The Capstone Team Project

MECT 411

Name of Project: AUTOMATED GUIDED VEHICLE

Group Name: WHIZKID

Group Members:

17700943 Shayan Falahatdoost

16700755 Abdallah Ziad Salh Abu Alhaj

17700866 Osinachi Mbah

17700216 Omer Jamal Ghauri

17701323 Aderinsola Daniel Sontan

Supervisor: Assist. Prof. Dr. Babak Safaei

Semester: Spring 2020/2021.

Submission Date: May 31, 2021.

Eastern Mediterranean University

Department of Mechanical Engineering

ABSTRACT

In recent times, one of the most common problems is related to public health. The year 2020 was a year the world was ravaged by the Covid-19 Pandemic. Ever since it began, the behaviours and relations of humans have been affected and scientists, doctors and engineers started a never-ceasing fight against this virus. The aim of this project was to contribute to the fight against Covid-19. AGVs are used in a wide range of applications such as warehouses, Houses, factories even public facilities for material handling purposes. Incorporating a UV-C lamp on an AGV redefines its definition to killing virus and bacteria. UV-C has the highest energy. UV light from the sun is mostly absorbed in the Earth's ozone. UV-C light kills virus and bacteria through damaging molecules like nucleic acids and proteins68.This incapacitates it from performing the processes that it needs to survive. This report was about designing and controlling a sanitization AGV to be used in offices, walkways and hospitals. From the first chapter, the concept and history of AGV were introduced together with the types. Then ultraviolet light and its types were explained. In the design, our robot has two layers: the base layer that contains all the electronic components and the upper layer where the lamp is placed. The chassis is an aluminium frame of sigma cross-section. The base and upper layer is aluminium PVDF composite. PIR sensor was used to turn off the UV-C light when it detects the motion of humans (due to the harmful effect of UV-C light). The UVC can kill 99.999% virus and bacteria.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

AGV: Automated Guided Vehicle

BMS: Battery Management System

DC motor: Direct Current motor

DFA: Design for Assembly

DFE: Design for Environment

DNA: Deoxyribonucleic acid

FMS: Flexible Manufacturing System

IR sensor: Infrared sensor

IDE: Integrated Development Environment

MHS: Material Handling System

PVDF: Polyvinylidene fluoride

SOC: State of Charge

UVC: Ultraviolet-C

CHAPTER 1 - INTRODUCTION

AGVs (Automated guided vehicle) are programmable computer-remote-controlled driverless mobile vehicle which may be equipped with a robotic arm that operates automatically along pathways with fluorescent stripes, in-floor wiring, optical scanning of various markings or other navigation solutions mainly used to transport materials in industries.

Automated guided vehicles are used for tasks that would normally be performed by forklifts, conveyor systems, or manual carts capable of repetitively transferring large quantities of material. They are also redefined for killing viruses and bacteria with UVC lamps, spraying insecticides and pesticides in farms, and for pick and place purposes with a robotic arm attached to it. Figure 1 shows a general block diagram of an Automated Guided Vehicle.

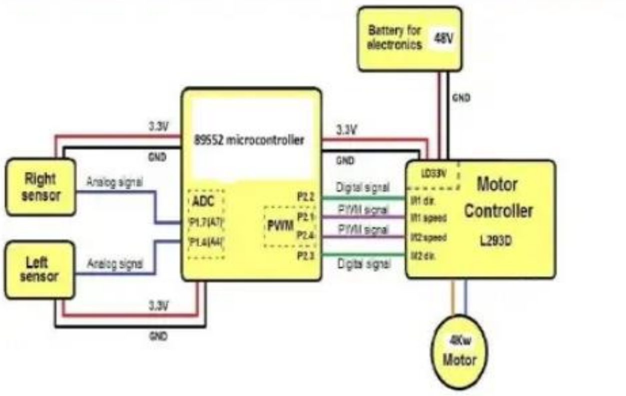


Figure 1: A general block diagram of an Automated Guided Vehicle

Ultraviolet or "UV" light is part of the electromagnetic spectrum, which includes microwaves, visible light, and infrared radiation. The wavelength of radiation consists of an electric and magnetic field, with energy moving between them back and forth. All radiation vibrates at a particular frequency and moves at the speed of light. Of the three types of UV light, UV-C light is the most effective in killing bacteria. UV-C utilizes short-wavelength ultraviolet radiation that is harmful to microorganisms as fungi, bacteria, and viruses. When exposed to UV light, the genetic material in cells is damaged as chemical bonds are severed within the DNA structure. Prolonged exposure to UV light inflicts more damage to the point where the DNA cannot be repaired and cells die as a result. UV-C sanitation is universally applicable to almost any environment (home, offices, and hospitals). An example of a UV-C lamp is shown in Figure 2.

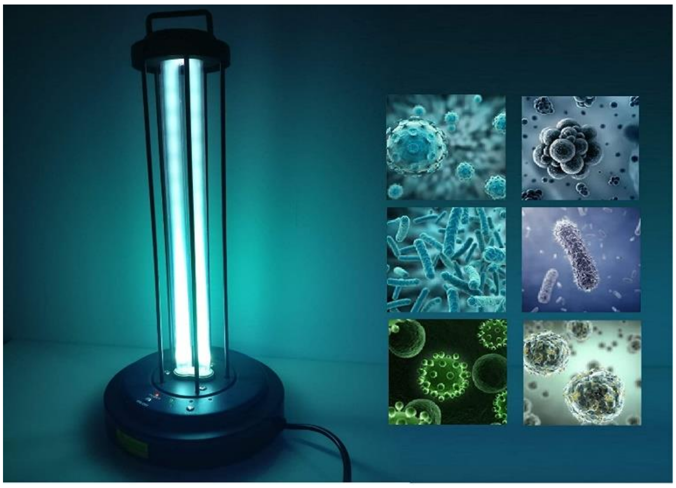


Figure 2: UV-C lamp

1.1. Detailed definition of the project

Our goal is to build an AGV that is light weight to disinfect surrounding using UV-C light and to ensure that the robot is safe to use around people. To achieve this purpose, we will use aluminium profile for the chassis because it is known for its light-weight properties. By using computer analysis on the chassis we will be able to know and calculate the correct diminutions we need to get a stable robust chassis. Also, we will design the electronic circuit, assembly the components and program it using Arduino IDE.

1.2. Significance of the project

Nicolai (2017), states that flat surfaces, such as countertops, are a perfect middleman for growing bacteria to be transferred to items like your cell phone which we use every day [12]. In addition to the harmful germs, most of the sprays and disinfectants used nowadays may pose a danger for children and pets as well. Some of these cleaners have been found to cause illnesses such as cancer, asthma, and reproductive disorders. With the current outbreak of COVID-19, there is going to be a higher need for new disinfection technologies. Without a reliable source that repeatedly disinfects areas, outbreaks such as COVID-19 will be a continuous issue. While sanitizing sprays and powders are the most commonly used cleaners, they're not the only source of cleaning available.

One of the main benefits of the UV-C sanitization AGV lies in its sustainability which is the ability to be maintained at a certain rate or level. Another major benefit to having the UV-C sanitization AGV is the luxury of a one-time cost to the customer unlike medical/chemical sanitizing products like sprays and powders. Once you buy the sanitizing robot, the only money needed to be put into the item after that would be simple repairs, battery replacement, or in our case, the electricity needed to charge the batteries. However, the monthly cost of cleaning supplies for the average household can be cut dramatically by using UV-C sanitation when applicable. Our budget estimates that the robot sanitizer will cost less than half the annual cost of cleaning supplies, and it's only a one-time purchase. Moreover, the UV-C sanitization AGV will replace the need to buy many UV-C lamps in rooms, hospitals, and factories since it will achieve the same objective of inactivating micro-organisms by being mobile and using only the UV-C lamp on it. Additionally, since the UV-C sanitization robot is all-electric, it is very environmentally friendly as there will be no CO2 emissions.

A key difference compared to other sanitization robots will be the use of less mechanical parts as all the moving parts normally found in a normal sanitization robot will be replaced by UV-C lamps which means it will be lighter and cheaper.

1.3. Detailed project objectives

The goal of this study is to develop and test a novel framework and new AGV algorithms to perform automatic disinfection in indoor environments in order to minimize pathogen transmission and exposure, thereby potentially preventing infectious disease outbreaks. The contribution of this study is focused on the geometries of areas of possible contamination and surrounding contexts to control an AGV to move to areas requiring disinfection, and generate trajectories. The adaptive motion will ensure disinfection quality and safety. The required material movement in a manufacturing floor shall be controlled and driven by Arduino.

There are a variety of things that need to be taken into account in order to provide adequate automation. The components of automation can be different depending on the product and location, but there are certain elements that must also be considered, such as the field of automation, navigation, scale or size of the place to be automated, and the degree of versatility that is needed.

The model proposed relies on the framework of close path steering system where a line is embedded on the ground and a sensor set at the bottom of the AGV detect the line in the near path steering system and direct the AGV in following the line and incorporates a special movement for AGVs and the framework steering model. It has the key benefit of traditional close-path approach but less drawbacks in employing the steering system with unique hardware and software architecture for technological decision taking processes and heuristic algorithms.

1.3.1. Design for cost

Cost optimization is the deliberate use of engineering processing technologies to cut down on production costs. This is achieved using reasonable low-cost products and manufacturing processes furthermore, the production technique was low cost, such as using mechanical fasteners methods, rather than high cost welding processes.

1.3.2. Design for safety

The design of the Automated Guided Vehicle involves UV-C light. For example, the PIR sensor is used to switch of the lamp whenever it senses movement of people around because of the negative effect of UV-C light on humans.

1.3.3. Design for assembly

Design for assembly (DFA) is a tool used to calculate the ease with which to assemble a component. DFA is also a tool which helps in product design. To accomplish the DFA goal, the following instructions are followed:

- Minimize the total count of the components.
- Reduce the use of welded joints to simplify maintenance.
- Avoid unstable positioning of machine components during assembly.
- Design all end-to-end symmetry components.

1.3.4. Design for performance

The Design of the Automated Guided Vehicle incorporates a few features that increase the performance. For example, using lithium ion battery, we can divide up the power distribution in a smart way in supplying power to the Arduino, Motors and UV-C lamp.

1.3.5. Design for the environment

Design for the environment (DFE) is an environmentally conscious design. The selected design of the automated guided vehicle itself included factors that addressed environmental design issues. For example, using aluminium PVDF composite which can be recycled.

1.4. Detailed project constraints

It is quite a tasking endeavour to build an AGV device that can move to the areas needing disinfection, and generate trajectories based on the geometries of areas of potential contamination and surrounding contexts. Many commercial AGVs are worked with electric power and powered by the use of electric motors, but not integrated with the UV-C lamp. The electric motor is attached to a mixture of suitable gears within the motor that are then linked to the AGV wheels. Through this process, the AGV will be able to move or navigate correctly along the path as needed to be disinfected with the aid of the necessary control system order for the AGV. On the basis of these considerations, the relationship between total loads that the AGV can withstand with the electrical power supplied to the system is very significant. However, both the configuration of the control system and the use of the sensor also play an important role in these AGVs. In addition, the selection of the right material used to build the

AGV frame is also quite crucial because it must be able to bear the weight of itself, UV-C lamp and navigate correctly. Based on that, these are the possible constraints:

- Economic: The design should be more or equally economical than other similar commercial design.
- Availability of the aluminium frame and DC motor is a constraint.
- Manufacturability: The product should be manufactured in the university mechanical engineering department workshop.
- Sustainability: The design should be robust and sustainable.
- Ethical: The design should be original, and the references should be cited in the design report.

1.4.1. Constraints and limitation of Sanitization AGV

Restrictive environment requirements: AGV sanitization calls for highly unique work environments. Unfavourable environmental conditions, compared to manual vehicles, may restrict or block the performance of the AGV. The floor, ambient light and dust are some of the principal environmental constraints. The floors must not be too rough, and it is important to consider any transition from one surface, height, etc. to another. Joints for building or expansion should be removed or decreased. Floors need to be as smooth as possible. Protection and navigation sensors may also be obscured by light or dust from the area.

High Initial Capital Cost: One of the key advantages of the AGV Sanitization System is that it improves overall efficiency and productivity, contributing to economic benefits.

The issue is that it is more costly, in the short term, to purchase an AGV device than to hire workers. Although automation is intended to replace non-value-added costs, AGVs are becoming increasingly interesting as the number of working hours increase.

Limited flexibility compared to manned vehicles. Compared to manual processes, this is one of the key drawbacks of the Sanitization AGV System. A human operator will respond in a second and change his task. He can go from a given place faster, slower, disinfect location, then go to another one (even if he's never gone before), he doesn't have to respect tight tolerances to disinfect location.

Not Suitable for Non-repetitive Tasks: In sanitization operations that deal with repetitive activities, the Sanitization AGV Method makes the most sense, because that is what they are programmed to do. If the activities in your operations appear not to be repetitive, then personnel operating other equipment will possibly do them more easily and effectively.

Multiple cycles – By line of sight, UV rays disinfect, meaning any area that UV energy does not reach will not be disinfected. UV also does not penetrate furniture or other objects. To ensure that all areas are disinfected, several cycles in a room will probably need to be performed. It is also important in this step to find the right dosage.

1.5. Report Organization

The first chapter introduces the concept of AGV and its significance.

The second chapter will discuss the past and context of AGVs and the recent developments in some aspects

Chapter three displays the configuration of the hardware and all of the AGV components. This should evaluate all potential steps and implement some of the device architecture that deals with hardware components and the kinematics, steering and simulation of AGV.

Chapter four describes the manufacturing process and material selection.

The fifth chapter will discuss the process of testing and will also provide the AGV with the best modifications and criteria to achieve the objectives under its particular conditions.

Ultimately all equipment is expected to be compatible with the planned AGV model design.

CHAPTER 2 - LITERATURE REVIEW

2.1. Background Information

2.1.1. AGV

In modern times, there is a growing need of automation in material handling processes in all segments. AGV is an important vehicle that can reduce the work load on humans in material handling processes. It is a robot that is built to follows markers or wires on the floor or uses magnets, vision or lasers to navigate itself without human intervention. It mostly used in industries to move materials around a factory or warehouse, but it can be used in the medical field to move pharmaceuticals, meal trays, medical/surgical tools to where they are needed. In the educational field, most especially in the library to move books to where they are needed. The origin of AGVs dates back to mid twentieth century when Arthur "Mac" Barrett, in 1953, converted a towing tractor to become automated by modifying it to follow an overhead wire as shown in Figure 3 **Error! Reference source not found.**. This towing tractor automatically followed a wire that was embedded in the floor. It was called "Guide-O-Matic" driverless vehicle **Error! Reference source not found.**.

Figure 3: The first AGV, "Guide-O-Matic" driverless vehicle.

Up until 1973 when Volvo developed a new assembly line that used 280 computer controlled AGVs which was more efficient than conveyor assembly line, AGVs had become popular in with factories in late 50's and early 60's. In 1975, the first unit load AGV was innovated and from that time, laser and magnetic tape guidance mechanism have been introduced. Now there are safer and easier Automated Guide Vehicles.

2.1.2. UV light

Present global affairs have given rise plenty of discussion on ultraviolet light sterilization as an important means to sterilize homes, businesses, institutions, including hospitals.

Ultraviolet (UV) light has been proven to be effective in removing the risk from many well-known viruses, dating back to 1877, when the first experimental analysis concluded that ultraviolet light has strong sterilization properties. Further experiments at the beginning of the 20th century indicated that ultraviolet light could inhibit the spread of diseases, both on the surface and in the air, but it would take several more decades for research and medicine to exploit the influence of UV radiation. With the rise in tuberculosis in the 1980s, Ultraviolet light was once again taken to the mainstream of medicine and used to fight the spread of this extremely infectious and lethal infection. In many widespread germicide uses, ultraviolet lamps are also being used to remove dangerous bacteria in air, water and surfaces.

Most electromagnetic waves are measured in meters, but certain wavelengths (like UV) are so short that they are measured in nanometres (nm). Ultraviolet (UV) light as shown in Figure 4, is electromagnetic radiation with a wavelength that is shorter than visible light and longer than x-ray produced at 100 to 400 nanometres (nm).

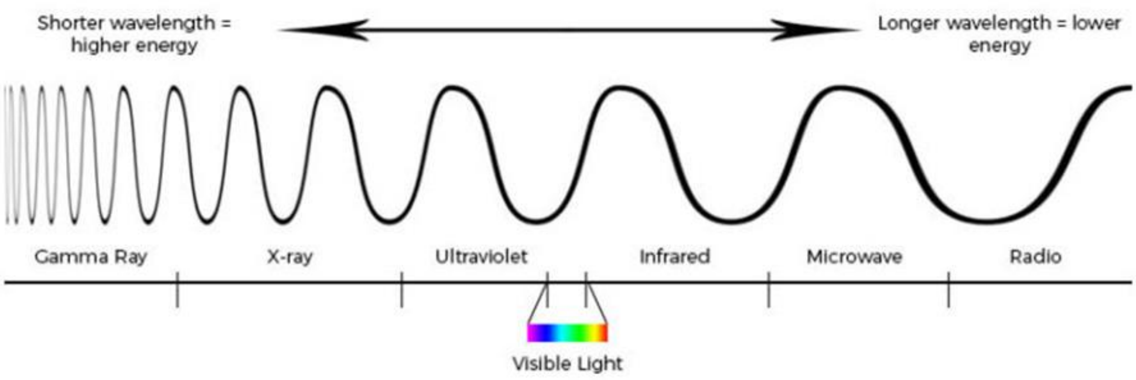


Figure 4: Electromagnetic wave spectrum

Unlike chemical disinfection methods (such as chlorine), UV offers rapid, efficient inactivation of microorganisms via a physical method. When talking about disinfection in terms of microorganisms, this means a loss of at least 3 logs (or 99.9 per cent). When bacteria, viruses and protozoa are exposed to UV radiation, UV radiation damages the genetic material (DNA) within as shown in Figure 5, eliminating their ability to reproduce and cause infection. Unable to propagate, microorganisms are "inactivated" and no longer pose a risk to health.

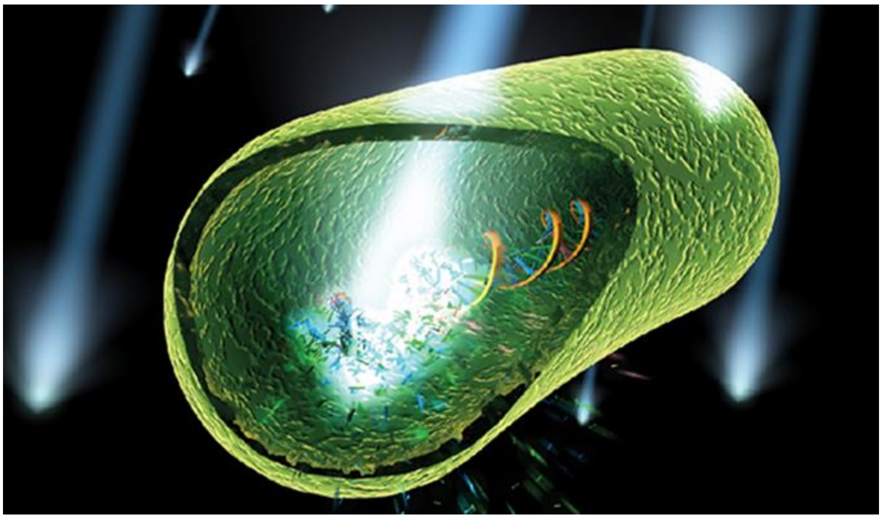


Figure 5: Damaged microorganism due to UV radiation

2.2. Concurrent Solutions.

2.2.1. Different Types of AGVs

There are different types of AGVs in industries used for material handling processes. The choice of AGVs in industries depends on the nature of the material processes industries carry out.

- Unit Load AGVs.

They are used to carry pallets or tote that contain different items in it. In most cases, they are used in place of humans to move loads that contain delicate items as shown in Figure 6.

Figure 6: Unit Load AGV Error! Reference source not found.**.**

- Forklift AGVs

There is no difference in forklift AGVs and the normal forklift, only that this is autonomous. It follows precise navigation paths and lifts and drops load without human intervention as shown in Figure 7.

Figure 7: Forklift AGV Error! Reference source not found..

- Towing AGVs.

These AGVs are used in applications that require moving heavy loads or carts from one point to another as shown in Figure 8. Such heavy loads may be wagon wheel style trailers, maintenance carts or they can be on steer carts or dollies. They have various drop-off and pick-up stops in the warehouse. They can also be used in the farm to pull non-powered trucks and ploughs.

Figure 8: Towing AGV Error! Reference source not found..

2.2.2. Types of navigation system.

The navigation of AGVs are guided through the different means below.

- Magnetic Tape: This tapes are glued to the ground as paths. AGV has to have a magnetic sensor to be able to navigate this paths.

- Wire Navigation: Wires that transmit signals are embedded on the ground and AGV detects this wire by a sensor or antenna.
- Laser Target Navigation: These AGVs have pole on it where the laser sensor is placed. There are laser targets placed on the wall, poles or fixed machines the environment where the AGV is to be used. The sensor sends rays that rotate in a 360^o pattern and reflect off the laser targets. This reflected rays are used to calculate the position of the target from the AGV.
- Infrared sensor navigation: Infrared sensors are placed on AGVs to navigate it through a black tape path.

2.2.3. Different Types of UV lights

UV radiation is classified into three groups based on the wavelength: UVA, UVB and UV-C. The shorter the wavelength, the more energetic the radiation, and the more dangerous it can be.

The UV spectrum shown in Figure 9 is divided into:

- UVA 315 to 400 nm.
- UVB 280 to 315 nm.
- UV-C 200 to 280 nm.
- Vacuum UV 100 to 200 nm.

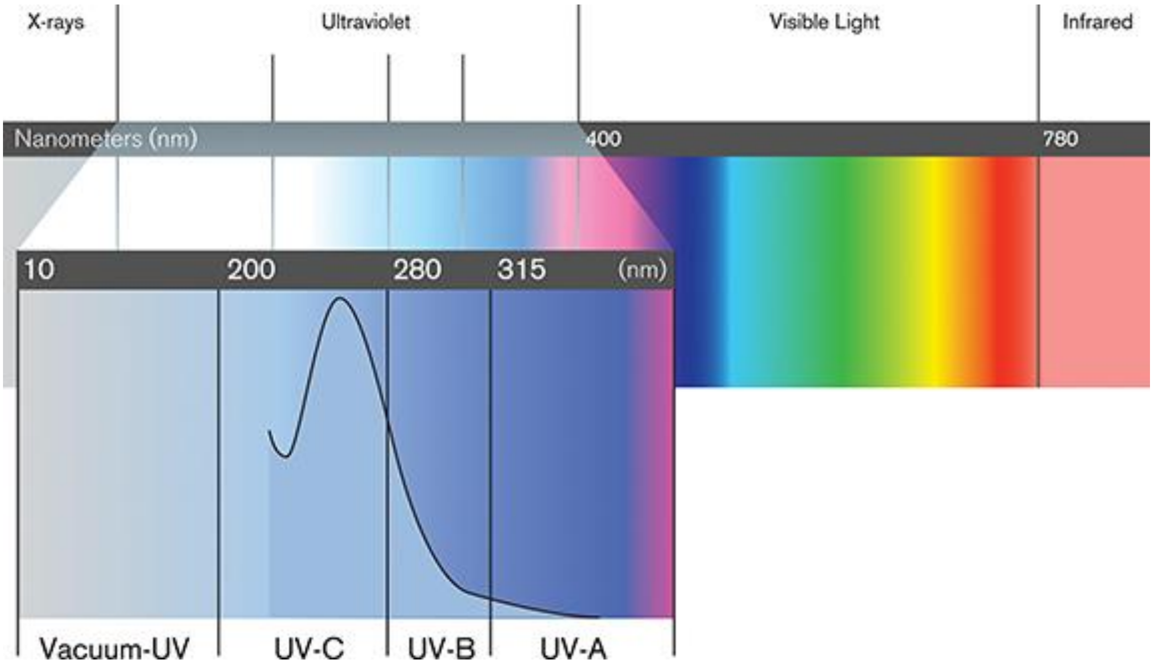


Figure 9: UV light spectrum

UV radiation emitted primarily at 253.7 nm effectively inactivates microorganisms and is referred to as ultraviolet germicidal irradiation (UVGI). UVGI interrupts the propagation of microbial microorganisms, including bacteria, viruses, moulds and even bioterrorism agents. Hence the reason for choosing UV-C lamp.

2.3. Comparison of the concurrent solutions

Based on the concurrent solutions mentioned above, comparison is made to choose the one most suitable for our project. Our robot is sanitization AGV, also disinfection robot, which moves the ultraviolet lamp fixed on it around with the purpose of disinfecting the environment, killing bacteria and virus. Unit Load AGVs carry a defined maximum load size, but it has been used in recent times for valued added purposes. Most manufacturers now make unit load AGVs with a robotic arm attached to it to ease loading and unloading of loads placed on it. Also, there are AGVs for library used. They are manufactured to suit the library in moving books around and even placing books in shelf. Unit load AGVs are manufactured for other purposes like sanitization in Figure 10, monitoring, assisting the handicapped, and also in restaurants for serving customers as shown in Figure 11.

Figure 10: Sanitization AGV

Figure 11: Food Delivery AGV

Forklift AGV is automated, which means it does not need human control, but that does not mean it's not monitored. It is precise and accurate in keeping and lifting stacked loads. Towing AGV is more useful in moving a much heavier load, especially in factories that need to move lots of materials at a time. For the navigation system of AGVs, wire navigation requires more power and there it's not efficient in terms of power consumption. Magnetic tape is more efficient in the case where the AGV need to follow a defined path. The only issue is that the magnetic tape has to be placed on the floor which exposes it to external factors and it affects the navigation of the AGV after some time. Also it expensive. Laser target navigation don't need to follow a defined path. It makes calculations and decisions based on the information it receives from the feedback ray from the laser target. Infrared sensor navigation is cheaper compared to other navigation systems. It requires an IR sensor connected to an Arduino and a black tape path which the sensor follows while the AGV navigates. The infrared sensor navigation will be used in this project. Also, our AGV will be unit load but value added (for sanitization purpose).

2.4. Engineering standards of the concurrent solutions

We took some standards into consideration before deciding on the materials and components to use.

- EN 1525:1997. Safety of Industrial Trucks. Driverless Trucks and their Systems. CEN, Brussels **Error! Reference source not found.Error! Reference source not found.**.
- EN ISO 12100:2010 Safety of Machinery. General Principles for Design. Risk Assessment and Risk Reduction. International Organization for Standardization, Geneva.
- ISO 10218-1: 2011: Robots and Robotics Devices -- Safety Requirements for Industrial Robots -- Part 1: Robots. International Organization for Standardization, Geneva.

- ISO 13482:2014: Robots and Robotic Devices --Safety Requirements for Personal Care Robots. International Organization for Standardization, Geneva.
- ISO/DIS 18497: Agricultural Machinery and Tractors -- Safety of Highly Automated Machinery. International Organization for Standardization, Geneva.
- ISO 13849-1:2015: Safety of machinery --Safety-related parts of control systems -- Part 1: General principles for design. International Organization for Standardization, Geneva.
- ANSI/ITSDF B56.5-2012 Safety Standard for Driverless, Automatic Guided Industrial Vehicles and Automated Function of Manned Industrial Vehicles. Industrial Truck Standards Development Foundation, Washington DC **Error! Reference source not found.**.

CHAPTER 3 - DESIGN AND ANALYSIS

3.1. Proposed/Selected Design

The procedure of designing an AGV is a complicated process. Figure 12 Shows the Automated Guided Vehicle configuration. The Design of each part (assembly) will be illustrated in the following sections.

Figure 12: Labelled parts of AGV.

3.1.1. Battery Pack

Life expectancy and reliability are two main elements which will be available 24/7 for robots and AGVs.

A Battery pack is any number of individual batteries which are arranged in series or parallel to provide electronic devices with the necessary power and appropriate Battery Management System.

As shown in figure 13, we used 12V lead acid battery. This technology is used in medium-power traction applications (robotics, AGV, E-mobility, etc.) because of its power density.

Figure 13: A 12V battery Pack

Some advantages that lead acid battery has is that it is capable of high discharge rate and it is reliable i.e. it can provide dependable service.

In our proposed design the battery pack is placed below the tray to evenly distribute and balance the weight and keep to it close to the centre. The power from the battery is split it into two and one part is given to microcontroller, display unit, driving unit and other part is given to motors. A typical 3.7V lithium ion battery specification is shown in Table 1.

Item	Specification
Weight	1.96Kg
Voltage	12VDC

Capacity	7Ah
Technology	Seal Lead Acid
Cycle Use	14.5 to 14.9VDC
Standby Use	13.6 to 13.8VDC
Initial Current	<2.8A
Standby Charge Voltage	13.8V
Estimated Standby Time	7hours

TABLE 1: A TYPICAL 12V LEAD ACID SPECIFICATIONS

3.1.2. Motor

A Stepper motor is designed to be run from a direct current power source, converting electric power to driving mechanical loads.

The stepper motor divides a full rotation into several steps. It converts input square waves into precise increment in shaft's rotational position. Stepper motors have two basic winding arrangements which are unipolar and bipolar. Unipolar has a single winding with a centre tap in each phase. Current is supplied to each section of winding for each direction of magnetic field. Without switching polarity of wire, magnetic pole can be reversed. Bipolar has a single winding for each phase, which means that to reverse a magnetic pole, the current in a winding needs to be reversed. Figure 14 displays the schematic diagram of the Stepper motor.

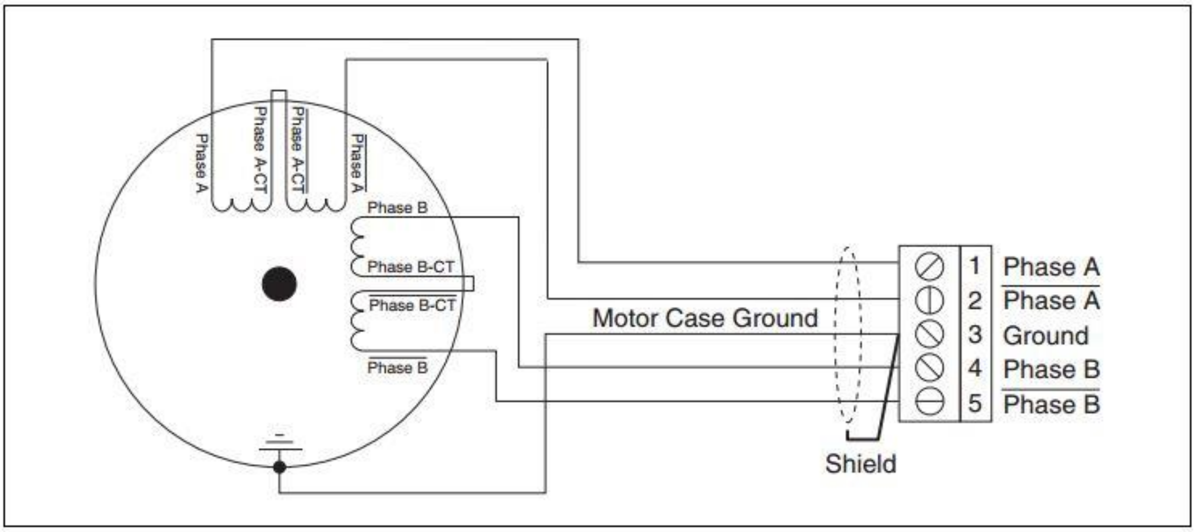


Figure 14: Schematic of a Stepper motor

Stepper motor is driven by sinusoidal current. To get the approximate of a sinusoid, a full-step waveform is needed. There are various drive techniques for stepper motor. Figure 15 shows the various drive modes for unipolar stepper motor.

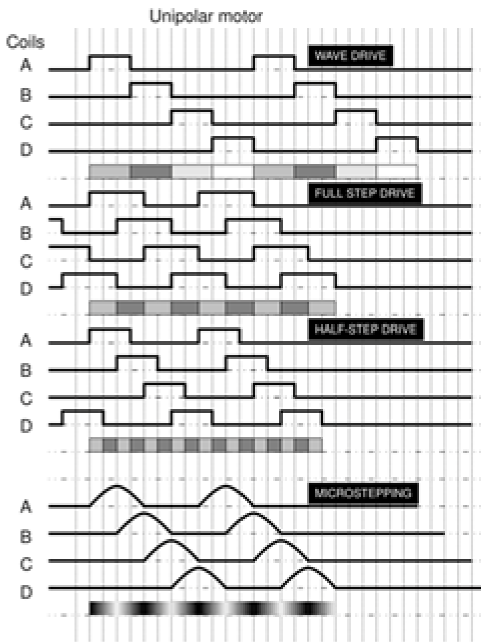


Figure 15: Drive Modes of Unipolar Stepper motor

The market for stepper motors is also quite large. It involves applications demanding precision. These motors deliver seamless running even at low speeds, quiet operation and high durability. Table 2 shows the specification of our stepper motor which include the output torque, the voltage supplied to it and other properties.

TABLE 2: SPECIFICATION OF MOTOR

Item	Specification
Step Angle	1.8 degree
Voltage	12VDC
Current/Winding	2A
Torque Range	0.2 – 1 Nm
Diameter	43mm
Number of Phase	4
DC Resistance	10Ohms
Phase Inductance	37mH

3.1.3 Infrared Sensor

This is an obstacle/object detection sensor. As shown in Figure 16, Its basic concept is that it emits infrared signals from the emitter. When it senses an object or surface, the signals bounce off the surface and reflects. The receiver receives the reflection and the signal goes through a comparator circuit. It goes with on-board potentiometer to adjust the sensitivity. It also interfaces with microcontrollers like Arduino UNO, Raspberry Pi, because its output signal is a digital signal. The Infrared sensor shown in Figure 16 consist of some basic components.

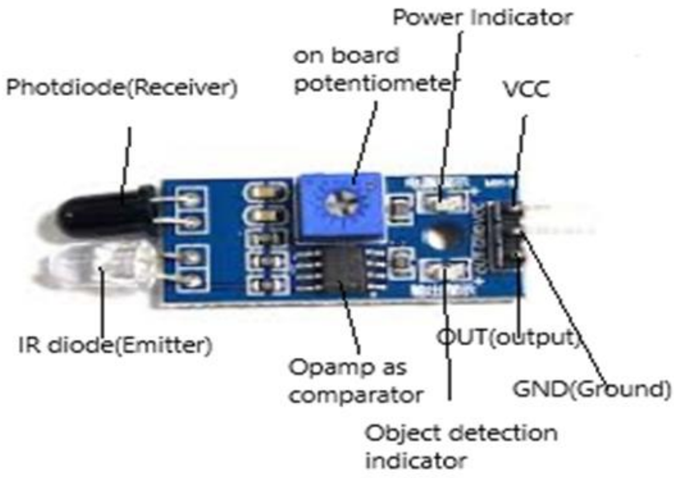


Figure 16: Infrared Sensor

- IR LED (Emitter): It emits light that is invisible to human eye. This light is invisible because the wavelength (700nm – 1mm) is much higher than the wavelength (400nm – 700nm) of visible light. Its light emitting angle is about 20-60 degrees and it covers a range of few centimetres to several feet or kilometres. For this project, IR LED angle of 35 degree and obstacle detection range of 2cm to 30cm will be used. The LED is transparent so it can give out large amount of light.
- Photodiode (Receiver): It conducts when light rays fall on it. This is a semiconductor with a P-N junction and operating in Reverse Bias (i.e. P-side is connected to negative terminal of power source and N-side is connected to positive terminal of power source) direction. When light rays fall on the depletion region of the P-N junction, holes in the region move to the anode and electrons move to the cathode and current is generated. The photodiode is black coated so that it can absorb the highest amount of light.
- Potentiometer: This is also known as variable resistor. It is used to calibrate the range at which an object or surface is detected. Turning it clockwise will increase the sensitivity which will the increase the detection range.

- Power LED indicator: It turns on when power is supplied to the IR sensor.
- Object Detection LED indicator: It turns on when an object is detected.
- Op-amp (Operational Amplifier): This is used as a voltage comparator. It compares its voltage (threshold voltage) and the photodiode voltage.

Photodiode voltage > threshold voltage = Op-amp output is High.

Photodiode voltage < threshold voltage = Op-amp output is Low.

When the Op-amp output is high, the Object Detection LED indicator turns ON which indicates an object is detected.

- VCC: It is the power supply input. It is connected to 3.3V or 5V power supply.
- GND: It is the power supply ground which is connected to the ground of the controller.
- OUT: It is the digital output pin which is connected to any digital input in the microcontroller.

For this project, 2 FC-51 Infrared Sensor are placed at the front wheels and are used with an Electric Black Tape. The black tape is used because it absorbs much light rays emitted from the IR LED and does not reflect it back to the photodiode. This system is used to navigate our AGV. The black tape is placed in such a way that it is in-between two Infrared Sensors. The sensors control the motion of the AGV. The AGV is programmed such that when the IR sensor receives reflected rays from the ground, it commands the AGV to move. When it does not receive rays, it means it is over the black tape so it sends a message to the AGV to stop.

3.1.4 Arduino Uno

This is a microcontroller board. It is one of the most common microcontroller boards used for automation and robotics. It has found its way into products of companies that manufacture robotic vacuum cleaner, moving from just being used by students and hobbyists. It is an open-source microcontroller board that is based on ATmega328P microcontroller.

For our project, Arduino UNO shown in Figure 17 will be used for the automation of the AGV. It has many components on it that receives input, sends output while the microcontroller processes the codes sent to it. From Techbro (n.d), “Some of the major components are 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analogue inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB connection, a power jack, an ICSP header and a reset button” **Error! Reference source not found.**.

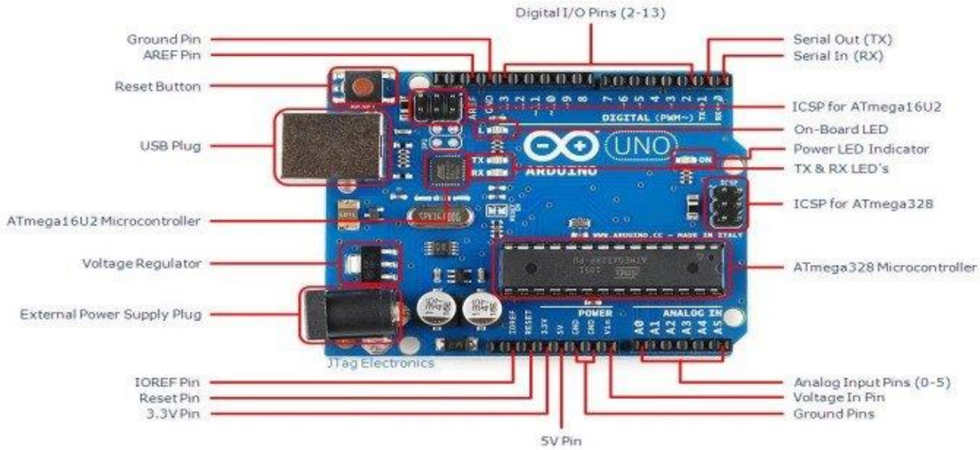


Figure 17: Arduino **Error! Reference source not found.**

Pins and there functions:

- LED pin: this is digital pin 13. It is connected to the on-board LED. When the pin is high value, the LED is on, when the pin is low value, the LED is off.
- VIN (Voltage In-Pin): it is used to supply voltage to the board. The voltage can be supplied to the board through the power jack using this pin.
- 5V pin: This pin outputs a regulated 5V from the regulator on the board but it's not used to supply voltage, doing so will damage the board.
- 3.3V pin: This pin outputs 3.3 volt from the on-board regulator.
- IOREF: This pin on the Arduino/Genuino board provides the voltage reference with which the microcontroller operates. A properly configured shield can read the IOREF pin voltage and select the appropriate power source, or enable voltage translators on the outputs to work with the 5V or 3.3V **Error! Reference source not found.**.
- Serial Out and Serial In pins: Used to transmit or receive serial data.
- AREF (analogue reference) pin: Reference voltage for the analogue inputs.
- TWI (two-wire interface): these are pins SDA (A4) and SCL (A5). They support TWI communication using the Wire library.
- SPI (Serial Peripheral Interface): these are pins 10 (SS), 11 (MOSI), 12 (MISO), and 13 (SCK).
- PWM (pulse-width modulation): these are pins 3, 5, 6, 9, 10, and 11. Using analogWrite() function, they are able to provide 8-bit PWM output.

3.1.5 UV lamps

In simple words, Ultraviolet (UV) light as shown in Figure 18, is a type of radiation. It has more energy than radio waves or visible light but less energy than X-rays or gamma rays **Error! Reference source not found.**.

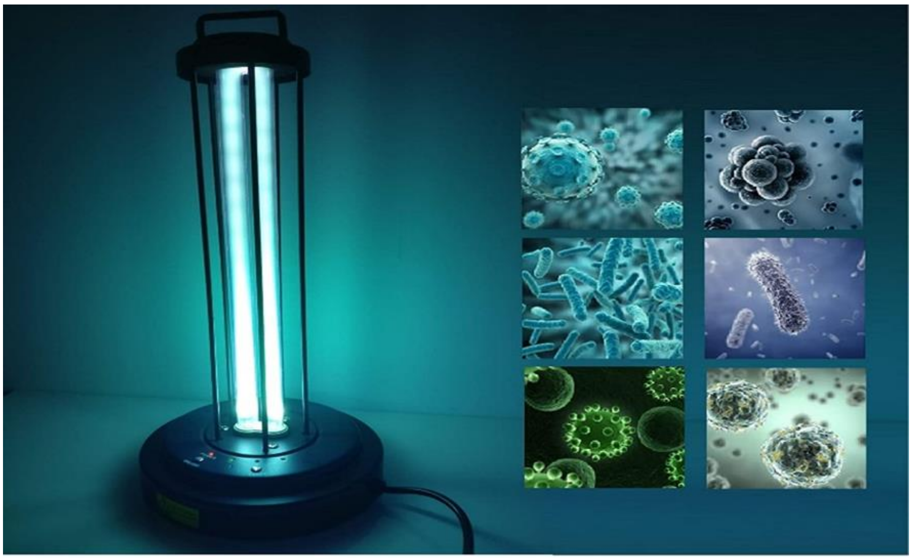


Figure 18: UV lamp

According to Philips (n.d), “Ultra-Violet (UV) light is invisible to the human eye and is divided into UV-A, UV-B and UV-C. UV-C is found within 100-280 nm range. In the graph can be seen that germicidal action is maximized at 265 nm with reductions on either side. Low pressure UV-C lamps have their main emission at 254 nm where the action on DNA is 85% of the peak value and 80% on the IES curve. As a result, our germicidal lamps are extremely effective in breaking down the DNA of micro-organisms. This means that they cannot replicate and cause disease” **Error! Reference source not found.**.

According to Seladi-Schulman (2020), “Micro-organisms effective resistance to UV light varies considerably, and also, the environment of the particular micro-organism greatly influences the radiation dose needed for its destruction” 0.

There are many types of UV light:

- UVA light: It has the lowest amount of energy. It’s the one you get exposed to under the sun
- UVB light: It sits in the middle of the UV light spectrum. Contained in the sun in little proportion and contributes to sunburns and causes most skin cancers.
- UV-C light: It has the most energy. It is contained in the sun, but absorbed by earth’s ozone layer. But then, there are various sources of UV-C light made by humans.

We will put our attention at UV-C light.

UV-C light can be used to kill coronavirus. From the post made by Seladi-Schulman, 2020 “Looking at the research discovered about UV-C light and coronavirus so far, a recent study in the American Journal of Infection Control (AJIC) investigated using UV-C light to kill large amounts of the new coronavirus in liquid cultures. The study found that UV-C light exposure completely inactivated the virus in 9 minutes. Another study, also published in the AJIC, looked at using a specific type of UV-C light to kill SARS-CoV-2 on laboratory surfaces. The study found that the UV-C light reduced the live coronavirus by 99.7 percent in 30 seconds” 0.

Far-UV-C light is still damaging to germs but is less of a hazard to your skin and eyes than other types of UV-C light. Figure 19 provides a reference guide for UV-C.

UVC germicidal products reference guide

UVC radiation has sanitizing properties, and has many uses in commercial, healthcare and consumer settings. UVC has germicidal benefits, killing bacteria and deactivating viruses depending on the exposure dose (based on source strength, proximity, and time). However, there are serious risks to UVC exposure, so proper safety precautions are essential.

What qualifies as UVC?

Electromagnetic wavelengths shorter than the visible spectrum of light are known as ultraviolet (UV) (180-400 nm). This reference guide is focused on UVC. Please note that UVA and UVB regions have certain benefits and pose some hazards of their own.

UVC (Short-wave)	UVB (Middle-wave)	UVA (Long-wave)
180-280 nm	280-315 nm	315-400 nm

What are the key risks of UVC?

There are serious risks to UVC exposure. UVC can be dangerous if improperly used. In only moments, UVC exposure can cause serious damage:

- **EYE:** pain, light sensitivity, and gritty sensation on eye can occur, since UVC does not trigger aversion response (blinking squinting, looking away)
- **SKIN (erythema):** similar to a sunburn

What are the dangers of breathing emitted ozone from a UVC device?

Some UVC lamps emit ozone, which enhance germicidal effects but can be hazardous in enclosed spaces:

- **LUNG DAMAGE:** ozone may also worsen underlying respiratory conditions

What if the UVC is contained?

Containment is a set of design criteria that ensures that people are not exposed to excessive UVC. Consumer products that contain the UVC radiation inside the equipment may be safe and eligible for safety certification based on evaluation per the applicable safety Standards.

What if you are a trained professional in a controlled setting taking safety precautions?

Commercial and healthcare related UVC products may have uncontained UVC sources. They are intended for use by trained professionals based on product and site safeguards. Such equipment may be safe and eligible for safety certification based on evaluation per the applicable safety Standards.

Warning labels are not enough!

Some consumer products without UVC source containment have warning labels or timers - this is not enough! Children and pets cannot be expected to follow written warnings, and home environments have too many variables that could result in misuse. Remember that UVC disrupts DNA; in a home environment, devices without containment pose a hazard to the residents, pets, and plants.

What will UL Certify?

UL will certify eligible UVC devices for safety using UL Standards for the product type (see following page for examples). Where the Standard does not already include personal injury requirements for UVC, ANSI/IES RP-27 or IEC 62471 for photobiological assessments will apply. Safety certifications address risks of electric shock, fire and personal injury; safety certifications do not address efficacy claims.

Safety Testing

1. Consumer products with contained UVC sources
2. Commercial and healthcare related products with UVC sources
3. Components integrated inside UVC equipment (Ballasts, LED drivers, UVC sources, Controls & Sensors)
4. Commercial lighting products (Upper Room UVGI, Hybrid lighting systems, UVA & 405 nm systems

Performance Assessments

Photobiologic, photometric testing to determine risk category, exposure dose, and UVC source characteristics. Performance can be assessed as an independent service with or without a safety certification. Performance evaluation will not result in a UL safety Mark.

Risk Categories for UVC

UVC lamps and lamp systems are classified into risk groups based on UVC exposure limits and the relative photobiological risk of the radiation source. The criteria for each risk group designation is based on the type of UVC source characteristics, the length of exposure under normal conditions, and other factors.

UL can help you understand what risk group your product/design falls into and the corresponding safety implications.

Figure 19: UV-C Germicidal Products Reference Guide [17].

3.2. Engineering standards

Standards for design are as follows:

ISO 10218-1:	Safety requirements for industrial robots
ANSI/ITSDF B56.5:	Safety Standard for Guided Industrial Vehicles
ASTM F45:	Driverless Automatic Guided Industrial Vehicles

3.3. Design Calculations

3.3.1. Simulation System Configuration

The configuration of the vehicle forces is shown in Figure 20. It is seen that the two sprockets in the middle of the AGV are driving wheels, which are actuated separately by two DC motors. So, there are two trajectories of line and arc for this kind of AGV. The centre of linking line between two driving wheels is the kinematics origin of AGV.

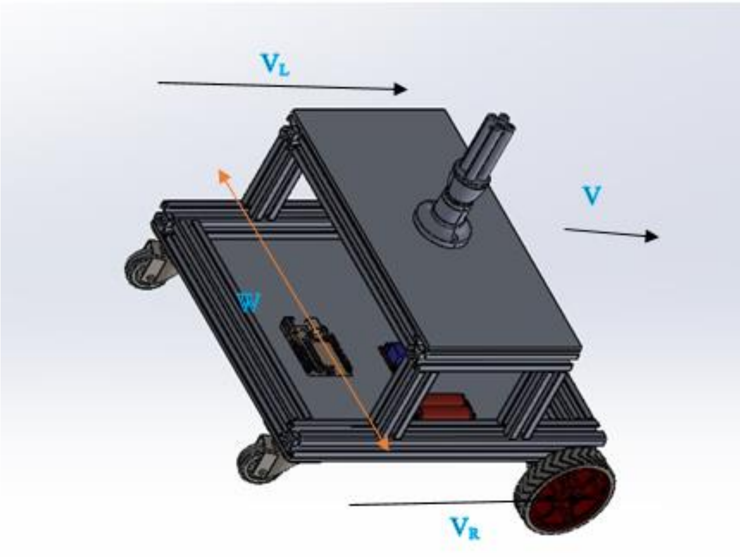


Figure 20: Vehicle Forces

V = linear AGV velocity (mm/s).

ω = angular AGV velocity (rad/s).

W = distance between two sprockets = 400mm.

V_R = velocity of right wheel (mm/s).

V_L = velocity of left wheel (mm/s).

3.3.2. Kinematic Computation

In order to be able to configure the kinematic computation of the AGV, it is assumed that all of the belt's wheel force is applied to a point which is at the centre of each wheel in each side.

Therefore, for the linear movement, velocity is calculated as follows:

$$V = \frac{V_R + V_L}{2} \text{ (mm/s)} \quad (2.1)$$

And for the angular movement, velocity is calculated as:

$$w = \frac{V_R - V_L}{w} \text{ (rad/s)} \quad (2.2)$$

Figure 21 shows how opposite rotation in motors with same speed enables the vehicle to rotate around its centre.

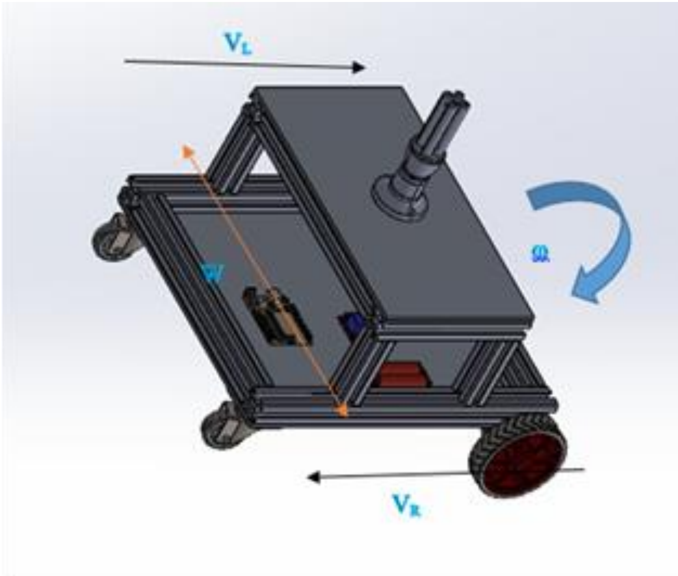


Figure 21: Rotation in Both Sides, Different Orientation, Same Speed

$$V_r = \text{V} \tag{2.3}$$

$$V = \frac{V_{r+}V_t}{2} = 0 \tag{2.4}$$

$$w = \frac{V_{r-}V_t}{w} = \frac{2V}{w} = \frac{V}{200} \tag{2.5}$$

Figure 22 shows no rotation in one motor and a normal rotation in the other motor, the vehicle turns whole at the centre which is 370 mm away from the vehicle centre.

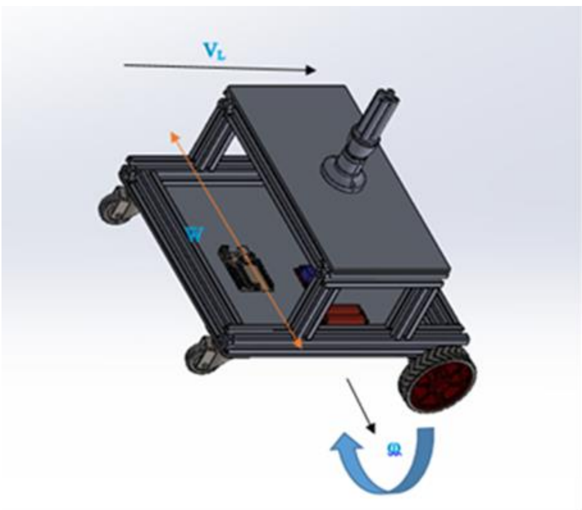


Figure 22: Rotation Just In one side

$$V_r = \mathrm{V} \tag{2.6}$$

$$V_l = 0 \tag{2.7}$$

$$V = \frac{V_{r+}V_t}{2} = \frac{V}{2} \tag{2.8}$$

$$w = \frac{V_{r-}V_t}{w} = \frac{V}{w} = \frac{V}{400} \tag{2.9}$$

Figure 23 shows the same oriented rotation in the motors with various velocities: the vehicle turns whole of a centre which can be from 370 mm away from the centre to infinity due to various amount of variation of the speed.

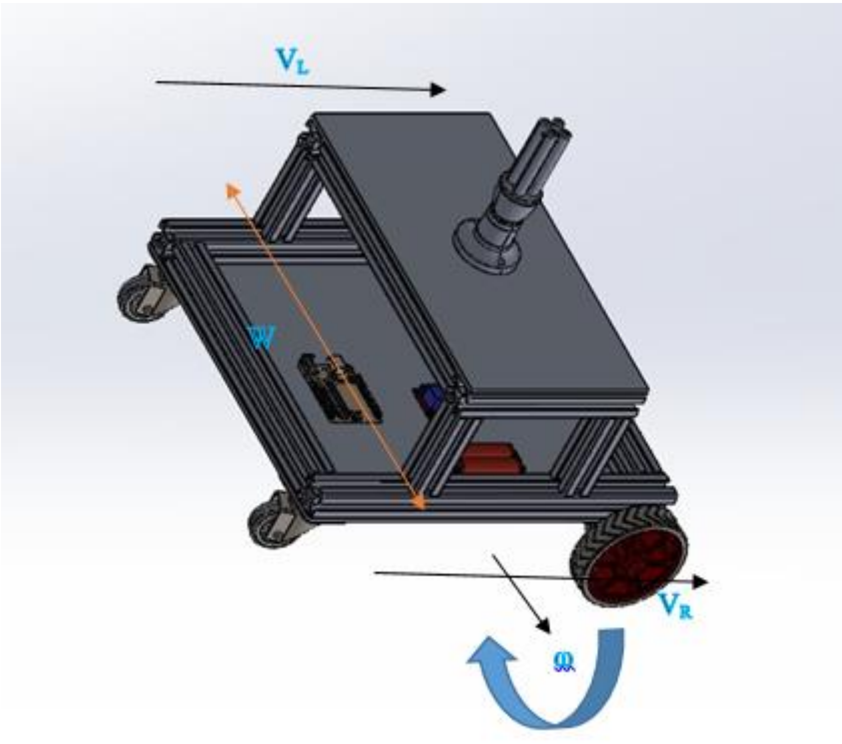


Figure 23: Rotation in Both sides, Same Orientation, Various Speeds

$$V_r = 2\mathrm{V} \tag{2.10}$$

V_t=2V (2.11)

$V = \frac{V_r + V_t}{2} = \frac{3}{2}$ V (2.12)

$w = \frac{V_r - V_t}{w} = \frac{V}{w} = \frac{V}{400}$ (2.13)

Figure 24 shows the opposite rotation in motors with variation in speed; vehicle turns whole of a centre which can be from the centre of the vehicle to 370 mm away, due to various amount of variation of the speed.

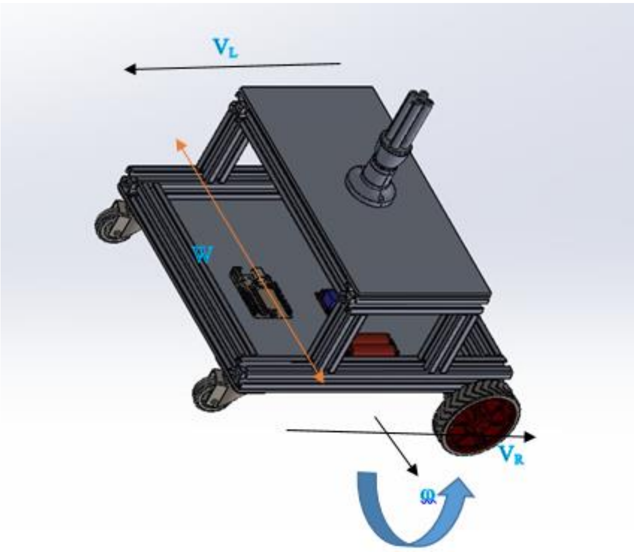


Figure 24: Rotation in Both Sides, Different Orientation, Various Speeds

V_r=2V (2.14)

V_t=-V (2.15)

$V = \frac{V_r + V_t}{2} = \frac{V}{2}$ (2.16)

$w = \frac{V_r - V_t}{w} = \frac{3V}{w} = \frac{3V}{400}$ (2.17)

In addition, this variation of the speed is perfectly assigned with respect to the orientation of the turn. The big advantage of using this model is that it does not require too large an area for all types of the movements, turns and manoeuvres.

3.3.3. Simulation

This is the simulation analysis of our project. We are looking at the effect displacement, safety factor, stress, strain of our load carrier has on the entire AGV system and the best material the load carrier should be made of . For this AGV, we are looking at a maximum load of 50Kg.

- Displacement

For a load carrier made of aluminium, when the maximum load is applied, it causes a maximum displacement of 0.1058mm on the front which deforms it as shown in figure 25.

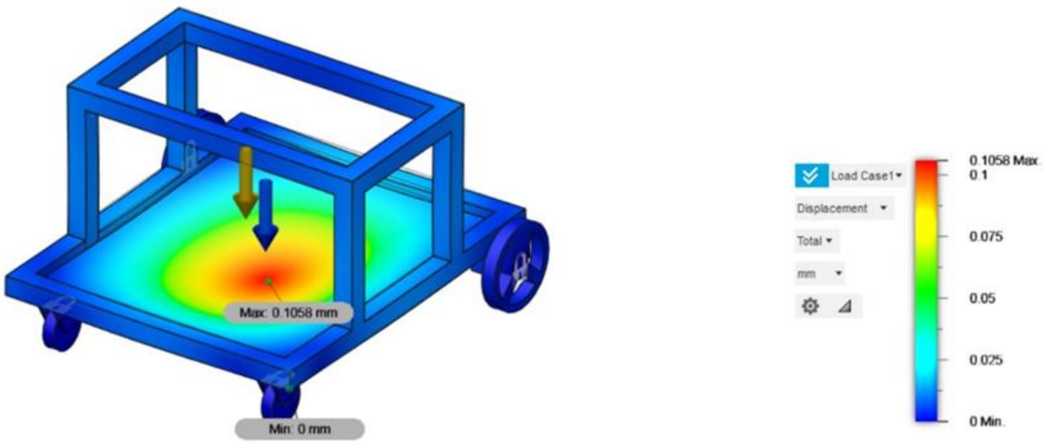


Figure 25: Displacement analysis of aluminium 6063

- Safety Factor

Safety factor is the ratio of the strength of a structure to maximum stress due to applied load. From the scale for safety factors shown above, the minimum values are important. For this system, the minimum factor of safety is 15 as shown in figure 26. Anything value below this will cause the system to experience fracture.

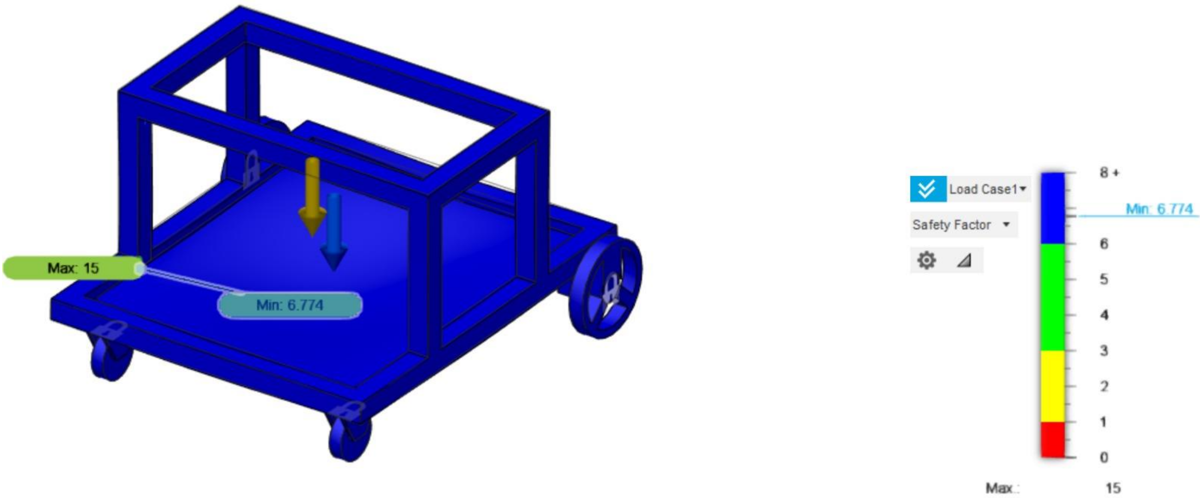


Figure 26: Safety Factor analysis of aluminium 6063

- Strain

This is the strain analysis of the AGV. The maximum strain occurs at the edges of the load carrier connected to the aluminium frame. The maximum strain for aluminium is 5.395E-04 as shown in figure 27.

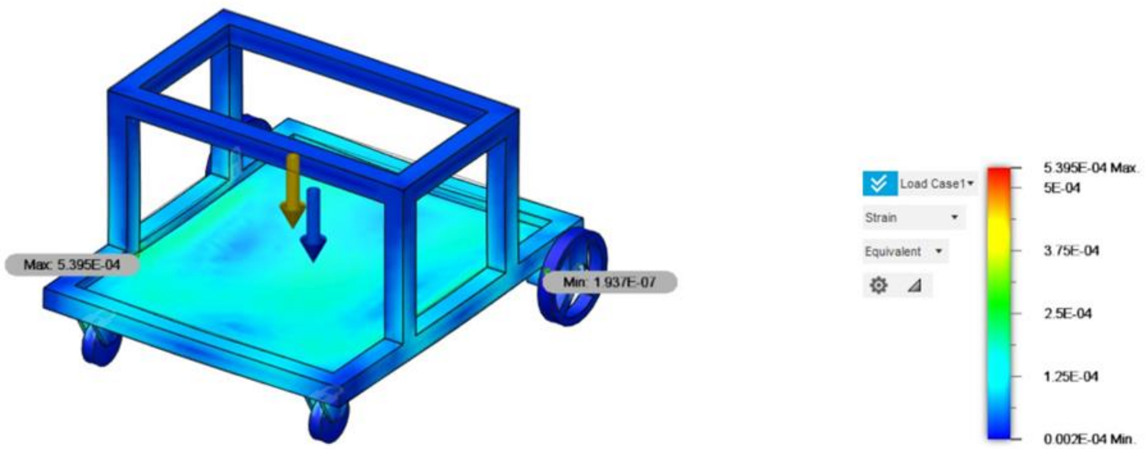


Figure 27: Strain analysis of aluminium 6063

- Stress

For the stress analysis of the AGV, The maximum stress is 40.6Mpa and it occurs at the joints between the load carrier and the aluminium frame as shown in figure 28. Table 3 shows the material properties from the simulation.

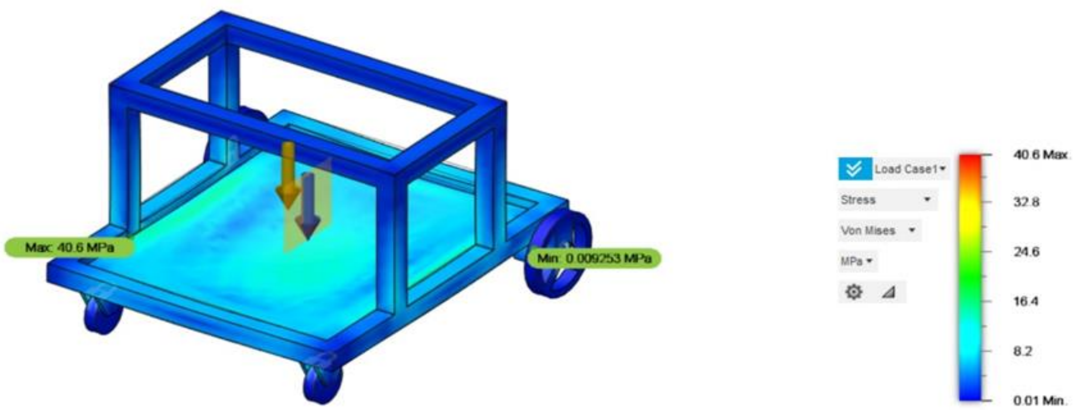


Figure 28: Stress analysis of aluminium 6063

TABLE 3: MATERIAL PROPERTIES

Material Properties	Aluminium 6063
Safety Factor	15
Stress (MPa)	40.6
Strain	5.395E-04
Displacement (mm)	0.1058

3.4. Cost Analysis

Building this project required some expenses to be made and materials to be bought. Table 4 below details the list of materials we bought to build the project, while Table 5 details other expenses made which involved shipping tax and transportation.

TABLE 4: BILL OF MATERIALS

S/N	Part Name	Description	Quantity	Cost (Turkish Lira)	Total Cost (Turkish Lira)	Vendor	Picture
1.	Caster Wheel		2	16	32	GENC, Famagusta	
2.	Stepper Motor	NEMA 17	2	70	140	Near East University, Lefkosa	
3.	Motor Driver	A4988	2	5	10	Near East University, Lefkosa	
4.	Arduino	Uno R3	1	30.57	30.57	Direnc, Turkey	
5.	Breadboard and jumpers	MB-102	1	3.71	3.71	Direnc, Turkey	

6.	IR Sensor	LM393	3	33.3	100	CypRobotics, EMU,Famgusta	
7.	PIR Sensor	HC-SR505	1	24.55	24.55	Direnc, Turkey	
8.	UV-C Sterilizer light	36W	1	540	540	Izmir Elektrik, Famagusta	
9.	Wheel	3D Printed	2	66	132	Near East University, Lefkosa	
10.	Relay Module	5V	1	5.09	5.09	Direnc, Turkey	
11.	Black Tape		1	6	6	FM INFO, Famagusta	
12.	Battery	Lead Acid	1	230	230	Izmir Elektrik, Famagusta	
13.	Sigma Aluminium Profile (6063)	40 x 40 4600mm	1	230	230	Gazikent, Famagusta	
14.	Aluminium Composite	360 x 400mm PVDF	1	3	3	Gazikent, Famagusta	
15.	Aluminium Composite	360 x 200mm PVDF	1	2	2	Gazikent, Famagusta	

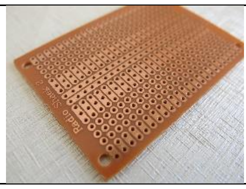
20.	Bracket		16	54	54	GENC, Famagusta	
21.	Veroboard		1	15	15	Eturk Elektronik	
22.	Screws		60	13	13	GENC Famagusta	
23.	Allen Keys Set		1	12	12	Mr Pound, Famagusta	
24.	Inverter		1	645	645	Eturk Elektronik	
-	Total	-	-	-	2227.92	-	-

TABLE 5: OTHER EXPENSES

Other Expenses	
Category	Cost (Turkish Lira)
Transportation	300
Shipping	9.19
Tax	120
Total	429.19

CHAPTER 4 – MANUFACTURING PLAN AND ASSEMBLY

4.1. Manufacturing process selection

This project involved certain manufacturing processes, as well as the mechanical and electrical assembly. After comparing several materials properties from Table 6 and Table 7 which include their modulus of elasticity, ultimate tensile strength, fatigue limit, and their availability and prices we decided to use PVDF Aluminium composite panel as shown in Figure 29 for our UV-C AGV base and Aluminium profile made of Aluminium 6063 for the body as shown in Figure 30.

TABLE 6: MATERIAL PROPERTIES

		Modulus of Elasticity, E (GPa)	Ultimate Tensile Strength (MPa)	0.2% Proof of Stress at Yield (MPa)	Elongation at Failure (%)	Fatigue Limit/ UTS (5x10 cycles)	Density(Mg – specific energy) (g/cm^3)
Steel	Medium Carbon	200	520	310	26	0.5	7.85
	CrMo (AISI 4130)	200	1425	1240	12	0.5	7.85
Aluminum Alloys	2024-T4	73.1	470	325	20	0.29	2.8
	6061-T6	68.9	310	276	12	0.31	2.8
	6063-T6	75	190	170	10	0.69	2.68
	7075-T6	71.7	570	503	11	0.265	2.8
Magnesium		44	248	200	5 to 8	0.37	1.79
Titanium Alloys	IMI 125	105 to 120	390 to 540	340	20 to 29	0.5	4.51

	IMI 318	105 to 120	1000	900	8	0.55	4.42
Composites	"S" glass-epoxy	90	3750	3450	3.5	0.16	2.63
	HT graphite-epoxy	221	3600	2000	1.25	0.25	1.75
	Boron-epoxy	250	1200	?	?	0.8	1.9
	Boron-Aluminum	165	1025	?	0.65	0.7	2.4
	Kevlar-49-resin	75	1380	?	2.75	0.7	1.45
	Glass-nylon	2.3	59.9	59.9	14	?	1.18
Woods		12	100	60	?	?	0.67

TABLE 7: ALUMINIUM COMPOSITE PROPERTIES

Composition	Tensile Strength	Young's Modulus (MPa)	Elongation at Brake Point
PVDF/CNF (95/5)	4.3 ± 0.2	40 ± 0.5	0.43327 ± 2
PVDF/CNF (90/10)	4.45 ± 0.2	10 ± 0.5	2.94526 ± 2
PVDF/CNF (85/15)	3.85 ± 0.2	6.9 ± 0.5	4.8309 ± 2
PVDF/CNF (80/20)	4.98 ± 0.2	7.85 ± 0.5	6.39141 ± 2


Figure 29: Aluminium Composite Sheets

Figure 30: Aluminium 6063 Profiles

The manufacturing process of each part (assembly) of the UV-C AGV was as follows:

- Base: Cutting tools from the workshop were used to cut the appropriate size of PVDF Aluminium composite panel needed for the base. Electric Drills were used to make the holes to attach the base to the aluminium chassis with mechanical fasteners such as screws.
- Tray/first floor: Cutting tools from the workshop were used to cut the appropriate size of PVDF Aluminium composite panel needed for the tray. Drills were then used to make the holes to attach the tray to the aluminium chassis with mechanical fasteners such as screws and nuts.
- Body: CNC cutting machine was used to cut Aluminium profile to appropriate lengths. Electric screwdriver was used to assemble the aluminium frame using brackets.

TABLE 8: CRITERIA FOR BODY MANUFACTURING METHOD SELECTION

Legend 1 ⟶ worst 20 ⟶ best	Priority	Importance	Automatic screw machine	CNC turning machine
High precision	1	20	6	10
Cost effectiveness	2	10	8	8
Weighted total			200	280

TABLE 9: CRITERIA MATRIX FOR BODY AND TRAY MANUFACTURING METHOD SELECTION

Legend 1 ⟶ worst 10 ⟶ best	Priority	Importance	Welding	Fasteners
Strength	1	10	10	8
Reliability	2	8	6	8
Maintenance	3	7	3	9
Cost	4	6	4	8
Weighted total			193	255

Welds are often more difficult to inspect and maintain than the fasteners. Some of the special equipment needed for weld testing costs excessive sums of money. Welds require some intensive tests to check the integrity throughout the weld, such as x-rays. Welds are also considerably more difficult to remove and replace than fasteners. Along with a joint, they can also be inconsistent in strength. Whereas Fasteners, installed at equal distances, will provide the same strength at each joint without any significant change. This makes them a better choice in terms of weight distribution. They are also easy to check for corrosion or other debilitating factors. Moreover, if the fastener is bad, it's easy to remove it and replace it with a new one. They can also be adjusted over time to compensate for changes in materials such as swelling or shrinkage with minimal effort.

- Wheels: 2 Robot wheels with Hex Brass Coupling were mounted on stepper motors in the front and 2 caster wheels were used in the back and tightened with screws to the aluminium chassis.

- Motor: Stepper motors were attached to wheels and assembled to aluminium chassis with the help of bracket and screws. Telephone Spiral wires and jumper wires were used to connect motors to motor drivers and then to Arduino Uno.
- Infrared Sensors: Glue was used to attach Infrared sensors near the front two wheels and then jumper wires were used to connect them with Arduino Uno.
- Arduino Uno: Drills and screws were used to attach Arduino Uno below the tray and then jumper wires were connected to motors, battery and sensors.
- UV-C Lamp and its holder: Hot glue was used to attach the Lamp above the tray and then connected to Arduino Uno and battery with the help of wires.

4.2. Detailed manufacturing process

Combining Aluminium frames together with screws and bracket, we placed the bracket on one aluminium frame and placed a second aluminium frame at 90 degree to the first and assembled them together with an electric screwdriver as shown in Figure 31 and Figure 32.

Figure 31: Screwing the bracket to both frames at 90 degree.

Figure 32: Using L angle bracket to make the joint stronger.

We repeated the same thing for all corners of the chassis. We assembled the Aluminium composite to the frame with screws, both the one for the base and for the lamp as shown in figure 33.

Figure 33: Screwing the Aluminium composite to the profile.

The four frames connecting the base and the top were screwed on both sides as shown in Figure 34. Due to unavailability of stepper motor holder in our location, we used a normal screw bracket as an alternative. Using the drilling machine in the workshop, we drilled holes for the shaft and screws as shown in Figure 35.

Figure 34: Screwing the four vertical frames to both the top and base.

This bracket was used as our motor holder. Figure 36 shows the machined bracket being screwed to the stepper motor. Also, the caster wheel was fixed to the base with screws as shown in Figure 37. Holes were created on the base composite to pass wires for the stepper motor. The electronics were attached with screws to the base. UV-C lamp was attached to the battery system and provide a consistent frequency of waves to deter and kill bacteria and viruses.

Figure 38 shows the assembled robot. Figure 39 and Figure 40 shows the side view and front view of the AGV robot with electronics together.

Figure 35: Drilling holes on a bracket to be used as stepper motor holder.

Figure 36: Fixing the bracket to the stepper motor.

Figure 37: Fixing the bracket to the stepper motor.

Figure 38: Assembled AGV

Figure 39: AGV with electronics (Side view)

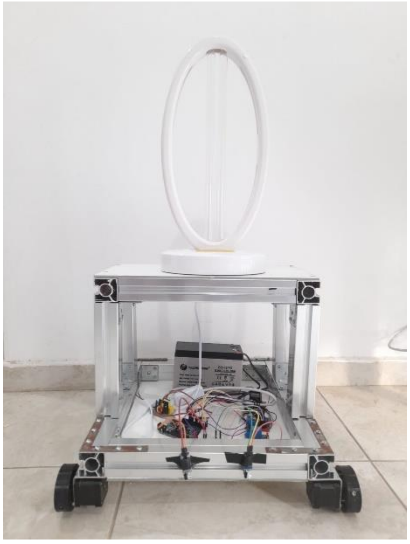


Figure 40: AGV with electronics (Front view)

CHAPTER 5 - PRODUCT TESTING PLAN

5.1. Verification plan of the objectives of the project.

In this period were the COVID-19 pandemic has brought fear, people are more careful of their environment and the surfaces they touch. According to E. Goldman, if a person having the virus coughs or sneezes, droplets containing particles of the virus travel through air and land on nearby surfaces **Error! Reference source not found.**. Due to this, our AGV sterilization robot is aimed at navigating through the room for disinfection at a specified low speed to have maximum impact and sterilizing both the air and surfaces. To achieve this purposes, tests have to be carried out on the readings from the IR sensor when brought close to the black line to obtain a better result for the navigation of the AGV sterilization robot and the on the effectiveness of the UV-C light in killing virus, fungus and bacteria.

5.1.1. Experiments to verify the objectives of the project.

To achieve the purposes of this project dimension test, bread mould test and IR sensor detection test is carried out.

- Dimension Test: Measuring tools available at the school's workshop can be used to obtain accurate dimensions. Generally, tape-meter is used for measuring the length and width of aluminium composite and length of the aluminium profile. It is the easiest and enough accurate to see the results. For drilled holes, Vernier calliper also can be used for more detailed accuracy measuring.
- Bread mould Test: This test is just to show how effective is the UV-C lamp. Bread will be soaked in water and allowed to dry to allow mould to grow on it. Then it will be

placed in an enclosed place with the UV-C lamp for some hours so as to see the effect of the lamp in killing the fungus.

- IR Sensor Detection Test: To obtain best navigation result, the IR sensor can be placed on the robot, 3cm from the ground. It is connected to the Arduino which is connected to the computer. By adjusting the potentiometer on the sensor we increase or decrease the detection of the sensor and obtain results in the computer. Doing this can help obtain a better navigation of the robot on the black line.

5.2. Verification plan of the applied engineering standards

Due to the fact that there are no standards specified for design for AGV sterilization robot, VDI 2510 Blatt 1:2009 standard is adopted. According to this standard, our project guidance control system, device for position sensing and other peripheral installations. In the planning and design, intended installation site is taken into account (mechanical department) **Error! Reference source not found.**. For the robot to operate as specified, in a reliable manner, the following is taken into consideration:- requirements regarding the operational environment of the AGVs (condition of the floor, layout of transport routes), -requirements regarding the navigation devices, equipment for AGV power supply, stationary safety devices (PIR sensor, UV-resistant eye wear, protective clothing which covers exposed skin), and peripheral installations. To comply with the requirements for AGV sensor system, our selection of sensors, especially for navigation is in accordance to VDI 4451-6:2003 standard of sensor systems for navigation and control.

In this project, safety in the use of UV-C lamp is a major priority. UV-C light emit enough energy to literally shred the DNA or RNA of any microorganisms that have the misfortune of being exposed to them **Error! Reference source not found.**. But then it causes eye injury (irritation and inflammation of cornea) and skin injury (erythema). Also, some UV-C light emit ozone, which can irritate the nose, throat and lungs **Error! Reference source not found.**. Due to this, our AGV sterilization robot is an autonomous robot with human intervention in accordance to ISO/TR 23482-1:2020. To test its safety, PIR sensor is employed to stop the motion of the robot and turn off the light when humans are close by. Factoring in human safety, calculations are made on UV-C safety requirements in accordance to ISO 15858:2016 and IEC 62471:2006 standards. For human safety, it is imperative that anyone working with UV-C light should wear appropriate PPE when operating or servicing the device at all times **Error! Reference source not found.**. Examples of PPE include UV-resistant eyewear (goggles/face shields/safety glasses) and Protective wear/clothing, which covers exposed skin.

In accordance to IEC 60417 - 6040, we have designed our hazard warning label. The label provides the following signage **Error! Reference source not found.**:

- UV-C warning symbol according to IEC 60417 – 6040.
- Warning sign that eyes and the skin must be protected – “UV HAZARD – PROTECT EYES AND SKIN” **Error! Reference source not found.**.
- Provide labels and indicator switches that illuminate when UV-C device is ON **Error! Reference source not found.**.
- For upper room UVGI lamps, place warning signs near the lamps **Error! Reference source not found.**.
- For HVAC UV-C systems, place signs on AHU access panels **Error! Reference source not found.**.
- Label activation switches and consider lockable switch guards to prevent access from unauthorized persons **Error! Reference source not found.**.

- Ozone warning symbol **Error! Reference source not found.**.
- Instructional safeguards **Error! Reference source not found.**.

Our UV-C lamp has the following qualities and specifications:

- 360 degree UV sterilization device kills 99.999% bacteria and viruses.
- This device kills up to 99.999% bacteria and viruses.
- Cleans the air, reducing allergic reactions.
- Thanks to the remote control and timer function, it automatically turns off when the set time (15min-30min-60min) is completed.
- Ozone ion bulb has an odor killing and elimination effect.
- Ozone generator - 157 nm UV-C converts oxygen into ozone to achieve bactericidal effect.
- UV-C: 253.7nm wavelength.
- Safe and easy to use.

There are various successful techniques for removing mould colonies, one of which is the use of ultraviolet radiation. When exposed to UV radiation for an extended period of time, the DNA is broken up, causing the cells to become infertile and finally die. However, unless the mould is isolated or concentrated in a small area, such as bathroom grout, where a UV sanitising wand may be used. Figure 41 shows a room subjected to UV-C light.

Fig 41: A room subjected to uv light

The exterior protein covering of the SARS-Coronavirus, which is a distinct virus from the present SARS-CoV-2 virus, has been found to be destroyed by UVC radiation. The virus is inactivated as a result of the destruction. UVC radiation may also help inactivate the SARS-CoV-2 virus, which causes Coronavirus Disease 2019. (COVID-19).However, information on the wavelength, dosage, and duration of UVC radiation necessary to inactivate the SARS-CoV-2 virus is still scarce. Because there is minimal published data concerning the wavelength, dosage, and duration of UVC radiation necessary to inactivate the SARS-CoV-2 virus, the efficiency of UVC lamps in inactivating the virus is uncertain.

It's vital to remember that if a virus or bacteria isn't directly exposed to UVC, it won't be inactivated. In other words, if a virus or bacteria is coated in dust or soil, entrenched in a porous surface, or on the bottom of a surface, it will not be inactivated.

UV-C kills live microorganisms, but viruses are not living things, thus we should say “inactivate viruses” instead. Individual, intense UV-C photons interact photo chemically with the RNA and DNA molecules in viruses and bacteria, rendering them non-infectious. Figure 42 shows the effect of UV-C light in killing bacteria. All of this takes place at a tiny level. Viruses are smaller than one micrometre in size (m, or one millionth of a metre), while bacteria are generally 0.5 to 5 m in size.

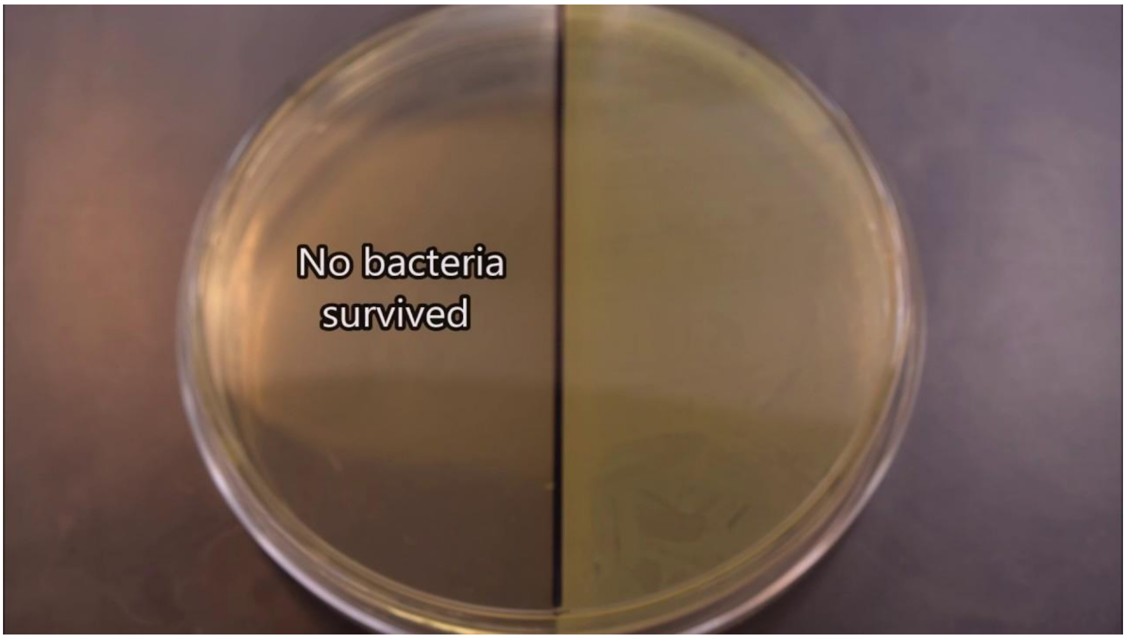


Fig 42: Bacteria and UV light effects on it.

Natural sources of water, such as dams, streams, bores, and rainwater tanks, may include germs that are harmful to your health. Before being used for drinking, bathing, filling swimming and paddling pools, food preparation, or cooking, all naturally derived water should be thoroughly tested and cleaned, according to the Department of Health. To eliminate microbiological pollutants that might cause sickness, a variety of water treatment technologies can be utilised. One water treatment technology that may be used to eliminate most types of microbial contamination from water is ultraviolet (UV) light disinfection as shown in Figure 43.

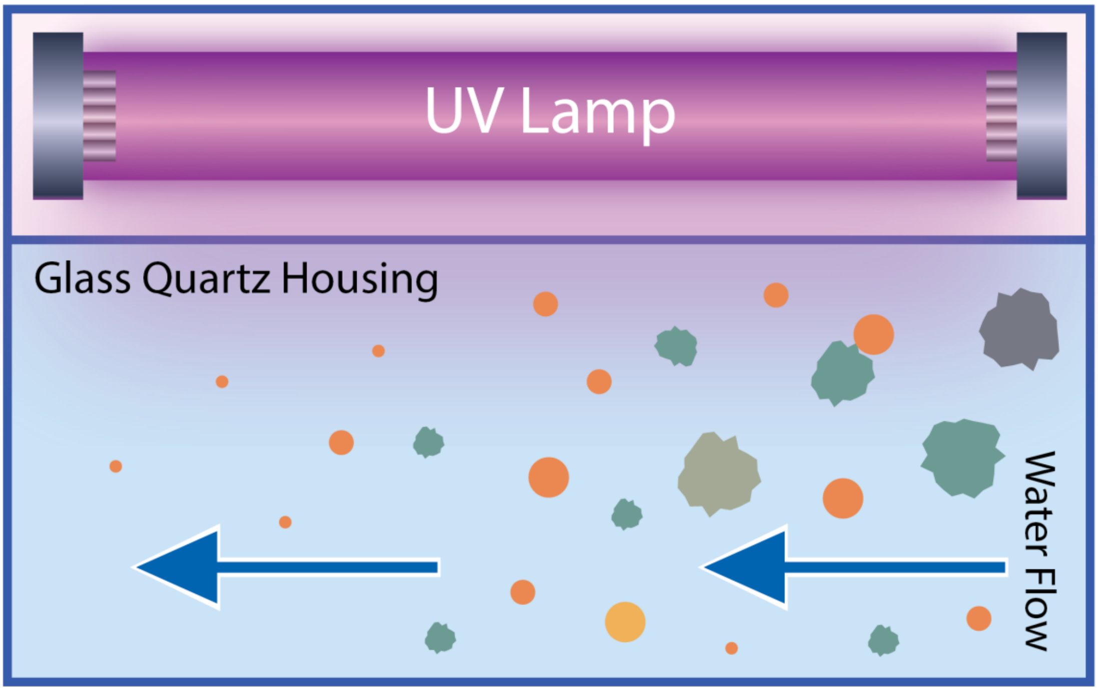


Figure 43: UV lamp effect on water and its purification

Figure 44 and 45 shows the result of mould test by agv sanitizer robot. The one bread was subjected to agv supervision and the other one was left without any uv protection.This test has been carried out within 4 days and agv sanitizer robot showed its supremacy in cleansing germs. This robot has been turning around the bread by following lines for 60 minutes each day.

Figure 44: UV lamp effect on bread after 4 days

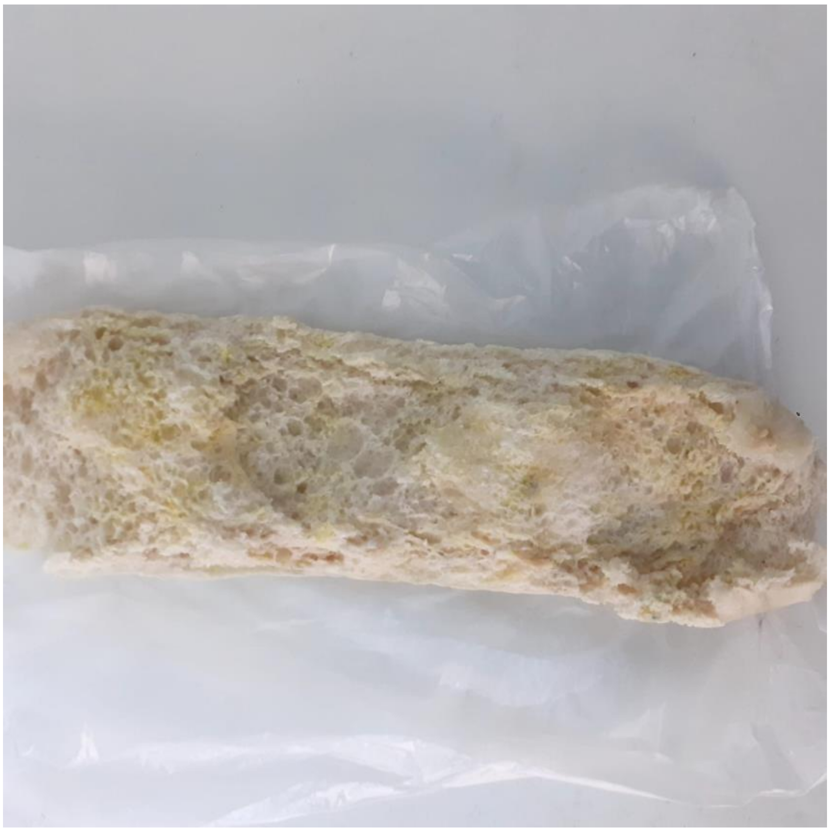


Figure 45: bread sample without protection

CHAPTER 6 - RESULTS and DISCUSSION

6.1. The results

The efficiency of germicidal UV is influenced by the exposure period, the wavelength of UV radiation, a microorganism's ability to survive UV during exposure, and the presence of UV-protecting particles. It's worth mentioning that in the proposed study, we recommend using a Xenon lamp source, which can provide the whole UV–vis spectrum (200 nm–800 nm), making it more effective in inactivating viruses. The majority of UV lamps on the market are cylindrical in shape and have a maximum wattage of 36 W. This robot has conducted a series of tests without human presence and removed bacteria and germs on different objects and food such as rotten food or a piece of bread covered by moulds. Furthermore, UV-C light is effective in inactivating dangerous viruses such as covid-19 and Tuberculosis but couldn't be subjected to the experiments because of their natural danger. After a lengthy period of UV exposure and according to our research and experiment the effective duration of exposure was found to be 15 minute, in our test sanitization AGV had partially cleansed the mouldy surfaces, and it may function much better with a longer operating time.

The AGV functioned as intended, it followed the black tape line with the help of IR sensors. The safety protocols were also executed as intended, due to the PIR sensor if any human movement is detected around the AGV stopped in its path and turned off the UV-C lamp, if it detected any obstacles in its path it would stop as well and turn off the UV-C lamp until the obstacle had been removed.

Although there are already many UV-C/sanitization AGVs in the market, we believe our design is although not superior it however serves its functions just as well with the benefit of being 10 times cheaper, lighter and much easier to make.

6.2. The engineering standards

ISO 10218-1:2011: Robots And Robotics Devices – Safety Requirements For Industrial Robots.

ISO 9787:2013: Robots and Robotics Devices – Coordinate Systems and Motion Nomenclature

ISO 9283:1998: Manipulating Industrial Robots: Performance Criteria and Related Test Methods.

IEC 62061:2005+AMD1:2012: Safety Of Machinery - Functional Safety Of Safety-Related Electrical, Electronic And Programmable Electronic Control Systems

ISO 225:2010: Fasteners — Bolts, Screws, Studs and Nuts — Symbols and Descriptions of Dimensions

6.3. The constraints

Through the course of manufacturing, assembly, programming and acquiring components we faced some constraints while working on our project.

- The biggest constraint we faced was acquiring all our components in TRNC especially the DC motor, we had to opt for Stepper motor instead.

- Because of COVID-19 pandemic we had even more difficulty getting our components on time due to many shops being closed due to lockdown and getting our components shipped due to borders being closed.
- Because we our initial plan was using DC motor but then because of difficulty in acquiring it we had changed to stepper motor we had to rewrite and redesign our codes all over again.
- Due to COVID-19 pandemic lockdowns and curfews we faced some difficulties going to workshop and had to start working on our parts and assembling them much later closer to deadline and had to rush in completing them.
- We also had to revaluate our budget to cover all the expenses due to the constraints encountered above

CHAPTER 7 - CONCLUSIONS and FUTURE WORKS

7.1. The conclusions

All deliverables put forth in the project proposal were effectively met. The designer originally envisioned the AGV to be a very speedy vehicle. Despite its ability to follow lines at high speeds, it had a tendency of skipping intersections. Despite the fact that our AGV had to be slowed, it was still far faster than it should have been, and it met the requirements. The design project for the AGV went relatively smoothly. Inverter was the source of the most vexing issues. The project had circuit problems and burned plenty of electronics for conversion of electricity.

The AGV sanitizer robot has shown a new approach towards cleansing and killing germs in closed rooms. This robot can reach non accessible parts and surfaces with higher speed and efficiency. Moulds, bacteria's and viruses are the germs which will be wiped out. The feature of line following will allow the robot to follow and cleanse high priority places.

7.2. The future works

There are many areas for improvement on this project. Smarter robots and safer UV lamps can be studied to improve this idea. Smart routing systems such as neural network and neuro fuzzy path fining techniques can be an idea to improve this systems movement and cleaning. Swarm UV sanitization robots and their connections can also be implemented and researched in this field. The easiest improvement would be to add iot systems to agv and improve control with graphical software in mobile phones.

REFERENCE

[1] AGV Network. (2020, June 6). *Automated Forklift*. Retrieved from agvnetwork: https://www.agvnetwork.com/automatic-forklift-agv

[2] ANSI Webstore. (2009). *Standards*. Retrieved from ANSI Webstore: https://webstore.ansi.org/standards/din/vdi2510blatt2009

[3] ANSI Webstore. (2012). *Standards*. Retrieved from Webstore: https://webstore.ansi.org/Standards/ANSI/ANSIITSDFB562019-2388609

[4] Arduino. (n.d.). *Arduino Uno*. Retrieved from Arduino: https://www.arduino.cc/en/pmwiki.php?n=Main/arduinoBoardUno

[5] Automated Guided Vehicles. (2020, June 6). *Towing Vehicles*. Retrieved from automatedguidedvehicles: https://www.automaticguidedvehicles.com/towing-vehicles/

[6] Barrett, A. “. (1953). *Automated Guided Vehicles*. Retrieved from https://www.automaticguidedvehicles.com/#read

[7] Bell, J., MacDonald, B., SeokAhn, H., & Scarfe, A. (2016). An Analysis of Automated Guided Vehicle Standards to Inform the Development of Mobile Orchard Robots. *Science Direct*, 1.

[8] Goldman, E. (2020, December 28). *Still Disinfecting Surfaces? It Might Not Be Worth It*. Retrieved from npr: https://www.npr.org/sections/health-shots/2020/12/28/948936133/still-disinfecting-surfaces-it-might-not-be-worth-it

[9] Indiamart. (2020, June 6). *Natural (Laser Based) Unit Load*. Retrieved from Indiamart: https://www.indiamart.com/proddetail/unit-load-100-kg-automated-guided-vehicle-agv-11840324930.html

[10] Jha, G., & Choudhary, S. (2020, August 28). *Pinaka - A UVD(UV Disinfect) Robot*. Retrieved from Hackster: https://www.hackster.io/covid-warrior/pinaka-a-uvd-uv-disinfect-robot-d2ccaa

[11] National Environmental Agency. (2020, September 9). *Safety Guidelines for Use of UVC Devices in Commercial/Industrial Settings*. Retrieved from National Environmental Agency: https://www.nea.gov.sg/our-services/radiation-safety/safety-guidelines-for-use-of-UV-C-devices

[12] Nicolai, L., Burns, B., & Vanderbei, M. (2017). *Automated Flat Surface UV Sanitizer*. Retrieved from https://sites.psu.edu/lan5200/files/2016/01/EE403WDesignProposal-19azlfq.pdf

[13] PE, Y., & Kelly, J. (n.d.). *All about Safety: UV-C Hazards and Risks*. Retrieved from glhn: https://glhn.com/wp-content/uploads/2020/10/All-About-Safety-UV-C-Hazards-and-Risks.pdf

[14] Philips. (n.d.). *UV-Disinfection*. Retrieved from usa lightings philip: https://www.usa.lighting.philips.com/products/uv-disinfection

[15] S, S. (2020, June 6). *Arduino Based Foot Pressure Sensitive Smart Safety System for Industrial Robots*. Retrieved from Research Gate: https://www.researchgate.net/figure/Labelled-Arduino-Board-11-ii-The-Arduino-IDE-Software-part-Arduino-environment-is_fig3_321262788

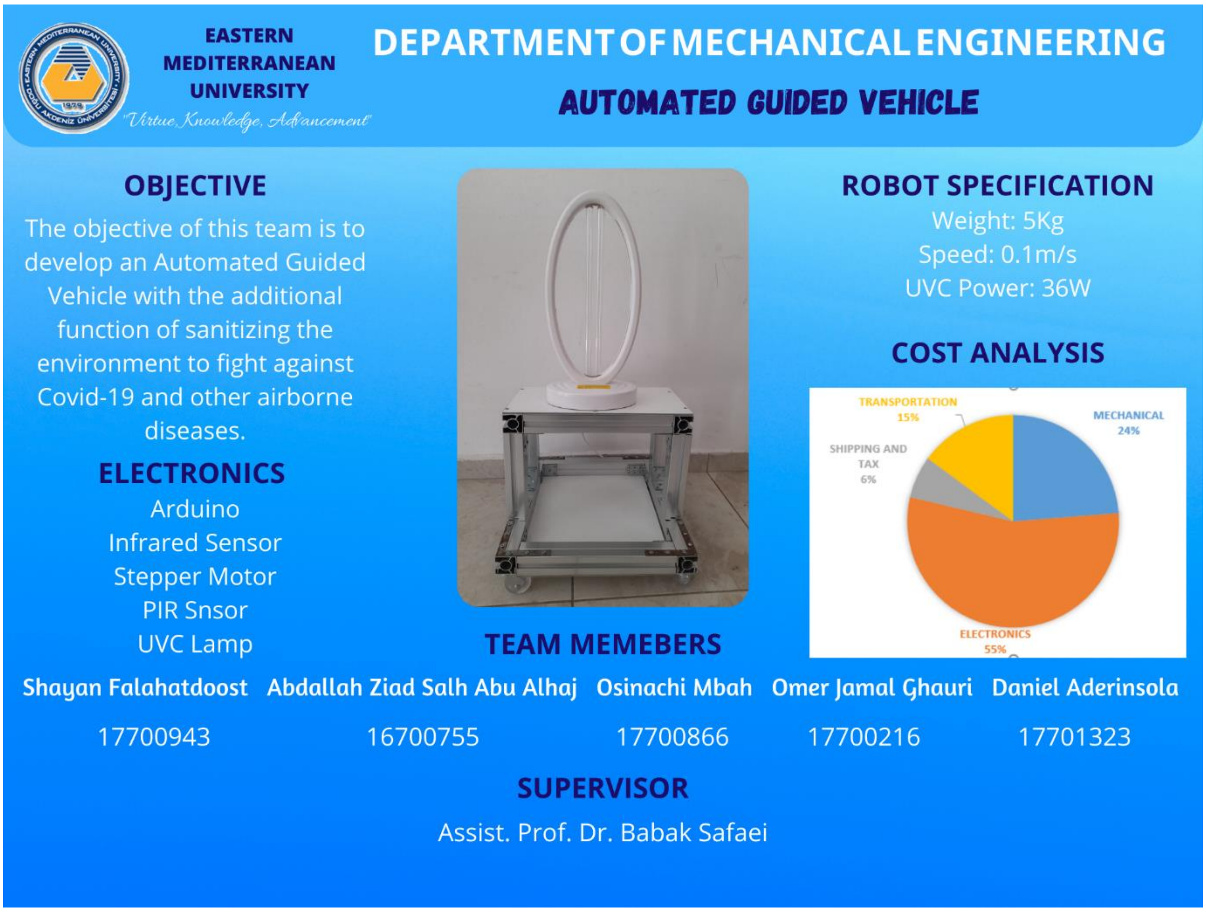
[16] Techbro. (n.d.). *Arduino Uno Rev 3*. Retrieved from Techbro: https://www.techbro.nl/en/developmentboards/15-arduino-uno-rev3.html

[17] UL. (2020). Retrieved from UL: https://www.google.com/url?sa=i&url=https%3A%2F%2Fcrc.ul.com%2Fshared%2Fdownload%2F27aLxy7HTQitFU5aWLvP1GRJ&psig=AOvVaw0ToivhDNb_YfHAkWV4GRVe&ust=1610264168373000&source=images&cd=vfe&ved=0CAIQjRxqFwoTCIjT49mrju4CFQAAAAAdAAAAABAD

[18] Wolf. (n.d.). *UV-C*. Retrieved from myuvcare: https://www.myuvcare.com/uv-c

[19] Zhang, J. (2020). *Automated Guided Vehicle*. Retrieved from media.timetoast: https://media.timetoast.com/timelines/automated-guided-vehicle

APPENDIX A: Electronic Media



APPENDIX B: Constraints

Table 9: Project constraints

Constraints	Yes	No
Economic	X	
Environmental	X	
Reliability	X	
Availability	X	
Manufacturability	X	
Ethical		X
Social		X
Political		X
Health & safety	X	
Efficiency	X	

APPENDIX C: standards

VDI 2510 Blatt 1:2009: Infrastructure and Peripheral Installations for Automated Guides Vehicle Systems (AGVS) (Foreign Standard)

ISO 15858:2016 : UV-C Devices — Safety information — Permissible human exposure

IEC 62471:2006: Photobiological safety of lamps and lamp systems

ISO 9283:1998: Manipulating industrial robots — Performance criteria and related test methods

VDI 4451-6: 2003: Compatibility Of Automated Guided Vehicle Systems (AGVS) - Sensor Systems For Navigation And Control

ISO/TR 23482-1:2020: Robotics — Application of ISO 13482 — Part 1: Safety-related test methods

IEC 60417: Graphical Symbols for Use on Equipment

ANSI B56.5 – 2012: Safety Standard for Driverless, Automatic Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles.

EN1525: 1997: Safety Of Industrial Trucks - Driverless Trucks And Their Systems.

ISO 15858:2016: UV-C Devices — Safety Information — Permissible Human Exposure

ISO 15727:2020: UV-C Devices — Measurement of the Output of A UV-C Lamp

ISO 3691-4:2020: Industrial AGV Trucks — Safety Requirements and Verification

ISO 10218-1:2011: Robots And Robotics Devices – Safety Requirements For Industrial Robots.

ISO 8373:2012: Robots and Robotics Devices – Vocabulary

ISO 9787:2013: Robots and Robotics Devices – Coordinate Systems and Motion Nomenclature

ISO 9283:1998: Manipulating Industrial Robots: Performance Criteria and Related Test Methods.

IEC 62061:2005+AMD1:2012: Safety Of Machinery - Functional Safety Of Safety-Related Electrical, Electronic And Programmable Electronic Control Systems

ISO 225:2010: Fasteners — Bolts, Screws, Studs and Nuts — Symbols and Descriptions of Dimensions

ISO 128-1:2003: Technical Drawings — General Principles of Presentation

ANSI/ITSDF B56.5 – 2005: Safety Standard for Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles

APPENDIX D: Logbook

TABLE 10: LOGBOOK

Date	Brief description of the performed work
5/10/2020	Team members meeting to brainstorm and share ideas about the project. Also, research task was assigned.
12/10/2020	Team members meeting to reach a consensus about the concept of the project. Also, a Gantt chart was developed and tasks was assigned. In addition, a skeleton of the report was make known to the team members by the team leader.
19/10/2020	Team members meeting to discuss tasks assigned on (12/4). Report writing commerce, and new task were also assigned.

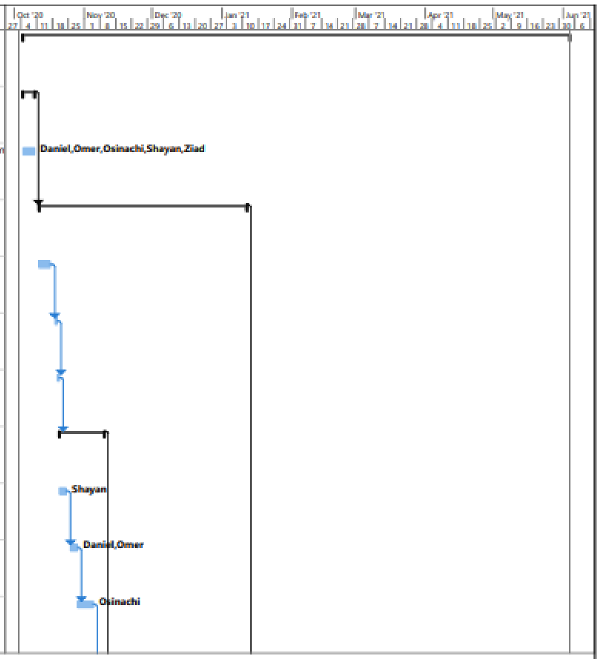
26/10/2020	Team members meeting to discuss tasks assigned on (19/4), and also a new report writing task was assigned.
3/11/2020	Team members meeting for a brief overview of the report, and also a new report writing task was assigned.
10/12/2020	Team members meeting to discuss tasks assigned on (3/5). New task was also assigned.
17/12/2020	Team members meeting to discuss tasks assigned on (10/5). Report compilation commenced.

31/12/2020	Team members meeting for an overview of the report and a task of Individual assessment of the report was assigned.
12/03/2021	Team members meeting to finalize the design and order the components.
19/03/2021	Team members meeting to edit the SOLIDWORKS design and do the simulation
26/03/2021	Team members meeting to receive the ordered components and buy the other components from local stores.
02/04/2021	Team members meeting at the workshop to assemble the frame.
09/04/2021	Team members meeting to write the Arduino codes and test the electronic components like sensor.

16/04/2021	Team members meeting at workshop to fit in the motors and wheels to the frame.
23/04/2021	Team members meeting to test the AGV and buy the damaged components.
30/04/2021	Team members meeting to connect the UV-C lamp to the AGV.
07/05/2021	Team members meeting to edit the Capstone 1 report
14/05/2021	Team members meeting to finish up the appendices and engineering drawings.
21/05/2021	Team members meeting to finalize the report and to do final test on line follower AGV.

APPENDIX E: Gantt chart

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1			**AUTOMATED GUIDED VEHICLE**	**174 days**	**Mon 10/5/20**	**Thu 6/3/21**		
2			**Initialization**	**5 days**	**Mon 10/5/20**	**Fri 10/9/20**		
3			Discussion on the project	1 wk	Mon 10/5/20	Fri 10/9/20		Daniel,Omer,Osin
4			**Planning**	**66 days**	**Mon 10/12/20**	**Mon 1/11/21**	**2**	
5			Research on the project	1 wk	Mon 10/12/20	Fri 10/16/20		
6			Meeting to discuss on our reseaech work	1 day	Mon 10/19/20	Mon 10/19/20	5	
7			Discussion about the report	1 day	Tue 10/20/20	Tue 10/20/20	6	
8			**Distribution of task**	**14 days**	**Wed 10/21/20**	**Mon 11/9/20**	**7**	
9			Prepare abstract	3 days	Wed 10/21/20	Fri 10/23/20		Shayan
10			Prepare introduction	3 days	Mon 10/26/20	Wed 10/28/20	9	Daniel,Omer
11			Design a concept of the robot	1 wk	Thu 10/29/20	Wed 11/4/20	10	Osinachi

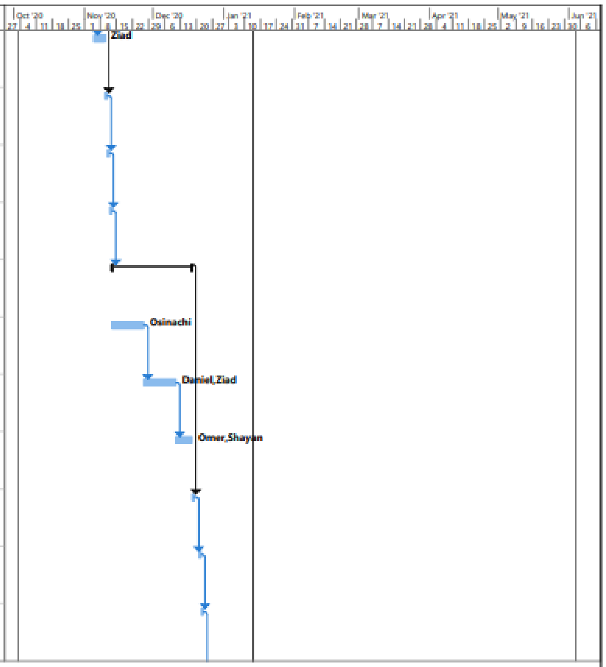


Project: g chart 2
Date: Sat 10/3/20

Task, Split, Milestone, Summary, Project Summary, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, External Tasks, External Milestone, Deadline, Progress, Manual Progress

Page 1

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names
12			Prepare report about UV lamps	3 days	Thu 11/5/20	Mon 11/9/20	11	Ziad
13			Discussion about the tasks done	1 day	Tue 11/10/20	Tue 11/10/20	8	
14			Review of AGV concept design and changes to me made	1 day	Wed 11/11/20	Wed 11/11/20	13	
15			Review on types UV lamp and the one needed for our project	1 day	Thu 11/12/20	Thu 11/12/20	14	
16			**Tasks assigned**	**25 days**	**Fri 11/13/20**	**Thu 12/17/20**	**15**	
17			Design of robot on solidworks	2 wks	Fri 11/13/20	Thu 11/26/20		Osinachi
18			Chapter 2 of report	2 wks	Fri 11/27/20	Thu 12/10/20	17	Daniel,Ziad
19			Research on electronic components needed	1 wk	Fri 12/11/20	Thu 12/17/20	18	Omer,Shayan
20			Discussion on task done and second concept of AGV	1 day	Fri 12/18/20	Fri 12/18/20	16	
21			Review of the report and discussion of where to buy	1 day	Mon 12/21/20	Mon 12/21/20	20	
22			Meeting with supervisor	1 day	Tue 12/22/20	Tue 12/22/20	21	

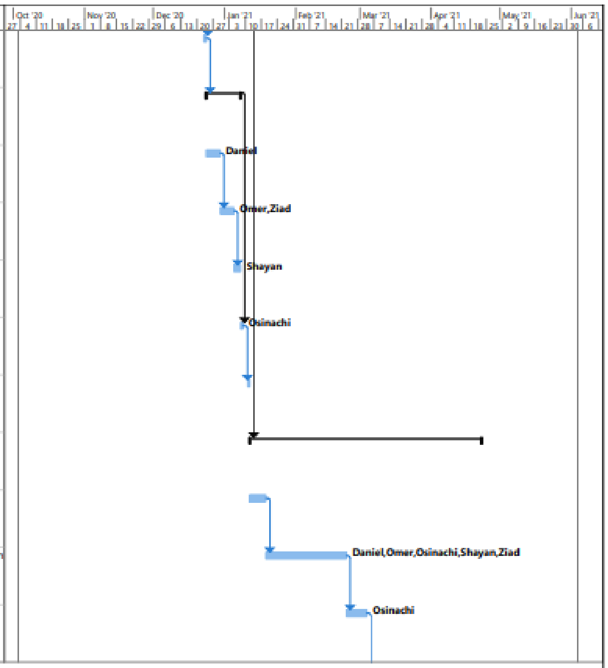


Project: g chart 2
Date: Sat 10/3/20

Task, Split, Milestone, Summary, Project Summary, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, External Tasks, External Milestone, Deadline, Progress, Manual Progress

Page 2

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names
23			Discussion on manufacturing and assembly process	1 day	Wed 12/23/20	Wed 12/23/20	22	
24			**Task assigned to complete the report**	**11 days**	**Thu 12/24/20**	**Thu 1/7/21**	**23**	
25			Chapter 3	4 days	Thu 12/24/20	Tue 12/29/20		Daniel
26			Chapter 4	4 days	Wed 12/30/20	Mon 1/4/21	25	Omer,Ziad
27			Chapter 5	3 days	Tue 1/5/21	Thu 1/7/21	26	Shayan
28			Reviewing report and making changes	1 day	Fri 1/8/21	Fri 1/8/21	24	Osinachi
29			Submission of report	1 day	Mon 1/11/21	Mon 1/11/21	28	
30			**Execution**	**73 days**	**Tue 1/12/21**	**Thu 4/22/21**	**4**	
31			Review solidworks design	1 wk	Tue 1/12/21	Mon 1/18/21		
32			Order components from online store	5 wks	Tue 1/19/21	Mon 2/22/21	31	Daniel,Omer,Osin
33			Get aluminium profile and Aluminium composite	7 days	Tue 2/23/21	Wed 3/3/21	32	Osinachi

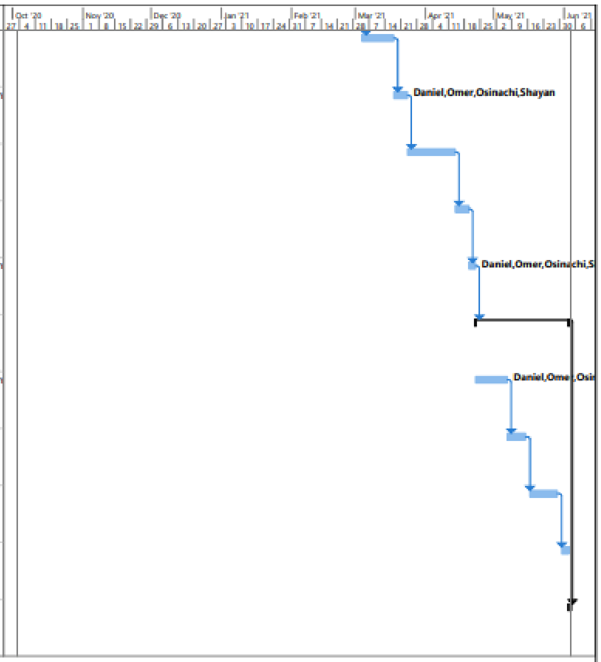


Project: g chart 2
Date: Sat 10/3/20

Task	Project Summary	Manual Task	Start-only	Deadline
Split	Inactive Task	Duration-only	Finish-only	Progress
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress
Summary	Inactive Summary	Manual Summary	External Milestone	

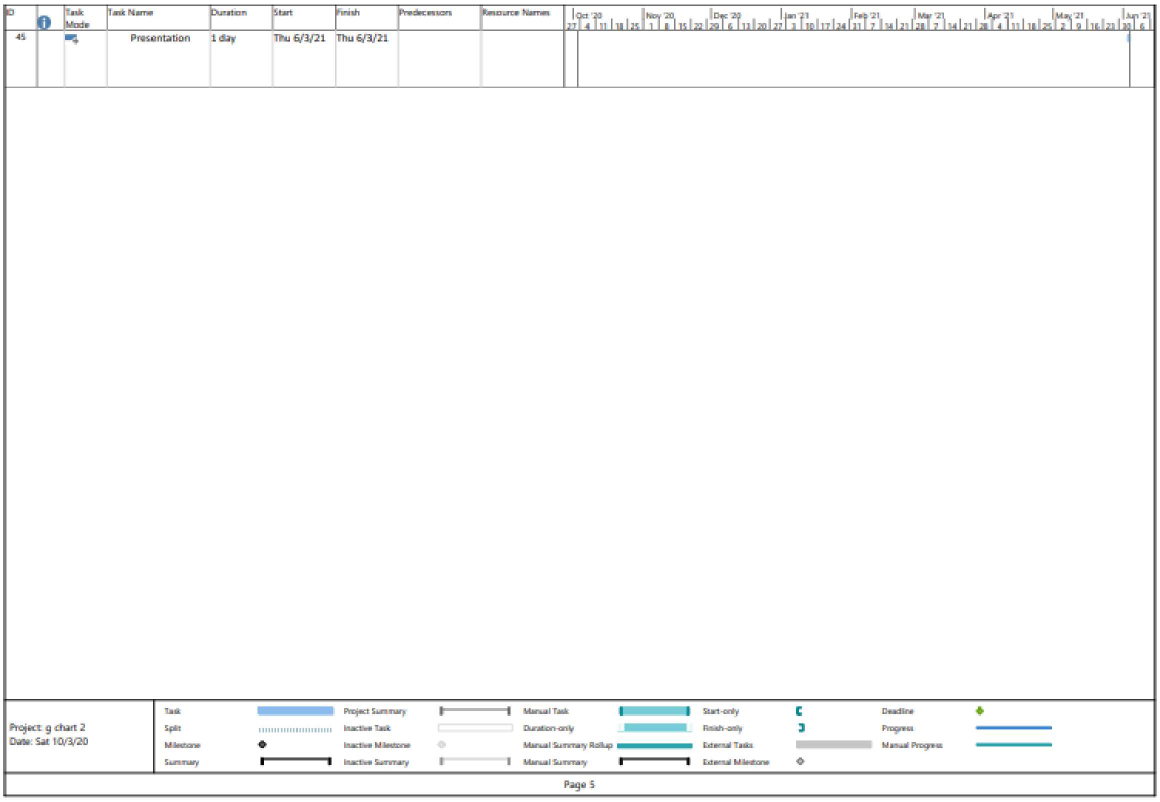
Page 3

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names
34			Buy electronics from local store	2 wks	Thu 3/4/21	Wed 3/17/21	33	
35			Assemble the aluminium profile at the workshop	4 days	Thu 3/18/21	Tue 3/23/21	34	Daniel,Omer,Osin
36			Source for and buy a better motor with high torque	3 wks	Wed 3/24/21	Tue 4/13/21	35	
37			Buy caster wheels and bracket	4 days	Wed 4/14/21	Mon 4/19/21	36	
38			Drill holes on bracket for motor	3 days	Tue 4/20/21	Thu 4/22/21	37	Daniel,Omer,Osin
39			**Monitoring and Controlling**	**29 days**	**Fri 4/23/21**	**Wed 6/2/21**	**38**	
40			Write and test codes to run the robot	10 days	Fri 4/23/21	Thu 5/6/21		Daniel,Omer,Osin
41			Perform Test on the performance of UV-C lamp	6 days	Fri 5/7/21	Fri 5/14/21	40	
42			Update report with manufacturing processes	10 days	Mon 5/17/21	Fri 5/28/21	41	
43			Submit report to supervisor	3 days	Mon 5/31/21	Wed 6/2/21	42	
44			**Closing**	**1 day**	**Thu 6/3/21**	**Thu 6/3/21**	**39**	

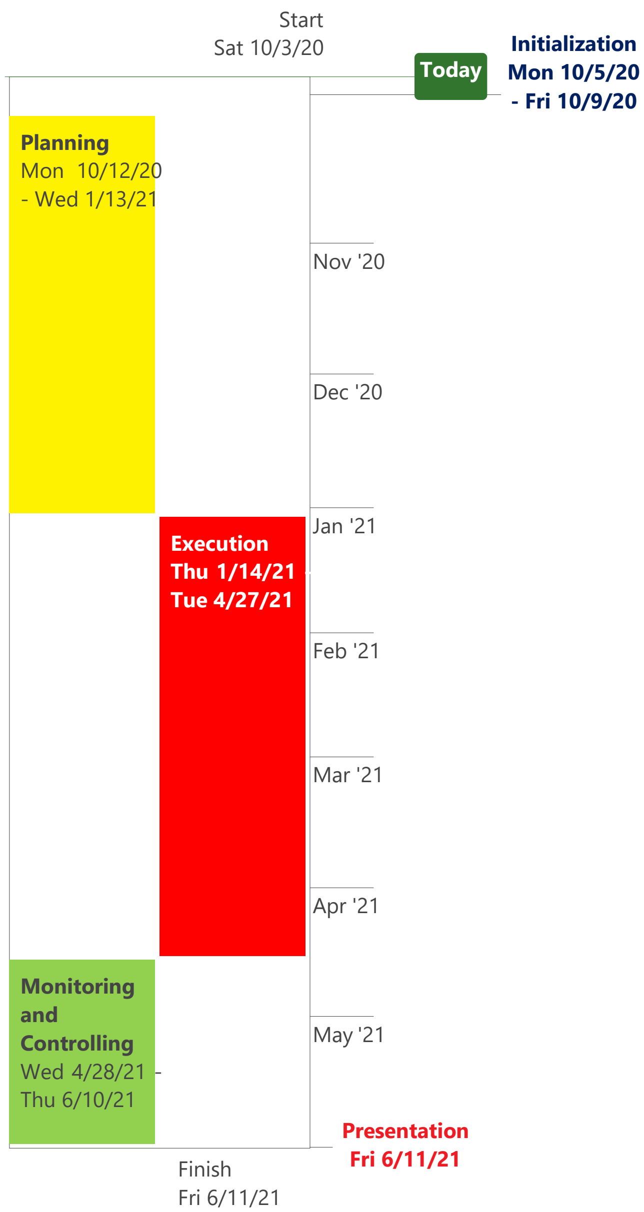


Project: g chart 2
Date: Sat 10/3/20

Task, Split, Milestone, Summary, Project Summary, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, External Tasks, External Milestone, Deadline, Progress, Manual Progress


ID
Task Mode
Task Name
Duration
Start
Finish
Predecessors
Resource Names
Oct '20
Nov '20
Dec '20
Jan '21
Feb '21
Mar '21
Apr '21
May '21
Jun '21
45
Presentation
1 day
Thu 6/3/21
Thu 6/3/21
Project: g chart 2
Date: Sat 10/3/20
Task
Split
Milestone
Summary
Project Summary
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
External Tasks
External Milestone
Deadline
Progress
Manual Progress
Page 5

APPENDIX F: Project Timeline



APPENDIX G: Arduino Codes

```
#include <Stepper.h>

#define Speed 50



//enter the steps per rev for your motors here

int stepsInRev = 200;



//Sensor Connection



const int dirPin1 = 2;

const int stepPin1 = 3;

const int dirPin2 = 4;

const int stepPin2 = 5;

const int relay_pin = 7;

const int pir_sensor_pin = 8;

const int left_sensor_pin = 11;
```

```
const int right_sensor_pin = 10;

const int trigPin = 12;

const int echoPin = 13;

int pir_sensor_state;

int left_sensor_state;

int right_sensor_state;

int toggleL=0,toggleR=0;

int duration, distance;

int num_of_steps=0;

Stepper myStepper1(stepsInRev, stepPin1, dirPin1); //Left Step 3, Dir2

Stepper myStepper2(stepsInRev, stepPin2, dirPin2); //Right Step 5, Dir4
```

```
void setup() {
  pinMode(dirPin1, OUTPUT);
  pinMode(stepPin1, OUTPUT);
  pinMode(dirPin2, OUTPUT);
  pinMode(stepPin2, OUTPUT);
  pinMode(relay_pin,OUTPUT);
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
  pinMode(pir_sensor_pin,INPUT);
  pinMode(left_sensor_pin, INPUT);
  pinMode(right_sensor_pin , INPUT);


  //Serial.begin(9600);
}
```

```
void loop() {

  //read ir sensors to know what crossed the tape

  left_sensor_state = digitalRead(left_sensor_pin);

  right_sensor_state = digitalRead(right_sensor_pin);



  pir_sensor_state = digitalRead(pir_sensor_pin);



  digitalWrite (trigPin, HIGH);

  digitalWrite (trigPin, LOW);

  duration=pulseIn(echoPin,HIGH);

  distance=(duration/2)/29.1;



 if(num_of_steps>=4000){
```

```
 delay(5000);

 num_of_steps=0;

}

  if(distance>=30){

   digitalWrite(relay_pin,LOW); //UV_C lamp on

  }

if (pir_sensor_state==1 || distance <=30){ //--------------------------

    //Stops

   digitalWrite(relay_pin,HIGH); // UV-C lamp off
```

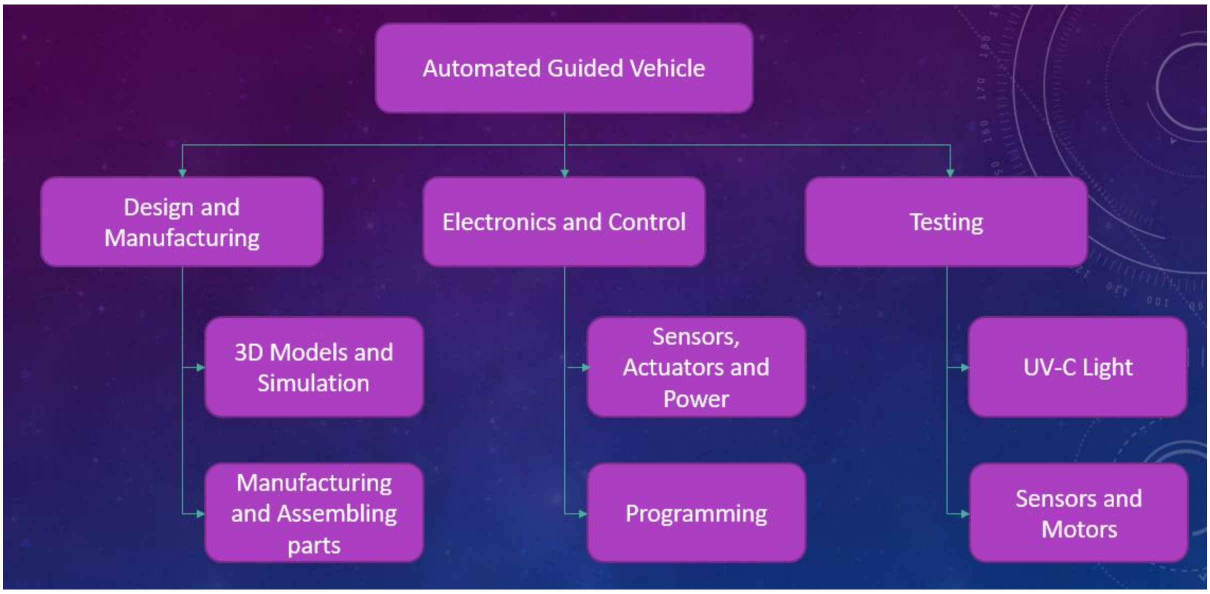
```
  digitalWrite(stepPin1, LOW);

  digitalWrite(stepPin2, LOW);



} else if (right_sensor_state && !left_sensor_state) { //--------------------------

  //turns right

  //Serial.println("Right");

  myStepper1.setSpeed(Speed);

  myStepper2.setSpeed(Speed);

  myStepper1.step(3);

  if (toggleL==0)

  myStepper2.step(1);

  toggleR=0;

  toggleL++;



} else if (!right_sensor_state && left_sensor_state) { //--------------------------

  //turns left
```

```
  //Serial.println("Left");

  myStepper1.setSpeed(Speed);

  myStepper2.setSpeed(Speed);

  if (toggleR==0)

  myStepper1.step(1);

  myStepper2.step(3);

  toggleL=0;

  toggleR++;



} else if (!right_sensor_state && !left_sensor_state) { //--------------------------

  //moves forward

  //Serial.println("Forward");

  myStepper1.setSpeed(Speed);

  myStepper2.setSpeed(Speed);

  myStepper1.step(1);

  myStepper2.step(1);
```

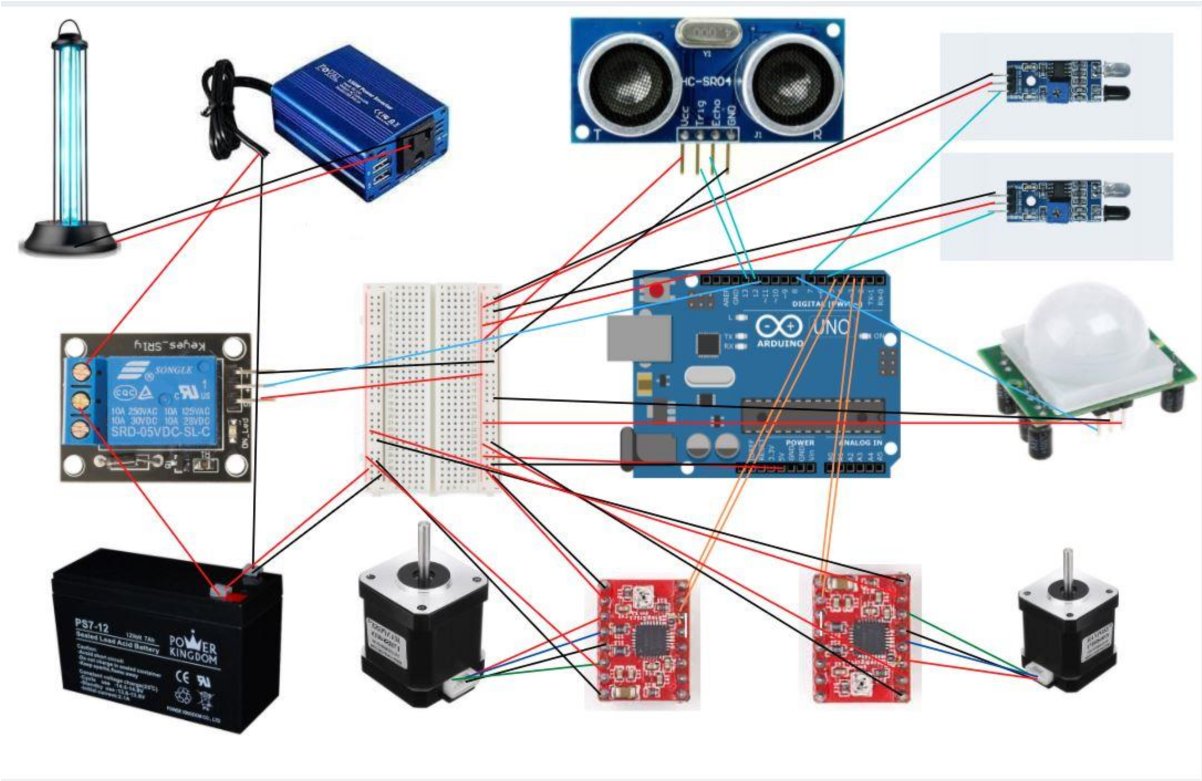
```
} else if (right_sensor_state && left_sensor_state) { //--------------------------

  //Stops

  digitalWrite(relay_pin,HIGH);

  digitalWrite(stepPin1, LOW);

  digitalWrite(stepPin2, LOW);



}




if (toggleL==4)

toggleL=0;

if (toggleR==4)

toggleR=0;

num_of_steps++;
```

}

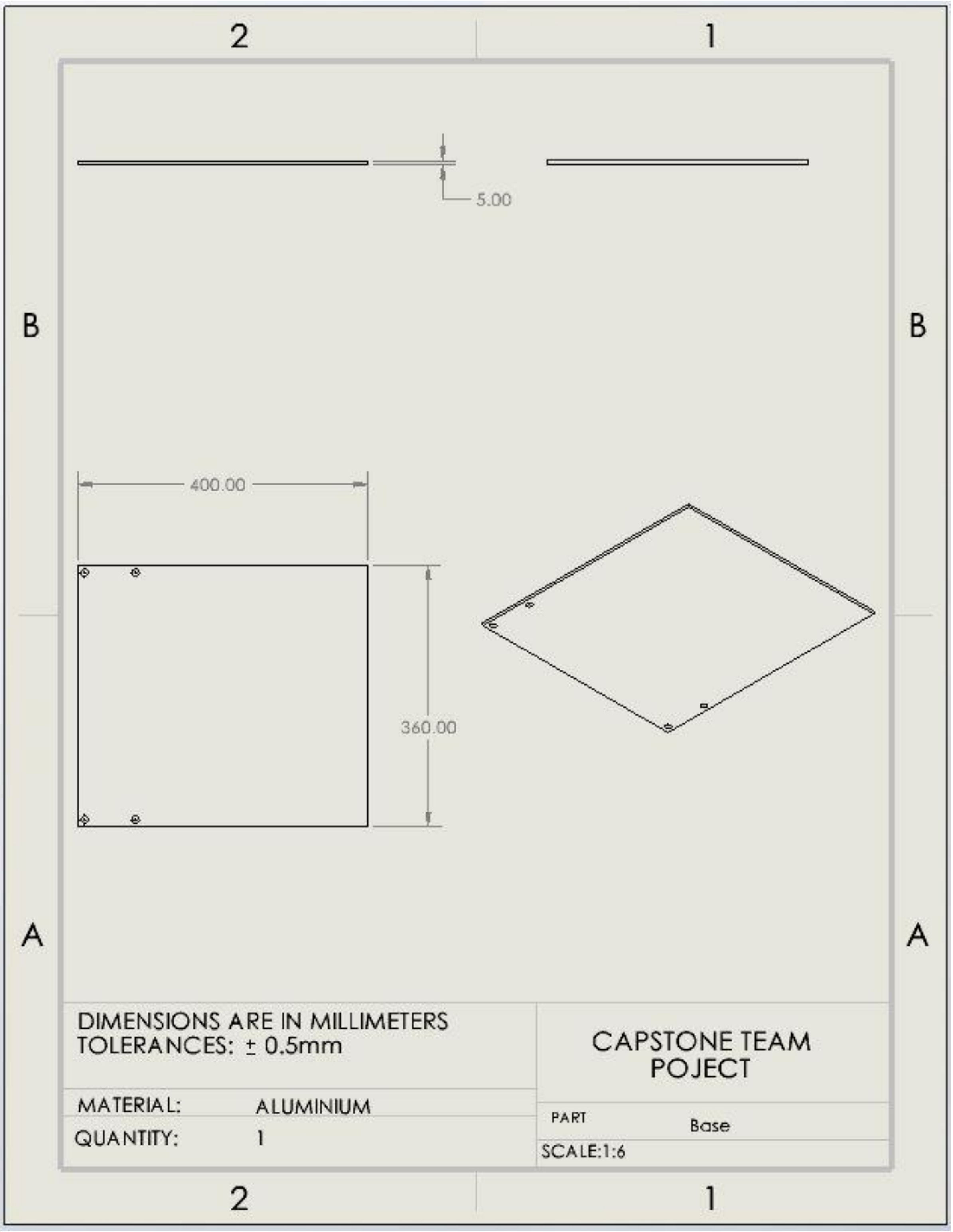
APPENDIX H: Structure Breakdown

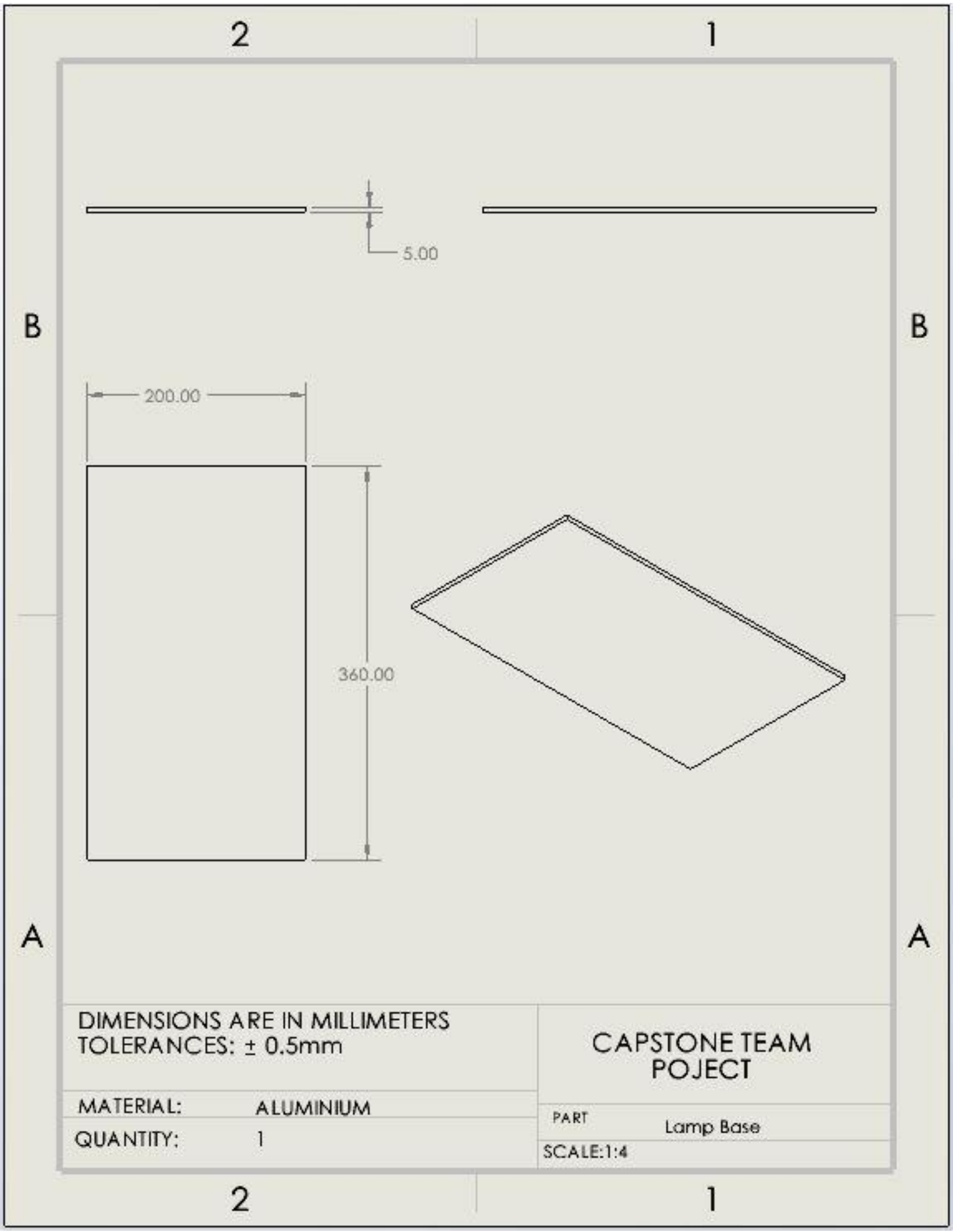


APPENDIX I: Circuit Design

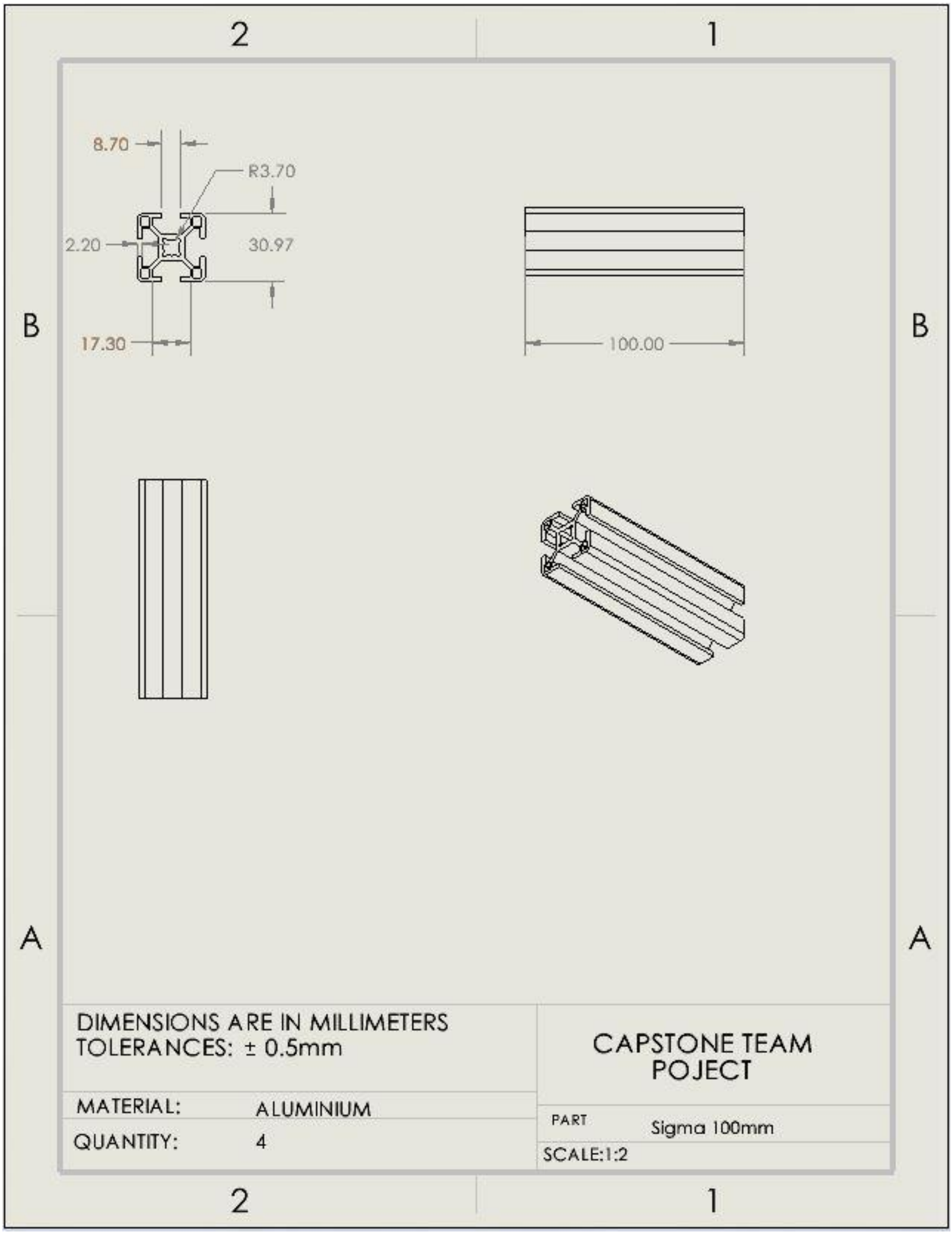


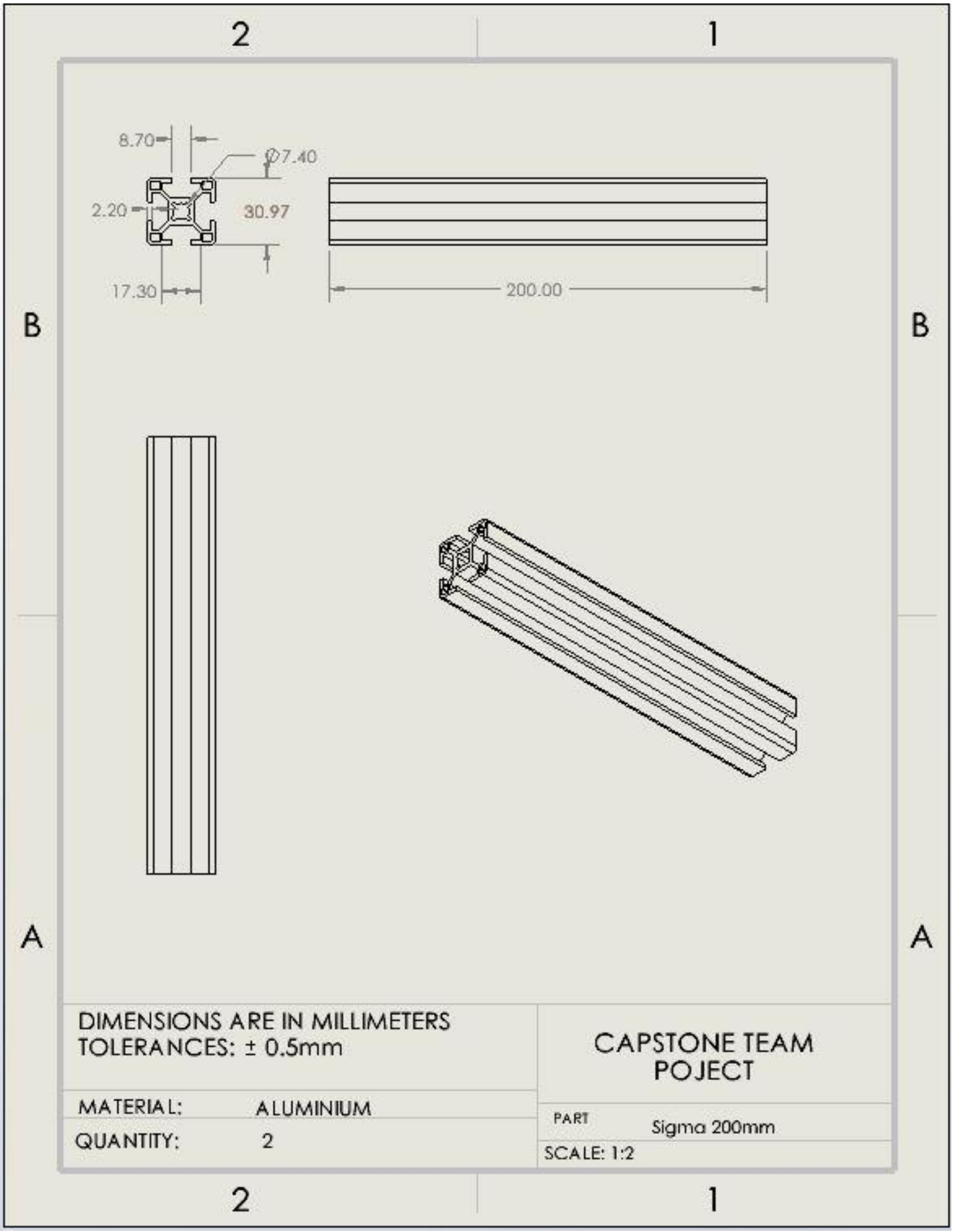
APPENDIX J: Engineering Drawing



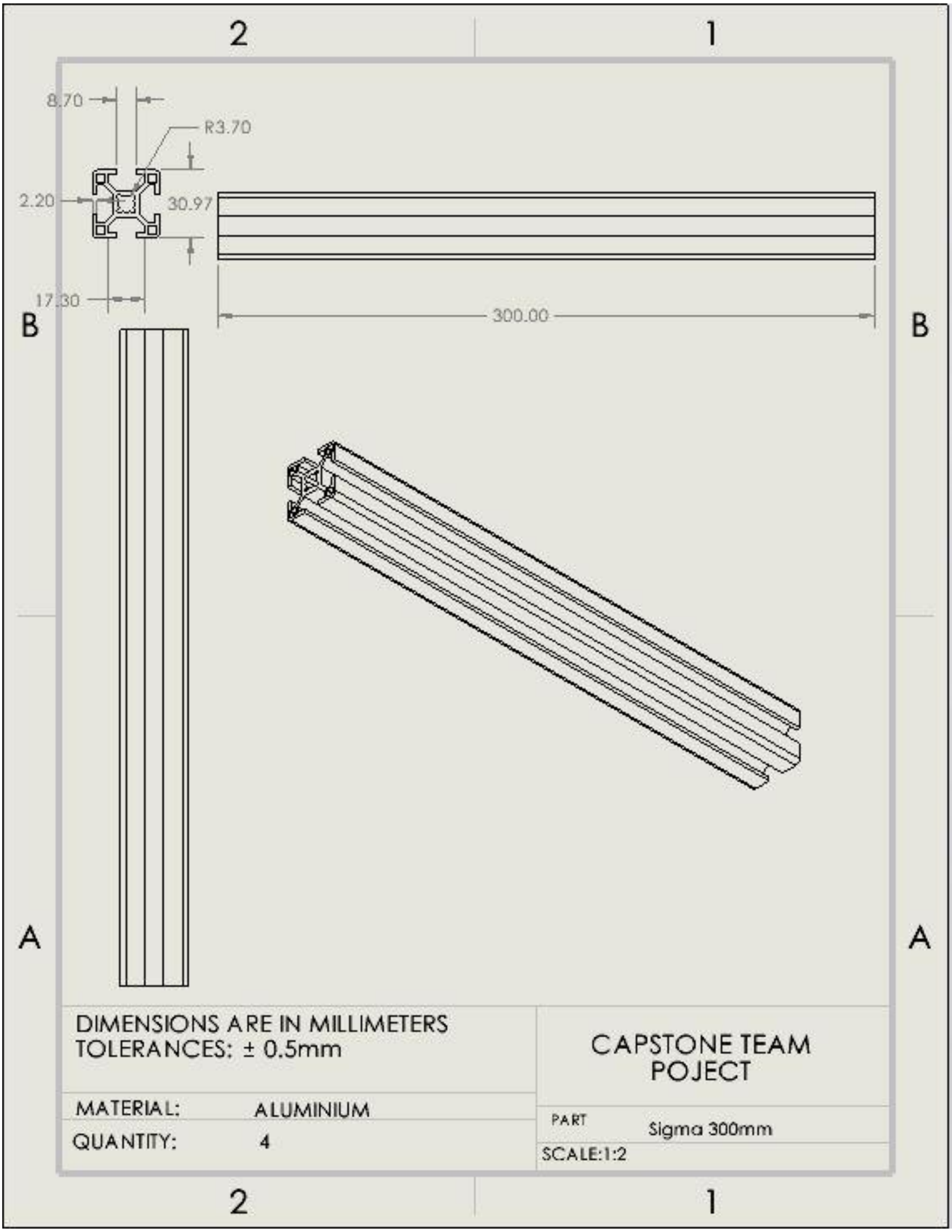


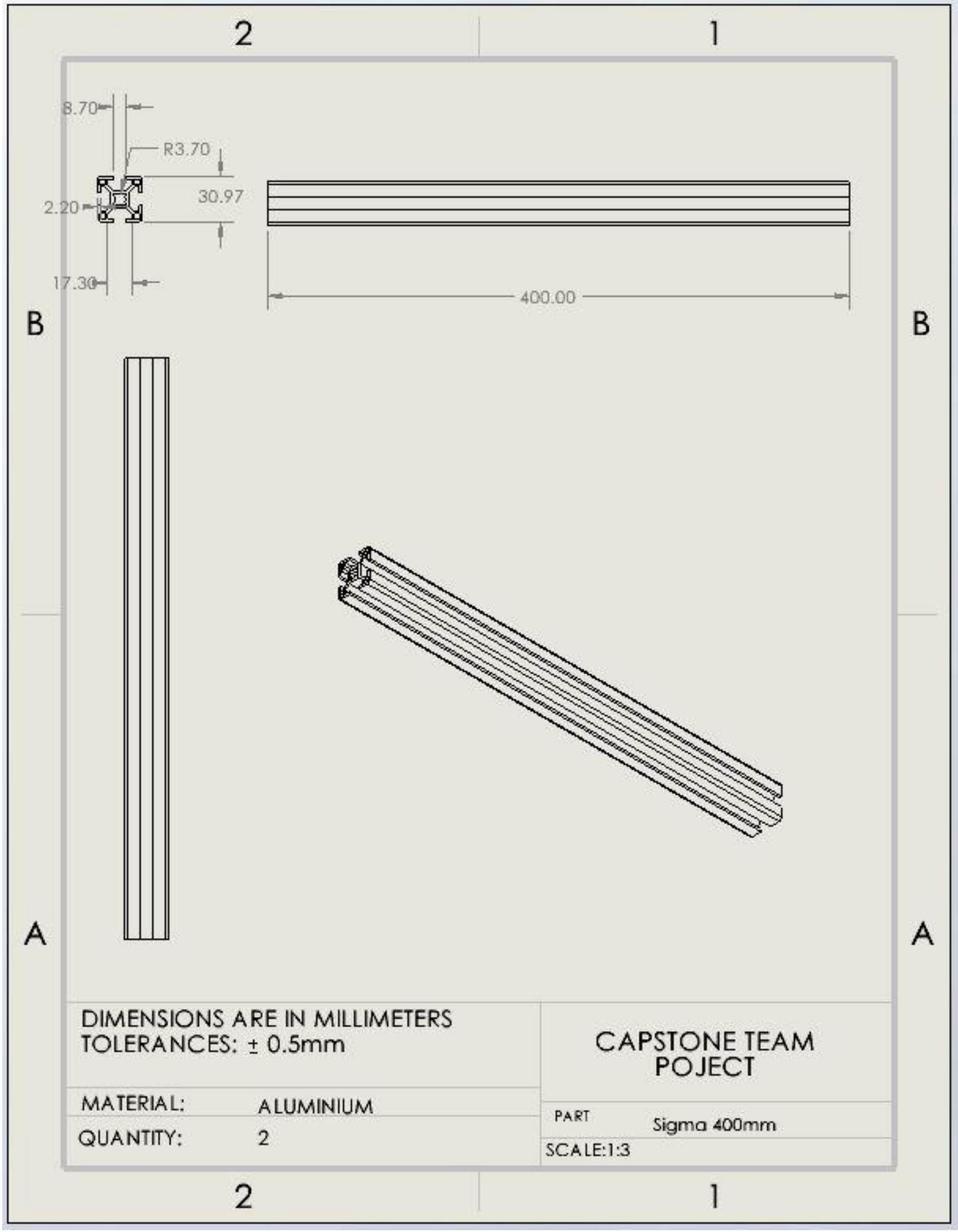
2
1
B
A
5.00
200.00
360.00
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: ± 0.5mm
MATERIAL: ALUMINIUM
QUANTITY: 1
CAPSTONE TEAM POJECT
PART Lamp Base
SCALE:1:4


2
1
8.70
R3.70
2.20
30.97
17.30
100.00
B
A
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: ± 0.5mm
MATERIAL: ALUMINIUM
QUANTITY: 4
CAPSTONE TEAM POJECT
PART Sigma 100mm
SCALE:1:2

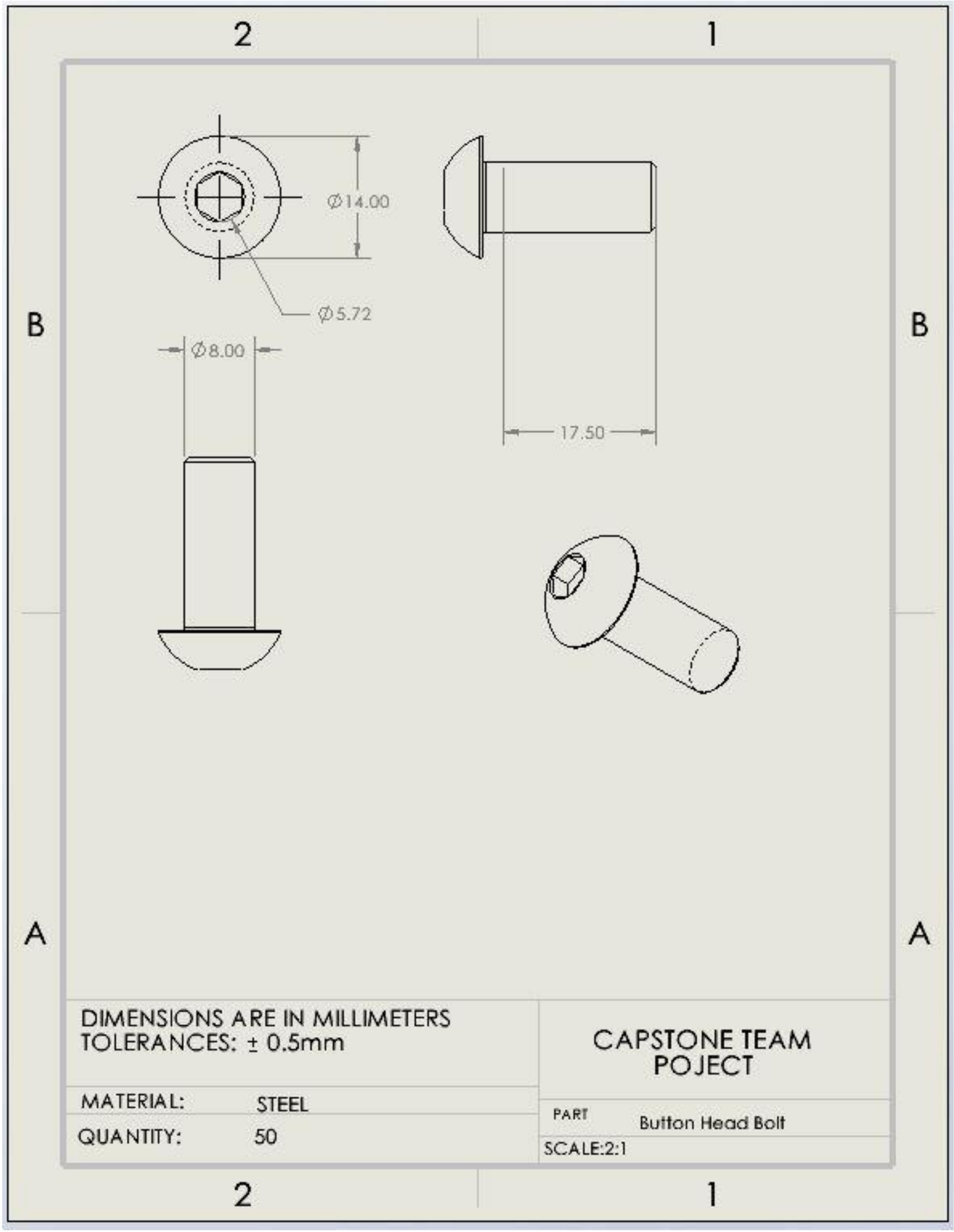


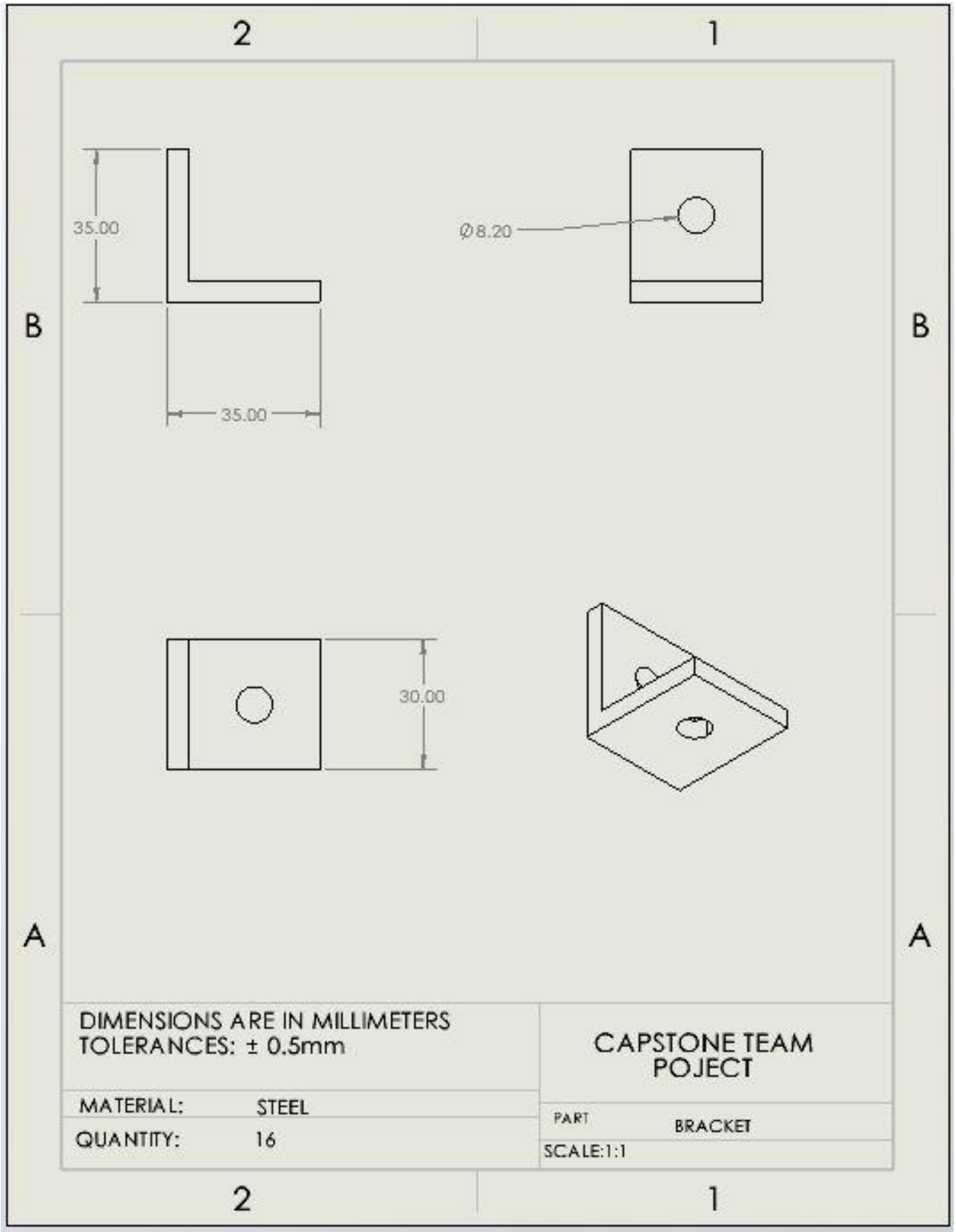
2
1
B
A
8.70
Ø7.40
2.20
30.97
17.30
200.00
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: ± 0.5mm
MATERIAL: ALUMINIUM
QUANTITY: 2
CAPSTONE TEAM POJECT
PART Sigma 200mm
SCALE: 1:2


2
1
8.70
R3.70
2.20
30.97
17.30
300.00
B
B
A
A
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: ± 0.5mm
MATERIAL: ALUMINIUM
QUANTITY: 4
CAPSTONE TEAM POJECT
PART Sigma 300mm
SCALE:1:2
2
1

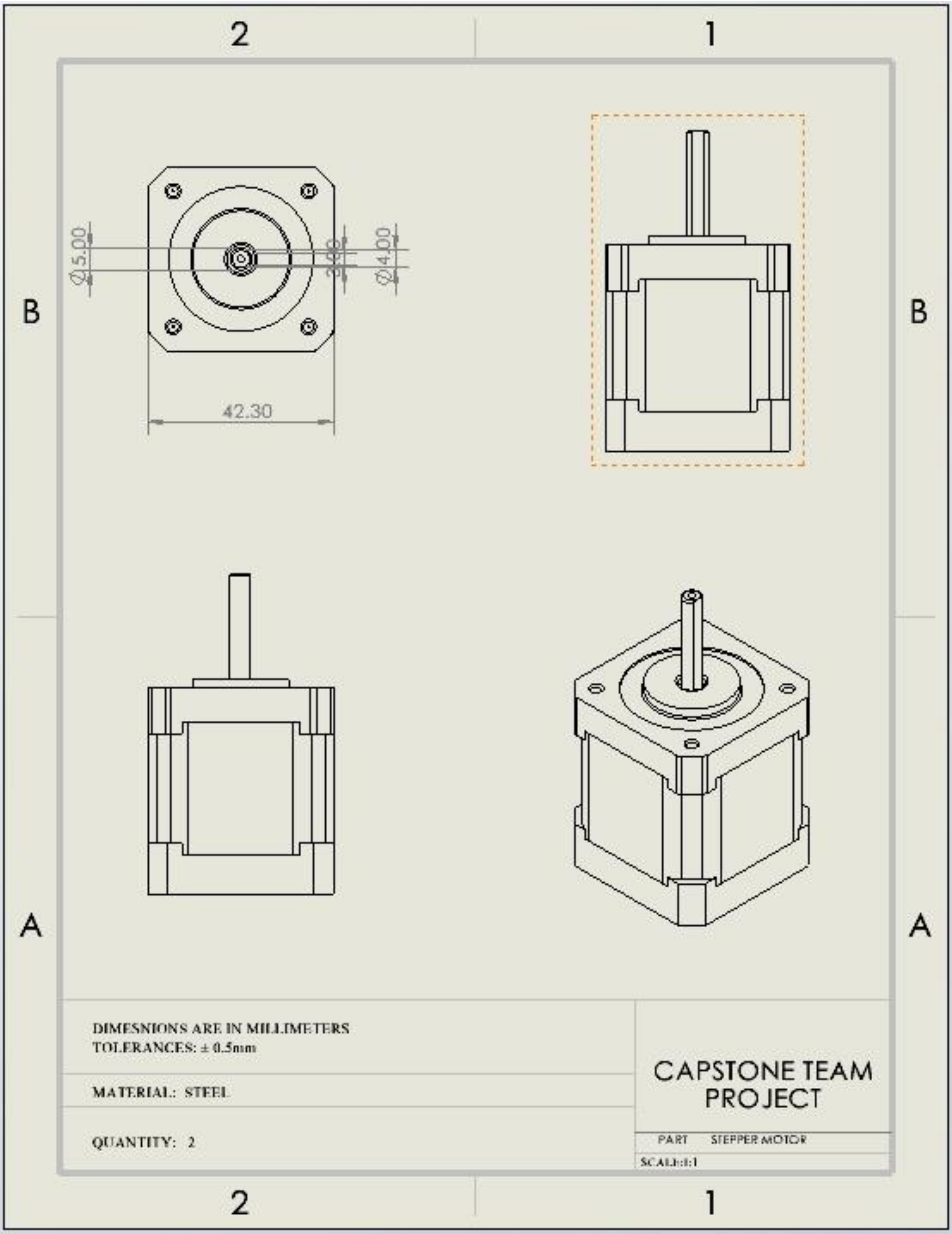


2
1
8.70
R3.70
30.97
2.20
17.30
400.00
B
A
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: ± 0.5mm
MATERIAL: ALUMINIUM
QUANTITY: 2
CAPSTONE TEAM POJECT
PART Sigma 400mm
SCALE:1:3

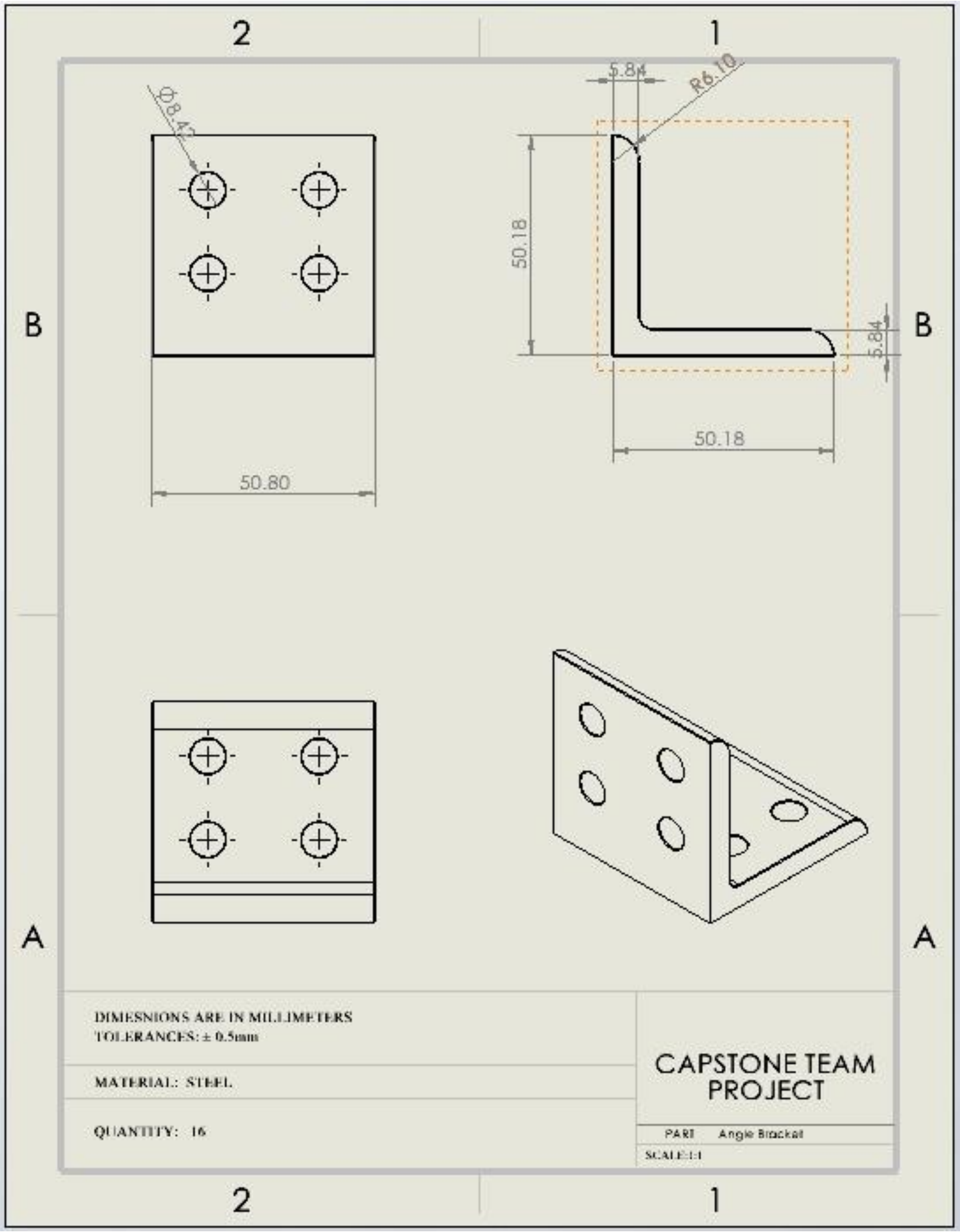

2
1
B
B
A
A
Ø14.00
Ø5.72
Ø8.00
17.50
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: ± 0.5mm
MATERIAL: STEEL
QUANTITY: 50
CAPSTONE TEAM POJECT
PART Button Head Bolt
SCALE:2:1



2
1
B
A
35.00
35.00
Ø8.20
30.00
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: ± 0.5mm
MATERIAL: STEEL
QUANTITY: 16
CAPSTONE TEAM POJECT
PART BRACKET
SCALE:1:1



2
1
B
A
Ø5.00
Ø4.00
42.30
DIMESNIONS ARE IN MILLIMETERS
TOLERANCES: ± 0.5mm
MATERIAL: STEEL
QUANTITY: 2
CAPSTONE TEAM PROJECT
PART STEPPER MOTOR
SCALE:1:1


2
1
Φ8.42
5.84
R6.10
50.18
5.84
50.18
50.80
B
B
A
A
DIMESNIONS ARE IN MILLIMETERS
TOLERANCES: ± 0.5mm
MATERIAL: STEEL
QUANTITY: 16
CAPSTONE TEAM PROJECT
PART Angle Bracket
SCALE:1:1
2
1