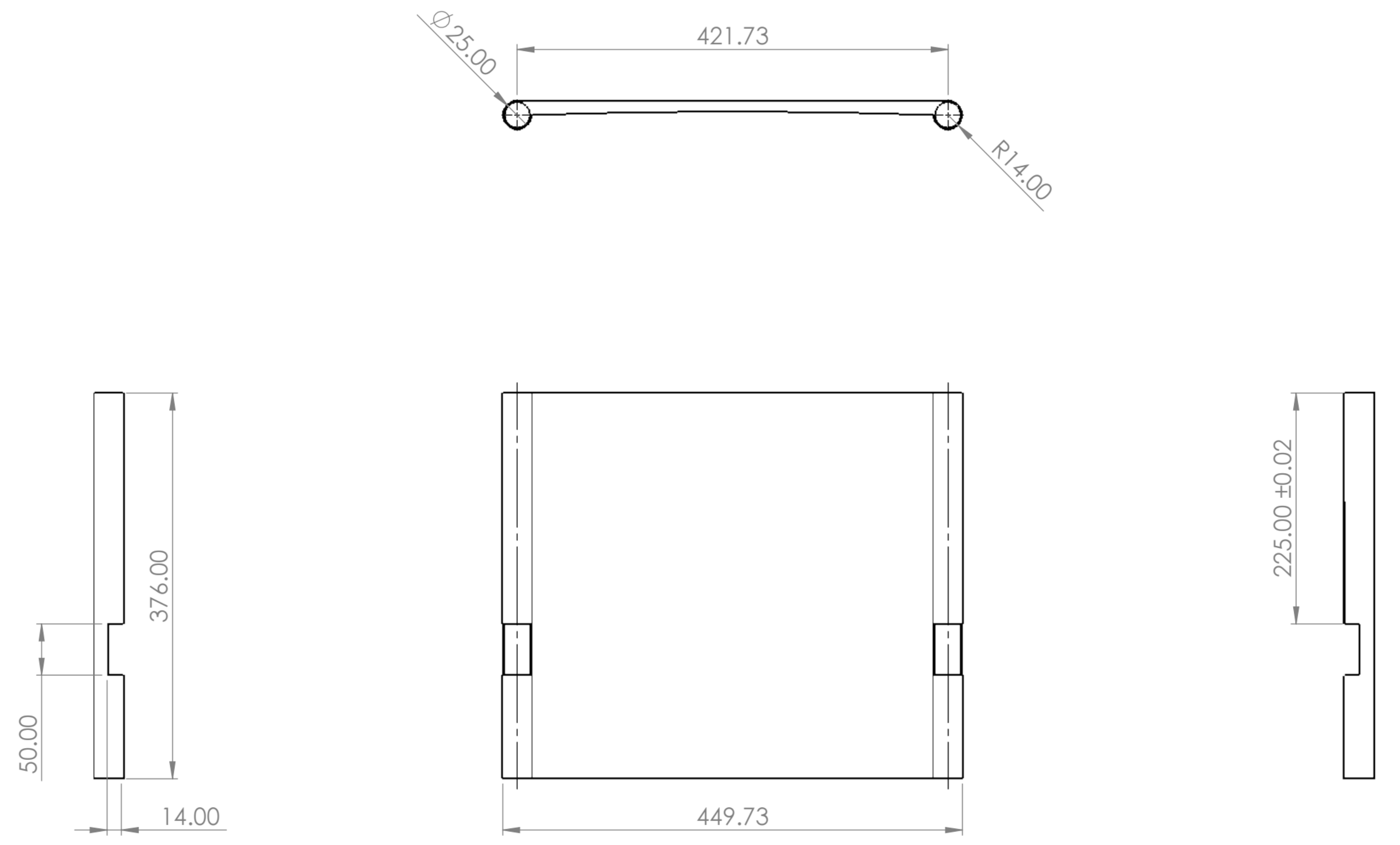
	NAME	SIGN.	DATE	
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	21/10/22	TITLE CASTER FORK
CHECKED BY	JURY		08/06/23	PART NO. 1-1-1-6-2
MATERIAL:	STEEL	SCALE:	1:3	



DIMENSIONS ARE IN MILLIMETERS & DEGREES

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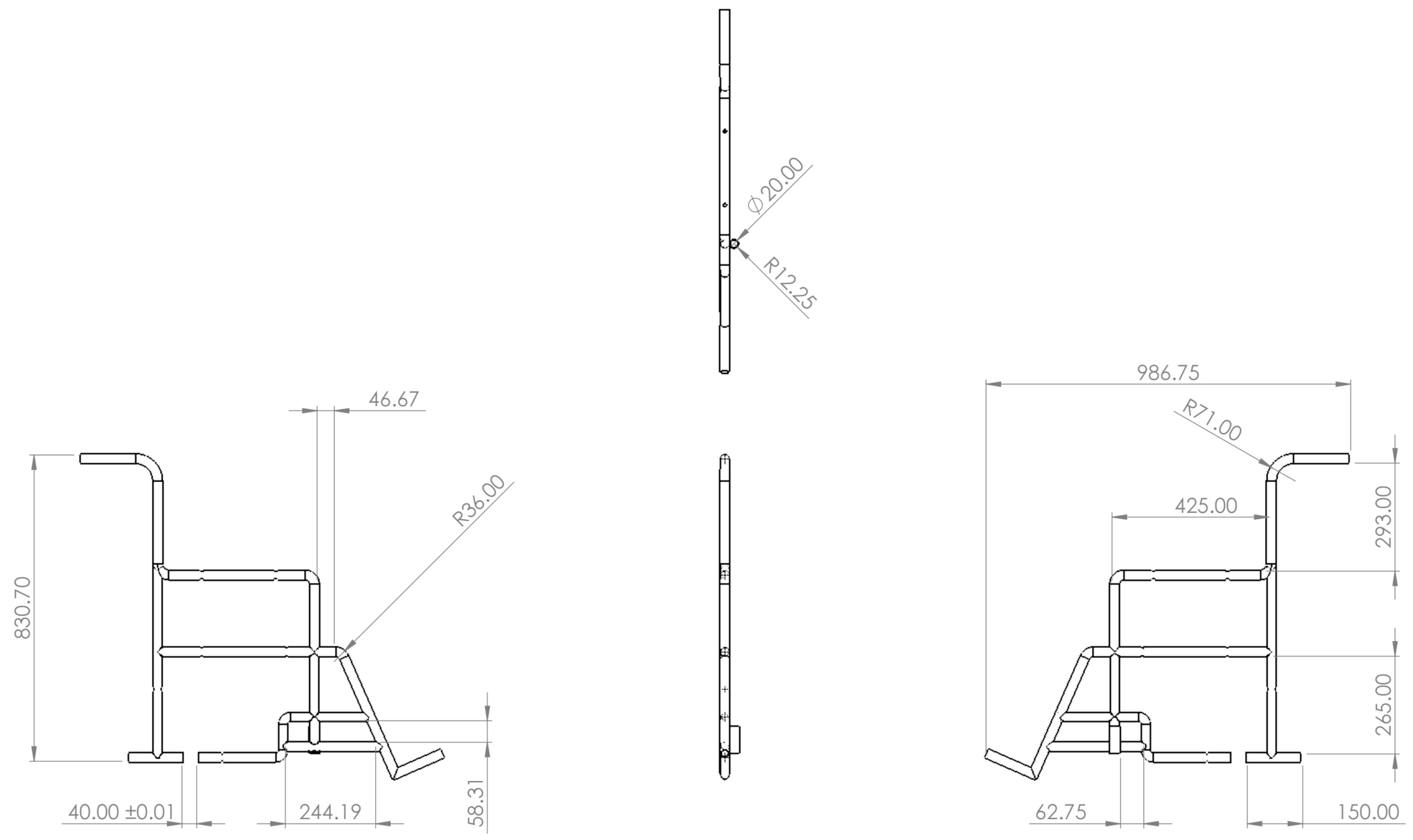
	NAME	SIGN.	DATE
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	21/10/22
CHECKED BY	JURY		08/06/23
MATERIAL:		SCALE:	1:5

TITLE BACK REST

PART NO. 1-1-1-10



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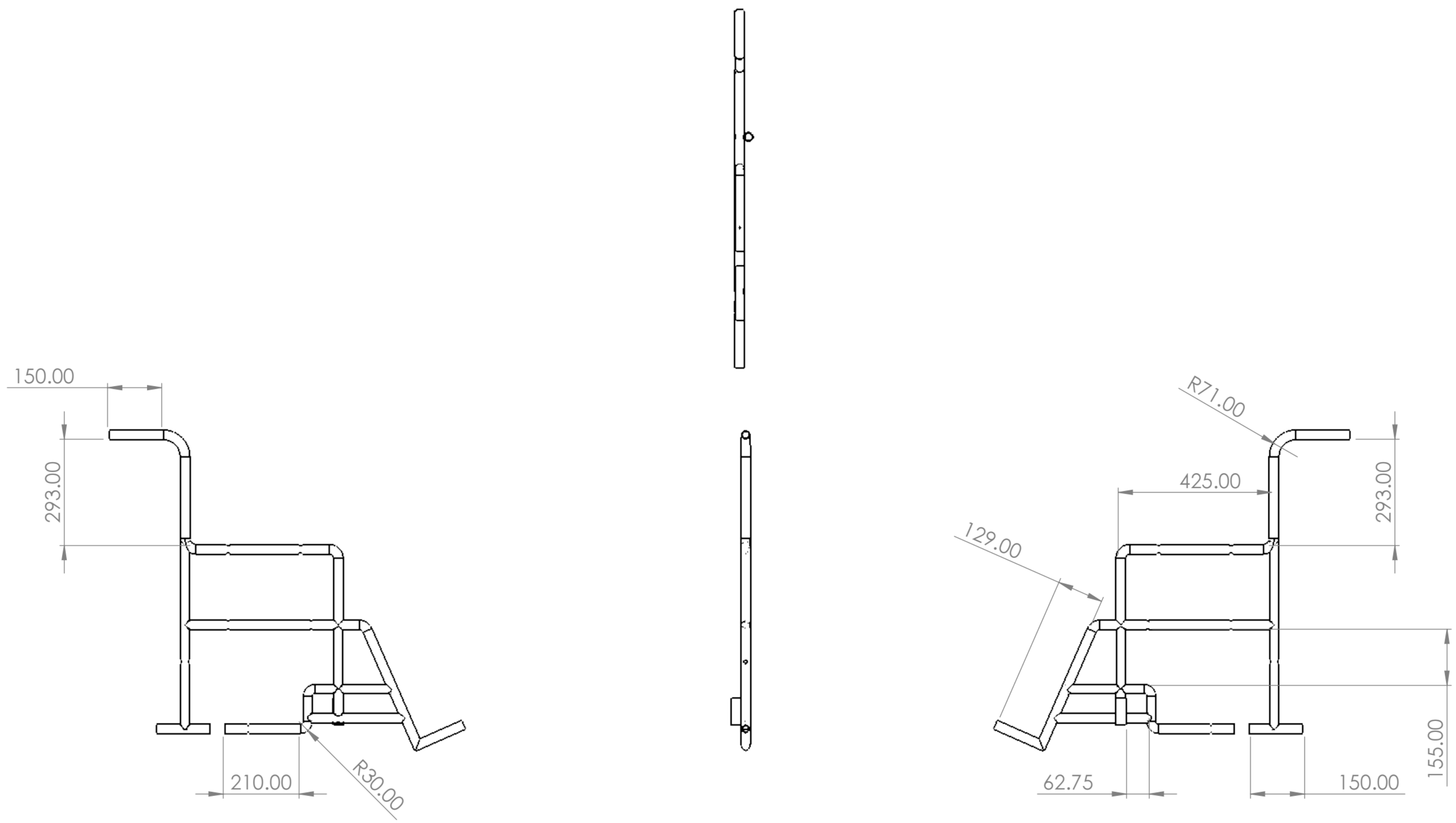
	NAME	SIGN.	DATE
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	21/10/22
CHECKED BY	JURY		08/06/23
MATERIAL:	STEEL	SCALE:	1:12

TITLE MAIN FRAME (LEFT)

PART NO. 1-1-1-11



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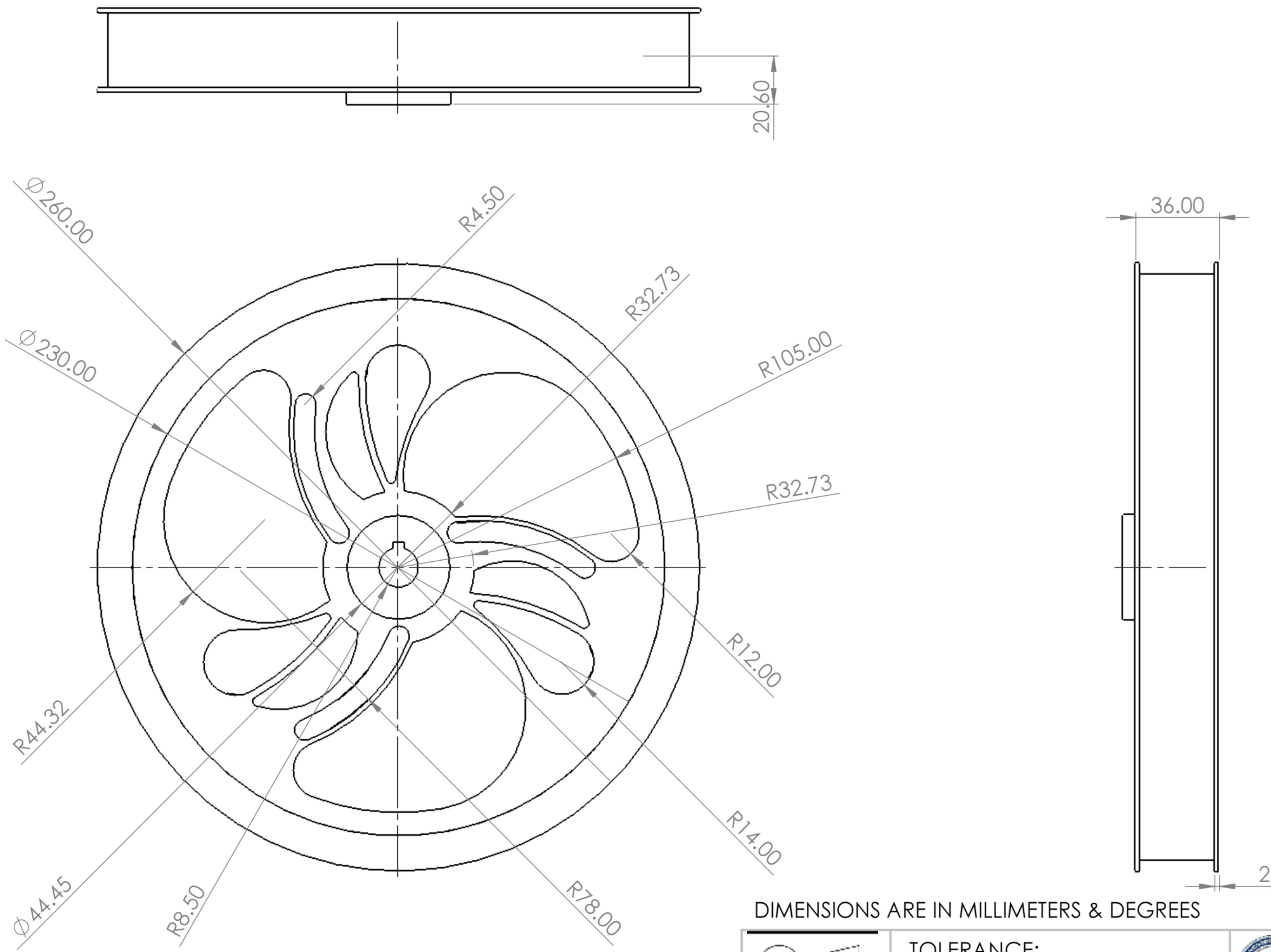
	NAME	SIGN.	DATE	
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	21/10/22	TITLE MAIN FRAME (RIGHT)
CHECKED BY	JURY		08/06/23	PART NO. 1-1-1-11-1
MATERIAL:	STEEL	SCALE:	1:12	



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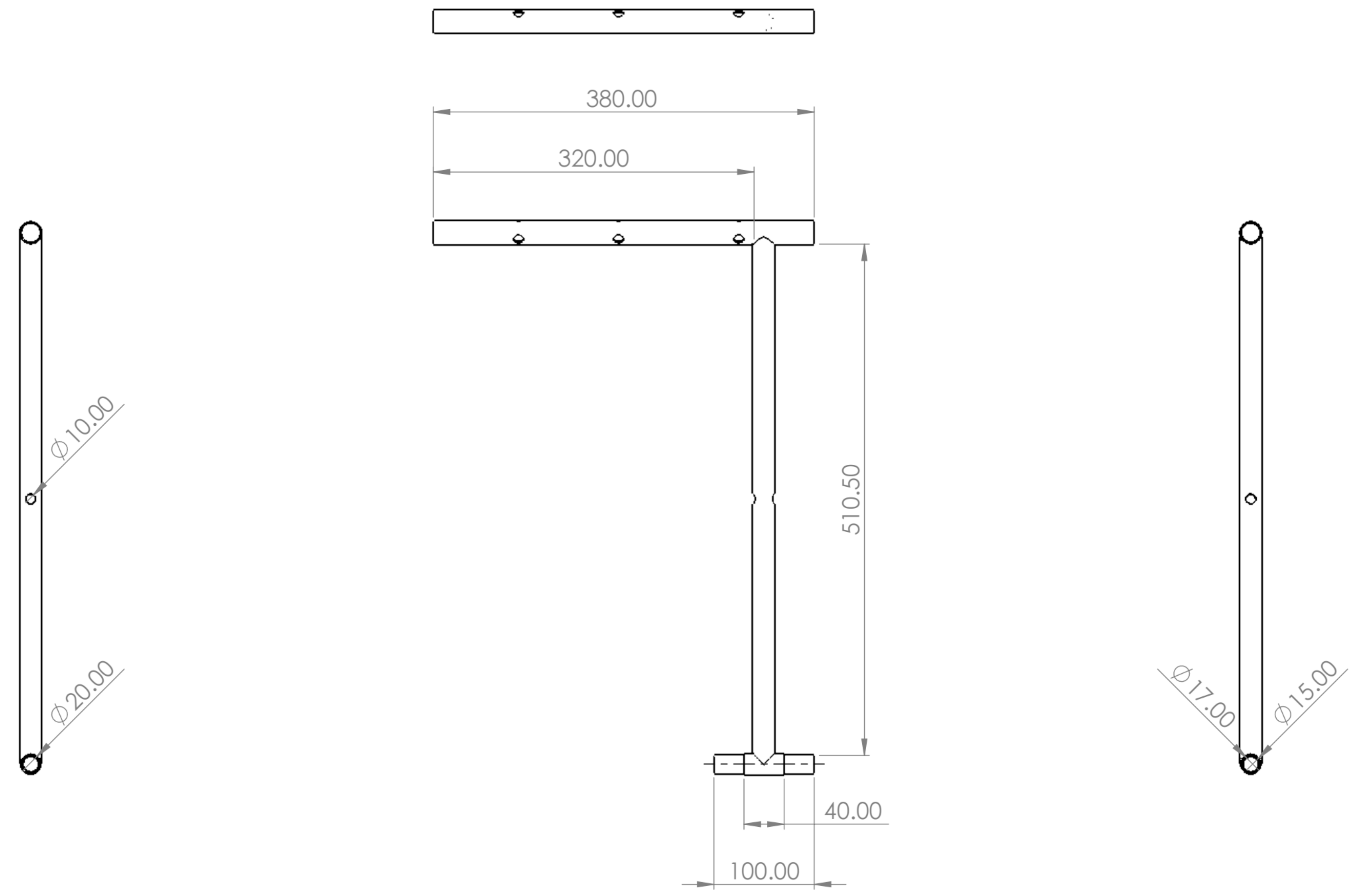
	NAME	SIGN.	DATE	
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	21/10/22	TITLE REAR WHEEL SPOKES
CHECKED BY	JURY		08/06/23	PART NO. 1-1-1-12-1
MATERIAL:	STEEL	SCALE:	1:2	



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DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	21/10/22
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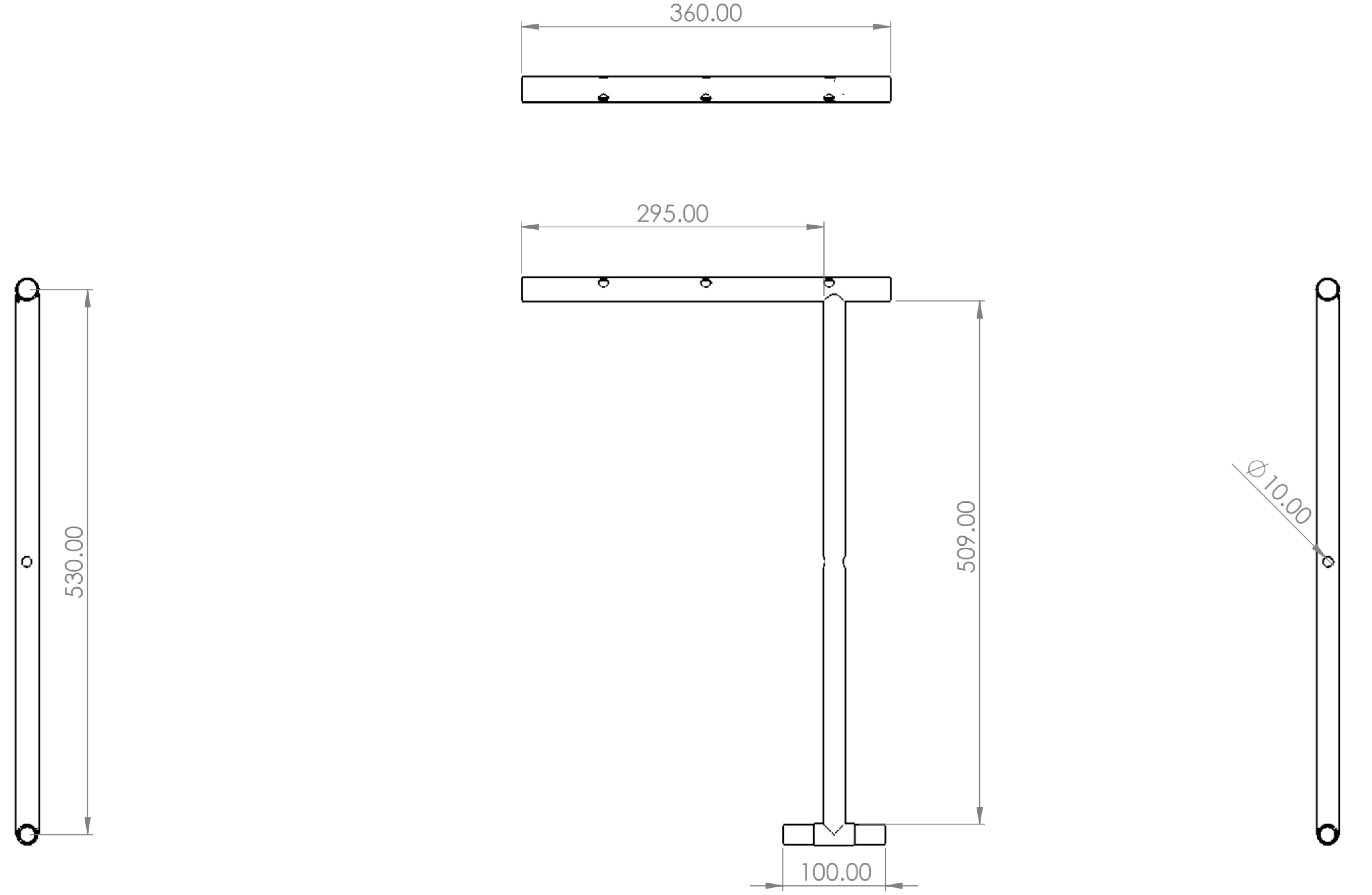
MATERIAL:	STEEL	SCALE:	1:5

TITLE LEFT X-FRAME

PART NO. 1-1-2-1



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DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	21/10/22
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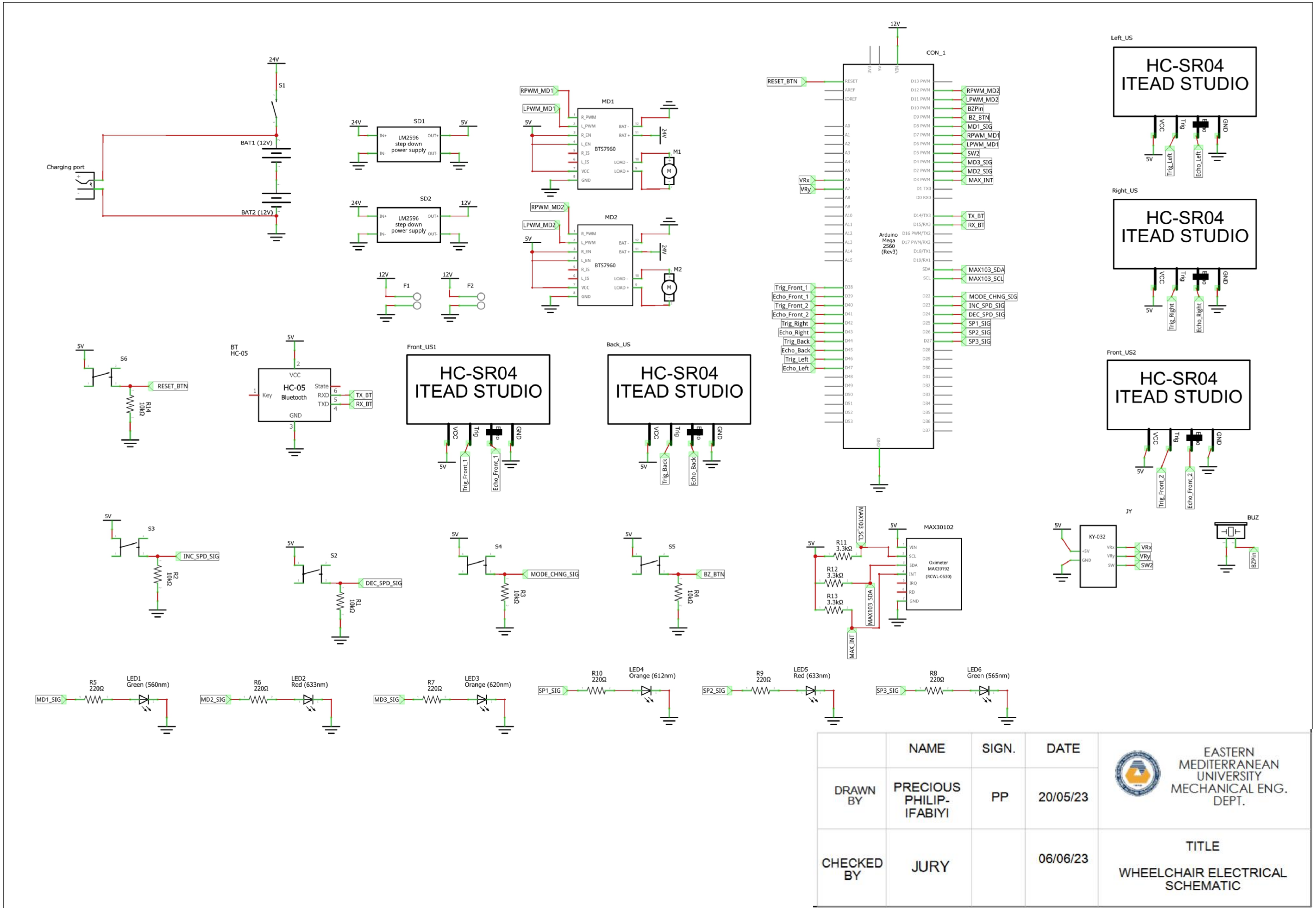
MATERIAL:	STEEL	SCALE:	1:5

TITLE RIGHT X-FRAME

PART NO. 1-1-2-2

APPENDIX F: Electrical Schematic



The table below describes the different electrical parts in the wheelchair.

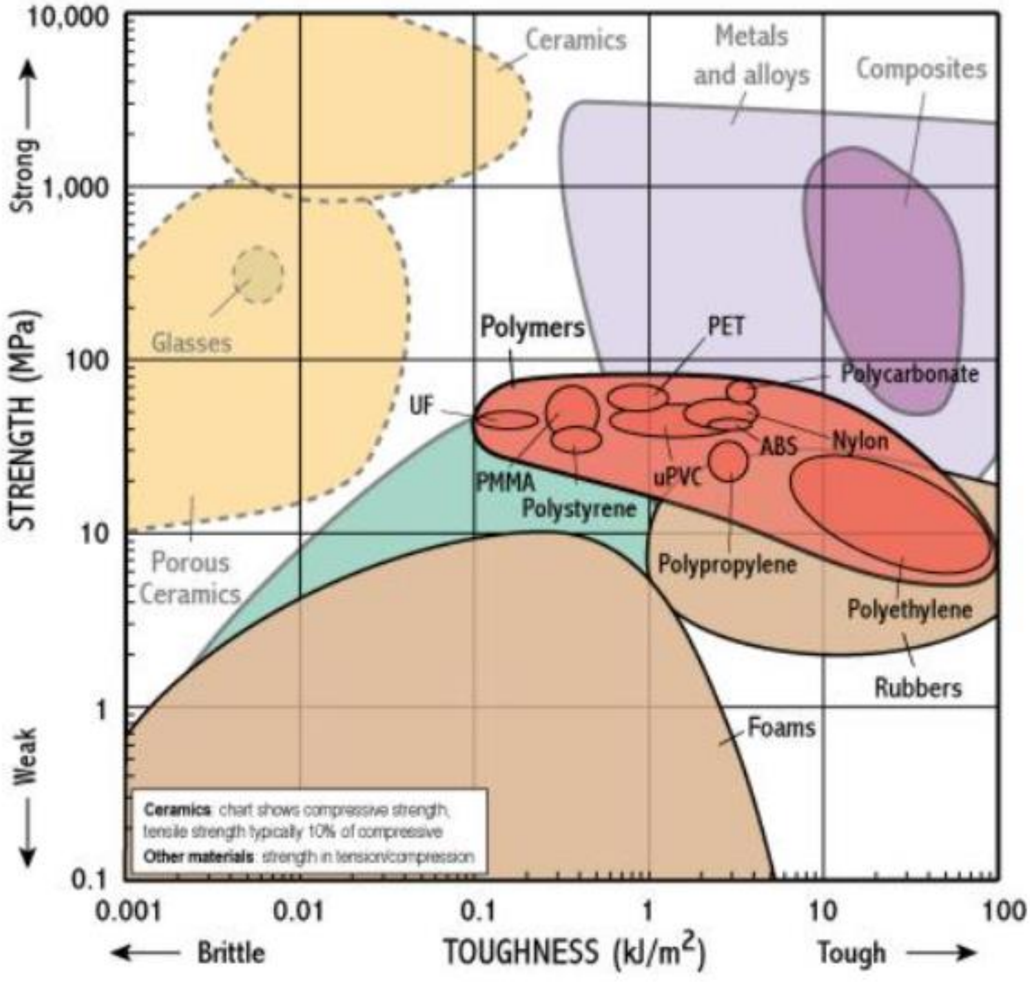
NAME OF COMPONENTS	DESCRIPTION
Back_US	Ultrasonic sensor that is placed at the back of the wheelchair
BAT1	Lead acid battery that powers the wheelchair
BAT2	Second lead acid battery that powers the wheelchair
BT	Bluetooth module that establishes connection between the controller and smartphone
BUZ	Buzzer of the wheelchair
Charging port	Port where the charger should be plugged in. It accepts only a 24 V charger
CON_1	Main controller of the wheelchair (Arduino Mega 2560)
F1	Fan for the left motor’s driver
F2	Fan for the right motor’s driver
Front_US1	Ultrasonic sensor that is placed on the left front position of the wheelchair
Front_US2	Ultrasonic sensor that is placed at the right front position of the wheelchair
JY	Joystick of the wheelchair
LED1	Green LED that shows that the control mode of the wheelchair is voice
LED2	Red LED that shows that the control mode of the wheelchair is joystick
LED3	Orange LED that shows that the control mode of the wheelchair is smartphone
LED4	Orange LED that shows that the speed of the wheelchair is low
LED5	Red LED that shows that the speed of the wheelchair is average
LED6	Green LED that shows that the speed of the wheelchair is high
M1	Left motor
M2	Right motor
MAX30102	Pulse oximeter and heart rate sensor
MD1	Motor driver for the left motor
MD2	Motor driver for the right motor
S1	Switch for turning on or off the power supply of the wheelchair
S2	Pushbutton that resets the controller
S2	Push button used for decreasing the speed of the wheelchair

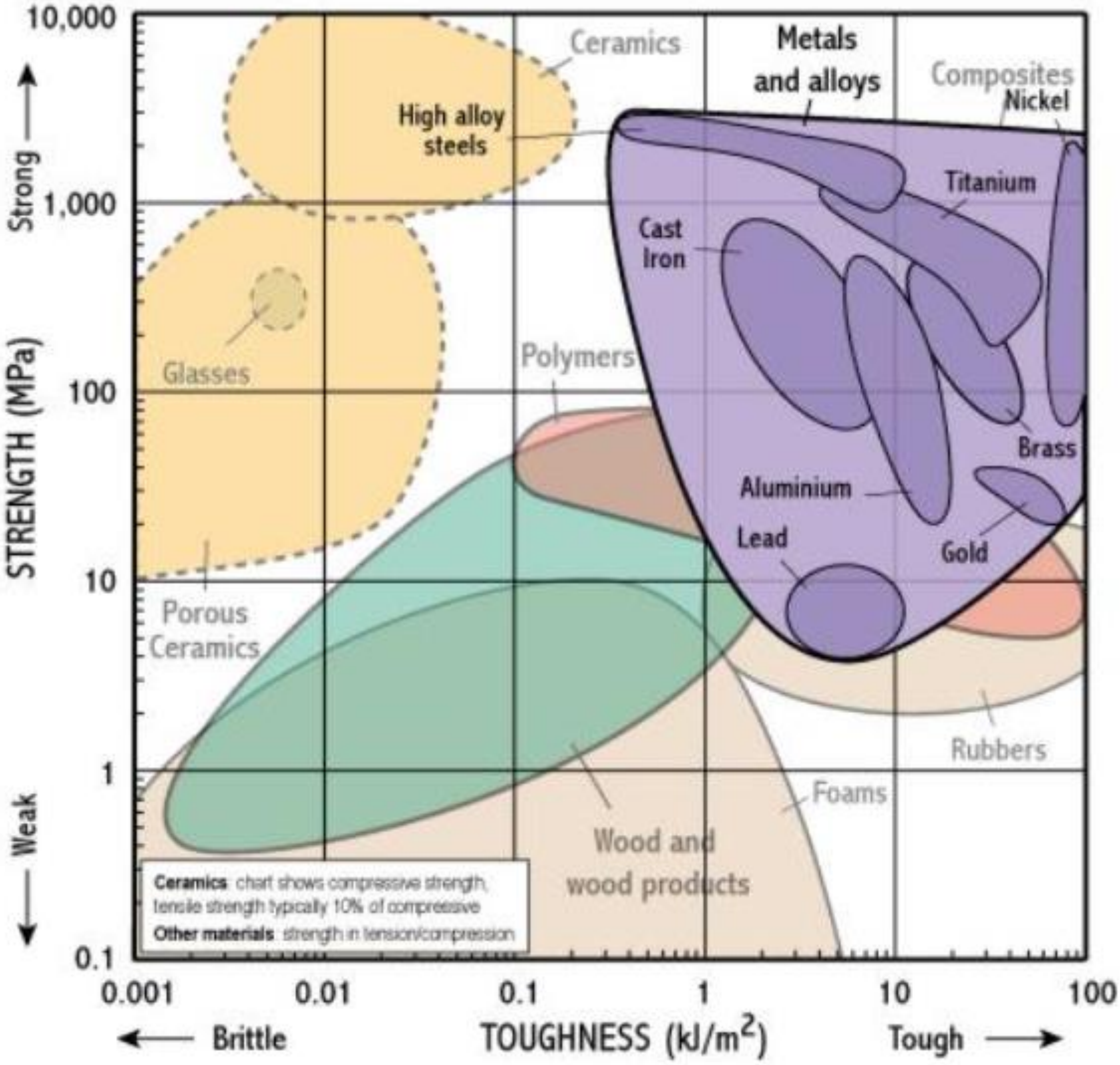
S3	Push button used for increasing the speed of the wheelchair
S4	Push button used for changing the mode of control of the wheelchair
S6	
SD1	Buck converter that converts 24 V to 5 V
SD2	Buck converter that converts 24 V to 12 V for the fans, Arduino, etc.

APPENDIX G: ARDUINO BOARDS SPECIFICATIONS

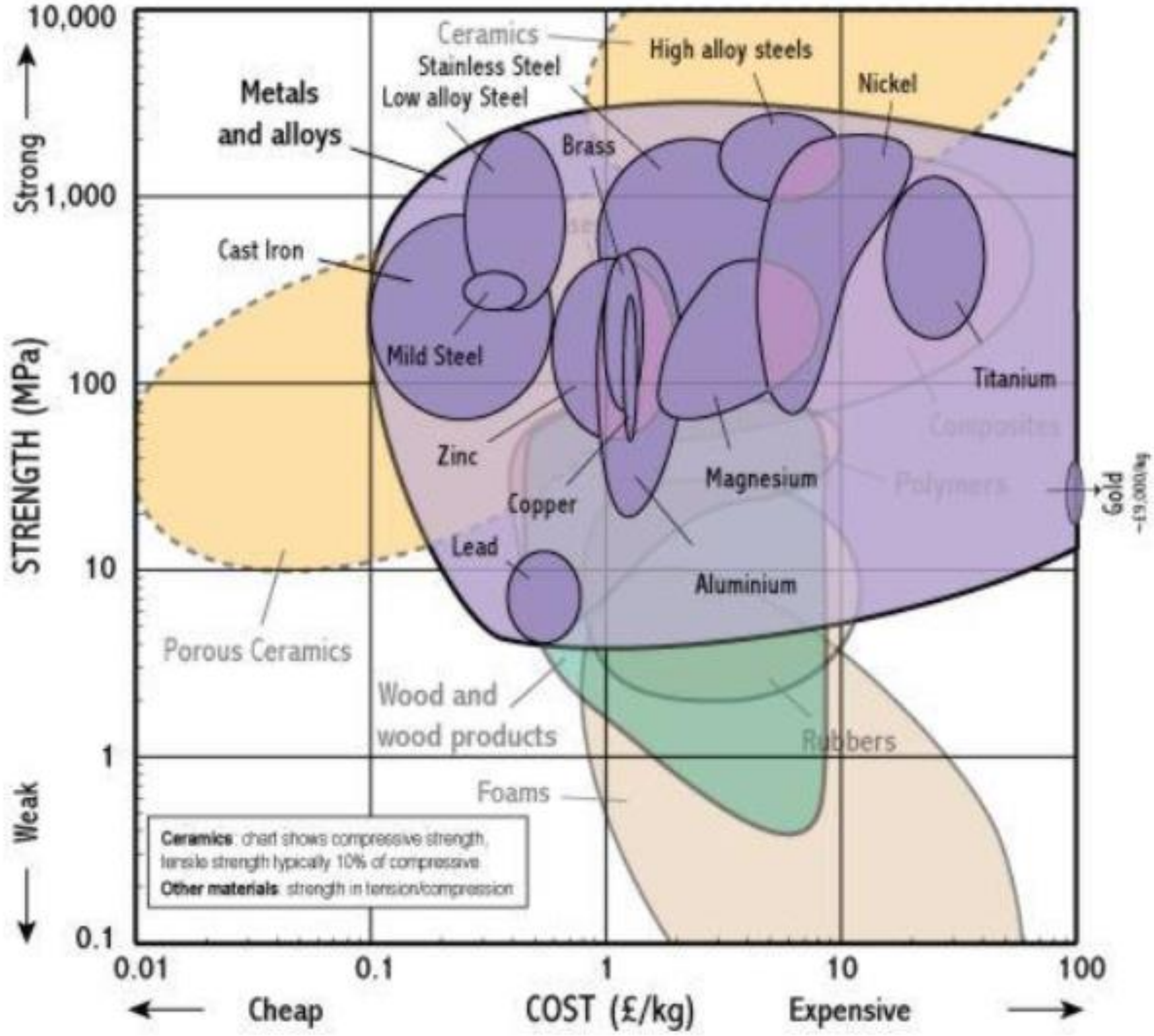
Board		Arduino Uno R3	Arduino Nano	Arduino Pro Mini	Leonardo	Micro	Nano Every	Mega2560 Rev3
Microcontroller		ATmega328p	ATmega328p	ATmega328p	ATmega32u4	ATmega32u4	ATMega4809	ATmega2560
FPGA		No	No	No	No	No	No	No
USB connector		USB-B	Mini-B USB	Mini-B USB	Micro USB (USB-B)	Micro USB	Micro USB	USB-B
I/O	Digital only I/O pin	14	14	14	20	20	14	54
	Analog input pins	6	8	8	12	12	8	16
	Analog output pin:	0	0	0	0	0	0	0
	PWM Pins	6	6	6	7	7	5	15
Communication	UART	yes	yes	yes	yes	yes	yes	yes, 4
	I2c	yes	yes	yes	yes	yes	yes	yes
	SPI	yes	yes	yes	yes	yes	yes	yes
	CAN	No	No	No	No	No	No	No
	Bluetooh	No	No	No	No	No	No	No
	WIFI	No	No	No	No	No	No	No
Power	I/O voltage	5v	5v	5v	5v	5v	5v	5V
	Input nominal volt	7-12V	7-12V	7-12V	7-12V	7-12V	7-21V	7-12V
	DC Current per I/O	20mA	20mA	20mA	10mA	10mA	20mA	20mA
	Powersupply conn	Barrel Jack	GPIO header	GPIO header	Barrel Jack	GPIO header	GPIO header	Barrel Jack
	Battery Powered	No	No	No	No	No	No	No
Clock speed	Main processor	ATmega328P 16MHz	ATmega328P 16MHz	ATmega328P 16MHz	ATmega32u4 16MHz	ATmega32u4 16MHz	20MHz	16MHz
RTC		No	No	No	No	No	No	No
USB to Serial		ATmega16U2 16MHz	FT232RL	No onboard USB-TTL Converter	Native	Native	ATSAMD11D14A	ATmega16U2 16MHz
Memmory	Flash	32KB	32KB	32KB	32KB	32KB	48KB	256KB
	SRAM	2KB	2KB	2KB	2.5KB	2.5KB	6KB	8KB
	EEPROM	1KB	1KB	1KB	1KB	1KB	256B	4KB
Dimensions	Weight	25 g	5 g	5 g	20 g	13 g	5 g	37 g
	Width	53.4 mm	18mm	18mm	53.3 mm	18 mm	18 mm	53.3 mm
	Length	68.6 mm	45mm	45mm	68.6 mm	48 mm	45 mm	101.5 mm

APPENDIX H: ASHBY CHARTS

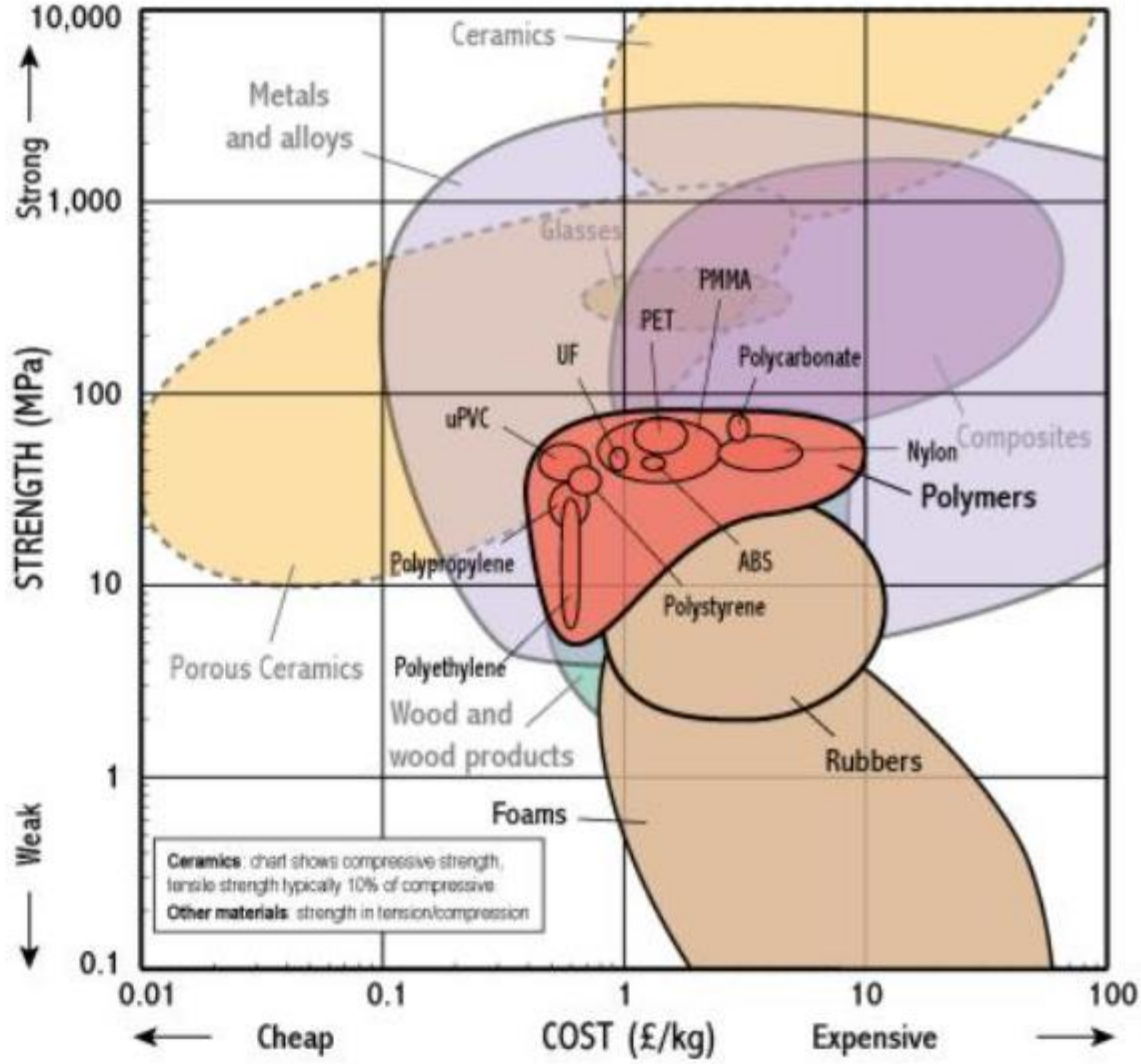




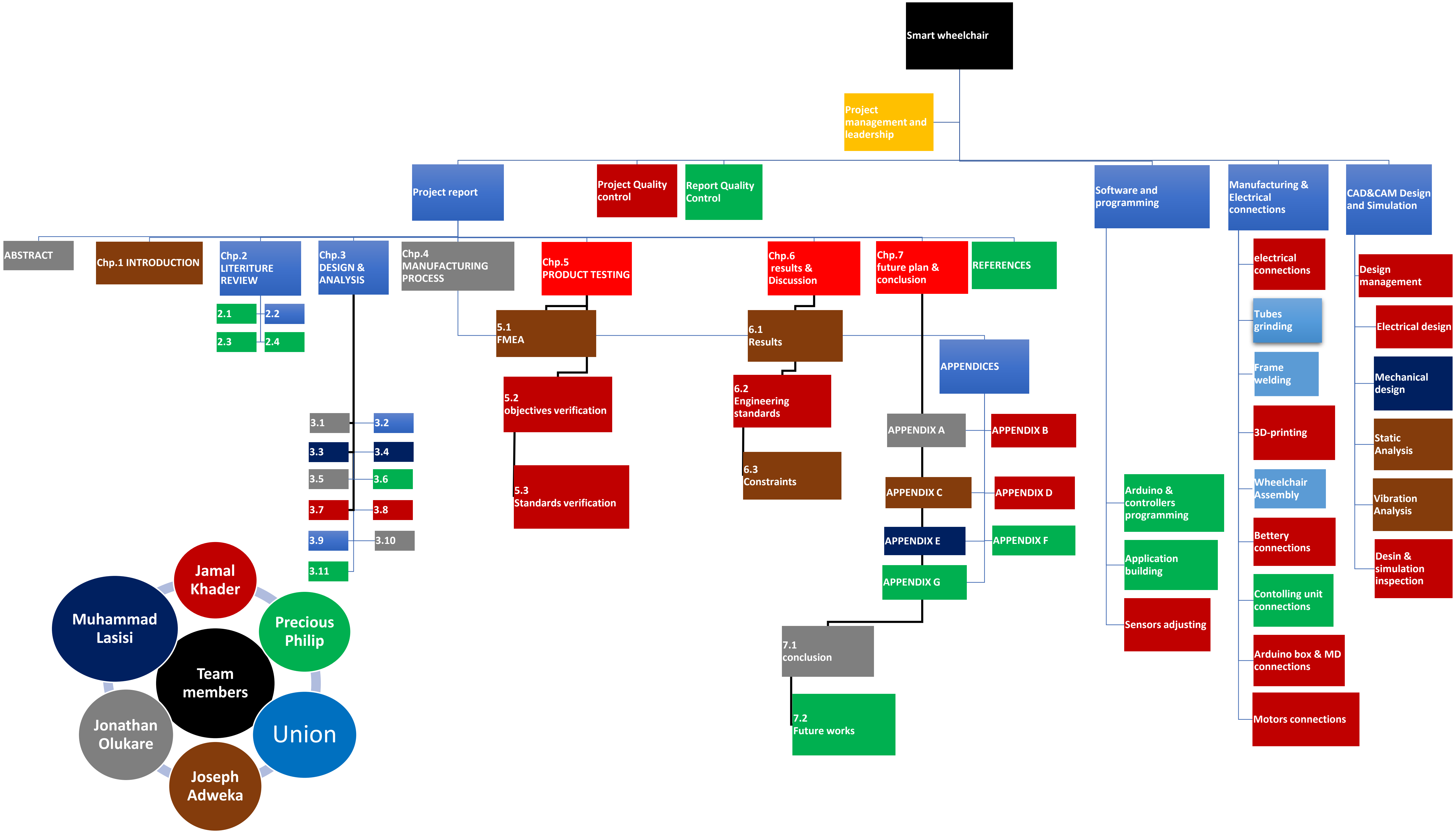
Ceramics
Metals and alloys
Composites
Nickel
High alloy steels
Titanium
Cast Iron
Glasses
Polymers
Brass
Aluminium
Lead
Gold
Porous Ceramics
Rubbers
Foams
Wood and wood products
Ceramics: chart shows compressive strength, tensile strength typically 10% of compressive
Other materials: strength in tension/compression
STRENGTH (MPa)
Strong
Weak
10,000
1,000
100
10
1
0.1
0.001
0.01
0.1
1
10
100
Brittle
TOUGHNESS (kJ/m²)
Tough



10,000
1,000
100
10
1
0.1
Strong
Weak
STRENGTH (MPa)
0.01
0.1
1
10
100
Cheap
COST (£/kg)
Expensive
Ceramics
High alloy steels
Stainless Steel
Nickel
Metals
and alloys
Low alloy Steel
Brass
Cast Iron
Mild Steel
Titanium
Composites
Zinc
Magnesium
Polymers
Gold
~£9,000/kg
Copper
Lead
Aluminium
Porous Ceramics
Wood and
wood products
Rubbers
Foams
Ceramics: chart shows compressive strength, tensile strength typically 10% of compressive
Other materials: strength in tension/compression


10,000
1,000
100
10
1
0.1
Strong
STRENGTH (MPa)
Weak
0.01
0.1
1
10
100
Cheap
COST (£/kg)
Expensive
Ceramics
Metals
and alloys
Glasses
PMMA
PET
UF
Polycarbonate
uPVC
Nylon
Composites
Polymers
Polypropylene
ABS
Polystyrene
Porous Ceramics
Polyethylene
Wood and
wood products
Rubbers
Foams
Ceramics: chart shows compressive strength, tensile strength typically 10% of compressive
Other materials: strength in tension/compression

APPENDIX I: WORK BREAKDOWN STRUCTURE



APPENDIX J: ARDUINO CODES

The Arduino code for this project can be found in the following link: https://github.com/squaredpied/Multi-controlled-Wheelchair

APPENDIX K: ERROR ANALYSIS

During the project, we noticed that the wheelchair was not able to move in a straight line when it was given a command to go forward and backwards. We tried solving this problem by varying the speed of the either the left or right motor. This solution worked, but it was dependent on the road condition. When the wheelchair was used in another location, the problem arose again.

This issue primarily stemmed from misalignment of the wheels, resulting from manufacturing tolerances. In addition, variations in tire pressures among the wheels contributed to the problem, causing inconsistent rolling resistance and unequal traction.

To fix this issue, we realised that we needed a control system in the wheelchair, but we were unable to do it due to time and cost constraints. Encoders should be placed on the shaft of the two wheelchair motors. The encoders needed for the motor can be found on Robotistan.com for 283.08 TL (Figure 1). Since two encoders are needed, the total cost is 566.16 TL. The output of the encoders will be sent to the Arduino Mega 2560 Rev3 in the wheelchair. Proportional, Integral and Derivative (PID) control will be implemented by the microcontroller to fix this issue.

Figure 1: Incremental Optical Rotary Encoder - 5-24V/DC 600 Pulses

APPENDIX L: USER MANUAL

Thank you for choosing our speech-controlled wheelchair. This user guide will provide you with the necessary information to set up, operate, and maintain your wheelchair effectively. Please read this guide carefully before using the wheelchair.

Introduction:

The multi-controlled autonomous wheelchair offers multiple control options, including smartphone, joystick, and speech commands. This innovative wheelchair provides enhanced mobility and convenience for users. We aim to ensure a smooth and comfortable experience for all users.

Setup:

- Ensure that the wheelchair is fully charged before use.
- Download the dedicated smartphone app from your app store and follow the provided instructions to pair your smartphone with the wheelchair.
- For joystick control, ensure the joystick is securely connected to the control unit.
- Connect the smartphone app via Bluetooth to the wheelchair.

Control Modes:

- To switch between control modes (smartphone, joystick, or speech), press the top yellow button on the control unit.
- The selected control mode will be indicated by the corresponding LED light on the control unit.
- Please refer to the specific instructions provided for each control mode for detailed operation guidelines.

Speech control activation on smartphone:

The APK file can be downloaded from the website https://smmobility.wordpress.com/ . The application should be installed after downloading.

These are the steps that should be followed after installation.

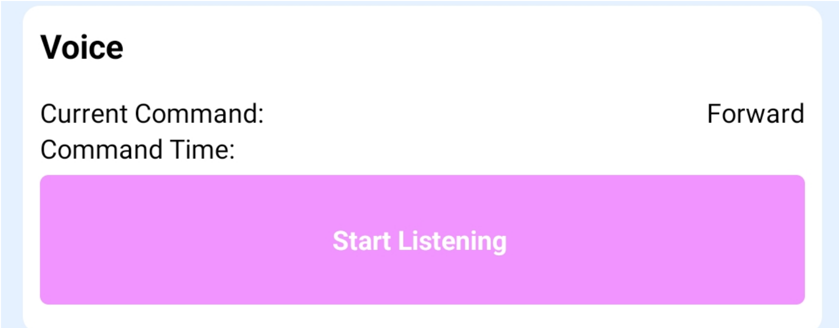
i. Ensure that microphone and nearby devices permissions are granted to the Android application. You may be prompted to allow access to these privileges when you open the application for the first time.

ii. The next step is to pair your phone with the Bluetooth Module in the wheelchair. You can do this by going to the Bluetooth settings in your phone and scanning for available devices. If the wheelchair is on, you should see a device called "HC-05". Click on it and input the passcode "1234". You have successfully paired your phone to the wheelchair.

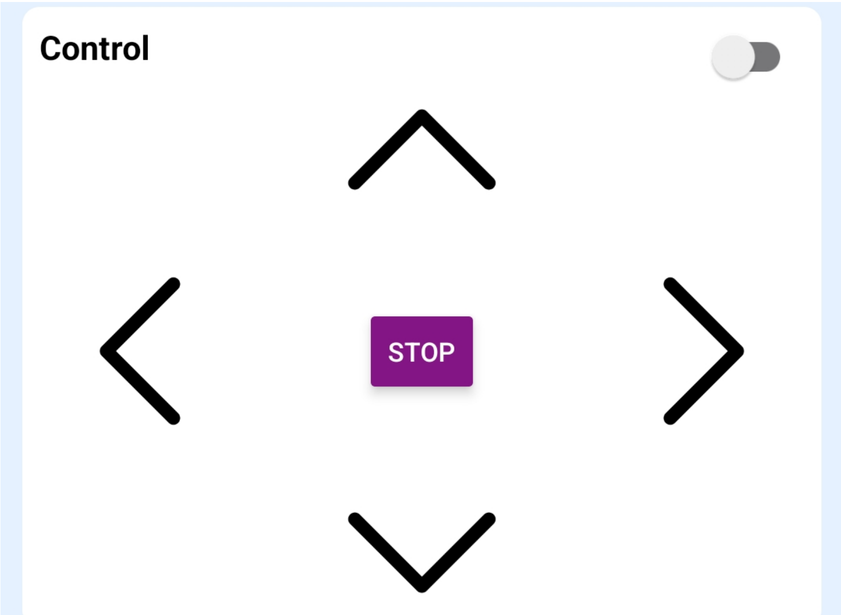
iii. Open the SMobility application in your phone and click on "Setup Bluetooth". This will open a dialog box that contains all the paired devices. Click on "HC-05". You should see a prompt "Connected to device HC-05" if you successfully connected to the wheelchair.

iv. The UI of the application is intuitive enough. To control the wheelchair using smartphone, the wheelchair must be set to smartphone control mode. Depending on your preference, you can control the wheelchair using voice or buttons.

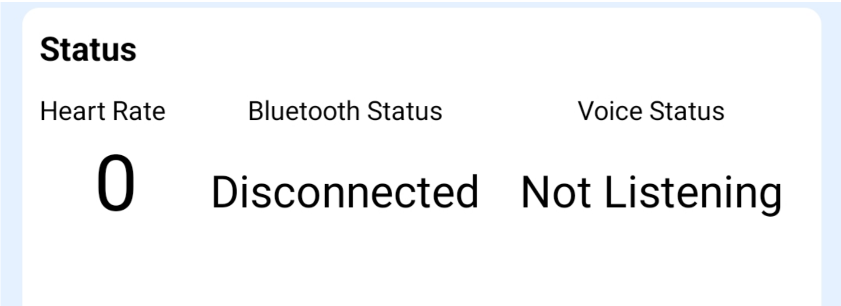
v. To control the wheelchair using voice, you should click on the button "Start Listening". Your phone's microphone will be used to record your voice. If you say the correct keywords which are: "Left", "Right", "Forward", "Backwards", and "Stop", the commands will be transmitted to the wheelchair and the wheelchair will move accordingly as far as there is no obstacle along its path.



vi. The wheelchair can be controlled using buttons by clicking on the toggle button next to the "Control" heading. The wheelchair will move in whatever direction pressed. To make the wheelchair move in a specific direction for a long time, you should long press the desired button.



vii. The heart rate of the user is also displayed at the top left corner of the application.



Additional Features:

- The red button to the left of the control unit can be pressed to activate the horn/buzzer feature, providing an audible alert to alert others in your vicinity.
- In case of an emergency, there is a big red emergency button to the right of the control unit. Press this button to immediately stop all operations of the wheelchair.

Safety Guidelines:

- Always prioritize your safety and the safety of others when using the wheelchair.
- Familiarize yourself with local traffic and safety regulations and always adhere to them.
- Be cautious when manoeuvring on uneven terrain, ramps, or curbs.
- Maintain a safe distance from obstacles and individuals.
- Keep hands, clothing, and other objects away from moving parts.
- Do not exceed the maximum weight capacity of the wheelchair.
- Familiarize yourself with the emergency stop button and use it in case of any emergency.

Maintenance and Care

- Regularly inspect the wheelchair for any signs of damage or wear. If any issues are identified, contact our customer support for assistance.
- Clean the wheelchair using a mild detergent and a soft cloth. Avoid using harsh chemicals or abrasive cleaners.
- Ensure that the battery is charged according to the provided instructions.
- Store the wheelchair in a dry and secure location when not in use.

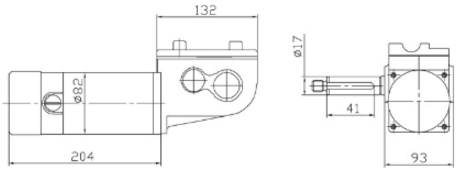
Troubleshooting:

If a problem occurs, turn off the wheelchair from the power supply and turn it on after a few seconds. If the problem persists, contact the manufacture with details on the issue.

24 V hybrid gearbox brushed DC motor:

PART NO.	VOLTS	GEAR RATIO	RATED SPEED	RATED TORQUE	RATED TORQUE	RATED CURRENT	RATED POWER	LENGTH
	V		RPM	Nm	Oz-in	A	W	mm
GMZJD8025A	12	1:60	40	37	5300	50	600	240
GMZJD8025B	12	1:90	48	50	7150	75	900	270

GMZJD8032 WORM GEAR MOTOR FOR WHEELCHAIRS



Attestation of Compliance

Reference No.	:	LCS220407020EE
Applicant	:	ZHEJIANG DONGZHENG MOTOR CO., LTD.
Address	:	No. 2 Zengping Rd, Xicheng industrial Zone, Dongyang, Zhejiang, China
Trade Mark	:	N/A
Product	:	MOTOR
Model(s)	:	80ZY115-2431, 22ZY38, 24ZY30, 28ZY38, 28ZY47, 35ZY30, 35ZY40, 36ZY50, 36ZY57, 36ZY83, 36ZY85, 38ZY63, 42ZY60, 42ZY66, 42ZY68, 45ZY68, 45ZY78, 52ZY75, 52ZY80, 52ZY85, 52ZY95, 52ZY98, 52ZY105, 52ZY125, 60ZY75, 60ZY95, 60ZY105, 60ZY125, 63ZY75, 63ZY93, 63ZY95, 63ZY97, 63ZY105, 63ZY125, 63ZY134, 63ZY185, 80ZY100, 80ZY115, 80ZY125, 80ZY130, 80ZY135, 80ZY170, 96ZY140
Tested according to	:	EN IEC 55014-1:2021 EN IEC 55014-2:2021 EN IEC 61000-3-2:2019+A1:2021 EN 61000-3-3:2013+A1:2019+A:2021

The submitted products have been tested by us with the listed standards.

This Attestation of Compliance is issued according to the council Directive 2014/30/EU, Referred to as the Electromagnetic Compatibility. It confirms that the listed product complies with all essential requirements of the EMC directive and applies only to the sample and its technical documentation submitted to Ningbo LCS Standard Technology Service Co., Ltd. for testing.

After preparation of the necessary technical documentation as well as the EC conformity declaration the required CE marking can be affixed on the product.Other relevant Directives have to be observed.

CE

Date of issue: June 23, 2022

LCS TESTING LABORATORY APPROVED

Manager

Ningbo LCS Standard Technology Service Co., Ltd.
Room 101-106, 202-206, Building 037, No. 166, Jinghua Road, Meixu Street, Ningbo High-tech Zone, Yinzhou District, Ningbo City, Zhejiang Province, China
Tel: (0574) 8790 8011 Fax: (0574) 8790 6976
Http://www.lcs-cert.com Email: webmaster@lcs-cert.com

Attestation of Compliance

Reference No.	:	**LCS220407010EE**
Applicant	:	**ZHEJIANG DONGZHENG MOTOR CO., LTD.**
Address	:	**No. 2 Zengping Rd, Xicheng industrial Zone, Dongyang, Zhejiang, China**
Trade Mark	:	**N/A**
Product	:	**MOTOR**
Model(s)	:	**80ZY115-2431, 22ZY38, 24ZY30, 28ZY38, 28ZY47, 35ZY30, 35ZY40, 36ZY50, 36ZY57, 36ZY83, 36ZY85, 38ZY63, 42ZY60, 42ZY66, 42ZY68, 45ZY68, 45ZY78, 52ZY75, 52ZY80, 52ZY85, 52ZY95, 52ZY98, 52ZY105, 52ZY125, 60ZY75, 60ZY95, 60ZY105, 60ZY125, 63ZY75, 63ZY93, 63ZY95, 63ZY97, 63ZY105, 63ZY125, 63ZY134, 63ZY185, 80ZY100, 80ZY115, 80ZY125, 80ZY130, 80ZY135, 80ZY170, 96ZY140**
Tested according to	:	**BS EN IEC 55014-1:2021** **BS EN IEC 55014-2:2021** **BS EN IEC 61000-3-2:2019+A1:2021** **BS EN 61000-3-3:2013+A1:2019+A:2021**

The submitted products have been tested by us with the listed standards.

This Attestation of Compliance is issued according to the UK legislation: Electromagnetic Compatibility Regulations 2016 (SI 2016 No.1091 and amendments), Referred to as the UK Electromagnetic Compatibility. It confirms that the listed product complies with all essential requirements of the Electromagnetic Compatibility Regulations 2016 (SI 2016 No.1091 and amendments) and applies only to the sample and its technical documentation submitted to Ningbo LCS Standard Technology Service Co., Ltd. for testing.

After preparation of the necessary technical documentation (Which must be kept for up to 10 years after the product is placed on the GB market as well as the UK declaration of conformity, the required UKCA marking can be affixed on the product. Other relevant Regulations have to be observed.

UK
CA

Date of issue: June 23, 2022

LCS TESTING LABORATORY
APPROVED

Manager

Ningbo LCS Standard Technology Service Co., Ltd.
Room 101-106, 202-206, Building 037, No. 166, Jinghua Road, Meixu Street, Ningbo High-tech Zone, Yinzhou District, Ningbo City, Zhejiang Province, China
Tel: (0574) 8790 8011 Fax: (0574) 8790 6976
Http://www.lcs-cert.com Email: webmaster@lcs-cert.com

UL Product iQ™

PRGY2.E514409 - Motors for Appliance Applications - Component

Motors for Appliance Applications - Component

See General Information for Motors for Appliance Applications - Component

DONGYANG CITY DONGZHENG MOTOR CO LTD E514409
PERIOD 3, XICHENG INDUSTRIAL ZONE
DONGYANG, ZHEJIANG,CHINA 322100 CHINA

Model No.	Output	Hz/DC	Volts	FL Amps	Service Factor	SF Amps	Poles	Number of Speeds	RPM	Capacitor Rating	Phases	Ins Class	Duty	Prot. Type
(click on a model number to see complete product details)														
52ZY125-2420	30W	dc	24	1.8	-	-	2	1	1600	-	1	A	Cont	-
52ZY125-2430	40W	dc	24	2.4	-	-	2	1	2400	-	1	A	Cont	-
52ZY125-2435H	50W	dc	24	2.6	-	-	2	1	3400	-	1	A	Cont	-
63ZY125-2430	65W	dc	24	4.0	-	-	2	1	2500	-	1	A	S3(3/10)	-
63ZY125-2435	95W	dc	24	5.3	-	-	2	1	2800	-	1	A	S3(3/10)	-
80ZY100W-18045, 5879-0002	72W	dc	180	0.6	-	-	2	1	3900	-	1	A	Cont	-
80ZY100W-9045, 5879-0001	72W	dc	90	1.01	-	-	2	1	3900	-	1	A	Cont	-
80ZY115W-18035, 5867-0002	72W	dc	180	0.6	-	-	2	1	3200	-	1	A	Cont	-
80ZY115W-9035, 111161	72W	dc	90	1.01	-	-	2	1	3200	-	1	A	Cont	-
80ZY115W-9035, 5867-0001	72W	dc	90	1.01	-	-	2	1	3200	-	1	A	Cont	-
80ZY115W-9036, 5762-0001	72W	dc	90	1.01	-	-	2	1	3225	-	1	A	Cont	-
80ZY115W-9036, 5761-0001	72W	dc	90	1.01	-	-	2	1	3225	-	1	A	Cont	-
80ZY115W-9036, 5761-0004	72W	dc	90	1.01	-	-	2	1	3225	-	1	A	Cont	-

Marking: Company name, motor type and model (or model designation).

Last Updated on 2020-08-28

The appearance of a company's name or product in this database does not in itself assure that products so identified have been manufactured under UL's Follow-Up Service. Only those products bearing the UL Mark should be considered to be Certified and covered under UL's Follow-Up Service. Always look for the Mark on the product.

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STQ

TEST REPORT

Client :	Dongyang City Dongzheng Motor Co.Ltd
Address :	No.2 Zengping Rd.,Xicheng Industrial Zone, Dongyang City , Zhejiang Province, 322100, CHINA

The following merchandise was (were) submitted and identified by the client as:

Name of Product :	Gear Motor
Test Model :	36ZWNP57-2450-36JXF30K71G / 70YN18-2/70JB200G 1025 / 63ZY100-18.538G0834-KB-LC
May Cover Model:	36ZWN / 36ZY / 38ZY / 42ZY / 45ZY / 52ZY / 60ZY / 63ZY / 70ZY / 71ZY / 80ZY /83ZY / 96ZY / 60YN / 70YN / 80YN / 90YN / 60JB / 70JB / 80JB / 90JB / 63JW / 90JW / 22JX / 24JX / 28JX / 36JX / 42JX / 45JX / 56JX / 60JX / 72JX / 82JX / 110JX / 120JX
Sample Received :	Sep. 21, 2018 Dec. 04, 2018
Test Period :	Sep. 21, 2018 - Dec. 07, 2018

As requested by the client, According to RoHS Directive 2011/65/EU(RoHS 2.0) and its subsequent amendments Directive (EU) 2015/863. Split the sample and determine the Pb, Cd, Hg, Cr (VI), PBBs, PBDEs, DEHP, BBP, DBP&DIBP content of the parts.

Test Items	Conclusion
RoHS Directive 2011/65/EU(RoHS 2.0)	PASS

Prepared By :	Reviewed By :	Issued By :
Ada Wang Testing Engineer	Cookie Chen Project Supervisor	Kevin Chen Lab Manager

STQ Testing Services Co., Ltd.

Add.:3F,B3,218 Xinghu St., Suzhou Industrial Park,China,215123
Tel.:+86/(0)512 87661878 Fax: +86/(0)512 87661802 Web:www.stq-cert.com
Technical service: TS@stq-cert.com Customer service: CS@stq-cert.com

TEST REPORT

Client :	ZHEJIANG DONGZHENG MOTOR Co., LTD
Address :	No. 2 Zengping Rd., Xicheng Industrial Zone,Dongyang, Zhejiang 322100 CHINA

The following merchandise was (were) submitted and identified by the client as:

Name of Product :	Motor
Test Model :	52ZY98-2440G0834-KB-2B, 3657-2433/36JX27B0826, 60YN10-2/60JB75G0830
Model May Cover :	38ZY,42ZY,45ZY,52ZY,60ZY,63ZY,70ZY,71ZY,80ZY,83ZY,96ZY,60YN,70YN,80YN,90YN,60JB,70JB,80JB,90JB,42CJB,45CJB,80CJB,63JW,90JW,22JX,24JX,28JX,36JX,42JX,45JX,52JX,56JX,63JX,72JX,82JX,110JX,120JX
Main Material:	/
Supplier:	/
Buyer:	/
Sample Received :	May. 06, 2022 May. 19, 2022
Test Period :	May. 06, 2022 - May. 11, 2022 May. 19, 2022 - May. 23, 2022

As requested by the client, According to RoHS Directive 2011/65/EU(RoHS 2.0) and its subsequent amendments Directive (EU) 2015/863. Split the sample and determine the Pb, Cd, Hg, Cr (VI), PBBs, PBDEs, DEHP, BBP, DBP&DIBP content of the parts.

Test Specification and Conclusion:

RoHS Directive 2011/65/EU(RoHS 2.0) and its subsequent amendments Directive (EU) 2015/863	PASS

Prepared By : Miley
Miley Zhang
Testing Engineer

Reviewed By : Sarah
Sarah Feng
Reporter Supervisor

Issued By : Alika
Alika Su
Lab Manager

FS2022050074-1E

STQ Testing Services(Foshan) Co., Ltd.

Add.: RM601, Jialiyuan Business Center Building 5, No4, Xingye Road, Beijiao Town, Shunde District, Foshan, China
Tel.: +86/ (0)757-23600626   Fax: +86/ (0)757 23600120   Web:www.stq-cert.com
Technical service: TS@stq-cert.com   Customer service: CS@stq-cert.com

TEST REPORT

Reference No. : FS2021110100-1E   Date : Nov. 25, 2021

Client : ZHEJIANG DONGZHENG MOTOR CO., LTD.
Address : No. 2 Zengping Rd., Xicheng Industrial Zone, Dongyang, Zhejiang 322100 CHINA

The following merchandise was (were) submitted and identified by the client as:

Name of Product :	Motor
Test Model :	52ZY98-2240G0834-KB-2A,3657-2433/36JX27B0826, 24JX5K139G/24ZY30-2460,60JB7.5G0828
Model May Cover :	/
Main Material:	/
Supplier:	/
Buyer:	/
Sample Received :	Nov. 08, 2021
Test Period :	Nov. 08, 2021 - Nov. 12, 2021

Test Specification and Conclusion:

According to European Commission Regulation 1907/2006 (REACH Act), the test result of SVHC are >0.1% in the article of submitted sample.	See remark 1 for obligation under REACH

Prepared By : Miley
Miley Zhang
Testing Engineer

Reviewed By : Sarah
Sarah Feng
Reporter Supervisor

Issued By : Alika
Alika Su
Lab Manager

TESTING SERVICES CO., LTD.

FS2021110100-1E

STQ Testing Services(Foshan) Co., Ltd.

Add.: RM601, Jialiyuan Business Center Building 5, No4, Xingye Road, Beijiao Town, Shunde District, Foshan, China
Tel.: +86/ (0)757-23600626   Fax: +86/ (0)757 23600120   Web:www.stq-cert.com
Technical service: TS@stq-cert.com   Customer service: CS@stq-cert.com

QUALITY MANAGEMENT SYSTEM CERTIFICATE

Certificate No. 00122Q34903R6M/3600

We hereby certify that

Zhejiang Dongzheng Motor Co., Ltd.

Unified Social Credit Code: 91330783747723098U

Baiyun Street, Xicheng Industrial Zone, Dongyang City,Zhejiang Province, China.

by reason of its

Quality Management System

has been awarded this certificate for compliance with the standard

GB/T 19001-2016 / ISO 9001:2015

The Quality Management System Applies in the following area:

Qualification within the Export of AC/DC Motor , the Design and Production of AC/DC Motor below 36V& Gear Reducer

Certified since: August 10, 2005 **Valid from:** July 5, 2022 **Valid until:** July 27, 2025

After a surveillance cycle, the certificate is valid only when used together with an Acceptance Notice of Surveillance Audit issued by CQC

Please access www.cqc.com.cn for checking validity of the certificate.

This certificate and its relevant information can query in the website of Certification and Accreditation Administration of the People's Republic of China (www.cnca.gov.cn).

中国认可 国际互认 管理体系 MANAGEMENT SYSTEM CNAS C001-M

谢肇煦

Signed by: Xie ZhaoXu

CHINA QUALITY CERTIFICATION CENTRE 中国质量认证中心

CHINA QUALITY CERTIFICATION CENTRE

Section 9, No.188, Nansihuan(the South Fourth Ring Road) Xilu(West Road), Beijing 100070,China

http://www.cqc.com.cn

A 0068594 2021年版

CQC

OCCUPATIONAL HEALTH AND SAFETY MANAGEMENT SYSTEM CERTIFICATE

Certificate No. 00121S31622R1M/3600

We hereby certify that

Zhejiang Dongzheng Motor Co., Ltd.

Baiyun Street ,Xicheng Industrial Zone, Dongyang City, Zhejiang Province, China.

has been awarded this certificate for compliance with the standard

GB/T 45001-2020 / ISO45001:2018

The Occupational Health and Safety Management applies in the following area:

The Design and Production of AC/DC Motor & Gear Reducer and the Related Management Activities

Certified since: July 3, 2018 **Valid from:** June 4, 2021 **Valid until:** July 2, 2024

After a surveillance cycle, the certificate is valid only when used together with an Acceptance Notice of Surveillance Audit issued by CQC.
Please access www.cqc.com.cn for checking validity of the certificate.
This certificate and its relevant information can query in the website of Certification and Accreditation Administration of the People's Republic of China (www.cnca.gov.cn).

CNAS 中国认可 管理体系 MANAGEMENT SYSTEM CNAS C001-M

Signed by: Lu Mei

Partner of IQNet

CHINA QUALITY CERTIFICATION CENTRE 中国质量认证中心

CHINA QUALITY CERTIFICATION CENTRE

Section 9, No.188, Nansihuan(the South Fourth Ring Road) Xilu(West Road), Beijing 100070,China

http://www.cqc.com.cn

B 0035035 2018年版

ENVIRONMENTAL MANAGEMENT SYSTEM CERTIFICATE

Certificate No. 00121E32137R1M/3600

We hereby certify that

Zhejiang Dongzheng Motor Co., Ltd.

Baiyun Street ,Xicheng Industrial Zone, Dongyang City, Zhejiang Province, China.

by reason of its

Environmental Management System

has been awarded this certificate for compliance with the standard

GB/T 24001-2016 / ISO 14001:2015

The Environmental Management System Applies in the following area:

The Design and Production of AC/DC Motor ＆ Gear Reducer and the Related Management Activities

Certified since: July 5, 2018 **Valid from:** June 4, 2021 **Valid until:** July 4, 2024

After a surveillance cycle, the certificate is valid only when used together with an Acceptance Notice of Surveillance Audit issued by CQC. Please access www.cqc.com.cn for checking validity of the certificate.
This certificate and its relevant information can query in the website of Certification and Accreditation Administration of the People's Republic of China (www.cnca.gov.cn).

中国认可
国际互认
管理体系
MANAGEMENT SYSTEM
CNAS C001-M

Signed by: Lu Mei

Partner of IQNet

CHINA QUALITY CERTIFICATION CENTRE 中国质量认证中心

CHINA QUALITY CERTIFICATION CENTRE

Section 9, No.188, Nansihuan(the South Fourth Ring Road) Xilu(West Road), Beijing 100070,China

http://www.cqc.com.cn

A 0125315

2018年版

HC-SR04 Ultrasonic sensor:

Ultrasonic Ranging Module HC - SR04

Product features:

Ultrasonic ranging module HC - SR04 provides 2cm - 400cm non-contact measurement function, the ranging accuracy can reach to 3mm. The modules includes ultrasonic transmitters, receiver and control circuit. The basic principle of work:
(1) Using IO trigger for at least 10us high level signal,
(2) The Module automatically sends eight 40 kHz and detect whether there is a pulse signal back.
(3) IF the signal back, through high level , time of high output IO duration is the time from sending ultrasonic to returning.
Test distance = (high level time×velocity of sound (340M/S) / 2,

Wire connecting direct as following:

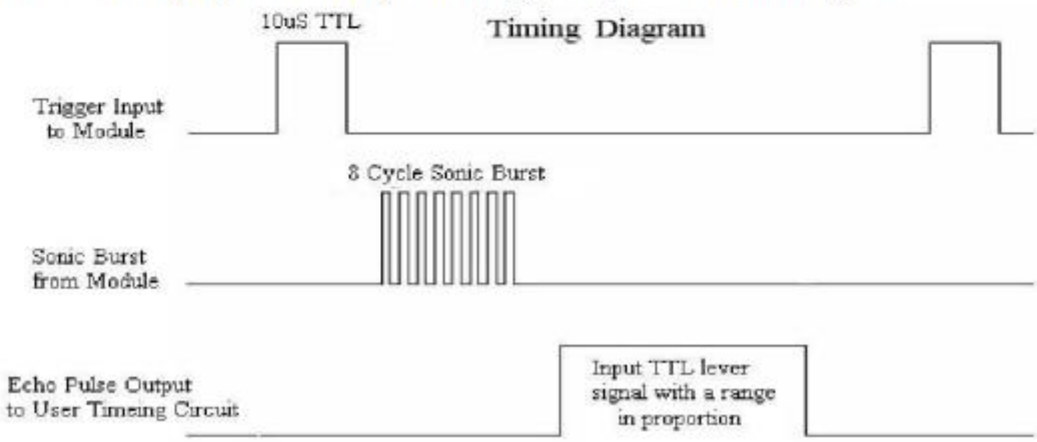
- 5V Supply
- Trigger Pulse Input
- Echo Pulse Output
- 0V Ground

Electric Parameter

Working Voltage	**DC 5 V**
Working Current	**15mA**
Working Frequency	**40Hz**
Max Range	**4m**
Min Range	**2cm**
MeasuringAngle	**15 degree**
Trigger Input Signal	**10uS TTL pulse**
Echo Output Signal	**Input TTL lever signal and the range in proportion**
Dimension	**45*20*15mm**

Timing diagram

The Timing diagram is shown below. You only need to supply a short 10uS pulse to the trigger input to start the ranging, and then the module will send out an 8 cycle burst of ultrasound at 40 kHz and raise its echo. The Echo is a distance object that is pulse width and the range in proportion .You can calculate the range through the time interval between sending trigger signal and receiving echo signal. Formula: uS / 58 = centimeters or uS / 148 =inch; or: the range = high level time * velocity (340M/S) / 2; we suggest to use over 60ms measurement cycle, in order to prevent trigger signal to the echo signal.



Attention:

- The module is not suggested to connect directly to electric, if connected electric, the GND terminal should be connected the module first, otherwise, it will affect the normal work of the module.
- When tested objects, the range of area is not less than 0.5 square meters and the plane requests as smooth as possible, otherwise ,it will affect the results of measuring.

www.Elecfreaks.com

24V lead acid battery:

FEATURES SPECIFICATIONS TERMINAL OPTIONS

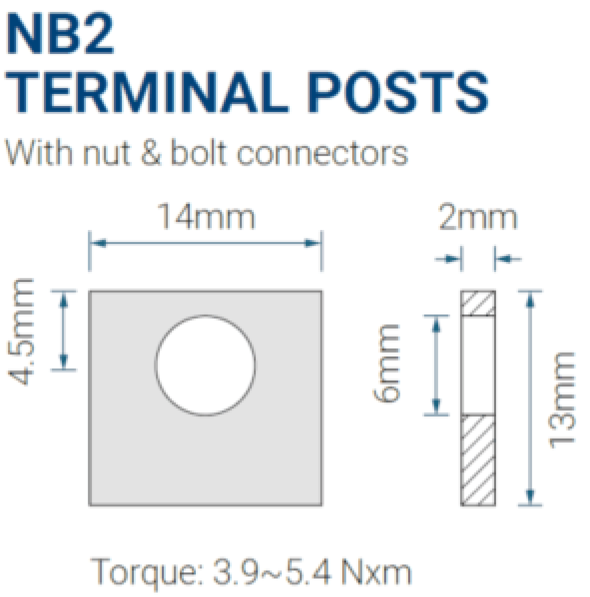
- 12V 18Ah General purpose VRLA battery
- Absorbent Glass Mat (AGM) technology for superior performance
- Power and volume ratio yielding unrivalled energy density
- Valve regulated, maintenance free spill proof construction
- Rugged impact resistant ABS case and cover
- 5 year design life
- Approved for transport by air. D.O.T., I.A.T.A., F.A.A. and C.A.B certified

FEATURES SPECIFICATIONS TERMINAL OPTIONS

Model Number:	**PS-12180**
Nominal voltage:	**12V**
Capacity @20HR (AH):	**18.00 Ah**
Capacity @10HR (AH):	**17.10 Ah**
Weight:	**5.6kg / 12.32lbs**
Case: **ABS UL94:HB (flame retardant UL94:V0 version also available)**	

Dimensions	
Length:	**7.13" / 181mm**
Width:	**3.00" / 76mm**
Height:	**6.59" / 167mm**
Recommended Charger: PSC-122000-PC PSC-124000-PC PSC-124000ACX	

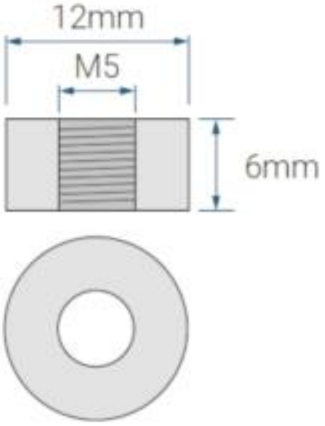
NB2



FEATURES SPECIFICATIONS TERMINAL OPTIONS

T12

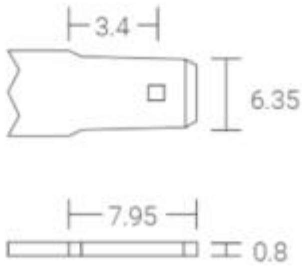
T12 THREADED INSERT – 5mm STUD



F2

F2 FASTON

0.250" x 0.032" quick disconnect tabs.



MODEL SUMMARY

The PS-12180 is part of our PS range of sealed lead acid batteries (often referred to as VRLA) which have been specifically designed for general purpose and standby applications. The 12V 18.00Ah battery offers excellent performance in a wide range of applications including security and fire systems, medical devices, emergency lighting and UPS systems.

All Power Sonic batteries are subject to stringent quality controls through every step of the manufacturing process ensuring both consistency and reliability.

Battery charger:

FEATURES SPECIFICATIONS DIMENSIONS USE WITH BATTERY

- Battery charger designed for SLA / VRLA batteries
- Universal input voltage range 100VAC - 240VAC
- Automatic, current sensing dual-rate charging for efficient, care-free and safe operation
- L.E.D indicators
- Alligator clip connectors or alligator/ring clips
- DOE, CE and FCC compliant
- ETL approved
- Available with NEMA-A, CEE-C or BS-G input plugs

FEATURES SPECIFICATIONS DIMENSIONS USE WITH BATTERY

Nominal voltage:	12V	Output Current:	2000mA
		Output Voltage Float:	13.2V
		Output Voltage Fast Charge:	14.7V
		Charger Design:	Desk top
		Charger Type:	Dual rate

FEATURES SPECIFICATIONS DIMENSIONS USE WITH BATTERY

Length:	6.06" / 154mm	Weight:	0.60kg / 1.32lbs
Width:	2.83" / 72mm		
Height:	1.85" / 47mm		

FEATURES SPECIFICATIONS DIMENSIONS USE WITH BATTERY

Voltage:	12V
Capacity:	8 - 20 Ah

Buck Converter:

1 Features

- New product available: LMR33630 36-V, 3-A, 400-kHz synchronous converter
- 3.3-V, 5-V, 12-V, and adjustable output versions
- Adjustable version output voltage range: 1.2-V to 37-V ±4% maximum over line and load conditions
- Available in TO-220 and TO-263 packages
- 3-A output load current
- Input voltage range up to 40 V
- Requires only four external components
- Excellent line and load regulation specifications
- 150-kHz Fixed-frequency internal oscillator
- TTL shutdown capability
- Low power standby mode, I_Q, typically 80 μA
- High efficiency
- Uses readily available standard inductors
- Thermal shutdown and current-limit protection
- Create a custom design using the LM2596 with the WEBENCH Power Designer

2 Applications

- Appliances
- Grid infrastructure
- EPOS
- Home theater

3 Description

The LM2596 series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving a 3-A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3 V, 5 V, 12 V, and an adjustable output version.

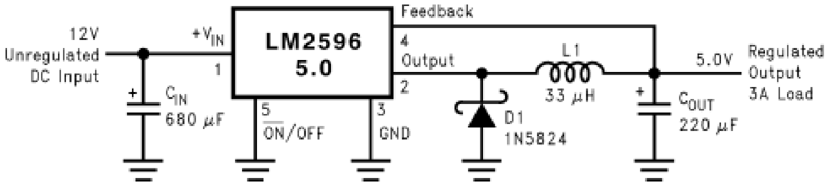
Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation, and a fixed-frequency oscillator.

The LM2596 series operates at a switching frequency of 150 kHz, thus allowing smaller sized filter components than what would be required with lower frequency switching regulators. Available in a standard 5-pin TO-220 package with several different lead bend options, and a 5-pin TO-263 surface mount package.

The new product, LMR33630, offers reduced BOM cost, higher efficiency, and an 85% reduction in solution size among many other features. Start WEBENCH Design with the LMR33630.

PART NUMBER	PACKAGE[1]	BODY SIZE (NOM)
LM2596	TO-220 (5)	14.986 mm × 10.16 mm
	TO-263 (5)	10.10 mm × 8.89 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.



5 Description (continued)

A standard series of inductors are available from several different manufacturers optimized for use with the LM2596 series. This feature greatly simplifies the design of switch-mode power supplies.

Other features include a ±4% tolerance on output voltage under specified input voltage and output load conditions, and ±15% on the oscillator frequency. External shutdown is included, featuring typically 80 μA standby current. Self-protection features include a two stage frequency reducing current limit for the output switch and an overtemperature shutdown for complete protection under fault conditions.

6 Pin Configuration and Functions

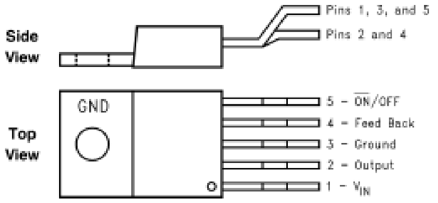


Figure 6-1. 5-Pin TO-220 NDH Package Top View

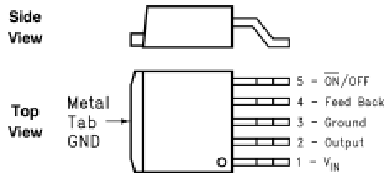


Figure 6-2. 5-Pin TO-263 KTT Package Top View

Table 6-1. Pin Functions

PIN		I/O	DESCRIPTION
NO.	NAME		
1	V_{IN}	I	This is the positive input supply for the IC switching regulator. A suitable input bypass capacitor must be present at this pin to minimize voltage transients and to supply the switching currents required by the regulator.
2	Output	O	Internal switch. The voltage at this pin switches between approximately ($+V_{IN} - V_{SAT}$) and approximately −0.5 V, with a duty cycle of V_{OUT} / V_{IN}. To minimize coupling to sensitive circuitry, the PCB copper area connected to this pin must be kept to a minimum.
3	Ground	—	Circuit ground
4	Feedback	I	Senses the regulated output voltage to complete the feedback loop.
5	$\overline{\text{ON}}$/OFF	I	Allows the switching regulator circuit to be shut down using logic signals thus dropping the total input supply current to approximately 80 µA. Pulling this pin below a threshold voltage of approximately 1.3 V turns the regulator on, and pulling this pin above 1.3 V (up to a maximum of 25 V) shuts the regulator down. If this shutdown feature is not required, the $\overline{\text{ON}}$/OFF pin can be wired to the ground pin or it can be left open. In either case, the regulator will be in the ON condition.

7 Specifications

7.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)[1] [2]

			MIN	MAX	UNIT
Maximum supply voltage (V_{IN})				45	V
$\overline{SD}$/SS pin input voltage[3]				6	V
Delay pin voltage[3]				1.5	V
Flag pin voltage			–0.3	45	V
Feedback pin voltage			–0.3	25	V
Output voltage to ground, steady-state				–1	V
Power dissipation			Internally limited		
Lead temperature	KTW package	Vapor phase (60 s)		215	°C
		Infrared (10 s)		245	°C
	NDZ package, soldering (10 s)			260	°C
Maximum junction temperature				150	°C
Storage temperature, T_{stg}			–65	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

(2) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/ Distributors for availability and specifications.

(3) Voltage internally clamped. If clamp voltage is exceeded, limit current to a maximum of 1 mA.

7.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001[1]	±2000	V

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

7.3 Operating Conditions

	MIN	MAX	UNIT
Supply voltage	4.5	40	V
Temperature	–40	125	°C

7.5 Electrical Characteristics – 3.3-V Version

Specifications are for T_J = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN[1]	TYP[2]	MAX[1]	UNIT
SYSTEM PARAMETERS [3] (see Figure 9-13 for test circuit)							
V_{OUT}	Output voltage	4.75 V ≤ V_{IN} ≤ 40 V, 0.2 A ≤ I_{LOAD} ≤ 3 A	T_J = 25°C	3.168	3.3	3.432	V
			–40°C ≤ T_J ≤ 125°C	3.135		3.465	
η	Efficiency	V_{IN} = 12 V, I_{LOAD} = 3 A			73%		

(1) All room temperature limits are 100% production tested. All limits at temperature extremes are specified via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
(2) Typical numbers are at 25°C and represent the most likely norm.
(3) External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2596 is used as shown in Figure 9-13, system performance is shown in the test conditions column.

7.6 Electrical Characteristics – 5-V Version

Specifications are for T_J = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN[1]	TYP[2]	MAX[1]	UNIT
SYSTEM PARAMETERS [3] (see Figure 9-13 for test circuit)							
V_{OUT}	Output voltage	7 V ≤ V_{IN} ≤ 40 V, 0.2 A ≤ I_{LOAD} ≤ 3 A	T_J = 25°C	4.8	5	5.2	V
			–40°C ≤ T_J ≤ 125°C	4.75		5.25	
η	Efficiency	V_{IN} = 12 V, I_{LOAD} = 3 A			80%		

(1) All room temperature limits are 100% production tested. All limits at temperature extremes are specified via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
(2) Typical numbers are at 25°C and represent the most likely norm.
(3) External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2596 is used as shown in Figure 9-13, system performance is shown in the test conditions column.

7.7 Electrical Characteristics – 12-V Version

Specifications are for T_J = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN[1]	TYP[2]	MAX[1]	UNIT
SYSTEM PARAMETERS [3] (see Figure 9-13 for test circuit)							
V_{OUT}	Output voltage	15 V ≤ V_{IN} ≤ 40 V, 0.2 A ≤ I_{LOAD} ≤ 3 A	T_J = 25°C	11.52	12	12.48	V
			–40°C ≤ T_J ≤ 125°C	11.4		12.6	
η	Efficiency	V_{IN} = 25 V, I_{LOAD} = 3 A			90%		

(1) All room temperature limits are 100% production tested. All limits at temperature extremes are specified via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
(2) Typical numbers are at 25°C and represent the most likely norm.
(3) External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2596 is used as shown in Figure 9-13, system performance is shown in the test conditions column.

Datasheet of LM35DZ Temperature Sensor:

1 Features

- Calibrated Directly in Celsius (Centigrade)
- Linear + 10-mV/°C Scale Factor
- 0.5°C Ensured Accuracy (at 25°C)
- Rated for Full −55°C to 150°C Range
- Suitable for Remote Applications
- Low-Cost Due to Wafer-Level Trimming
- Operates From 4 V to 30 V
- Less Than 60-µA Current Drain
- Low Self-Heating, 0.08°C in Still Air
- Non-Linearity Only ±¼°C Typical
- Low-Impedance Output, 0.1 Ω for 1-mA Load

2 Applications

- Power Supplies
- Battery Management
- HVAC
- Appliances

3 Description

The LM35 series are precision integrated-circuit temperature devices with an output voltage linearly-proportional to the Centigrade temperature. The LM35 device has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from the output to obtain convenient Centigrade scaling. The LM35 device does not require any external calibration or trimming to provide typical accuracies of ±¼°C at room temperature and ±¾°C over a full −55°C to 150°C temperature range. Lower cost is assured by trimming and calibration at the wafer level. The low-output impedance, linear output, and precise inherent calibration of the LM35 device makes interfacing to readout or control circuitry especially easy. The device is used with single power supplies, or with plus and minus supplies. As the LM35 device draws only 60 µA from the supply, it has very low self-heating of less than 0.1°C in still air. The LM35 device is rated to operate over a −55°C to 150°C temperature range, while the LM35C device is rated for a −40°C to 110°C range (−10° with improved accuracy). The LM35-series devices are available packaged in hermetic TO transistor packages, while the LM35C, LM35CA, and LM35D devices are available in the plastic TO-92 transistor package. The LM35D device is available in an 8-lead surface-mount small-outline package and a plastic TO-220 package.

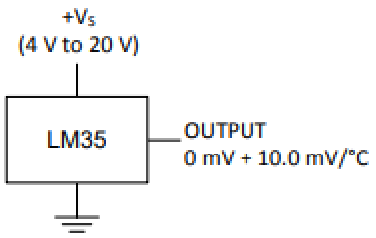
Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LM35	TO-CAN (3)	4.699 mm × 4.699 mm
	TO-92 (3)	4.30 mm × 4.30 mm
	SOIC (8)	4.90 mm × 3.91 mm
	TO-220 (3)	14.986 mm × 10.16 mm

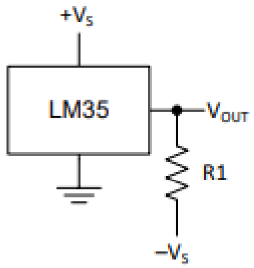
(1) For all available packages, see the orderable addendum at the end of the datasheet.

Local sensor accuracy (Max) (+/- C)	1
Operating temperature range (C)	-40 to 110, -55 to 150, 0 to 100, 0 to 70
Supply voltage (Min) (V)	4
Supply voltage (Max) (V)	30
Supply current (Max) (uA)	114
Interface type	Analog output
Sensor gain (mV/Deg C)	10
Rating	Catalog
Features	UL recognized

Basic Centigrade Temperature Sensor (2°C to 150°C)



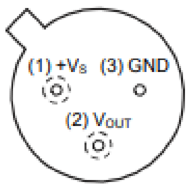
Full-Range Centigrade Temperature Sensor



Choose $R_1 = -V_S$ / 50 µA
V_{OUT} = 1500 mV at 150°C
V_{OUT} = 250 mV at 25°C
V_{OUT} = –550 mV at –55°C

5 Pin Configuration and Functions

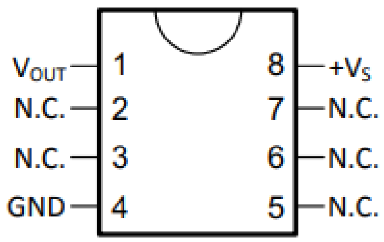
NDV Package
3-Pin TO-CAN
(Top View)



Case is connected to negative pin (GND)

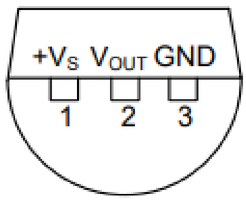
Refer the second NDV0003H page for reference

D Package
8-PIN SOIC
(Top View)

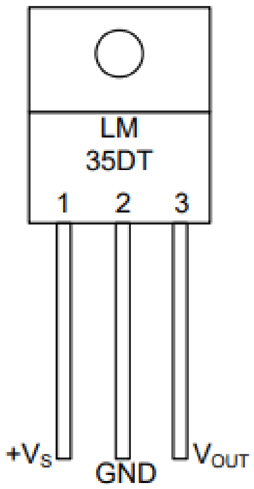


N.C. = No connection

LP Package
3-Pin TO-92
(Bottom View)



NEB Package
3-Pin TO-220
(Top View)



Tab is connected to the negative pin (GND).

NOTE: The LM35DT pinout is different than the discontinued LM35DP

Pin Functions

PIN					TYPE	DESCRIPTION
NAME	TO46	TO92	TO220	SO8		
V_{OUT}	2	2	3	1	O	Temperature Sensor Analog Output
N.C.	—	—	—	2	—	No Connection
	—	—	—	3		
GND	3	3	2	4	GROUND	Device ground pin, connect to power supply negative terminal
N.C.	—	—	—	5	—	No Connection
	—	—	—	6		
	—	—	—	7		
$+V_S$	1	1	1	8	POWER	Positive power supply pin

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1)(2)

		MIN	MAX	UNIT
Supply voltage		–0.2	35	V
Output voltage		–1	6	V
Output current			10	mA
Maximum Junction Temperature, $T_J$max			150	°C
Storage Temperature, T_{stg}	TO-CAN, TO-92 Package	–60	150	°C
	TO-220, SOIC Package	–65	150	

(1) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/ Distributors for availability and specifications.
(2) Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001(1)	±2500	V

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	MAX	UNIT
Specified operating temperature: T_{MIN} to T_{MAX}	LM35, LM35A	–55	150	°C
	LM35C, LM35CA	–40	110	
	LM35D	0	100	
Supply Voltage ($+V_S$)		4	30	V

6.4 Thermal Information

THERMAL METRIC(1)(2)		LM35				UNIT
		NDV	LP	D	NEB	
		3 PINS		8 PINS	3 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	400	180	220	90	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	24	—	—	—	

Unless otherwise noted, these specifications apply: −55°C ≤ T_J ≤ 150°C for the LM35 and LM35A; −40°C ≤ T_J ≤ 110°C for the LM35C and LM35CA; and 0°C ≤ T_J ≤ 100°C for the LM35D. V_S = 5 Vdc and I_{LOAD} = 50 μA, in the circuit of Full-Range Centigrade Temperature Sensor. These specifications also apply from 2°C to T_{MAX} in the circuit of Figure 14.

PARAMETER	TEST CONDITIONS	LM35A			LM35CA			UNIT
		TYP	TESTED LIMIT[(1)]	DESIGN LIMIT[(2)]	TYP	TESTED LIMIT[(1)]	DESIGN LIMIT[(2)]	
Accuracy[(3)]	T_A = 25°C	±0.2	±0.5		±0.2	±0.5		°C
	T_A = –10°C	±0.3			±0.3		±1	
	$T_A = T_{MAX}$	±0.4	±1		±0.4	±1		
	$T_A = T_{MIN}$	±0.4	±1		±0.4		±1.5	
Nonlinearity[(4)]	$T_{MIN} \le T_A \le T_{MAX}$, –40°C ≤ T_J ≤ 125°C	±0.18		±0.35	±0.15		±0.3	°C
Sensor gain (average slope)	$T_{MIN} \le T_A \le T_{MAX}$	10	9.9		10		9.9	mV/°C
	–40°C ≤ T_J ≤ 125°C	10	10.1		10		10.1	
Load regulation[(5)] 0 ≤ I_L ≤ 1 mA	T_A = 25°C	±0.4	±1		±0.4	±1		mV/mA
	$T_{MIN} \le T_A \le T_{MAX}$, –40°C ≤ T_J ≤ 125°C	±0.5		±3	±0.5		±3	
Line regulation[(5)]	T_A = 25°C	±0.01	±0.05		±0.01	±0.05		mV/V
	4 V ≤ V_S ≤ 30 V, –40°C ≤ T_J ≤ 125°C	±0.02		±0.1	±0.02		±0.1	
Quiescent current[(6)]	V_S = 5 V, 25°C	56	67		56	67		μA
	V_S = 5 V, –40°C ≤ T_J ≤ 125°C	105		131	91		114	
	V_S = 30 V, 25°C	56.2	68		56.2	68		
	V_S = 30 V, –40°C ≤ T_J ≤ 125°C	105.5		133	91.5		116	
Change of quiescent current[(5)]	4 V ≤ V_S ≤ 30 V, 25°C	0.2	1		0.2	1		μA
	4 V ≤ V_S ≤ 30 V, –40°C ≤ T_J ≤ 125°C	0.5		2	0.5		2	
Temperature coefficient of quiescent current	–40°C ≤ T_J ≤ 125°C	0.39		0.5	0.39		0.5	μA/°C
Minimum temperature for rate accuracy	In circuit of Figure 14, I_L = 0	1.5		2	1.5		2	°C
Long term stability	$T_J = T_{MAX}$, for 1000 hours	±0.08			±0.08			°C

6.6 Electrical Characteristics: LM35A, LM35CA

Unless otherwise noted, these specifications apply: $-55°C \le T_J \le 150°C$ for the LM35 and LM35A; $-40°C \le T_J \le 110°C$ for the LM35C and LM35CA; and $0°C \le T_J \le 100°C$ for the LM35D. V_S = 5 Vdc and I_{LOAD} = 50 µA, in the circuit of Full-Range Centigrade Temperature Sensor. These specifications also apply from 2°C to T_{MAX} in the circuit of Figure 14.

PARAMETER	TEST CONDITIONS		LM35A			LM35CA			UNIT
			MIN	TYP	MAX	TYP	TYP	MAX	
Accuracy(1)	T_A = 25°C			±0.2			±0.2		°C
		Tested Limit(2)			±0.5			±0.5	
		Design Limit(3)							
	T_A = –10°C			±0.3			±0.3		
		Tested Limit(2)							
		Design Limit(3)						±1	
	$T_A = T_{MAX}$			±0.4			±0.4		
		Tested Limit(2)			±1			±1	
		Design Limit(3)							
	$T_A = T_{MIN}$			±0.4			±0.4		
		Tested Limit(2)			±1				
		Design Limit(3)						±1.5	
Nonlinearity(4)	$T_{MIN} \le T_A \le T_{MAX}$, $-40°C \le T_J \le 125°C$			±0.18			±0.15		°C
		Tested Limit(2)							
		Design Limit(3)			±0.35			±0.3	
Sensor gain (average slope)	$T_{MIN} \le T_A \le T_{MAX}$			10			10		mV/°C
		Tested Limit(2)			9.9				
		Design Limit(3)						9.9	
	$-40°C \le T_J \le 125°C$			10			10		
		Tested Limit(2)			10.1				
		Design Limit(3)						10.1	
Load regulation(5) $0 \le I_L \le 1$ mA	T_A = 25°C			±0.4			±0.4		mV/mA
		Tested Limit(2)			±1			±1	
		Design Limit(3)							
	$T_{MIN} \le T_A \le T_{MAX}$, $-40°C \le T_J \le 125°C$			±0.5			±0.5		
		Tested Limit(2)							
		Design Limit(3)			±3			±3	
Line regulation(5)	T_A = 25°C			±0.01			±0.01		mV/V
		Tested Limit(2)			±0.05			±0.05	
		Design Limit(3)							
	$4 V \le V_S \le 30$ V, $-40°C \le T_J \le 125°C$			±0.02			±0.02		
		Tested Limit(2)							
		Design Limit(3)			±0.1			±0.1	

Electrical Characteristics: LM35A, LM35CA (continued)

Unless otherwise noted, these specifications apply: −55°C ≤ T_J ≤ 150°C for the LM35 and LM35A; −40°C ≤ T_J ≤ 110°C for the LM35C and LM35CA; and 0°C ≤ T_J ≤ 100°C for the LM35D. V_S = 5 Vdc and I_{LOAD} = 50 μA, in the circuit of Full-Range Centigrade Temperature Sensor. These specifications also apply from 2°C to T_{MAX} in the circuit of Figure 14.

PARAMETER	TEST CONDITIONS		LM35A MIN	LM35A TYP	LM35A MAX	LM35CA TYP	LM35CA TYP	LM35CA MAX	UNIT
Quiescent current[6]	V_S = 5 V, 25°C			56			56		μA
		Tested Limit[2]			67			67	
		Design Limit[3]							
	V_S = 5 V, –40°C ≤ T_J ≤ 125°C			105			91		
		Tested Limit[2]							
		Design Limit[3]			131			114	
	V_S = 30 V, 25°C			56.2			56.2		
		Tested Limit[2]			68			68	
		Design Limit[3]							
	V_S = 30 V, –40°C ≤ T_J ≤ 125°C			105.5			91.5		
		Tested Limit[2]							
		Design Limit[3]			133			116	
Change of quiescent current[5]	4 V ≤ V_S ≤ 30 V, 25°C			0.2			0.2		μA
		Tested Limit[2]			1			1	
		Design Limit[3]							
	4 V ≤ V_S ≤ 30 V, –40°C ≤ T_J ≤ 125°C			0.5			0.5		
		Tested Limit[2]							
		Design Limit[3]			2			2	
Temperature coefficient of quiescent current	–40°C ≤ T_J ≤ 125°C			0.39			0.39		μA/°C
		Tested Limit[2]							
		Design Limit[3]			0.5			0.5	
Minimum temperature for rate accuracy	In circuit of Figure 14, I_L = 0			1.5			1.5		°C
		Tested Limit[2]							
		Design Limit[3]			2			2	
Long term stability	T_J = T_{MAX}, for 1000 hours			±0.08			±0.08		°C

6.7 Electrical Characteristics: LM35, LM35C, LM35D Limits

Unless otherwise noted, these specifications apply: −55°C ≤ T_J ≤ 150°C for the LM35 and LM35A; −40°C ≤ T_J ≤ 110°C for the LM35C and LM35CA; and 0°C ≤ T_J ≤ 100°C for the LM35D. V_S = 5 Vdc and I_{LOAD} = 50 µA, in the circuit of Full-Range Centigrade Temperature Sensor. These specifications also apply from 2°C to T_{MAX} in the circuit of Figure 14.

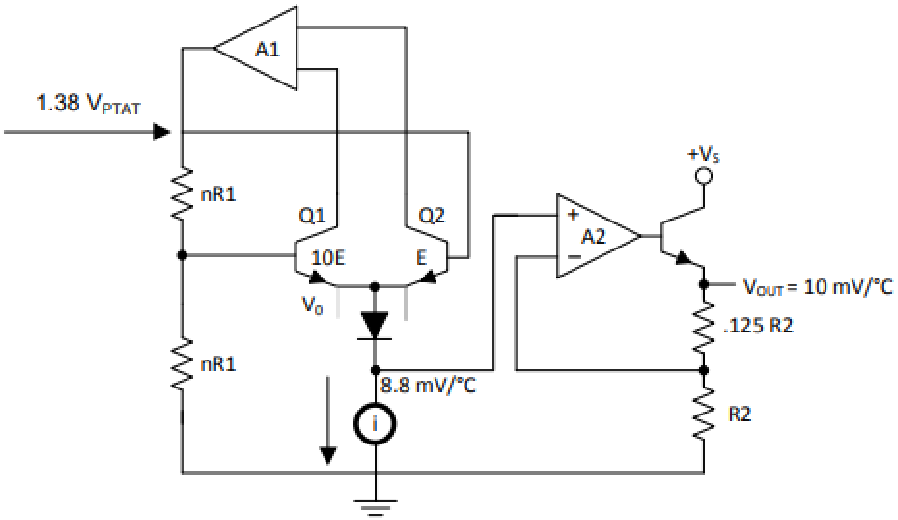
PARAMETER	TEST CONDITIONS	LM35 TYP	LM35 TESTED LIMIT[1]	LM35 DESIGN LIMIT[2]	LM35C, LM35D TYP	LM35C, LM35D TESTED LIMIT[1]	LM35C, LM35D DESIGN LIMIT[2]	UNIT
Accuracy, LM35, LM35C[3]	T_A = 25°C	±0.4	±1		±0.4	±1		°C
	T_A = –10°C	±0.5			±0.5		±1.5	
	T_A = T_{MAX}	±0.8	±1.5		±0.8		±1.5	
	T_A = T_{MIN}	±0.8		±1.5	±0.8		±2	
Accuracy, LM35D[3]	T_A = 25°C				±0.6	±1.5		°C
	T_A = T_{MAX}				±0.9		±2	
	T_A = T_{MIN}				±0.9		±2	
Nonlinearity[4]	T_{MIN} ≤ T_A ≤ T_{MAX}, –40°C ≤ T_J ≤ 125°C	±0.3		±0.5	±0.2		±0.5	°C
Sensor gain (average slope)	T_{MIN} ≤ T_A ≤ T_{MAX}, –40°C ≤ T_J ≤ 125°C	10	9.8		10		9.8	mV/°C
		10	10.2		10		10.2	
Load regulation[5] 0 ≤ I_L ≤ 1 mA	T_A = 25°C	±0.4	±2		±0.4	±2		mV/mA
	T_{MIN} ≤ T_A ≤ T_{MAX}, –40°C ≤ T_J ≤ 125°C	±0.5		±5	±0.5		±5	
Line regulation[5]	T_A = 25°C	±0.01	±0.1		±0.01	±0.1		mV/V
	4 V ≤ V_S ≤ 30 V, –40°C ≤ T_J ≤ 125°C	±0.02		±0.2	±0.02		±0.2	
Quiescent current[6]	V_S = 5 V, 25°C	56	80		56	80		µA
	V_S = 5 V, –40°C ≤ T_J ≤ 125°C	105		158	91		138	
	V_S = 30 V, 25°C	56.2	82		56.2	82		
	V_S = 30 V, –40°C ≤ T_J ≤ 125°C	105.5		161	91.5		141	
Change of quiescent current[5]	4 V ≤ V_S ≤ 30 V, 25°C	0.2	2		0.2	2		µA
	4 V ≤ V_S ≤ 30 V, –40°C ≤ T_J ≤ 125°C	0.5		3	0.5		3	
Temperature coefficient of quiescent current	–40°C ≤ T_J ≤ 125°C	0.39		0.7	0.39		0.7	µA/°C
Minimum temperature for rate accuracy	In circuit of Figure 14, I_L = 0	1.5		2	1.5		2	°C
Long term stability	T_J = T_{MAX}, for 1000 hours	±0.08			±0.08			°C

7.1 Overview

The LM35-series devices are precision integrated-circuit temperature sensors, with an output voltage linearly proportional to the Centigrade temperature. The LM35 device has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from the output to obtain convenient Centigrade scaling. The LM35 device does not require any external calibration or trimming to provide typical accuracies of ± ¼ °C at room temperature and ± ¾ °C over a full −55°C to 150°C temperature range. Lower cost is assured by trimming and calibration at the wafer level. The low output impedance, linear output, and precise inherent calibration of the LM35 device makes interfacing to readout or control circuitry especially easy. The device is used with single power supplies, or with plus and minus supplies. As the LM35 device draws only 60 µA from the supply, it has very low self-heating of less than 0.1°C in still air. The LM35 device is rated to operate over a −55°C to 150°C temperature range, while the LM35C device is rated for a −40°C to 110°C range (−10° with improved accuracy). The temperature-sensing element is comprised of a delta-V BE architecture.

The temperature-sensing element is then buffered by an amplifier and provided to the VOUT pin. The amplifier has a simple class A output stage with typical 0.5-Ω output impedance as shown in the *Functional Block Diagram*. Therefore the LM35 can only source current and it's sinking capability is limited to 1 µA.

7.2 Functional Block Diagram



Elechouse Voice Recognition Module V3:

Parameter

- Voltage: 4.5-5.5V
- Current: <40mA
- Digital Interface: 5V TTL level for UART interface and GPIO
- Analog Interface: 3.5mm mono-channel microphone connector + microphone pin interface
- Size: 31mm x 50mm
- Recognition accuracy: 99% (under ideal environment)

Feature

- Support maximum 80 voice commands, with each voice 1500ms (one or two words speaking)
- Maximum 7 voice commands effective at same time
- Arduino library is supplied
- Easy Control: UART/GPIO
- User-control General Pin Output

Terminology

- VR3 -- Voice Recognition Module V3
- Recognizer -- a container where acting voice commands (max 7) were loaded. It is core part of voice recognition module. For example, it works like "playing balls". You have 80 players in your team. But you could not let them all play on the court together. The rule only allows 7 players playing on the court. Here the Recognizer is the list which contains names of players working on the court.
- Recognizer index -- max 7 voice commands could be supported in the recognizer. The recognizer has 7 regions for each voice command. One index corresponds to one region: 0~6
- Train -- the process of recording your voice commands
- Load -- copy trained voice to recognizer

- Voice Command Record -- the trained voice command store in flash, number from 0 to 79
- Signature -- text comment for record
- Group -- help to manage records, each group 7 records. System group and user group are supported.

Instruction

Here we will introduce the Arduino Library and VR3 Protocol

For Arduino

Prepare

- Voice Recognition V3 module with microphone
- Arduino board (UNO recommended)
- Arduino Sensor Shield V07 (optional)
- Arduino IDE
- Voice Recognition V3 library (Download zip file)

Hardware and Software Preparation

1. Connect your Voice Recognition V3 Module with Arduino, By Default:

```
Arduino                    VR Module
  5V          ---->          5V
   2          ---->          TX
   3          ---->          RX
 GND          ---->          GND
```

2. Download VoiceRecognitionV3 library. (download zip file or use `git clone https://github.com/elechouse/VoiceRecognitionV3.git` command)
3. If using zip file, extract **VoiceRecognitionV3.zip** to `Arduino Sketch\libraries` folder, or if you use `git clone` command copy **VoiceRecognitionV3** to `Arduino Sketch\libraries` .

CC2541 HM-10 Bluetooth Module:

1. Product parameters

- BT Version: Bluetooth Specification V4.0 BLE
- Send and receive no bytes limit.
- Working frequency: 2.4GHz ISM band
- Modulation method: GFSK(Gaussian Frequency Shift Keying)
- RF Power: -23dbm, -6dbm, 0dbm, 6dbm, can modify through AT Command AT+POWE.
- Speed: Asynchronous: 6K Bytes
  Synchronous: 6K Bytes
- Security: Authentication and encryption
- Service: Central & Peripheral UUID FFE0,FFE1
- Power: +3.3VDC 50mA
- Long range: Open space have 100 Meters with iphone4s
- Power: In sleep mode 400uA~1.5mA, Active mode 8.5mA.
- Working temperature:–5 ~ +65 Centigrade
- Size: HM- 10 26.9mm x 13mm x 2.2 mm; HM-11 18*13.5*2.2mm

2. Product overview

Thanks for you choose our products. If you want to know more, www.jnhuamao.cn can help you (Videos, New version datasheet, Module work flow, project Codes, etc.)

HM Bluetooth module use CSR BlueCore or TI CC2540, Master and slave roles in one, transmission version and remote control version and PIO state acquisition functions in one, Support the AT command modify module parameters, Convenient and flexible.

Transmission version can be used to transmit data between two Bluetooth devices.

Remote Control version can be used to Control PIO ports output high or low level without any other MCU.

The PIO state acquisition version can be used to acquisition PIO ports state without any other MUC. (Only support Bluetooth V2.1)

HM-01, HM-02, HM-03, HM-04, HM-05, HM-06, HM-07, HM-08, HM-09 is Bluetooth V2.1 version. Use CSR Chip.

HM-10, HM-11, HM-12 is Bluetooth V4.0 BLE version. Use TI Chip.

HM-01, HM-02, HM-09, HM-10 have same size and same pins.

HM-05, HM-06, HM-07, HM-11 have same size and same pins.

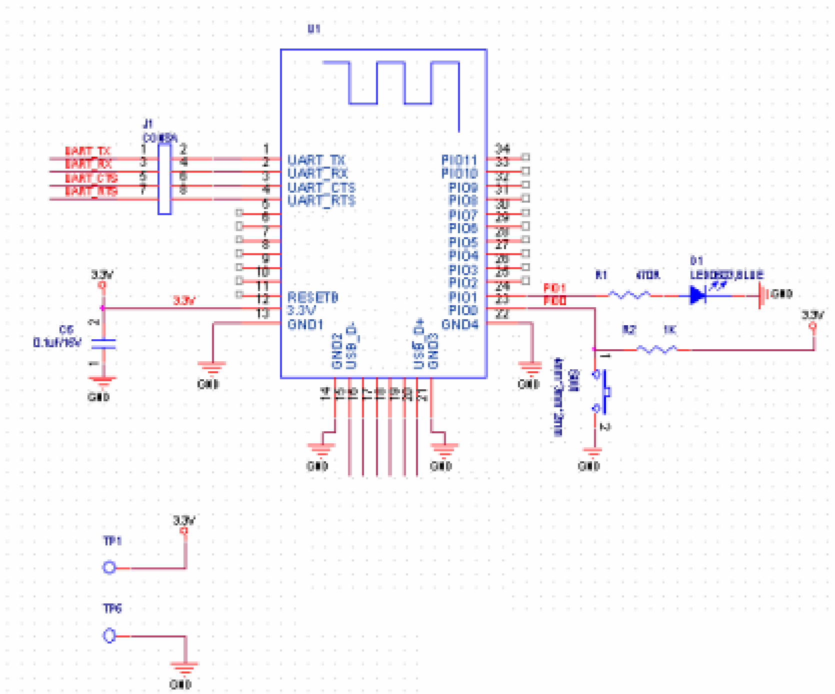
3. Product model

Models	VDD	Size(mm)	Flash	Chip	BT Version
HM-01	3.3V	26.9*13*2.2	8M	BC417143	V2.1+EDR
HM-02A	2.5-3.7V	26.9*13*2.2	6M	BC31A223	V2.1
HM-02B	2.5-3.7V	26.9*13*2.2	6M	BC41C671	V2.1+EDR
HM-03A	2.5-3.7V	27.4*12.5*4.3	6M	BC31A223	V2.1
HM-03B	2.5-3.7V	27.4*12.5*4.3	6M	BC41C671	V2.1+EDR
HM-04A	3.3V	Not for sale			
HM-04B	3.3V	Not for sale			
HM-05/06A	2.5-3.7V	13.5*18.5*2.3	6M	BC31A223	V2.1
HM-05/06B	2.5-3.7V	13.5*18.5*2.3	6M	BC41C671	V2.1+EDR
HM-07	2.5-3.7V	13.5*18.5*2.3	8M		V2.1+EDR
HM-08	3.3V	26.9*13*2.5	8M	Class 1	V2.1+EDR
HM-09	2.5-3.7V	26.9*13*2.2	8M		V2.1+EDR
HM-10	2-3.7V	26.9*13*2.2	256Kb	CC2540	V4.0 BLE
HM-11	2.5-3.7V	13.5*18.5*2.2	256Kb	CC2540	V4.0 BLE

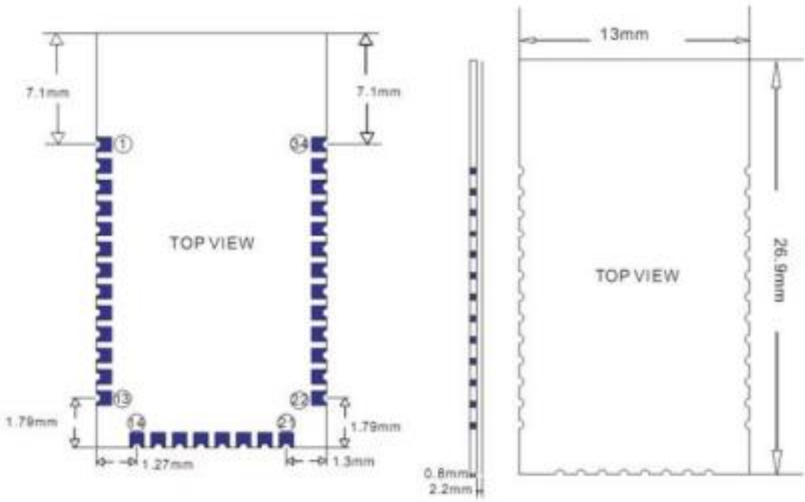
6. Product technical specifications

This document only include Bluetooth BLE 4.0 document, You can goto http://www.jnhuamao.cn/bluetooth_en.rar get Bluetooth V2.1 version datasheet. That document include: HM-01, HM-02, HM-03, HM-04, HM-05, HM-06, HM-07, HM-08, HM-09.

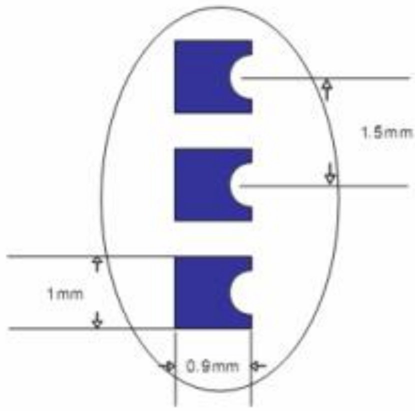
6.1 HM-10 Schematic



6.2 HM-10 Size



6.3 HM-10 package information

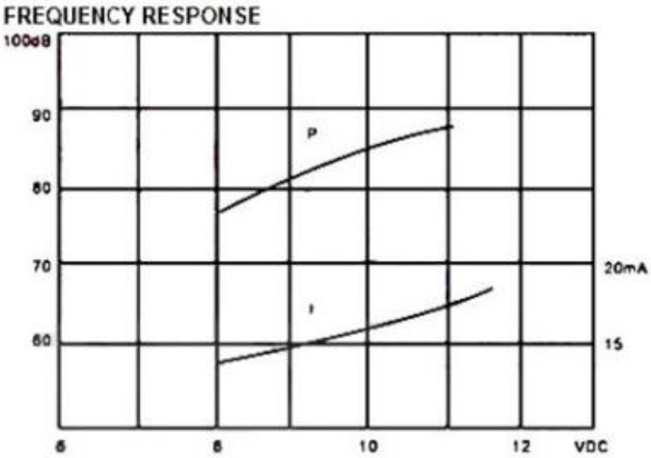


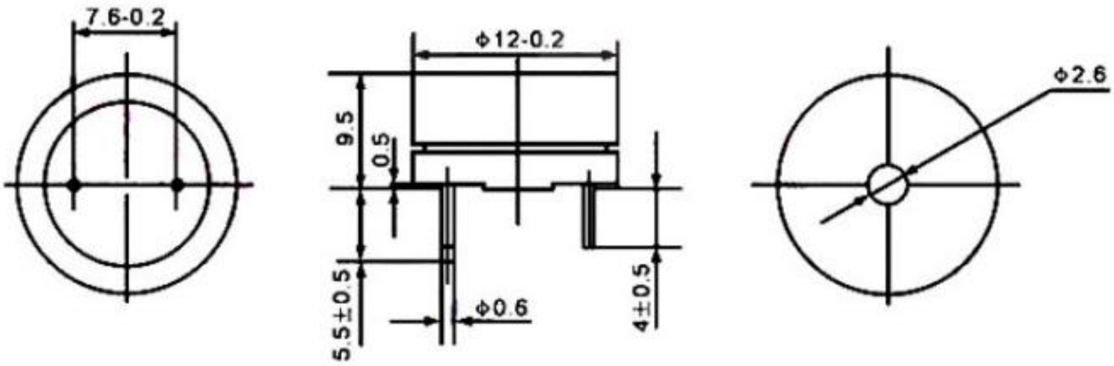
Active buzzer:

LTE12

Active Buzzer

SPECIFICATIONS:				
Type	**Unit**	**LTE12-03**	**LTE12-05**	**LTE12-12**
Rated Voltage	V	3	5	12
Operating Voltage	V	2-5	4-8	8-15
*Rated Current(MAX)	mA	30	30	30
*Min Sound Output at 10cm	dB	80	85	85
*Resonant Frequency	Hz	2300±300		
Operating Temperature	℃	-20 ~ +70		
Storage temperature	℃	-30 ~ +105		



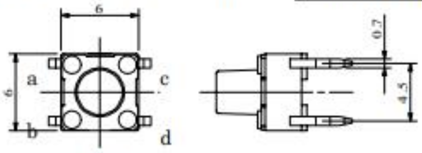


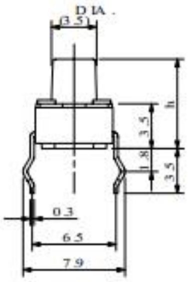
Pushbutton:

■Features
- Crisp clicking by tactile feedback
- Prevent flux rise by insert-molded terminal
- Ground terminal is attached
- Snap-in mount terminal

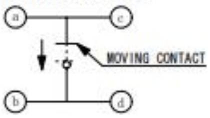
■Dimensions (Unit : mm)

Without ground terminal

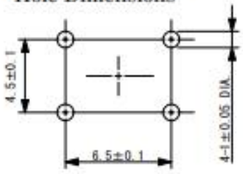




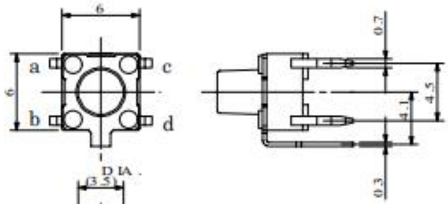
■Circuit Diagram

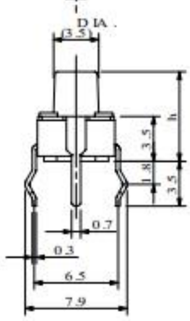


■ Recommended Mounting Hole Dimensions

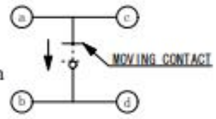


With ground terminal

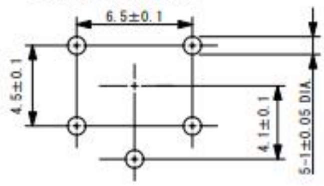




■Circuit Diagram



■ Recommended Mounting Hole Dimensions



■Specifications

Item	Specification	Unit	Note
Operating Temperature Range	-20～+70	℃	
Storage Temperature Range	-40～+85	℃	
Type of Operation	Tactile Feedback		
Circuit Configuration	Push-On Momentary, 1 pole-1 throw		
Power Rating	MAX 50mA 24VDC		
Contact Resistance	MAX 100	mΩ	
Insulation Resistance	100MΩ Min. at 100VDC		
Dielectric Withstanding Voltage	250VAC for 1 minute		
Contact Bounce	MAX 5	ms	
Operating Force	0.98±0.49	N	A type
	1.57±0.49	N	B type
Return Force	MIN 0.10	N	A type
	MIN 0.49	N	B type
Travel	0.25 +0.2/-0.1	mm	

■Model Designation

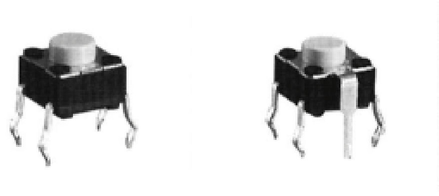
KSMC6 1 2 A

- A — Operation Force
- 2 — Mount Height
- 1 — Terminal Option (1:Without ground terminal, 2:With ground terminal)
- KSMC6 — Model No.

	h (mm)
1	4.3
2	5
3	7
4	9.5

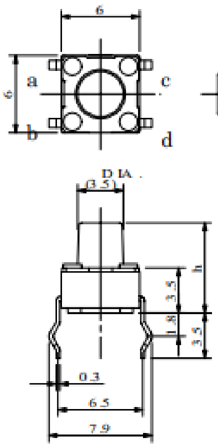
■Features

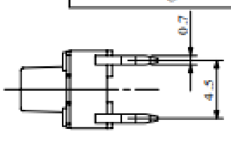
- Crisp clicking by tactile feedback
- Prevent flux rise by insert-molded terminal
- Ground terminal is attached
- Snap-in mount terminal



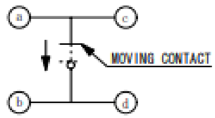
■Dimensions (Unit : mm)

Without ground terminal

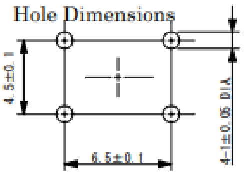




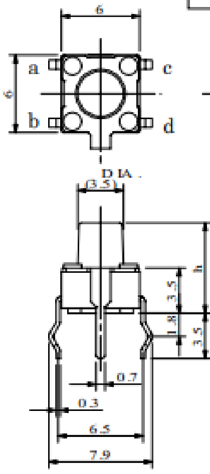
■Circuit Diagram

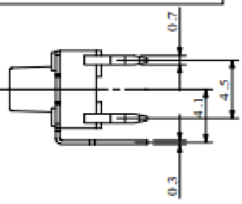


■ Recommended Mounting Hole Dimensions

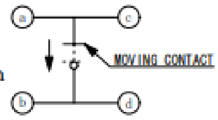


With ground terminal

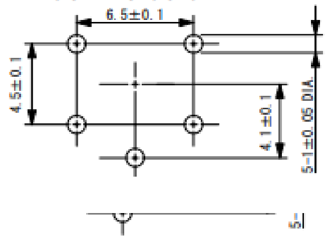




■Circuit Diagram



■ Recommended Mounting Hole Dimensions



■Specifications

Item	Specification	Unit	Note
Operating Temperature Range	-20～+70	℃	
Storage Temperature Range	-40～+85	℃	
Type of Operation	Tactile Feedback		
Circuit Configuration	Push-On Momentary, 1 pole-1 throw		
Power Rating	MAX 50mA 24VDC		
Contact Resistance	MAX 100	mΩ	
Insulation Resistance	100MΩ Min. at 100VDC		
Dielectric Withstanding Voltage	250VAC for 1 minute		
Contact Bounce	MAX 5	ms	
Operating Force	2.55±0.69	N	
Return Force	MIN 0.49	N	
Travel	0.25 +0.2/-0.1	mm	

■Model Designation

KSM06 1 2 C

- C — Operation Force
- 2 — Mount Height →
- 1 — Terminal Option (1:Without ground terminal, 2:With ground terminal)
- KSM06 — Model No

	h (mm)
1	4.3
2	5
3	7
4	9.5

Arduino Mega Rev 3:

Description

Arduino® Mega 2560 is an exemplary development board dedicated for building extensive applications as compared to other maker boards by Arduino. The board accommodates the ATmega2560 microcontroller, which operates at a frequency of 16 MHz. The board contains 54 digital input/output pins, 16 analog inputs, 4 UARTs (hardware serial ports), a USB connection, a power jack, an ICSP header, and a reset button.

Target Areas

3D Printing, Robotics, Maker

Features

- **ATmega2560 Processor**
  - Up to 16 MIPS Throughput at 16MHz
  - 256k bytes (of which 8k is used for the bootloader)
  - 4k bytes EEPROM
  - 8k bytes Internal SRAM
  - 32 × 8 General Purpose Working Registers
  - Real Time Counter with Separate Oscillator
  - Four 8-bit PWM Channels
  - Four Programmable Serial USART
  - Controller/Peripheral SPI Serial Interface
- **ATmega16U2**
  - Up to 16 MIPS Throughput at 16 MHz
  - 16k bytes ISP Flash Memory
  - 512 bytes EEPROM
  - 512 bytes SRAM
  - USART with SPI master only mode and hardware flow control (RTS/CTS)
  - Master/Slave SPI Serial Interface
- **Sleep Modes**
  - Idle
  - ADC Noise Reduction
  - Power-save
  - Power-down
  - Standby
  - Extended Standby

- **Power**
  - USB Connection
  - External AC/DC Adapter
- **I/O**
  - 54 Digital
  - 16 Analog
  - 15 PWM Output

1 The Board

Arduino® Mega 2560 is a successor board of Arduino Mega, it is dedicated to applications and projects that require large number of input output pins and the use cases which need high processing power. The Arduino® Mega 2560 comes with a much larger set of IOs when we compare it with traditional Uno board considering the form factor of both the boards.

1.1 Application Examples

- **Robotics**: Featuring the high processing capacitity, the Arduino Mega 2560 can handle the extensive robotic applications. It is compatible with the motor controller shield that enables it to control multiple motors at an instance, thus making it perfect of robotic applications. The large number of I/O pins can accommodate many robotic sensors as well.
- **3D Printing**: Algorithms play a significant role in implementation of 3D printers. Arduino Mega 2560 has the power to process these complex algorithms required for 3D printing. Additionally, the slight changes to the code is easily possible with the Arduino IDE and thus 3D printing programs can be customized according to user requirements.
- **Wi-Fi**: Integrating wireless functionality enhances the utility of the applications. Arduino Mega 2560 is compatible with WiFi shields hence allowing the wireless features for the applications in 3D printing and Robotics.

1.2 Accessories

1.3 Related Products

- Arduino® Uno Rev 3
- Arduino® Nano
- Arduino® DUE without headers

,

2 Ratings

2.1 Recommended Operating Conditions

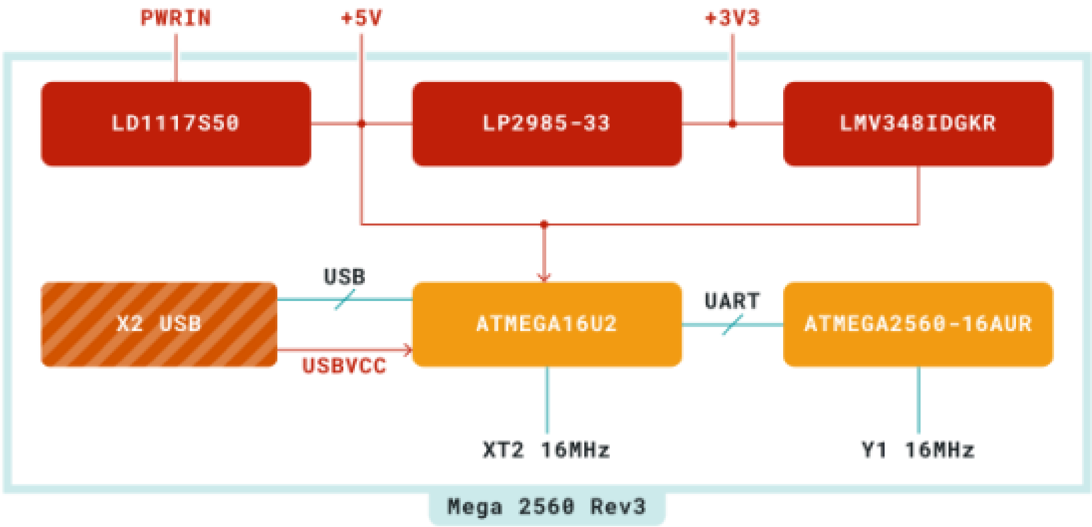
Symbol	Description	Min	Max
TOP	Operating temperature:	-40 °C	85 °C

2.2 Power Consumption

Symbol	Description	Min	Typ	Max	Unit
PWRIN	Input supply from power jack		TBC		mW
USB VCC	Input supply from USB		TBC		mW
VIN	Input from VIN pad		TBC		mW

3 Functional Overview

3.1 Block Diagram



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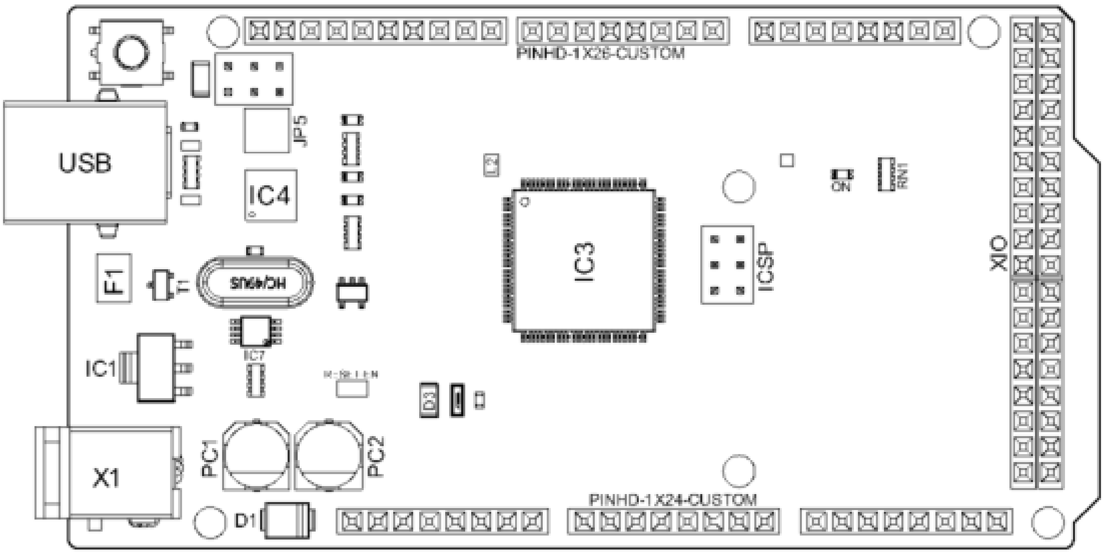


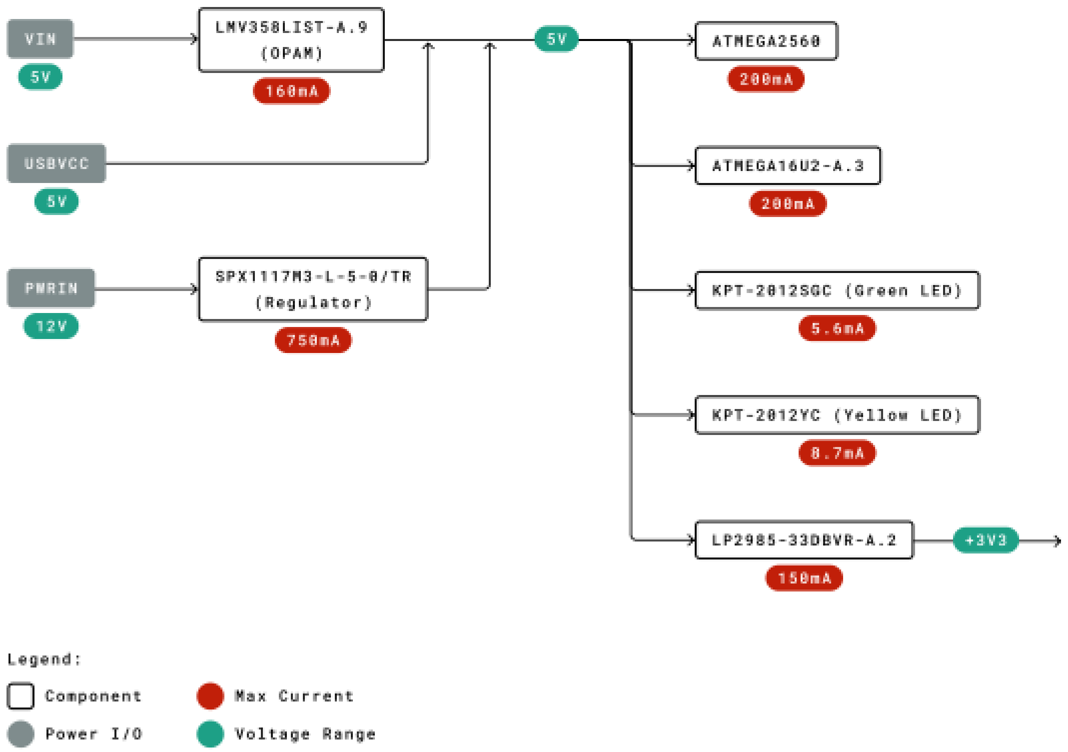
Arduino MEGA Top View

Ref.	Description	Ref.	Description
USB	USB B Connector	F1	Chip Capacitor
IC1	5V Linear Regulator	X1	Power Jack Connector
JP5	Plated Holes	IC4	ATmega16U2 chip
PC1	Electrolytic Alumninum Capacitor	PC2	Electrolytic Alumninum Capacitor
D1	General Purpose Rectifier	D3	General Purpose Diode
L2	Fixed Inductor	IC3	ATmega2560 chip
ICSP	Connector Header	ON	Green LED
RN1	Resistor Array	XIO	Connector

3.3 Processor

Primary processor of Arduino Mega 2560 Rev3 board is ATmega2560 chip which operates at a frequency of 16 MHz. It accommodates a large number of input and output lines which gives the provision of interfacing many external devices. At the same time the operations and processing is not slowed due to its significantly larger RAM than the other processors. The board also features a USB serial processor ATmega16U2 which acts an interface between the USB input signals and the main processor. This increases the flexibility of interfacing and connecting peripherals to the Arduino Mega 2560 Rev 3 board.

3.4 Power Tree



4 Board Operation

4.1 Getting Started - IDE

If you want to program your Arduino® MEGA 2560 while offline you need to install the Arduino® Desktop IDE **[1]** To connect the Arduino® MEGA 2560 to your computer, you'll need a Type-B USB cable. This also provides power to the board, as indicated by the LED.

4.2 Getting Started - Arduino Web Editor

All Arduino® boards, including this one, work out-of-the-box on the Arduino® Web Editor **[2]**, by just installing a simple plugin.

The Arduino® Web Editor is hosted online, therefore it will always be up-to-date with the latest features and support for all boards. Follow **[3]** to start coding on the browser and upload your sketches onto your board.

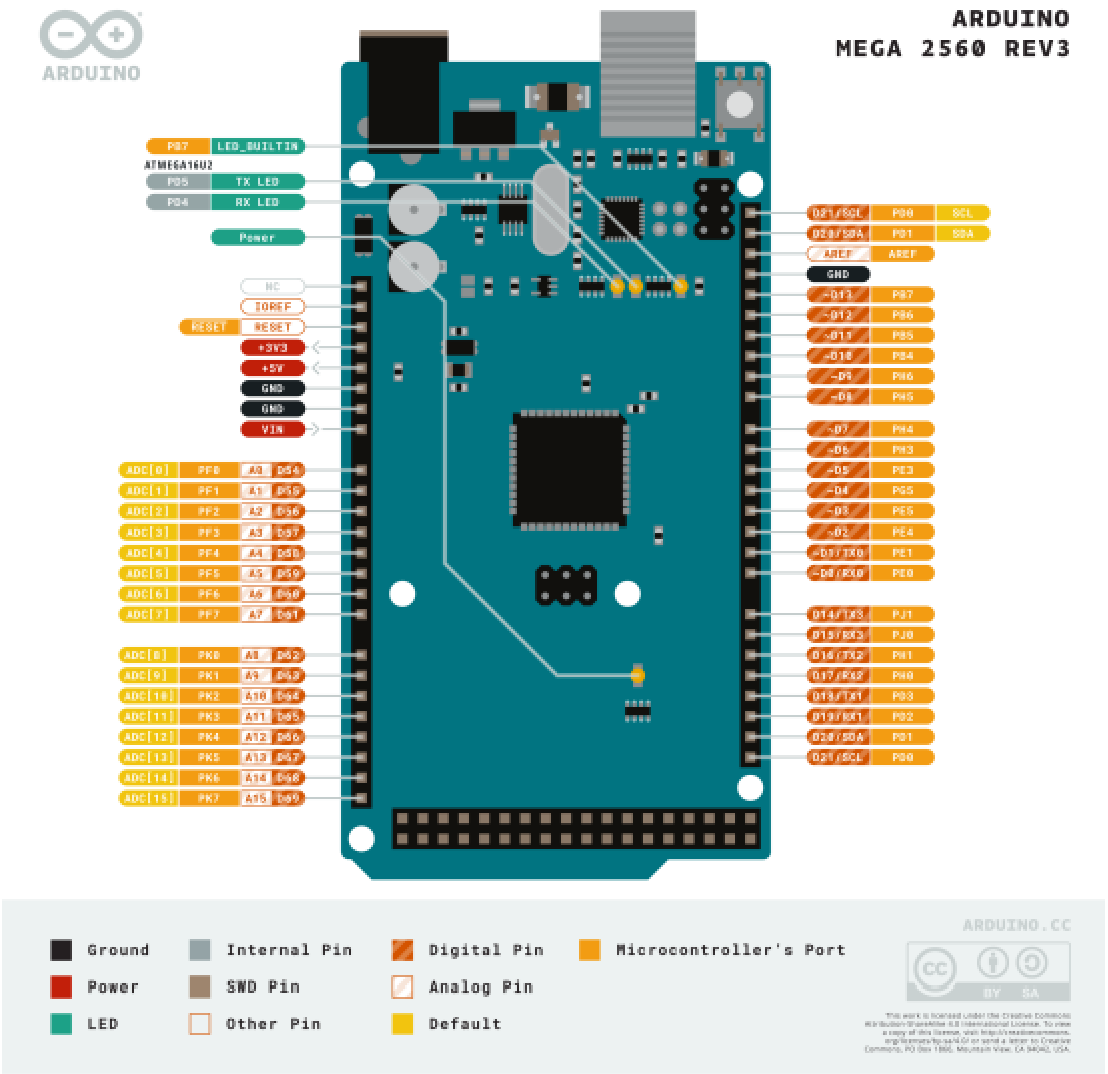
4.3 Sample Sketches

Sample sketches for the Arduino® MEGA 2560 can be found either in the "Examples" menu in the Arduino® IDE

4.4 Online Resources

Now that you have gone through the basics of what you can do with the board you can explore the endless possibilities it provides by checking exciting projects on ProjectHub **[5]**, the Arduino® Library Reference **[6]** and the online store **[7]** where you will be able to complement your board with sensors, actuators and more.

5 Connector Pinouts


ARDUINO
ARDUINO
MEGA 2560 REV3
LED_BUILTIN
TX LED
RX LED
Power
IOREF
RESET
+3V3
+5V
GND
GND
VIN
AREF
GND
Ground
Internal Pin
Digital Pin
Microcontroller's Port
Power
SWD Pin
Analog Pin
LED
Other Pin
Default
ARDUINO.CC

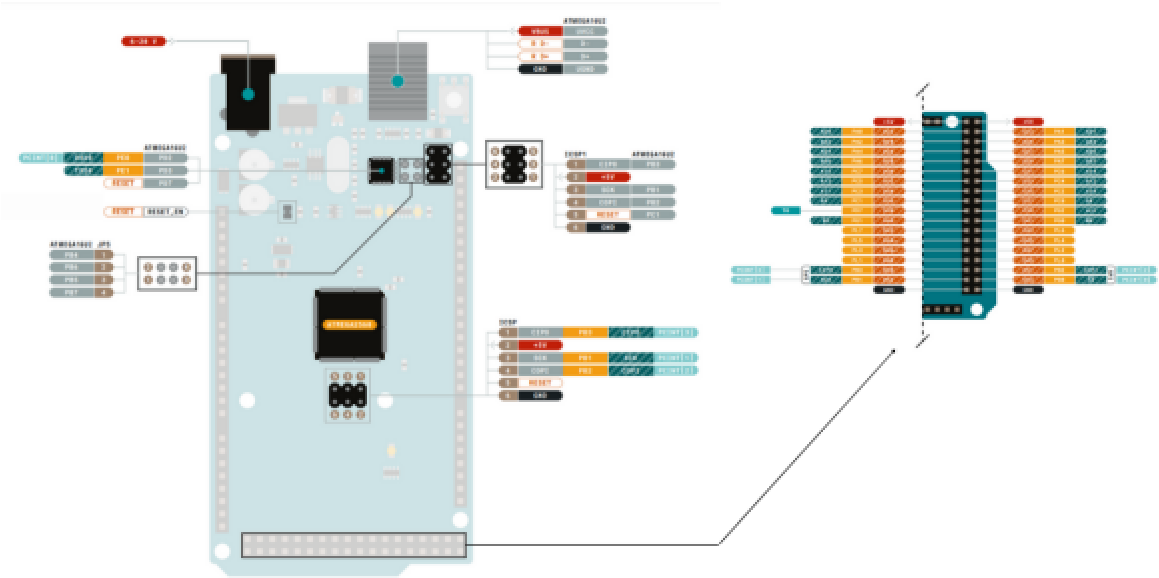
5.1 Analog

Pin	Function	Type	Description
1	NC	NC	Not Connected
2	IOREF	IOREF	Reference for digital logic V - connected to 5V
3	Reset	Reset	Reset
4	+3V3	Power	+3V3 Power Rail
5	+5V	Power	+5V Power Rail
6	GND	Power	Ground
7	GND	Power	Ground
8	VIN	Power	Voltage Input
9	A0	Analog	Analog input 0 /GPIO
10	A1	Analog	Analog input 1 /GPIO
11	A2	Analog	Analog input 2 /GPIO
12	A3	Analog	Analog input 3 /GPIO
13	A4	Analog	Analog input 4 /GPIO
14	A5	Analog	Analog input 5 /GPIO
15	A6	Analog	Analog input 6 /GPIO
16	A7	Analog	Analog input 7 /GPIO
17	A8	Analog	Analog input 8 /GPIO
18	A9	Analog	Analog input 9 /GPIO
19	A10	Analog	Analog input 10 /GPIO
20	A11	Analog	Analog input 11 /GPIO
21	A12	Analog	Analog input 12 /GPIO
22	A13	Analog	Analog input 13 /GPIO
23	A14	Analog	Analog input 14 /GPIO
24	A15	Analog	Analog input 15 /GPIO

5.2 Digital

Pin	Function	Type	Description
1	D21/SCL	Digital Input/I2C	Digital input 21/I2C Dataline
2	D20/SDA	Digital Input/I2C	Digital input 20/I2C Dataline
3	AREF	Digital	Analog Reference Voltage
4	GND	Power	Ground
5	D13	Digital/GPIO	Digital input 13/GPIO
6	D12	Digital/GPIO	Digital input 12/GPIO
7	D11	Digital/GPIO	Digital input 11/GPIO
8	D10	Digital/GPIO	Digital input 10/GPIO
9	D9	Digital/GPIO	Digital input 9/GPIO
10	D8	Digital/GPIO	Digital input 8/GPIO
11	D7	Digital/GPIO	Digital input 7/GPIO
12	D6	Digital/GPIO	Digital input 6/GPIO
13	D5	Digital/GPIO	Digital input 5/GPIO
14	D4	Digital/GPIO	Digital input 4/GPIO

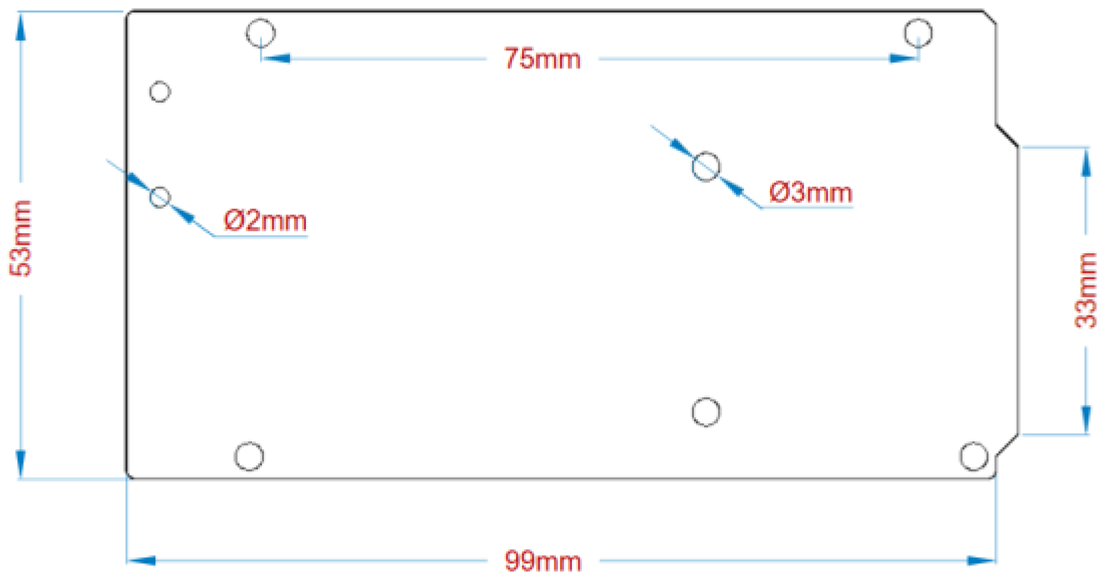
Pin	Function	Type	Description
15	D3	Digital/GPIO	Digital input 3/GPIO
16	D2	Digital/GPIO	Digital input 2/GPIO
17	D1/TX0	Digital/GPIO	Digital input 1 /GPIO
18	D0/Tx1	Digital/GPIO	Digital input 0 /GPIO
19	D14	Digital/GPIO	Digital input 14 /GPIO
20	D15	Digital/GPIO	Digital input 15 /GPIO
21	D16	Digital/GPIO	Digital input 16 /GPIO
22	D17	Digital/GPIO	Digital input 17 /GPIO
23	D18	Digital/GPIO	Digital input 18 /GPIO
24	D19	Digital/GPIO	Digital input 19 /GPIO
25	D20	Digital/GPIO	Digital input 20 /GPIO
26	D21	Digital/GPIO	Digital input 21 /GPIO



Arduino Mega Pinout

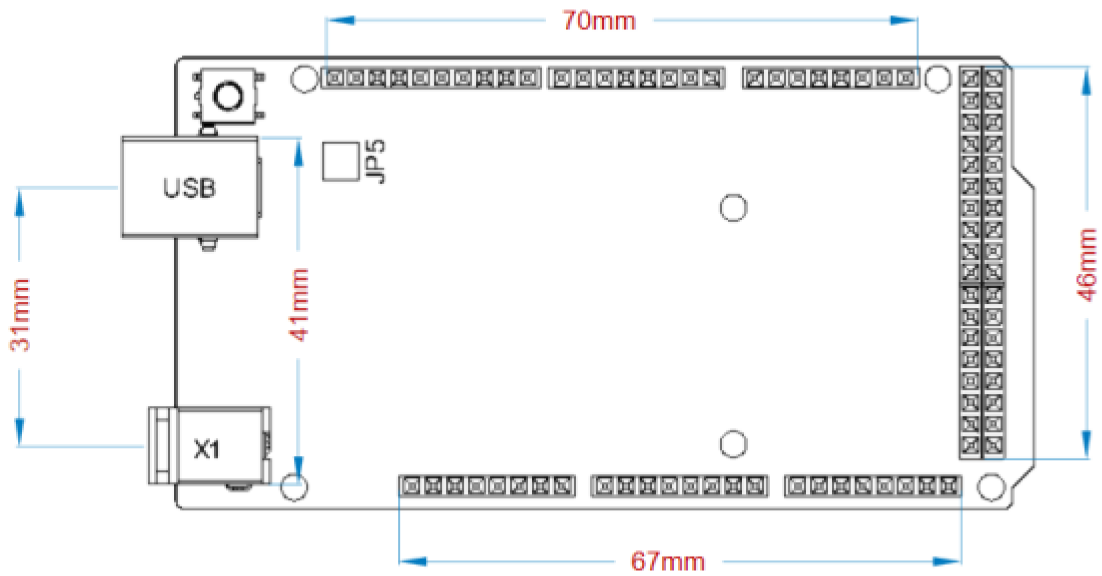
6 Mechanical Information

6.1 Board Outline



Arduino Mega Outline

6.2 Board Mount Holes



Arduino Mega Mount Holes

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8 Declaration of Conformity to EU RoHS & REACH 211 01/19/2021

Arduino boards are in compliance with RoHS 2 Directive 2011/65/EU of the European Parliament and RoHS 3 Directive 2015/863/EU of the Council of 4 June 2015 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

Substance	Maximum Limit (ppm)
Lead (Pb)	1000
Cadmium (Cd)	100
Mercury (Hg)	1000
Hexavalent Chromium (Cr6+)	1000
Poly Brominated Biphenyls (PBB)	1000
Poly Brominated Diphenyl ethers (PBDE)	1000
Bis(2-Ethylhexyl} phthalate (DEHP)	1000
Benzyl butyl phthalate (BBP)	1000
Dibutyl phthalate (DBP)	1000
Diisobutyl phthalate (DIBP)	1000

Exemptions : No exemptions are claimed.

Arduino Boards are fully compliant with the related requirements of European Union Regulation (EC) 1907 /2006 concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH). We declare none of the SVHCs (https://echa.europa.eu/web/guest/candidate-list-table), the Candidate List of Substances of Very High Concern for authorization currently released by ECHA, is present in all products (and also package) in quantities totaling in a concentration equal or above 0.1%. To the best of our knowledge, we also declare that our products do not contain any of the substances listed on the "Authorization List" (Annex XIV of the REACH regulations) and Substances of Very High Concern (SVHC) in any significant amounts as specified by the Annex XVII of Candidate list published by ECHA (European Chemical Agency) 1907 /2006/EC.

9 Conflict Minerals Declaration

As a global supplier of electronic and electrical components, Arduino is aware of our obligations with regards to laws and regulations regarding Conflict Minerals, specifically the Dodd-Frank Wall Street Reform and Consumer Protection Act, Section 1502. Arduino does not directly source or process conflict minerals such as Tin, Tantalum, Tungsten, or Gold. Conflict minerals are contained in our products in the form of solder, or as a component in metal alloys. As part of our reasonable due diligence Arduino has contacted component suppliers within our supply chain to verify their continued compliance with the regulations. Based on the information received thus far we declare that our products contain Conflict Minerals sourced from conflict-free areas.

10 FCC Caution

Any Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions:

(1) This device may not cause harmful interference

(2) this device must accept any interference received, including interference that may cause undesired operation.

FCC RF Radiation Exposure Statement:

1. This Transmitter must not be co-located or operating in conjunction with any other antenna or transmitter.
2. This equipment complies with RF radiation exposure limits set forth for an uncontrolled environment.
3. This equipment should be installed and operated with minimum distance 20cm between the radiator & your body.