

# Introduction to Capstone Design

## MENG 411

**Name of Project:** *Multifunctional Robotic Arm MFRA*

**Group Name:** *MFRA Manufacturers*

**Group Members:**

*15700828                      Mustafa Ghadri*

*16002481                      Emre Kaya*

*16700848                      Mahmoud Akkawi*

*17700140                      Abdullah Alfasieh*

*17700169                      Rana Khaled*

**Supervisor:** *Assoc. Prof. Dr. Mohammed Ismael*

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**Eastern Mediterranean University**  
**Department of Mechanical Engineering**

## **Abstract**

The project discusses a multi-functional robotic arm from the zero phase to its final phase, although it is a completion of a previous term's project, it goes over the plan from the beginning. The project concerns with the manufacturing, advantages, places of use, and design of the multi-functional robotic arm. The significance of the project is to produce a robotic arm with a minimum cost, feasible manufacturing process, and ensuring safety when used. It also shows how to be able to utilize different manufacturing processes using one single machine. Robotic arms are widely used in automotive industry to perform functions such as welding, drilling, packaging, moving parts, and further more, where we usually see the robotic arm as a huge product. This project discusses a possible product where it can carry out these mentioned processes (welding, drilling, and gripping) and maintain a small geometry that can be carried and moved anywhere, and ensure at the same time safety, accuracy, and precision. One of the constraint of this product is its ability to carry out these procedures over large parts due to its small size.

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# **1 Chapter 1 – Introduction**

## **1.1 Detailed Definition of the Project**

We usually see robotic arms in industry as an assist to a manufacturing process in mass production factories; we often see them in huge shapes, each carrying an independent function. Modern robotic arms have decreased in size and updated a lot throughout the past years. Robotic arms are basically mechanical arms that are usually programmable that can assist humans by carrying out difficult or hazardous processes, such as welding, painting, assembly, drilling, screw driving, packaging, and labeling, or gripping.

This project combines the different functions of different robotic arms into one robotic arm. Multifunctional or multipurpose robotic arms are not so popular, thus this project where we can show and discuss the manufacturing process of a multipurpose robotic arm and shed more light on it through the process. This project concerns on three basic functions of a robotic arm; welding, screw driving, and gripping.

Welding can be carried out in a number of different ways and methods that include: Shielded Metal Arc Welding, Gas Tungsten Arc Welding, Gas Metal Arc Welding, along with many others. The one technique which will be discussed in this project is TIG, also known as GTAW. Non-consumable tungsten metal rods are used in this type of arc welding to generate the weld between the two materials. The metals that are welded using TIG are usually steel or aluminum.

Screw driving or tightening process is the application of torque force to fix a screw into a thread or a hole. Screwdrivers come in many shapes and sizes that match different heads. In this

project, a screwdriver of a chosen shape and size will be fixed to the robotic arm in a way that torque can be applied. Screwdriver tips are of steel that is plated by nickel.

Gripping is the process of moving or changing the location of an object or mass from one place to another. Grippers can be of two, three, or even four fingers, and carry huge masses but in this project, a 3D printed two-finger gripper is used where it can carry as a maximum 3kg.

The main aim of the project is to create a suitable multifunctional robotic arm that carries out the mentioned processes on a small scale. It also aims to provide a safer welding tool where it is less dangerous and more easy for first users since it performs a G-code automated TIG welding process. The whole robotic arm is 3D printed, which is more cost-effective than buying the parts, except for the welding components and the screwdriver body. The robotic arm performs the welding process, according to our choice, on steel where it joins the two pieces into one; so accordingly, DC motors are utilized for the overall processes.

## **1.2 Significance of the Project**

Firstly, welding is known to be a very dangerous job because of the chemicals emitted while welding. New statistics have been released by the Health & Safety Executive (HSE) who were working on an initiative with BOHS (The Chartered Society for Worker Health

Protection) called ‘Breathe Freely’ to bring issues to light of the fatal dangers presented to welders in the manufacturing industry. Out of the 190,000 welders who do welding activities every year, 150 of them die due to cancer. This could be caused as a result of breathing in invisible welding fumes which contain potential cancer-causing agents and many welders die by accidents, such as falling from a high distance, explosions or burns. Secondly, screw driving may not seem easy, safe as it looks, according to the National Safety Council, “misuse of

screwdriver can compromise the integrity of the tool by breaking the handle, bending the shaft or dulling the tip, making workers susceptible to hand injury when the tool is used correctly”.

Here comes the significance of the multifunctional robotic arm where safety level is raised by getting human workers out of that hazardous welding environment, and away from the fumes and extreme heat. Besides, automated TIG welding is very productive in the manufacturing processes since it is more efficient compared to humans. While screwdriving allows manufacturers to achieve more challenging applications than a typical operator may be comfortable with. However, Weber (2005) stated that “American manufacturers can achieve higher cycles per screwdriver spindle and faster cycle time per screw, while improving quality”. Continuously, electric grippers, mainly the ones driven by servo or stepper motors, can give you much finer control over gripping forces, speeds, etc. This means that the robot repeats the same process exactly every time, therefore the results are more likely to be consistent. Moreover, humans need a break during welding, screwdriving, and picking-placing, while robots can work continuously without any interruptions. Also, robots can do tasks that are impossible for humans to do, in which a torch rotation in different angles is needed.

### **1.3 Detailed Project Objectives**

The multipurpose robotic arm project is a programmable arm that can do multifunctional processes including gripping, screw driving, and TIG welding. The project concerns more with the programming aspect, where it utilizes a 3D printer, to design and produce a six degree of freedom multipurpose robotic arm. The project follows the normal movement and ensures the continuity of TIG welding, gripping, screw driving operations. It utilizes G-coding along with inverse kinematics to frame and program automatic TIG welding, screw driving, and

gripper size and shape regardless of productivity, quality, flexibility, speed, robustness, and precision to reduce potential security risks and vulnerabilities in many industrial enterprises, factories, and workshops. There are numerous advantages of using a robot arm; for example, in unsanitary conditions, human labor is replaced by a robotic arm for more effective results as it is very sensitive and is programmable to perform the same movement each time correctly where product losses are minimized. In many industrial plants, 24-hour human labor is impossible, so robotic arms can operate continuously as well as their necessity at performing processes that are hazardous to human workers. They can carry out difficult jobs that may cause serious injuries or death, and for these specific reasons, these industrial robotic arms' prices are acceptable, thus the aim of the project; providing a safer, cheaper, and a multifunctional robotic arm.

#### **1.4 Detailed Project Constraints**

There are four main constraints of the robotic arm we must consider. First constraint is to automate all movements. That involves a decent operating program which gives us the desired accuracy especially in the welding process. Secondly and essential constraint is the degree of freedom. The arm should support six degrees of freedom. That will give the flexibility to the head to move freely in the working zone. The last constraint is that the arm should be fixed to a stand and the specimen will be provided by the supply chain. The last constraint is related to the duty time of the robotic arm. Since the welding machine itself has a duty cycle of sixty percent, it can only provide the required parameters for six minutes and then it will be automatically switched off for four minutes. This parameter limits the operation period of the robotic arm, which makes it unable to perform long and consecutive welding operations. However, it increases safety by ensuring that no overheating or possible fire hazards occur.



## 1.5 Report Structure

In this report, there are six chapters, the first chapter provides an introduction that gives a general perception for the project " Multi-Functional Robotic Arm " regarding screw driving, gripping and TIG welding and the possible benefits of automating these process.

The second chapter briefly explains the historical events of Robotic Arms, Screw Driving, Gripping, welding, and automation. It also explains the possible in-market solutions to automate these processes whilst providing their pros and cons, and the possible solutions which could be obtained through downscaling the system for a better Return on Investment and feasibility.

Moreover, the third chapter discusses the exploited project's equipment, along with the simplified prototype calculations which are used to predict the torque output of the stepper motors. It finally depicts the preliminary cost analysis of the project.

The fourth chapter discusses the use of a 3d printer in the manufacturing process to attain the design required as well as the connections of electrical systems to operate the system.

In the fifth chapter reveals testing techniques, and possible errors were given.

Eventually in chapter six, comprehensive conclusion including achievements of the project, subsequently recommendations and suggestions for future projects.

## **2 Chapter 2 – Literature Review**

### **2.1 Background Information**

The area of robotics carries many branches of engineering including electronics, mechanical, digital logic, artificial intelligence, nanotechnology, and bioengineering. A robot can do numerous types of tasks depending on the application and performance, hence the suitable robot. Some of them are simple and some of them are quite intricate. A robot might be designed to accomplish one particular task or a range of tasks. For instance, one robotic arm can be utilized for welding, drilling, screw-driving, and pick-and-place, or a single robotic arm that utilizes each independent task using the same arm only changing the adapter. The "Multi-Functional Robotic arm" has become an important thing in the production sector. Some companies spend a huge sum of money using independent machines to do independent tasks, while ignoring the versatility of a robotic arm. Nowadays, they can replace several manual processes by a Multi-functional arm with less amount of money. A good example on a Multi-Functional Robotic arm is an arm that can perform TIG welding, pick-and-place, screw-driving, and drilling, where this arm is especially utilized in automobile companies. This research is concerned with automated TIG welding, Gripping, and Screw-driving.

#### **2.1.1 History of Robotic Arms**

A robot arm is a type of robot consisting of parts linked together in the same way as those of a human arm, mounted on a stand. The most common manufacturing robot is the robotic arm which is usually made up of several metal segments. Robots are designed to perform tasks that people may or may not be able to perform. They are used to build cars, pack boxes, and several various tasks [7].

The first robotic arm was introduced at the General Motors plant in Ewing Township, New Jersey in 1962. It was named 'Unimate' and was created by George Devol. Its duty was lifting and stacking hot metal parts. The arm weighed about 1,815 kilograms and cost \$25,000. Before this, robotics were largely the products of science fiction and the imagination. The development of robotics was slow for a while, with many of the most useful applications being involved with space exploration, until the late 1970s when several big Japanese conglomerates began producing similar industrial robots. In 1969, Victor Scheinman invented the Stanford arm, an all-electric, 6-axis articulated robot designed to authorize an arm solution, at Stanford University [17]. This allowed it accurately to follow arbitrary paths in space and widened the potential use of the robot to more sophisticated applications such as assembly and welding. Robots were initially retained to perform precise welding chores and other repetitive tasks that humans had long found difficult, hazardous and dangerous. By using robots to weld, handle dangerous objects and place them, auto manufacturers were able to ensure a consistent product with a minimal worker injury. Currently, a lot of robots that are in use today are used in automobile manufacturing. Throughout the last decade, many improvements were made on the original collaborative designs to make them more reliable and accurate.

### **2.1.2 Robotic TIG Welding History**

Robotic welding, also called automated welding, is the automated process of using mechanized programmable tools to weld and handle apart. This relatively new application of robotics has filled the gap left by the growing shortage of welding professionals, effectively taking over a large portion of welding jobs the North American industry.

The history of robotic welding is deeply rooted in the history of industrial robots in general, going back to the mid-20th century. where the integration of robots for welding

purposes firstly took place in the US industries during the 1960s, when General Motors began using robots for welding. George Devol and Joseph Engelberger developed the first spot welding robot, UNIMATE, which was used on automobiles going through the assembly line. A robot welding unit, also called a robot welding cell, consists of several components working together to weld pieces [17]. These components include those actively taking part in the welding, as well as accessories and safety features to ensure the smooth operation of the cell. Robotic welding makes up 29% of all robotic applications in industry, topped only by robotic material handling. Automatic welding is most commonly used in the manufacturing and engineering industries to increase the efficiency of companies and labs. Moreover, Robotic welding systems get the job done quickly and efficiently, making fewer mistakes than their human counterparts while increasing production speed tremendously. Additionally, robots can work 24/7, unlike human workers who require sleep, breaks, and vacations. Human operators typically have less than 50% arc-on time, and human on-time percentages decrease as fatigue sets in later on in the shift. Robots, on the other hand, have 75%-80% arc-on time. This number increases to 95% for parts with longer seams. Beside, Automated welding systems conserve energy by running consistently, cutting the energy-expensive start-ups. Additionally, robots do not over weld and reduce the need for corrective welding, cutting energy expenditure [7].

### **2.1.3 History of Gripping**

As we discussed before, the robot arm can be used to pick-and-place, that is mean moving objects from one place to another, or packing boxes.

The first robotic arm with a gripper adaptor was built by mechanical-engineering student Victor Scheinman at Stanford University in 1969 after much toil in school's machine

and computer labs. By the early 1980s, rougher gripper designs inspired by the Stanford arm (and made possible with increasingly powerful microchips) were in mass production, and used in heavy industry. The original Stanford arm included something called a *parallel gripper*; this ubiquitous design, still common today, consists of two straight-bar fingers actuated to simply slide together or move apart to grip and release objects. “Two-finger grippers are most commonly used in industry today, because of their stroke versatility,” says Jesse Hayes, product manager of automation components at Schunk Inc., Morrisville, N.C. [1].

In this era, with the help of the modern technology, designing grippers with three or four fingers or more has been done to perform tasks. Not that only, diverse functions have been added to the gripper such as magnetic grippers, pressure grippers etc.

### **2.1.3.1 Screwdriver History**

The earliest documented screwdrivers were used in the late middle ages. They were probably invented in the late 15th century, either in Germany or France. The tool's original names in German and French were *Schraubendreher* (screw turner) and *tournevis* (turn screw), respectively. The first documentation of the tool is in the medieval house book of Wolfegg Castle, a manuscript written sometime between 1475 and 1490. These earliest screwdrivers had pear-shaped handles and were made for slotted screws (diversification of the many types of screwdrivers did not emerge until the gilded age). The screwdriver remained inconspicuous, however, as evidence of its existence throughout the next 300 years is based primarily on the presence of screws.

Screws were used in the 15th century to construct screw-cutting lathes, for securing breastplates, back plates, and helmets on medieval jousting armor—and eventually for multiple

parts of the emerging firearms, particularly the matchlock. Screws, hence screwdrivers, were not used in full combat armor, most likely to give the wearer freedom of movement.

The jaws that hold the pyrites inside the Wheelock guns were secured with screws, and the need to constantly replace the pyrites resulted in considerable refinement of the screwdriver. The tool is more documented in France, and took on many shapes and sizes, though all for slotted screws. There were large, heavy-duty screwdrivers for building and repairing large machines, and smaller screwdrivers for refined cabinet work.

Screws were very hard to produce before the first industrial revolution, requiring the manufacture of a conical helix. The brothers Job and William Wyatt found a way to produce a screw on a novel machine that first cut the slotted head, and then cut the helix. Though their business ultimately failed, their contribution to low-cost manufacturing of the screw ultimately led to a vast increase in the screw and the screwdriver's popularity. The increase in popularity gradually led to refinement and eventually diversification of the screwdriver. Refinement of the precision of screws also significantly contributed to the boom in production, mostly by increasing its efficiency and standardizing sizes, important precursors to industrial manufacture [18].

## **2.2 Concurrent Solutions**

Welding and screw driving are two of the most important mechanical processes that are applied to almost every product manufactured worldwide. In industry, large welding tools are utilized, which deal with heavy armatures, and huge parts that usually require a manual coordination and precision and mostly operate on one or two axes. Thus, they require long welding hours and are not feasible for small applications.

Solutions have been introduced, for example, circumferential TIG welders where they operate on a circumference of a rotating table, which holds the work piece. Some of these machines can be controlled for an extra axis to perform more complex tasks for instance CAM INNOVATION™ for both of its products CWM. HORIZONTAL TIG WELDER®, shown in Figure 1 [13], and VWT VERTICAL TIG WELDER®, shown in Figure 2. They operate with 3-axes on heavy armatures and they are in a CAM based environment in which is helpful for repetition and G-code accuracy. However, they are not feasible for small production lines.



Figure 1 CWM Horizontal TIG Welder [10]



Figure 2 VWT Vertical TIG Welder [10]

Industries also utilize another common type of automated TIG welding that is longitudinal seam welder. It is limited to straight welds; thus, it operates on a single axis. This type is provided by GET WELD™ as shown in Figure 3 [15].



Figure 3 Longitudinal Seam TIG Welder [15]

Robotic arms that features a welding machine are by far the most flexible welders. An industrial robotic arm operates in 6 different DOF such as HWASHI™ HS-R6-08®, shown in Figure 4 [13], which is a more adaptable and flexible mean of welding due to its multiple DOF. Thus, enabling the arm to reach spots that are hard for fixed rail-based systems in longitudinal and circumferential machines. They utilize industrial servo-motors and high quality signal carrier circuits enabling the performance of repetitive jobs with a minimal deviation. However, such robotic arms are expensive and their ROI is incomparably low if used in small production systems.



Figure 4 HWASHI TIG Robotic Arm [16]

Screw driving is one of the most important steps in the assembly of a part or a product. In industry, huge products are produced that need to be joined together in a way that makes it



more difficult for everyday effects to disassemble or break the final product; like aircrafts or cars.

Concurrent solutions to the need of strong screw driving is utilizing an automated screw driving machines, like Dimai High Accuracy Auto-screwdriving Machine, manufactured by Dimai Automation, shown in Figure 5 [5], which has been widely used in LED module assembly, mobile assembly, electric switch assembly and other fields. It has stable performance, high quality, affordable price, and easy installation, but only operates on the horizontal and vertical axes [5].



Figure 5 Dimai High Accuracy Auto-screwdriving Machine [5]

Multi-spindle screw driving machines are also utilized in industries, where the product or the part is located on a rotating table that rotates and fastens the screws with a torque of 3 to 5kgf.cm, as well as it helps in packaging, as shown in Figure 6. Its features include a multi-axis design that ensures reliability and accuracy, it has a more user-friendly touch screen or teaching pendant operation, it is easy to operate and external technical parameters and manual test functions can be directly adjusted by the technician [5], but it can only work on relatively small parts or products.



Figure 6 Multiple Spindle Rotation Automatic Screw Tightening and Automatic Screw Fastening Machine [9]

### 2.3 Comparison of Concurrent Solutions

All of the proposed concurrent solutions are very suitable for the industry, yet each has its pros and cons. Below is a comparison matrix that better compares the proposed concurrent solutions.

Table 1 Comparison Matrix on Concurrent Solutions

Machine Criteria	CWM Horizontal TIG Welder	VWT Vertical TIG Welder	Longitudinal Seam TIG Welder	HWASHI TIG Robotic Arm	Dimai High Accuracy Auto- screwdriving Machine	Multiple Spindle Screwdriving Machine
Cost	6	6	4	2	7	5
Safety	7	7	7	8	7	7
Reliability	5	5	4	9	5	8
Total	18	18	15	19	19	20

Table 1 shows a comparison between each of the solutions. Firstly, CWM Horizontal TIG Welder and VWT Vertical TIG Welder are suitable for welding pipes, shafts and cylindrical tubes, but cannot perform welding for curved seams, which requires an additional axis. Longitudinal Seam TIG Welder is suitable for welding two plates together, but is limited

to a single axis making the welding of non-flat objects impossible to accomplish as well as welding a cylindrical or circumferential piece unless an extra turning axis is added. Then, Dimai High Accuracy Auto-screwdriving Machine is widely used in LED assemblies, mobile assemblies, but it only operates on the vertical and horizontal axes. Multiple Spindle Screwdriving Machine has high accuracy and reliability since it operates on multiple axes, however, it can only work on relatively small parts or products [9]. Between the welding machines, the comparison based on cost, safety, and reliability shows that the robotic arm is the best option; and between the screwdriving machines, the multiple spindle screwdriving machine represents the best option.

#### **2.4 Engineering Standards of the Concurrent Solutions**

Standards are very important when it comes to selecting component and joining them together. They ensure safety and compatibility, which are the minimal requirements for achieving performable device. Below are some standards utilized for TIG welding machines and screw driving tools.

- American Society for Testing and Materials - ASTM
- American Welding Society - AWS D9.1 Sheet metal welding
- International organization of standardization - ISO 15607 Specification and qualification of welding procedures for metallic materials - General rules
- American National Standards Institute – ANSI Z49.1 safety in welding, cutting and allied processes

- International organization of standardization - ISO/TR 20218-2:2017 Safety design for industrial robot systems
- International organization of standardization – ISO/CD 10218-2 safety requirements for industrial robots
- International Organization of Standardization – ISO 2380:2 specifies the general requirements, lengths of blades and the marking of hand-operated screwdrivers.
- International Organization of Standardization – ISO 2725-2 specifies dimensions, designation, and marking of machine-operated "impact" square drive.

### 3 Chapter 3 – Design and Analysis

#### 3.1 Proposed/selected Design

At the design stage, our main focus will be on four criteria safety, manufacturability, cost, and reliability. Safety is our first concern, since all the three processes achieved by the proposed design can be dangerous and hazardous to human working, especially when it comes to welding. Then comes manufacturability, where ease of manufacture means less time consuming, no need for high-tech manufacturing machines, and easy to maintain and sustain which reflects positively on the total cost. Also, robotic arm design reflects mostly on the accuracy, precision, and reliability of its work. Overall, the design is meant to be safe, strong, reliable, and cost effective meaning that it will not break or fail especially in welding process and cause a hazardous working zone.

In order to carry on design stages, we choose the material of robotic arm structure according to decision matrix below.

Table 2 Decision matrix for Material selection

<b>Criteria</b>	<b>Sustainability</b>	<b>Cost</b>	<b>Manufacturability</b>	<b>Reliability</b>	<b>Availability</b>	<b>Total</b>
<b>Steel</b>	6	7	7	8	7	35
<b>Aluminum</b>	8	6	9	6	7	36
<b>CFRP</b>	9	4	5	7	5	30
<b>ABS</b>	10	8	10	8	6	42
<b>Filament</b>						

The table above shows that ABS Filament is the most suitable choice to our proposed design. It is the most cost effective, the most sustainable, as well as the most reliable material to work with when manufacturing a robotic arm.

Besides the manufacturing of the arm design, we reached a conclusion in which we required a conveyor belt. Conveyor belts are used to move goods and products due to their size or due to the fact that they require stability through transportation. Some products cannot be transported using roller conveyors, so a belt can be used [6]. We can also utilize it as a processing point where the robotic arm can deal with the products

It functions by the movement of a continuous support, where the belt assembled on a platform that may have different accessories including side rails, end stops, wheels and other type of pneumatic or mechanical accessories. The speed and load capacity of the conveyor vary depending on the characteristics of the material that is being transported, for example, dust, fine grain, packages, etc., as well as the type of conveyor belt [6].



Figure 7 Conveyor Belt

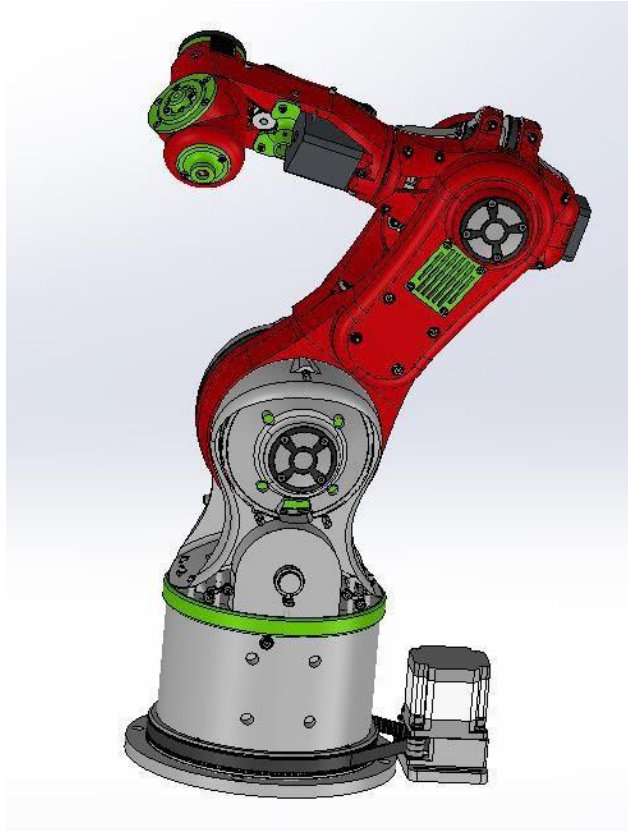


Figure 8 Chosen Open Source Robotic Arm Design

The design is based on an open source robotic arm, shown in Figure 8 which is built upon three adapters with three different functions; screwdriver, TIG welding torch holder adapter and a gripper. The robotic arm is manufactured from ABS plastic filaments through 3d printing with design modification. Also, strength enhancement of the robotic arm is achieved through infill topology based on honeycomb structure, and high torque stepper motors.

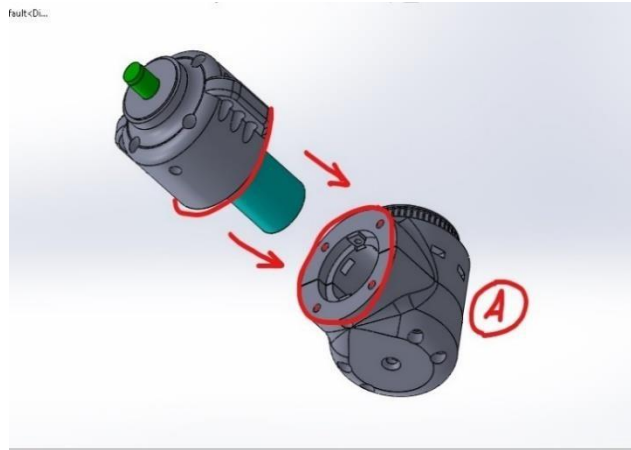


Figure 9

Part A at the bottom of Figure 9 is the piece which all adapters will be installed on it. Four threaded holes allow an easy assembly through screws. The upper one is the screwdriver adapter with the ability to change heads easily. Figure 10 shows the gear and motor which was bought, modified, and assembled to the robotic arm.



Figure 10



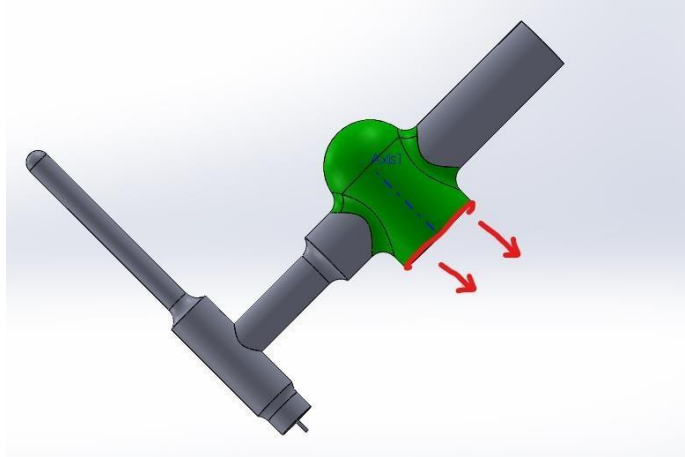


Figure 11 TIG welding Adapter

Figure 11 shows a 3D simple CAD drawing for the TIG welding adapter. The bottom of the green part is to be attached to part A in figure3-2, the head of arm after removing any other adapter. Operation and suspension are to be automated with the use of Raspberry board.

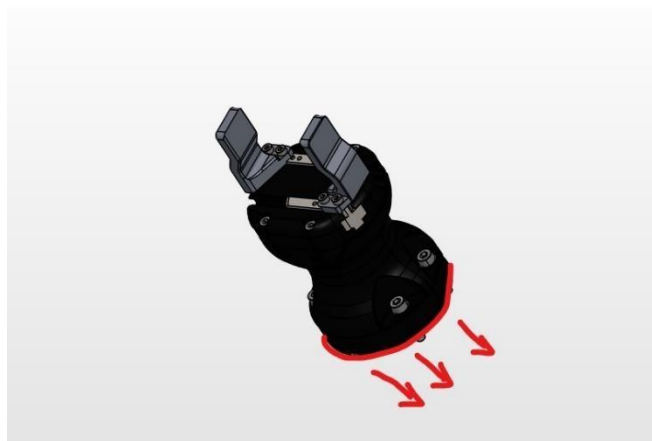










Figure 12 Gripper Adapter

One of the functions of the robotic arm is to be able to grip and move objects with a range of 1kg of mass. The design in Figure 12 will be tested multiple times to make sure that it provides the desired strength and sustainability

### 3.2 Engineering Standards

Engineering standards is the foundation which all design stages are based on. As International Organization of Standardization (ISO) states, “Standards are documents which provide requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose [8].” Below is a list of common engineering standards that are used:

Table 3 Engineering Standards

Component selection	Following standard
Raspberry Pi Circuit	  Federal Communications Commission CE, FCC
HITBOX Tig Welding Machine TIG200P With 220V Inverter Welder	 CE, RoHS certificate
Deep Groove ball bearing 160*200*20mm	  QECISO9001, UKAS
Control Box	  CE, TSE
Nema 17/23 Stepper Motors	 CE, Screw standard: DIN912
M3/M4 Hex Nut 304 Stainless Steel Fastener	DIN 934
KSOL Metric M3/M4 Hex Nut 304 Stainless Steel Fastener	DIN 934
High Quality Stainless Steel M8 Hex Nut	DIN 985

Original Tech 15001K DSO-SHELL DIY Digital Oscilloscope Kit with Housing case box	CE
M4 M4*32 M4x32 M4*55 M4x55 304 316 Stainless Steel	DIN912
Thin square nut M4 Color Zinc Plated Square Nuts	DIN562
Allen Key Head M3 Stainless steel 304 hex socket Flat countersunk head screw	DIN7991
M4 GB96 304/A2-70 Stainless Steel Large Size Flat Washer	DIN9021
stainless steel half thread screw M8 screws External hex screws	DIN931
M4 A2-70 304 Stainless Steel Button Head Hex Hexagon Socket Allen Screw Bolt L=3-80mm	ISO7380
M3 304 Stainless Steel Flat Washer Plain Washer Flat gasket	DIN125
M4 Stainless Steel Hexagonal Screws Outer Hex Bolts For Electrical Machine Equipment Wheel Construction	DIN933
M4 304 Stainless Steel Hexagon Socket Head Cap Screws Inner Hex Socket Bicycle Bolt Metric Thread	DIN912
M3 Set Screw 304 Stainless Steel Inner Hex Hexagon Socket Plain Point End Grub Screws	DIN913 GB77
Micro Speed Reduction DC 6V 15RPM to 3000RPM Gear motor 3mm Shaft Mini Metal Gearwheel Gear Motor N20 Geared Motors	ISO9001

### 3.3 Design Calculations

The primary design needs a set of evaluations that could be later emphasized into a harmonically working system. Hence, we originally assume a simple model to initialize the torque flexibility needs of the different stepper motors.

First of all, we obtain the mass of the 5th axis plastic by the following equation:

$$m_{5th\ axis} = \rho_{ABS} \pi(r_{out}^2 - r_{in}^2) * l_{5th\ axis} \quad \text{Equation 3-1}$$

Where:

$m_{5th\ axis}$  = mass of 5th axis plastic [kg]

$r_{out}$  = outer radius 0.5m /  $r_{in}$  = inner radius 0.44m

$\rho_{ABS}$  = ABS density 1070kg/m<sup>3</sup> /  $l_{5th\ axis}$  = 0.114 m

Based on the result of the equation,  $m_{5th\ axis} = 0.216\ \text{kg}$  which is equivalent to 2.12N. The following step is adding the welding torch, or gripper adapter, or scwdriver adapter, and feeder motor system weights and figure the center of mass. The nth axis driving motor is assumed to be left in n-1 th axis, thus there will be less load application over the arm. The total estimated weight of the arm is 7.51N. The next step is identifying the torque around the center of mass using Equation 3-2 for center of mass identification.

$$x_{COM} = \sum_i^N m_i x_i / M \quad \text{Equation 3-2}$$

where,

$x_{COM}$  = Displacement to Centre of Mass /  $m_i$  = Different masses /  $x_i$  = Different lengths /  $M$  = Total masses

Once identified, torque is obtained through the product of force and distance which is later placed in an equality with the timing pulley torque, thus the required torque over the stepper motor is the inverse of the gear ratio of the joint timing pulley and the stepper timing pulley as shown in Equation 3-3.

$$T_{motor} = T_{joint} (r_{joint} / r_{motor}) \times (d_{motor} / d_{joint}) \quad \text{Equation 3-3}$$

where,

$T_{motor}$  = Torque required at the motor /  $T_{joint}$  = Torque at joint /  $r_{joint}$  = Radius of joint timing pulley

$r_{motor}$  = Radius of the motor timing pulley /  $d_{motor}$  = Distance of motor torque effect

$d_{joint}$  = Distance for torque of joint effect

The process will be repeated and reoccurred till the last axis is reached. Same orientation of axis is assumed due to the high torque requirement which forces a choice of strong enough motors with adequate torque resilience ability.

The design payload which support stems from the base, , is concerned with the 3rd axis's masses and beyond based on the estimation. Thus, for simplification we estimated the calculations into two sections; masses caused by prints and motors, and masses supported by the motors. The following set of calculations are to solve the torque required, shown in Figure 12, and the torque that can be given.

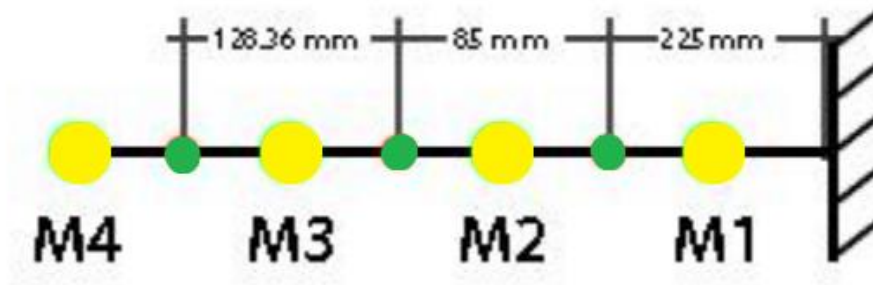


Figure 13 Representation of the Masses of the System

The masses M1 to M4 are representation of the 3D printed parts masses, while the green represents either a motor on link or just connection point.

$$T_{pR} = \{M1 \times (L1/ 2) + M2 \times (L1 + (L2 /2) ) + (M3 + M4) \times (L1 + L2 + (L3 /2) )\} \times g/ 10$$

Equation 3.4

$$T_{mR} = \{m1 \times (L1 - L2) + m2 \times (L1 + L2)\} \times g /106$$

Equation 3.5

where,

$T_{pR}$ : Torque Required to carry printed links in Nm

$T_{mR}$ : Torque Required to carry both motors in Nm

$L1= 225\text{mm}$ ,  $L2=85\text{mm}$ ,  $L3=128.36\text{mm}$

$M1=817\text{grams}$ ,  $M2=248\text{grams}$ ,  $M3=126\text{grams}$ ,  $M4=62\text{grams}$

$m1=500\text{grams}$ ,  $m2=400\text{grams}$

Then, we get  $T_{pR} = 2.24\text{Nm}$  and  $T_{mR} = 1.9 \text{ Nm}$

Thus, total **T = 4.14 Nm**

The motor support is to be calculated as follows:

$$EM2 = 3100Nmm \times 24.32mm \ 18.8125mm \times 62.25mm \ 18.8125mm \times 1m \ 1000mm$$
$$= 13.26Nm$$

$$EM3 = 3100Nmm \times 24.32mm \ 18.8125mm \times 47.25mm \ 18.8125mm \times 1m \ 1000mm$$
$$= 10.07N$$

where,

EM2: Torque supported by 2<sup>nd</sup> axis motor with an effect at start point

EM3: Torque supported by 3<sup>rd</sup> axis motor at a 225mm from start point

Thus, the torque at the starting point is cancelled by motor of second axis with a 9.12 Nm remaining as a lift torque at the starting point, and 10.07 Nm at the joint which follows. The 9.12 Nm at the starting point can lift a 5.5 N and the torque at next joint can lift a 13.3 N totaling a lift of 19 N and a payload of 2 kg, but this estimation excludes efficiency of the power train and weights of bolts and nuts.

### 3.4 Cost Analysis

Most of the components utilized in this project are either 3D printed, or bought. Basically, this project is a continuation of a past year graduation project, where the team members couldn't manage to complete the whole arm, they manufactured about half of the arm. In this project, a start from the beginning is accomplished where new components are printed and bought to finalize the product. An estimated bill of materials for the half arm

manufactured last term represented in Table 4 is compared below with this project's bill of materials shown in Table 5.

Compared to the last term's robotic arm project, it is cheaper and easier in terms of manufacturing and assembly. They had to manufacture a welding table, which is not accomplished in this project, as well as we have used the same pulleys, belts, stepper motors and motors drivers, the same welding machine, assortment kit, and bearings.

For the 3D printing, we utilized a friend's 3D printer who did not charge for the usage, but we bought the printing filaments, which made the manufacturing process even cheaper. The shipping and taxing expenses were relatively lower, since we ordered less materials, and 3D printed the rest. Hence, a lower overall cost.

Table 4 Last Term's Bill of Materials

<b>Item</b>	<b>Description</b>	<b>Supplier/Receiver</b>	<b>Quantity</b>	<b>Per Unit (\$)</b>	<b>Cost (\$)</b>
Welding Machine	HITBOX 200Amp, TIG welding machine with TIG pulse	Ali Express	1	30	370
Welding Electrodes	Tungsten Zirconated Electrodes	Ali Express	2	28	56
Stepper Motors	Nema 17	Ali Express	7	30	210
Stepper Motor Drivers	A4988 Driver	Ali Express	7	10	70
Timing Pulley	3d printed Aluminum GT2 Pulley	Ali Express	10	1	10
Timing Belt	Rubber Timing Belt	Ali Express	10	0.5	5
Filler Extruder	TywelMaster TIG Wire Feeder	Ali Express	1	20	20
Stm32 F4	Microcontroller	Ali Express	1	15	15
Raspberry PI 3	Single Board Computer	Ali Express	1	15	15
Prototyping board	8x12 Double Sided Copper Board	Ali Express	1	2	2
NVEM 5-axis CNC Controller	5-axis stepper motor controller	Ali Express	1	100	100
Header Pins	Male/Female	Ali Express	4	0.5	2



Cables	Jumper Cables	Ali Express	1	2	2
Cable Reels	30AWG Reel	Ali Express	2	10	20
Cable Sleeves	10m Cable sleeve	Ali Express	1	5	5
Shrink Tubes	Shrink Tubes 127pc	Ali Express	1	1.66	1.66
Steel Plates	AISI4130 Rectangular Profile steel plates	GENC	10	3.75	37.5
Steel Tubes	AISI4130 Square profile, hollow from inside tubes	GENC	14	15	210
Assortment Kit	Bolts and Nuts, m2, m3, m4	GENC	1	20	20
Bearings	5 cm outer diameter	GENC	8	10	80
Emergency Lamp	Rotating Warning Light	GENC	1	10	10
Trigger Switch	OOTDTY Electric Switch	Ali Express	7	0.28	2
Others	Shipping and Taxes	TRNC			400
<b>Total Cost</b>					<b>\$ 1663.16</b>

Table 5 Robotic Arm's Bill of Materials

Item	Description	Supplier	Quantity	Per Unit (\$)	Cost (\$)
Welding Electrodes	Tungesten Zincronated Electrodes	Ali Express	2	28	56
Cables	Jumper Cables	Ali Express	1	2	2
Cable Sleeves	10m Cable Sleeve	Ali Express	1	5	5
Gripper	Two Finger Gripper	3D printed	1	0	0
Screwdriver Machine	4.8V, DC motor, with an adjustable spindle	TEKZEN	1	13	13
ABS Filaments	White Color, ABS plastic, 1Kg	Turkey	3	13	39
Motor Driver	Stepper Motors (Nema 17,23,24)	Turkey	1	9	9
Bearings	M3 & M5	Ali Express	2	57	114
Control Box	Arduino	TRNC	1	33	33
Cables	LENGTH	Turkey	1	16	16
others	shipping and taxes				90
<b>Total Cost</b>					<b>\$ 377</b>

## 4 Chapter 4 – Manufacturing

### 4.1 Manufacturing Process Selection

Local machining companies offer high machining prices, and if we are to order machined parts from Turkey, and in addition to shipping costs, it will require us to pay taxes for both the local cargo contractor company and the customs at the airport. Making a steel part using CNC machining is expensive due to the scarcity of the material blocks and their high price in the market locally. Thus, it is decided to have the design 3D printed using a 3D printer of a friend, as it was the best prototyping technique available. Almost all parts are to be 3D printed and assembled with off-the-shelf components that are purchased from multiple vendors over AliExpress, online store.

Making a steel part using CNC machine is expensive because of the need of material blocks, due to high prices of the material blocks in the local market of North Cyprus, also ordering machine parts from Turkey will be expensive due to the delivery and customs. Therefore, the decision matrix below in Table 5 to decide on how to manufacture the most of the components.

Table 6 Make or Buy Decision Matrix

	<b>Make or Buy Decision Matrix</b>				
<b>Criteria</b>	<b>Weight</b>	<b>3D Printer</b>	<b>3D Printer (Weighted)</b>	<b>Supplier</b>	<b>Supplier (Weighted)</b>
<b>Time</b>	3	10	30	2	6
<b>Cost</b>	4	10	40	5	20
<b>Quality</b>	5	6	30	10	50
<b>Total</b>		26	<b>100</b>	17	76

According to the decision matrix above, it is better to 3D print most of the arm, since some components require a specialized supplier to ensure quality and precision, and implementation of tolerances and standards.

## **4.2 Detailed Manufacturing Process**

After manufacturing selection is done this section will explain the manufacturing process. Firstly; all parts should be drawn and saved as 3D cad file then saved to [\*. STL] format, which most printers use. Then the file is exported to a “slicing” software, in this case (Ultimaker Cura 4.4) is used. After import STL file, print settings will be adjusted; layer height = 0.2 mm, shell thickness = 0.4 mm, fill density = 30%, etc. then the new file is going to be exported as [\*. gcode] and saved to a USB or SD-card. Secondly; for 3D printer; an adhesive material is going to be installed to the bed, settings adjusted, bed temperature = 70°, pre-heated nozzle 180°, calibrating nozzle with the bed, fan speed etc. thirdly; filament spool is loaded to the spool holder, filament is fed into Bowden feeder. Lastly; SD-card is plugged into the printer and the model is loaded. After that printing process is started. Once the object is finished the filament is taken-out. Then the object is taken-off the bed by using paint scraper to stick between the object and the adhesive and pry it off.

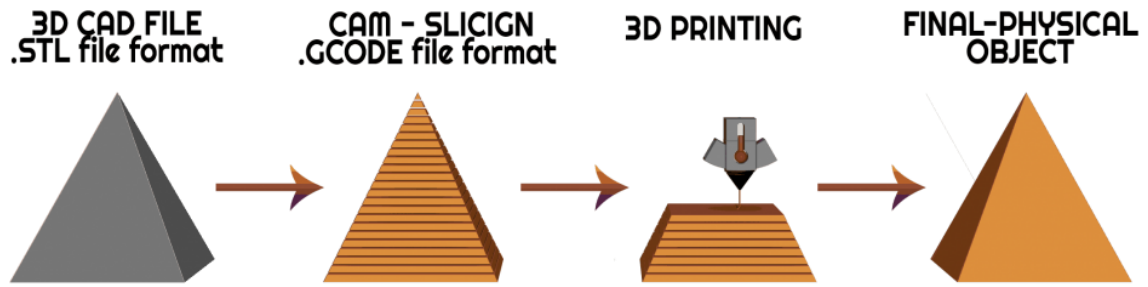


Figure 14 Steps of 3D Printing Process

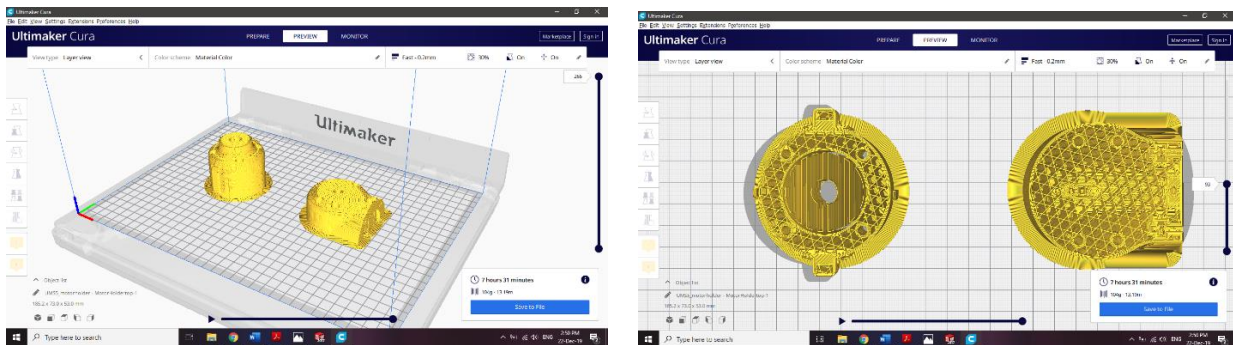


Figure 15 Ultimaker Cura 4.4 Slicing Software

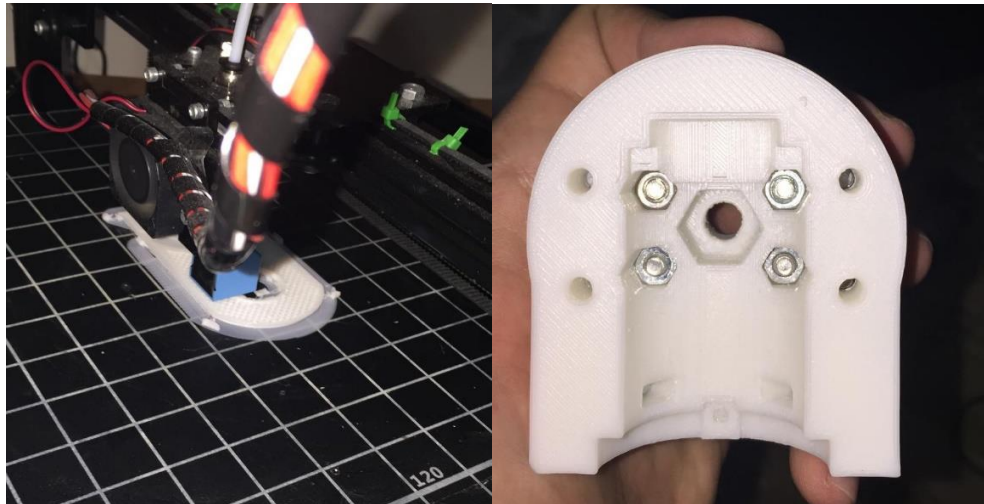


Figure 16 3D Printing Before and After

### 4.3 Assembly

Assembly is, by far, the second most important procedure of the project completion after the project design. Assembly ranges from bringing parts together to coming up with solutions when things do not go the road planned.

First off, tools organization is one of the most important steps of assembly, in which tools such as Allen keys, pliers, screwdrivers, drillers, hacksaw or handsaw, cutters, scotch tape, hammers, welder, and so much more had to be presented in an organized manner. Setting up all screwdriver types, all drill sizes, all Allen key sizes, where the first steps in this project's assembly.



Figure 17 Allen Keys [2]



Figure 18 Pliers and Cutter Set [4]



Figure 19 Electric Drill [6]

Then, sorting all screw sizes and types, all bearing and belt sizes came next to the assembly process. This is more of a sophisticated robot where a lot of screws were used, hence

precision and referencing to the CAD design were very important in accomplishing a perfectly assembled arm.



Figure 20 Deep Groove Ball Bearing [22]



Figure 21 Transmission Belt [10]

SKF groove ball bearings were used throughout the robotic arm, but of different sizes including 6mm, 8mm, 35mm, and 90mm all used in the shoulder, elbow, and forearm. Belts of sizes 500mm, 510mm, 600mm, and 630mm, were also used attached to every pulley to transmit power efficiently. Shafts were also used as part of the transmission mechanism. Screws utilized were of M3 and M4 diameters with lengths ranging from 10mm to 70mm.



Figure 22 Assembly

This far the mechanical part of the design has been properly assembled. Moving to the electrical part, a control box, watertight electrical enclosure, was used to unite all the electrical components, including batteries, wires, joysticks, and the emergency button. The motor drivers, microcontroller, power source and emergency button will be carried inside the control box. Each motor will be connected to its motor driver before reaching to the microcontroller. The energy needed will be distributed to all the elements in the project from the power supply and an emergency button will be attached for instant shut down.

A control box provides the physical interface that allows an operator to control equipment and monitor performances. Control boxes typically contain elements such as switches, knobs, sliders and buttons, in which they are connected to the equipment and are used to control them, allowing operations to start, stop, or adjust various functions. Controls are located inside electrical enclosures in order to prevent accidental contact, unauthorized access or damage to the controls [19].

The control box is the brain of the robotic arm. For controlling this MFRA, the control box consists of five motor drivers, two power supply (24v each), Arduino, emergency button, signal lights, and a small fan.



Figure 23 Control Box



## **5 Chapter 5 – Product Testing**

### **5.1 Verification of the Objectives of the Project**

The objectives of the product are; firstly, to carry out the three procedures using G-coding, welding, gripping , and drilling; secondly, perform TIG welding with repeatability and high quality and accuracy; and thirdly, ensure a safe environment for workers when operating.

The tests ran on, firstly ensuring smooth power transmission using the motor drivers, throughout all six degree of freedom. Secondly, ensuring the robot head performs the gripping and drilling functions properly. Thirdly, ensuring the maximum payload is carried with no side effects to arm. And lastly ensuring the welding is carried out smoothly without any breaks in the process.

The following Table 7 shows the FMEA (Failure Mode and Effects Analysis) of this project.

Table 7 FMEA(Failure Modes and Effects Analysis)

<b>FMEA (Failure Mode and Effects Analysis)</b>									
Product: Multifunctional Robotic Arm									
#	Process Step	Potential Failure Mode	Potential Failure Effect	Severity	Occurrence	Detection	RPN	Risk Mitigation	
1	Welding; Adhesion of Weld	Lack of fusion	Incomplete weld	4	1	9	36	Spare pieces	
2	Welding; Gas Coverage	Leakage of gas	Contamination	10	1	2	20	Adjust gas flow	
3	Welding; G-coding	Welding task not carried as desired	Undesired bead profile	4	4	2	32	Double check and test before carrying out process	
4	Welding; Filler Material	Insufficient filler material	Electrodes reacting with metal piece causing an electric fire	9	1	2	18	Ensure sufficiency and spare filler material	
5	Drilling; Shafts	Insufficient torque transmission	Bending or breaking	5	2	9	<b>90</b>	Change shaft	
6	Drilling; Bearings	Insufficient lubrication	Rough rotation and possible wear	4	2	9	72	Change bearing	
7	Drilling; Material	High ductility material	High friction and possible fire	6	1	1	6	Implement manual	
8	Drilling; G-coding	Drilling task not carried as desired	Dimensional inaccuracies	4	4	2	32	Double check and test before carrying out process	
9	Gripping; Gears	Gear backlash	Deviation and inaccuracy	4	2	9	<b>72</b>	Spare gears	
10	Gripping; Loading	Too much load	Gripper break and disassembly	2	1	1	2	Implement manual	

Based on Table 7 the most important components of the arm are the shafts, bearings, and gears. They pose the great threat due to the fact of their hidden locations within the arm, where problems might happen with their alignment or tightness and we could never know unless a process goes wrong. Thus, testing a smooth transmission in all 6 degrees of freedom helped reassure that there were no problems in this aspect.

## **5.2 Verification of the Applied Engineering Standards**

Failure Modes and Effect Analysis (FMEA) in Table 8, shows the tests carried out approach will be utilized for the verification, due to its ease for the large number of components. The current process controls are used to check for specific components' quality, suggest the recommended actions and provide all the tests to be carried out, as seen in Table 8.

Table 8 FMEA analysis of the automated TIG welding machine.

FMEA (Failure Modes and Effect Analysis)								
Product: Automated TIG Welding								
#	Component	Potential Failure Mode	Potential Failure Effect	Potential Cause of Failure	Current Process Control	Recommended Actions	Responsible Person	Actions Taken
1	Adhesion of weld	Lack of fusion	Incomplete weld	Unsteady motion & high travel speed	Visual Inspection/ microscopic Inspection	Steady motion & adjusted travel speed	Mustafa Ghadri	Spare pieces
2	Gas coverage	Leakage of gas	Contamination (oxidation)	No enough shielding gas	Visual Inspection (oxidation check)	Adjust flowrate and check for leaks	Mustafa Ghadri	Adjust gas flow
3	Amperage	Overset or underset for the welding task	Wide bead profile and HAZ	Incorrect amperes settings	Visual inspection	Adjust ampere	Mustafa Ghadri	Adjust amperage and/or travel speed
4	Stepper Motors	Steps insufficiency	Deviation	Steps accuracy	Minimal step test	Feedback hall sensor	Mahmoud Akkawi	Replace motor
5	Gears	Backlashes	More deviation and inaccurate motion	Improper loading	Proper tooth form and gear mesh alignment check	Changing gear material or checking for proper loading	Mustafa Ghadri	Spare gears
6	Shaft	No torque transmission	Bending/ breaking	Unbalanced moment	Visual Inspection	Routine checks	Mustafa Ghadri	Change the shaft
7	Bearings	No smooth rotation	Low torque transmission	Improper mounting	Smooth rolling of the element	Use appropriate lubrication	Mustafa Ghadri	Change the bearings
Prepared by: Hatim Shams								
Checked by: Mustafa Ghadri				Approved by: Rana Saleh				

## 6 Chapter 6 – Results and Discussions

### 6.1 The Results

Following the testing procedure, we obtained outstanding results regarding the aspects tested.



Figure 24 Assembled Robotic Arm

Results include:

- Smooth overall motion and rotation was achieved.
- Payload tolerance achieved slightly below theoretical value.
- Drilling power enough to penetrate through wood and foam.
- Welding achieved smoothly as you move the head near and away from the welded piece.

## **6.2 The Engineering Standards**

The plastic filament included engineering standards such as ISO 9001:2015 QMS System for quality management as all the filament was recycled material. It assures effective application of the system.

Also, ISO 45001 Occupational Health and Safety standard was used during testing and assembly. For example, gloves were used whenever drilling or grinding took place, as well as safety helmet when testing the welding function.

AWS 1.10 standard was used when testing the welding torch as guide for nondestructive examination of welds.

\*More standards available in Appendix C.

## **6.3 The Constraints**

Throughout the manufacturing of the arm a lot of constraints were faced limiting many options. These constraints were mainly economical, as one of the aims of this project is to manufacture at the lowest possible cost, which was achieved. Also, some manufacturability and health and safety constraints were taken into consideration, as well as environmental constraints. For example, this project was only limited to 3D printing except for a very few components that were needed to be steel. Also, the project aimed for a robot that can safely weld with no harm to the people surrounding. And environmentally, 3D printing may be tricky, thus the usage of recycled material, but also careful consumption of the plastic filament not to waste a lot to nature due to design errors.

## **7 Conclusions and Future Works**

### **7.1 The Conclusion**

As a conclusion, the manufacturing of a robotic arm is definitely not an easy process, it requires a lot of patience and thorough thinking to obtain desired results. A lot of changes and improvements have been done along the way of the manufacturing and assembly.

Robotic arms are widely used in a lot of industries, thus emerged the idea of creating this project. Welding is one of the most necessary processes in any manufacturing in any industry, yet not a lot of safe techniques have come through that are accessible and easy to use. Now, this MFRA can complete the welding task with only moving the joysticks in the direction of the pieces creating the weld bead.

The process or tasks can also be automated with a few changes in the Arduino codes written, where it can be programmed to weld every few seconds in a certain direction, as well as screw drive at a certain time increment, or even grip from one place to another without manual control.

### **7.2 Future Works**

The modern industrial world not only requires manufacturing, but also calls for innovation. Industry as we know it now will not be the same in the coming years, robotics will play a huge role in industry. Hence, this TIG wilding robotic arm would be utilized for larger, more critical purposes in the car and marine industries, for example, in manufacturing and maintenance sectors, more frequently.

Robotics now are starting to take their position in industries, but not as much as its needed for a modern future.

What we have reached in this project is an honor and a pleasure, and a true reflection of our hard work. It not only has one or two functions, but three main purposes. And we hope it gets the acknowledgment it seeks.



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[21] “What Is a Control Box,” [Online]. Available: <https://www.polycase.com/techtalk/heavy-duty-electronics-enclosures/what-is-a-control-box.html> [Accessed 6 04 2020].

[22] “8mm Deep Groove Ball Bearing 22mm,” [Online]. Available: <https://cy.rsdelivers.com/product/skf/608-2rsh/8mm-deep-groove-ball-bearing-22mm-od/4419953> . [Accessed 12 19 2020].

## 9 APPENDIX A: Electronic Me

# MULTI-FUNCTIONAL ROBOTIC ARM

### PROJECT OBJECTIVES

1. Cost
2. Safety
3. Manufacturability

### REQUIREMENTS & PRECAUTIONS

1. Welding helmet must be worn all times when welding.
2. Gripping load must not exceed 2 KG. Must weigh the load before gripping.
3. Screwdriving process can only be performed on wood and foam.

### FUTURE WORKS

TIG welding robotic arms would be utilized for larger, more critical purposes in the automotive & marine industries; in manufacturing and maintenance sectors.



### DESIGN AND PROJECT DEVELOPMENT

1. Brainstorming: The team members worked together in harmony deciding a sustainable project that helps the public.
2. Design selection: After deciding on a project, the selection of the design was an important factor that depended on cost & manufacturability.
3. Purchasing components: After selecting a manufacturable and cost effective design, components purchasing was an important step that required to be given its time.
4. Manufacturing: 3d printing was the manufacturing solution for this project using recycled abs plastic filament.
5. Assembly: After printing the robot components, assembly using screws, nuts, bolts, gears, and belts was developed creating the final shape of the robotic arm, weighing 12 Kg.

### PROJECT TEAM

*M.F.R.A*

### PROJECT DESCRIPTION

THE MULTI-FUNCTIONAL ROBOTIC ARM IS RESPONSIBLE FOR THREE MAIN PROCESS; WELDING, SCREWDRIVING, & GRIPPING.

IT IS A 3D PRINTED PROJECT WITH ABS RECYCLED PLASTIC FILAMENT AIMED TO PROVIDE SAFETY AND FEASIBILITY TO USERS.

MANUFACTURED IN THE EMU, MECHANICAL ENGINEERING DEPARTMENT, AS WELL AS PRIVATELY FOR THE 3D PRINTING .

IT CAN BE DESCRIBED AS PORTABLE, INEXPENSIVE, AND A SUSTAINABLE SOLUTION FOR WELDING HAZARDS.

### TEAM MEMBERS

MUSTAFA GHADRI	15700828
EMRE KAYA	16002481
MAHMOUD AKKAWI	16700848
ABDULLAH ALFASEIH	17700140
RANA SALEH	17700169

### PROJECT SUPERVISOR

ASSIST.PROF.DR. MOHAMMED BSHER A. ISMAEL

DEPARTMENT OF MECHANICAL ENGINEERING

FALL 2020-2021

## 10 APPENDIX B: Constraints

<b>Constraints</b>	<b>Yes</b>	<b>No</b>
Economic	X	
Environmental	X	
Social		X
Political		X
Ethical	X	
Health & safety	X	
Manufacturability	X	
Sustainability		X
Legality	X	
Inspect ability	X	

## 11 APPENDIX C: Standards

Utilized Standards	Definition
QEC ISO9001	International Organization for Standardization, quality management system
CE	CE marking is a certification mark that indicates conformity with health, safety, and environmental protection standards
RoHS	Certificate that restricts the use of specific hazardous materials found in electrical and electronic products
FCC	Federal Communications Commission standard specification for electronic equipment
UKAS	United Kingdom Accreditation Service that assess against internationally agreed standards
TSE	Turkish Standards Institution
DIN9021, DIN125	Standard Specification for Washer
DIN7991, DIN931, DIN933, DIN912, ISO7380,	Standards specification for screws
DIN562, DIN 934, DIN 985	Standard specification for Square Nuts
DIN913 GB77	Stainless Steel Inner Hex Hexagon Socket Plain Point End Grub Screws

## ASHBY CHARTS

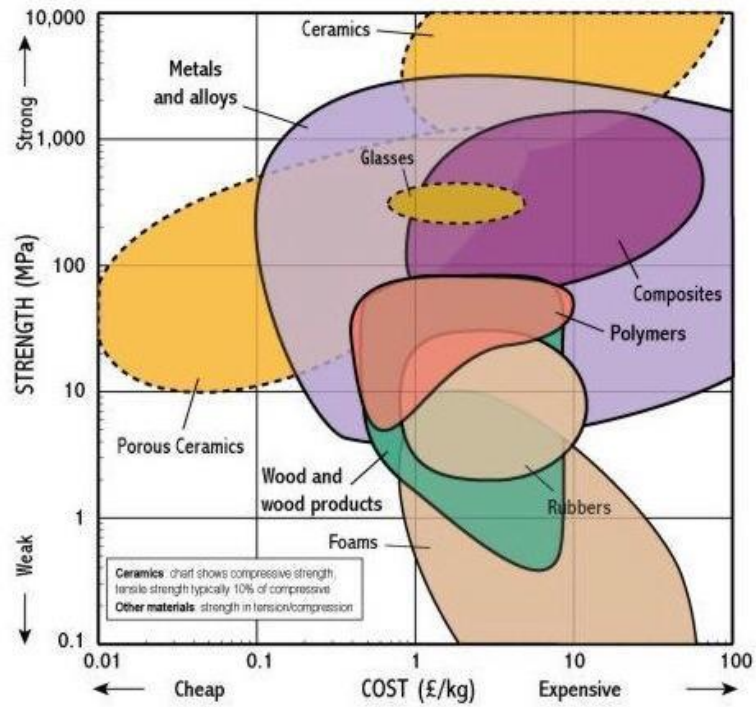


Figure 25 ASHBY Chart; Strength to Cost

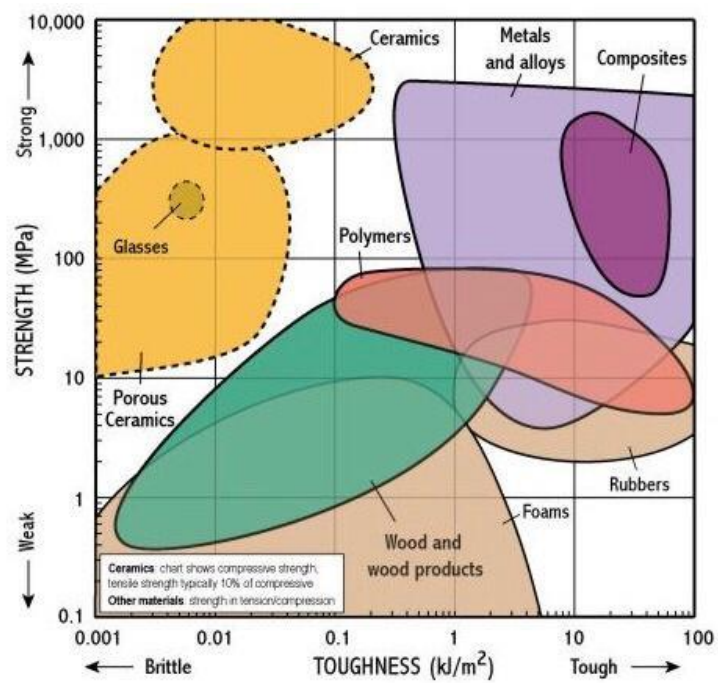


Figure 26 ASHBY Chart; Strength to Toughness



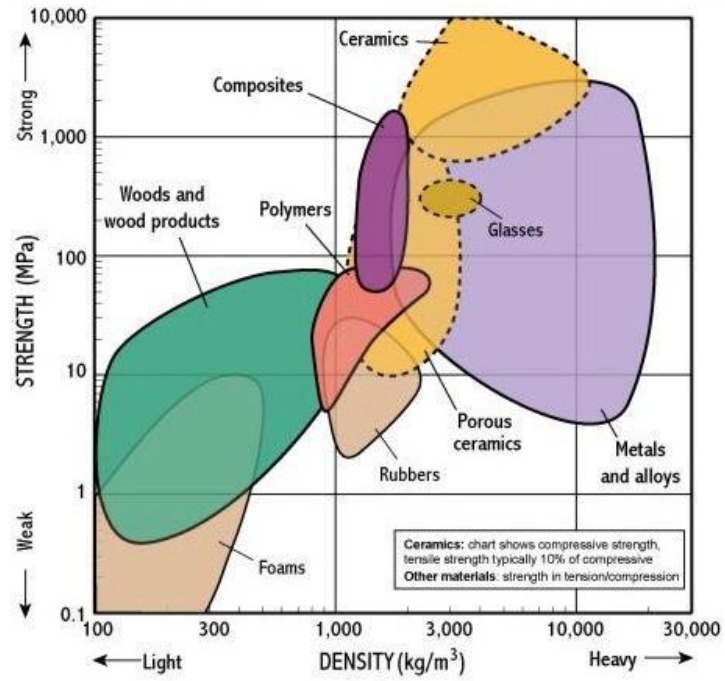


Figure 23 ASHBY Chart; Strength to Density

## 12 APPENDIX D: Logbook

Meeting No.	Team Meeting Minutes		
	Project Name: Multi-Functional Robotic Arm	Start Date: Feb., 1, 2019	Aimed End Date: May, 28 ,2020
	Discussion Topic	Meeting Duration	Dates of Meeting
1	Selection of Idea	2-hours	1-Feb
2	Division of Tasks	1.5-hours	8-Feb
3	Dismantling Available Components & Sorting Out Manufacturing Needs	2-hours	11-Feb
4	Reviewing Tasks Accomplished & Division of Next Tasks	2-hours	18-March
5	Agreeing on a Design & Reviewing Tasks Accomplished	2-hours	25-March
6	Buying Missing Components and Connecting Parts Together	3.5-hours	2-April
7	3D-Printing of Designed Components	5-hours	9-April
8	Division of Next Tasks & Going Through Design Calculations	3.5-hours	16-April
9	Reviewing Tasks and Design Calculations & Division of Next Tasks	4.5-hours	23-April
10	Finalizing Reporting and Fixing Missing Details	2.5-hours	17-May

	<b>Team Member</b>	<b>Member Responsibility</b>	<b>Days to Work</b>
<b>1</b>	Emre Kaya	Assigned Task Completion & Parts Buying	7-Days
<b>2</b>	Mahmoud Akkawi	Assigned Task Completion & Parts Assembly	30-Days
<b>3</b>	Rana Khaled	Assigned Task Completion, Report Organization, Report Reviewing, & Parts Assembly	30-Days
<b>4</b>	Mustafa Ghadri	Assigned Task Completion, Design of Components, & Parts Assembly & Purchase	30-Days
<b>5</b>	Abdullah Emad	Assigned Task Completion	7-Days

### 13 APPENDIX E: Project Timeline

PROJECT NAME		PROJECT DURATION	PROJECT START DATE	PROJECT END DATE
Multifunctional Robotic Arm		138	January 1, 2020	May 18, 2020

Task No.	Task Description	Task Duration	Start Date	End Date
1	Idea generation and selection	0	1-Jan	1-Jan
2	Collecting basic background info.	1	1-Jan	2-Jan
3	Understanding the project	0	2-Jan	2-Jan
4	Assigning tasks to team members and brain storming project plan	0	2-Jan	2-Jan
5	Gathering details about components and materials	3	2-Jan	5-Jan
6	Estimating a BOM and agreeing upon it	2	5-Jan	7-Jan
7	Comparing the preferable design with available designs	2	7-Jan	9-Jan
8	Concurrent solutions research	2	9-Jan	11-Jan
9	Selection of design	1	11-Jan	12-Jan
10	Performing the design process using softwares and CAD models	28	12-Jan	9-Feb
11	Buying components based on the accomplished CAD design	1	9-Feb	10-Feb
12	Manufacturing process (3D printing and assembly)	55	10-Feb	5-Apr
13	Testing and fixing	34	5-Apr	9-May
14	Taking notes and documenting data	100	1-Nov	18-May
15	Reviewing and editing	7	9-May	16-May
16	Printing	1	16-May	17-May
17	Representation	1	17-May	18-May

## 14 APPENDIX F: Manuals

### 14.1 Programming

- **AURDUINO CODE:**

```
/*  
  Stepper Motor Test  
  stepper-test01.ino  
  Uses MA860H or similar Stepper Driver Unit  
  Has speed control & reverse switch  
  DroneBot Workshop 2019  
*/  
  
// Defin pins  
int reverseSwitch = 2; // Push button for reverse  
int driverPUL = 7; // PUL- pin  
int driverDIR = 6; // DIR- pin  
int spd = A0; // Potentiometer  
  
// Variables  
  
int pd = 500; // Pulse Delay period  
boolean setdir = LOW; // Set Direction  
  
// Interrupt Handler  
void revmotor () {  
  setdir = !setdir;  
}  
  
void setup() {  
  pinMode (driverPUL, OUTPUT);
```

```

pinMode (driverDIR, OUTPUT);

attachInterrupt(digitalPinToInterrupt(reverseSwitch), revmotor, FALLING);

}

void loop() {

    pd = map((analogRead(sp)),0,1023,2000,50);

    digitalWrite(driverDIR, setdir);

    digitalWrite(driverPUL, HIGH);

    delayMicroseconds(pd);

    digitalWrite(driverPUL, LOW);

    delayMicroseconds(pd);

}

```

- **PYTHON CODE - RASPBERRY PI**

```

from time import sleep
import RPi.GPIO as GPIO

DIR = 20 # Direction GPIO Pin
STEP = 21 # Step GPIO Pin
CW = 1 # Clockwise Rotation
CCW = 0 # Counterclockwise Rotation
SPR = 200 # Steps per Revolution (360 / 1.8) <-- source code has 7.5 degree steps for
SPR of 48.

```

```

GPIO.setmode(GPIO.BCM)
GPIO.setup(DIR, GPIO.OUT)
GPIO.setup(STEP, GPIO.OUT)
GPIO.output(DIR, CW)

step_count = SPR
delay = .0208

for x in range(step_count):
    GPIO.output(STEP, GPIO.HIGH)
    sleep(delay)
    GPIO.output(STEP, GPIO.LOW)
    sleep(delay)

```

```

sleep(.5)
GPIO.output(DIR, CCW)
for x in range(step_count):
    GPIO.output(STEP, GPIO.HIGH)
    sleep(delay)
    GPIO.output(STEP, GPIO.LOW)
    sleep(delay)

GPIO.cleanup()

```

- STEPPER MOTORS CONNECTED TO AURDUINO AND MOTOR CONTROLLER.

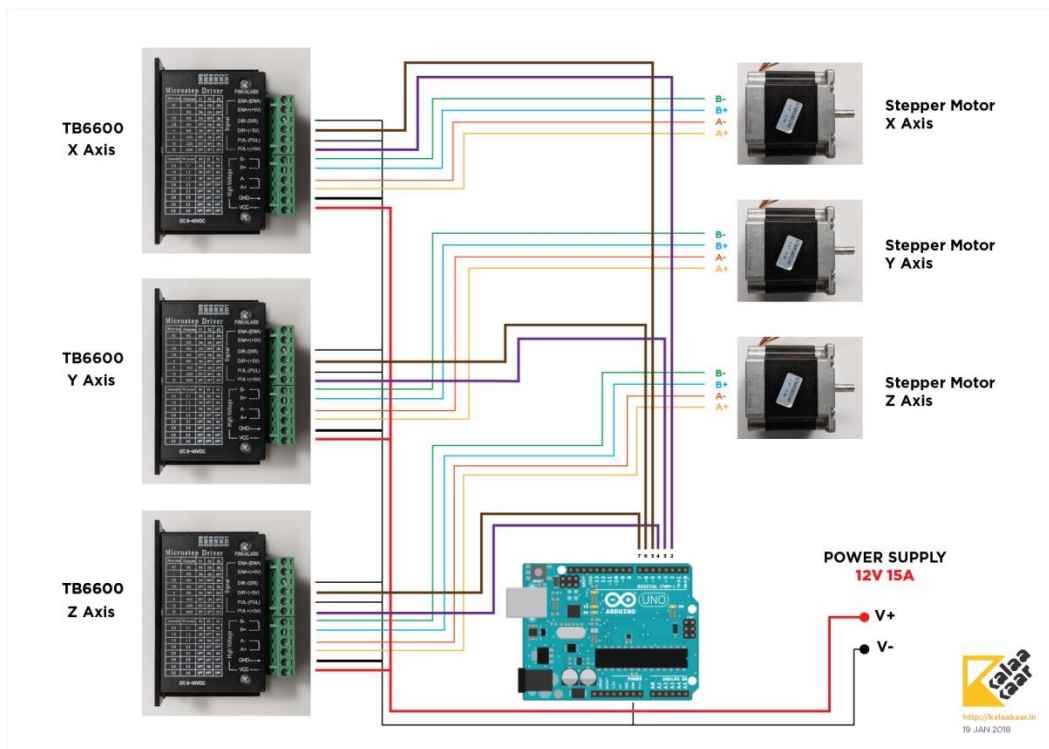


Figure 24 Arduino Board

- STEPPER MOTORS CONNECTED TO RESPBERRY PI AND MOTOR CONTROLLER

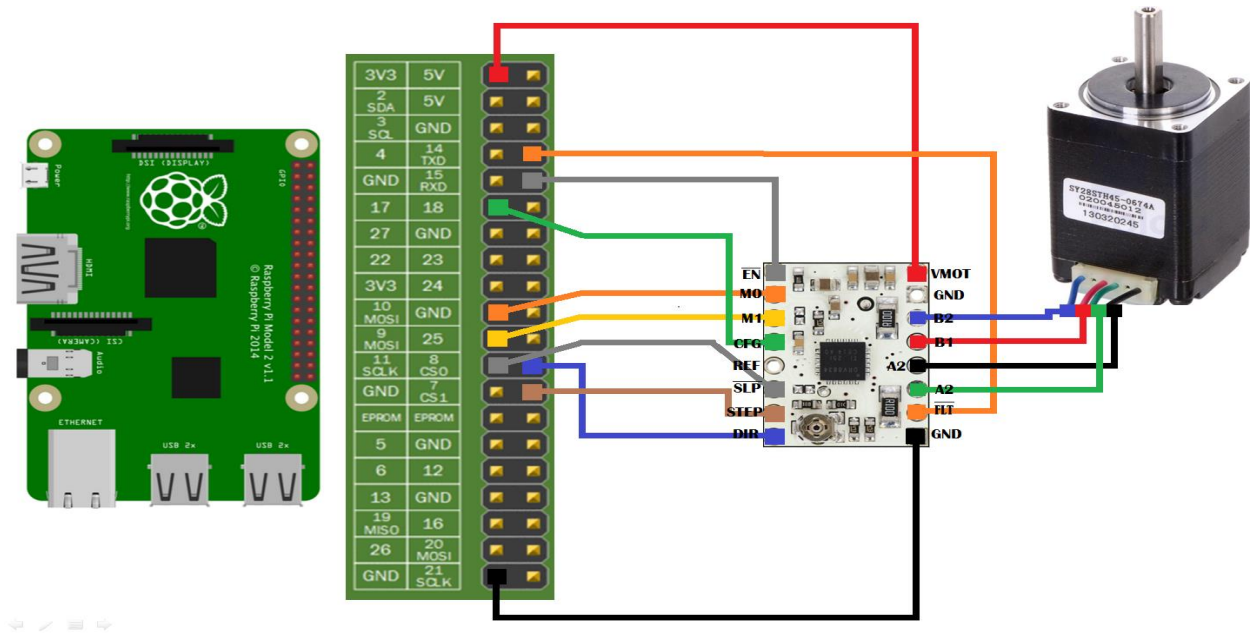


Figure 25 Raspberry Board

## 14.2 Welding

This TIG welder operates on a TIG (2T) mode, which is set firstly, before adjusting anything else, as it defines the way the welding will take place.

Then, all the welding components, the welding torch and the gas tube connections, should all be connected properly. One end of the earth clamp is connected to the welding table and the other connection is installed in the positive electrode.

The gas supply connection is fixed to the left of the earth clamp connection, properly securing the end of the tube to the gas tank.

Finally, the welding torch is connected to the third connection, from the right, as shown below.





Figure 30 Connections Panel

Then, operation proceeds to the control panel, where the welding current and the base current can be altered to the user's desire. The penetration of the welding torch highly depends on the welding and base currents; thicker materials require higher values.

To start operating, the orange button, shown below in Figure 27, should be pushed and rotated according to the desired function

Then, the button is pressed again to set its default position without altering any values.

Finally, the safety button should be released and the torch should be brought at about 5mm distance from the work piece to initiate the welding procedure.



Figure 31 Control Panel

### 14.3 Screw Driving

Firstly, a box that fits the screwdriver is to be attached to the arm head, where the screwdriver is to be connected.

The screwdriving tool holder comes with multiple screwdriving shapes that can all be attached to one spindle. The desired shape is to be selected before initiating the driving process.

A material, for example, wood, is to be placed on a fixed table perpendicular to the screwdriver head. The drilling tool has to be placed at the center of the screw, and the screwdriving process is initiated by turning on the switch on the right of the box holder.

### 14.4 Gripping

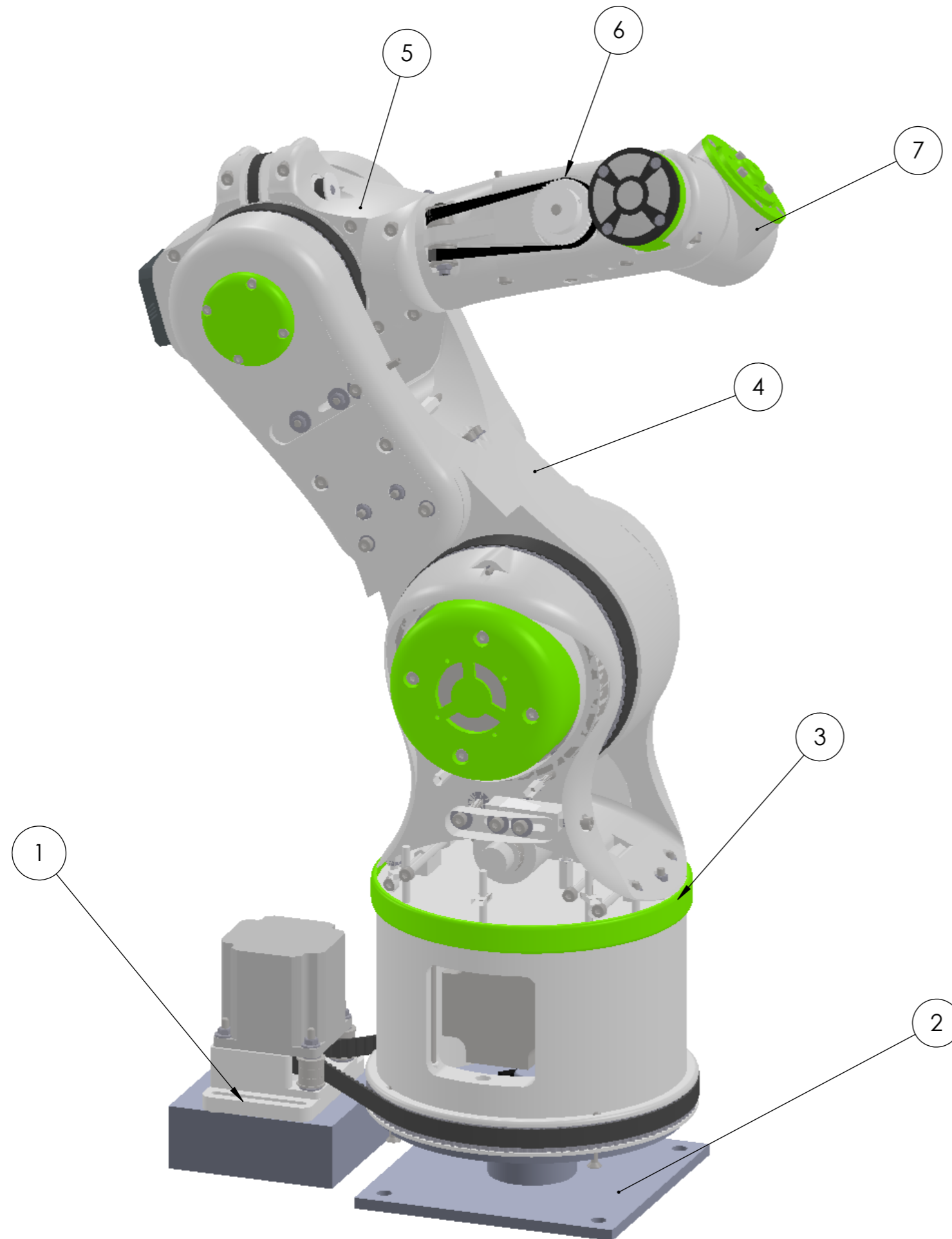
The gripping process initiation is by far the easiest and the simplest. Firstly, the same box that fits the screwdriver holder fits to the gripping fingers. The gripping to is to be fixed properly to the holding box.

A maximum mass of 2Kg can be carried by this gripper. The process is initiated after setting the initial position of the gripper and the displacement on the controller computer.

Place the work part at the initial position, and, finally, the process is initiated by turning on the switch at the right of the box holder.

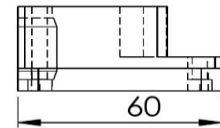
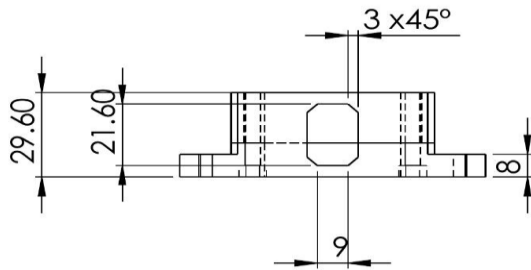
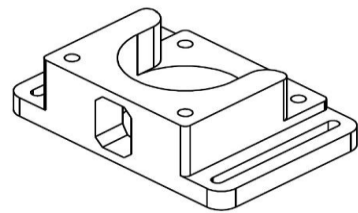
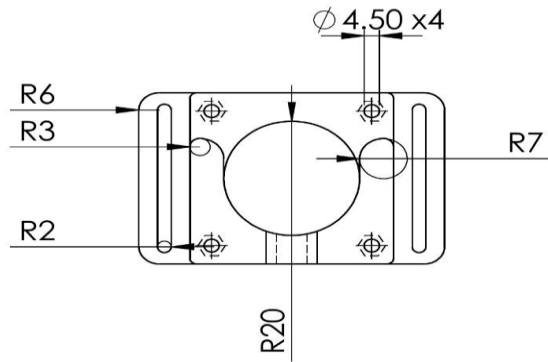
## **15 APPENDIX G: Engineering Drawing**

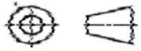
*Designed with the help of Hatim Shams*

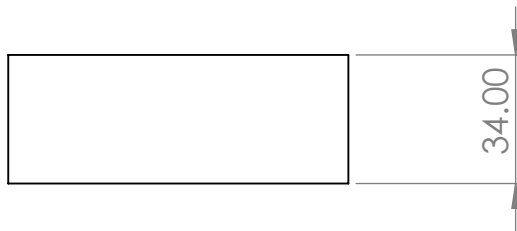
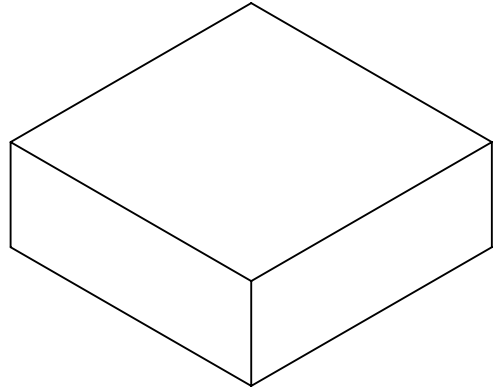
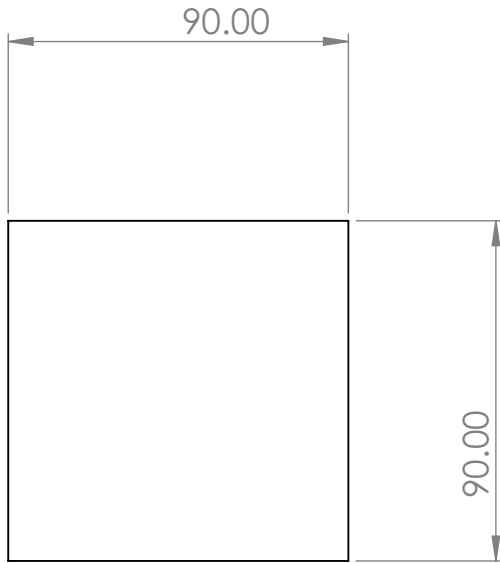


ITEM NO	ITEM NAME
1	NEMA 32 HOLDER
2	ROT BASE
3	SHOULDER
4	ELBOW
5	FOREARM
6	WRIST
7	WRESTROT

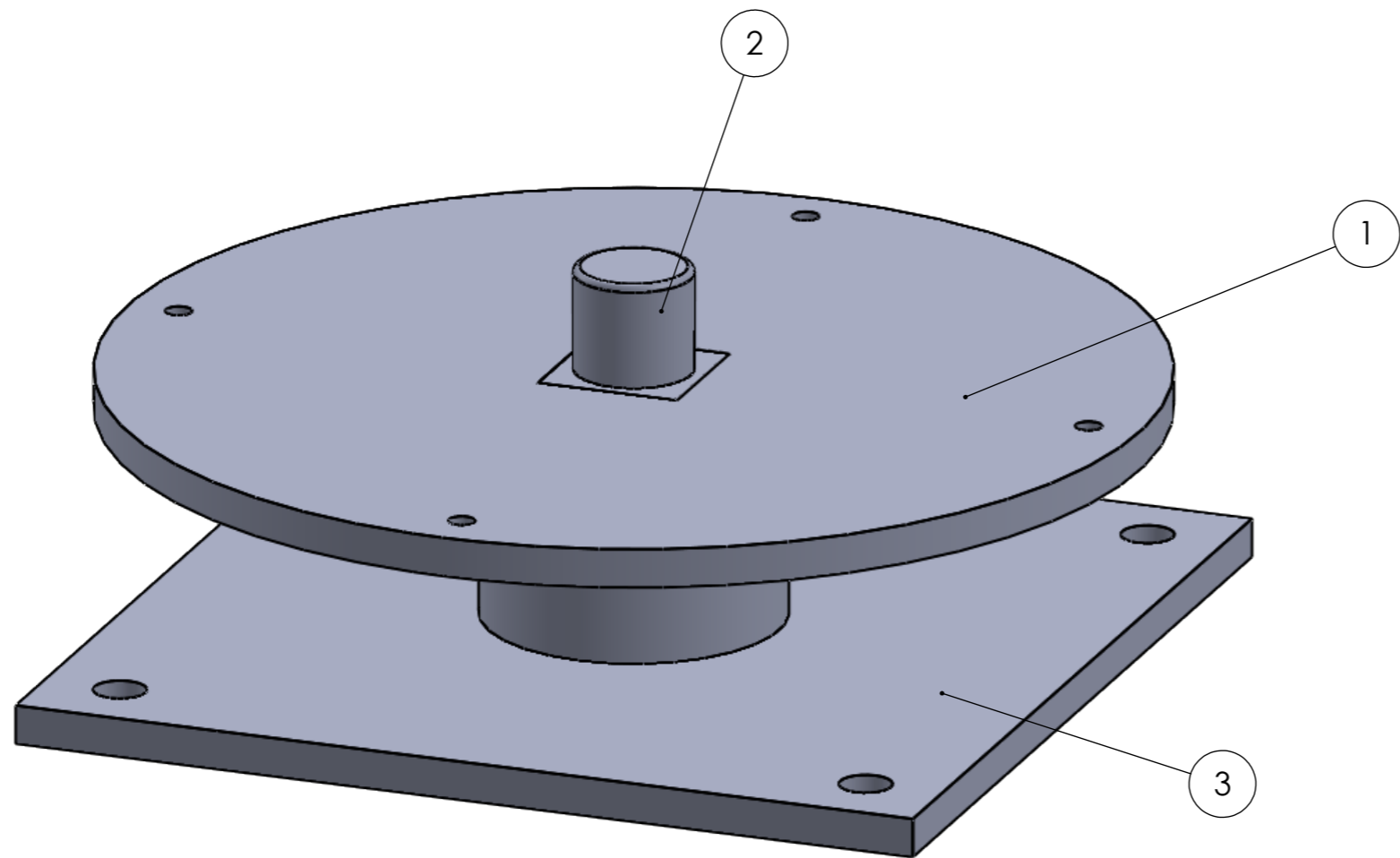
	NAME	DATE	SIGN	EMU
DRW. BY	MUST.	1/1/2021	M.G.	
CHK. BY	ABDU.	1/1/2021	A.F.	
SCALE 2:5	ARM ASEM.		DRAWING NO 111	



		NAME	DATE	SIGN	EMU
DRW. BY	Hatim	15-05-2019	H.S.		
CHK. BY	Sharif	15-05-2019	S.S.		
SCALE 1:2	Nema 23 Holder			DRAWNG NO 1-1	



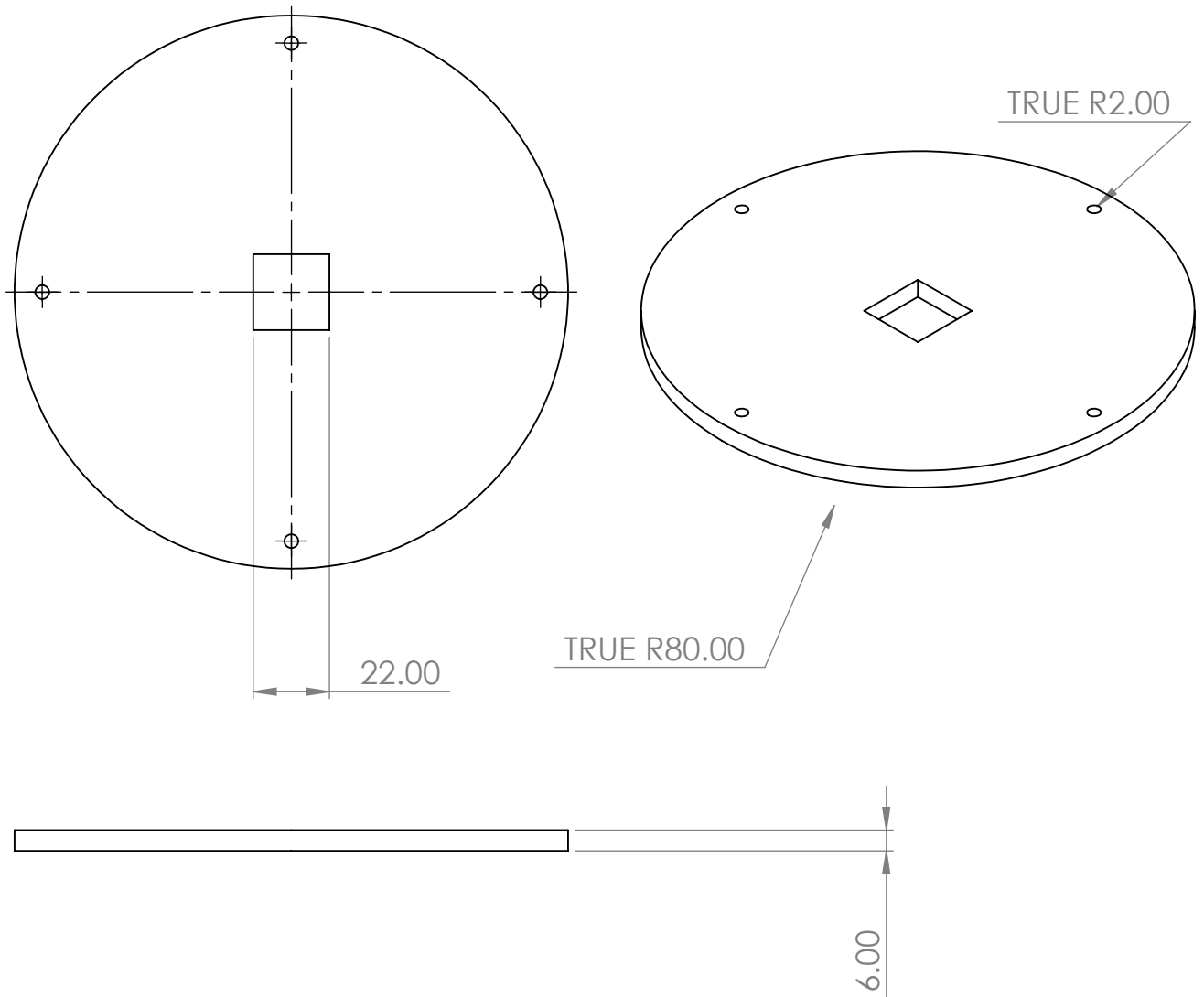
	NAME	DATE	SIGN	
DRW. BY	Mustafa	12/25/2020	M.G	EMU
CHK. BY	Abdullah	12/25/2020	A.E	
SCALE 1:2	end part			DRAWING NO 1-3-4



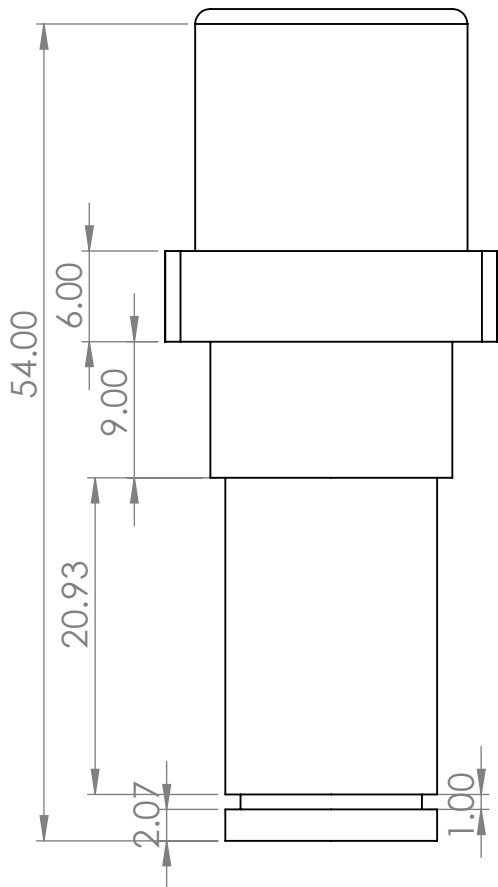
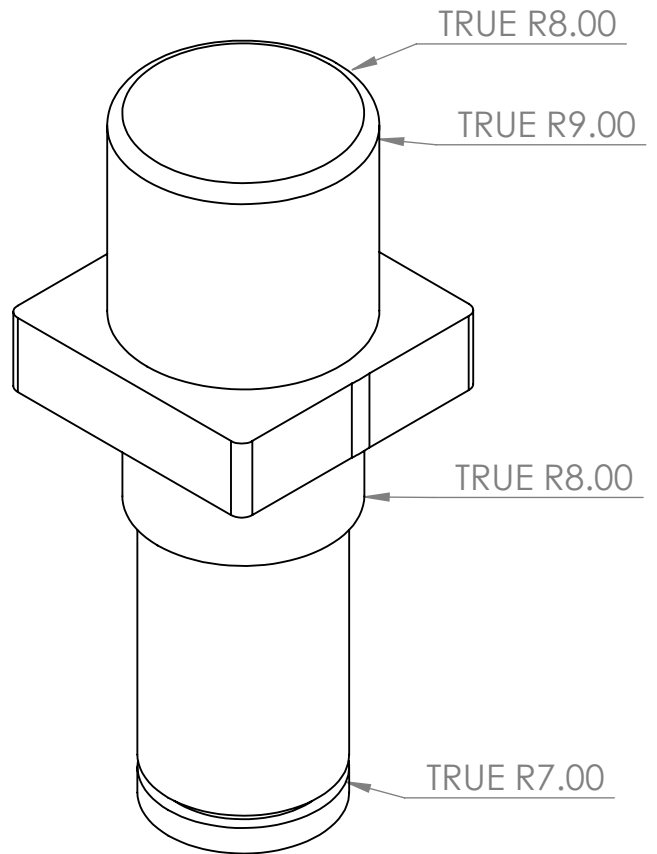
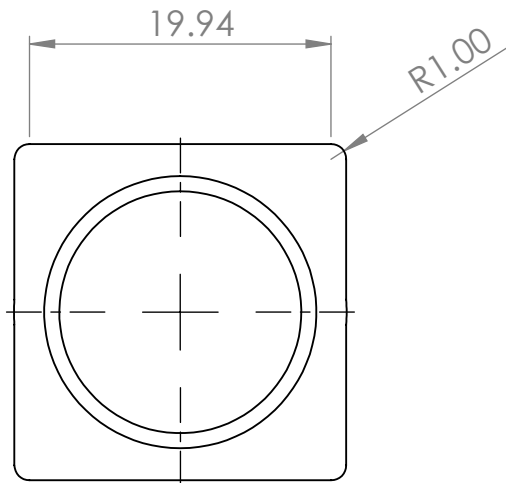
ITEM NO	ITEM NAME
1	TOP PART
2	SHAFT
3	BOTTOM

	NAME	DATE	SIGN	EMU
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CHK. BY	ABDU.	25-12-2020	A.FA.	
SCALE 1:2	TITLE BASE	DRAWING NO 1-2		

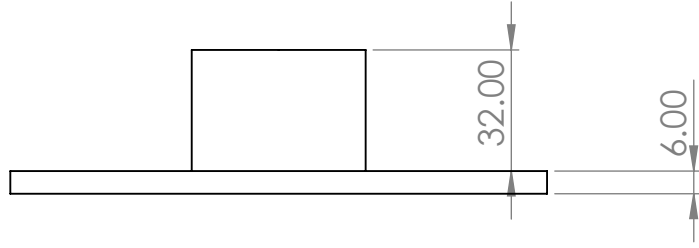
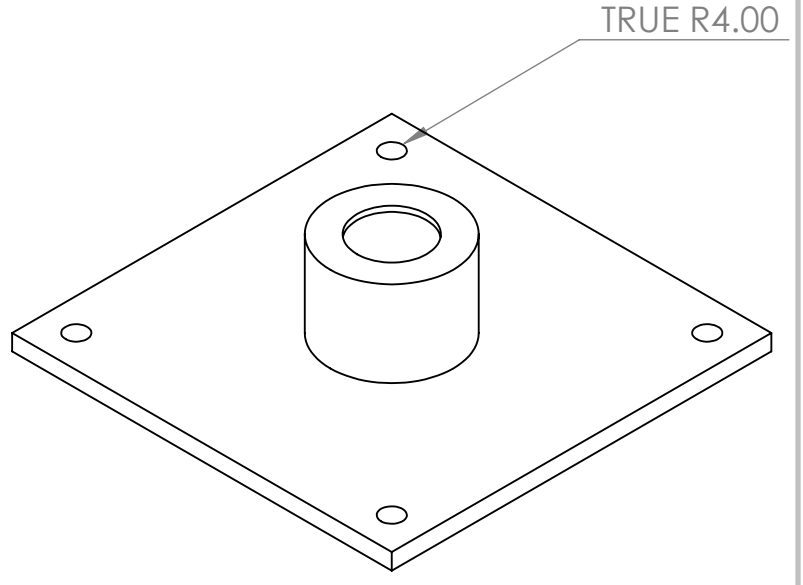
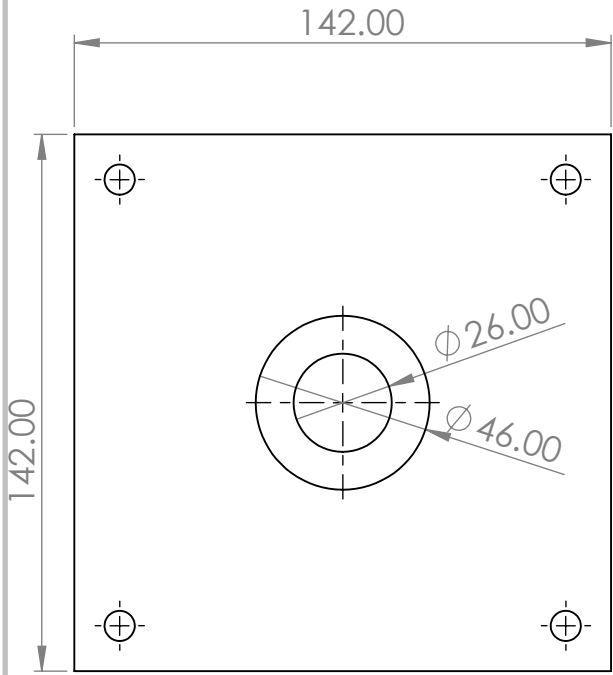




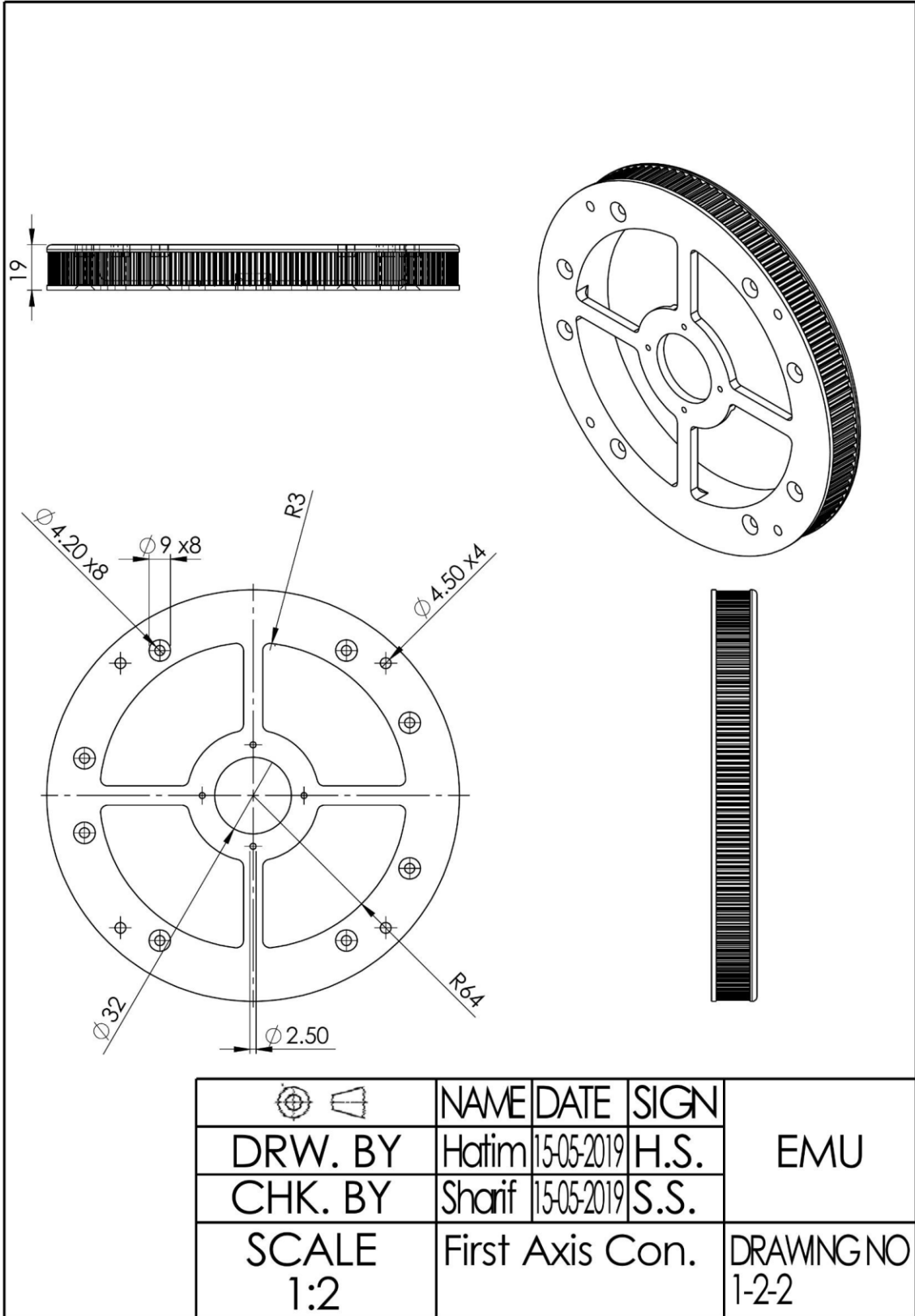
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DRW. BY	mustafa	12/25/2020	M.G	EMU
CHK. BY	abdullah	12/25/2020	A.E	
SCALE 1:2	Top Part			DRAWING NO 1-3-1

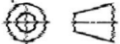


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CHK. BY	Abdullah	12/25/2020	A.E	
SCALE 2:1	Shaft			DRAWING NO 1-3-2

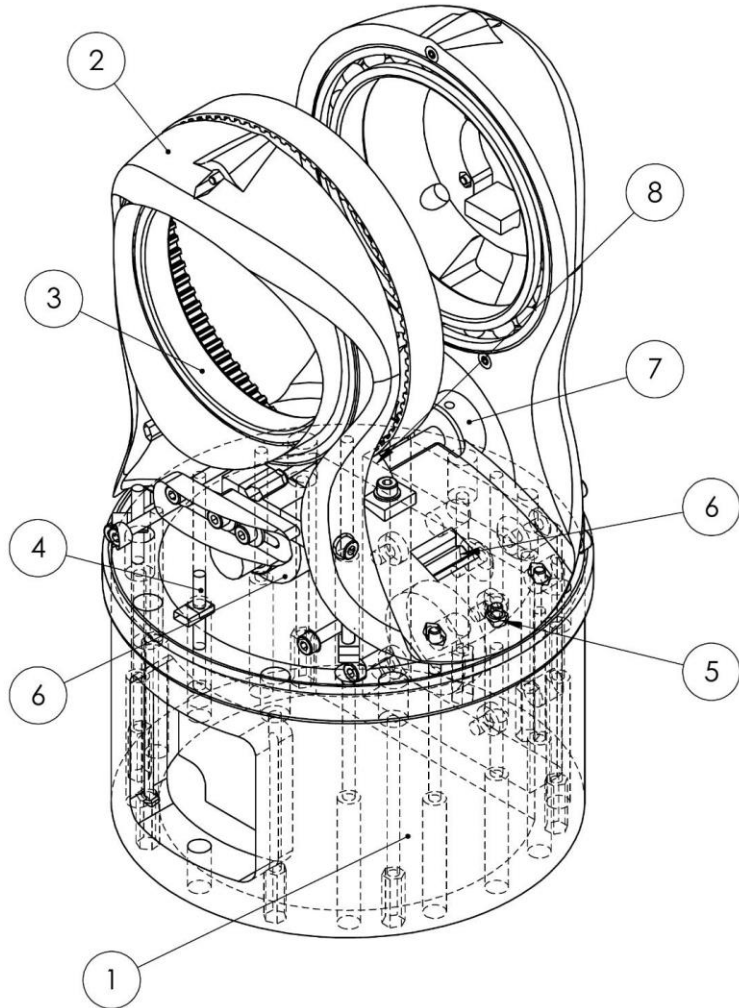



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CHK. BY	Abdullah	12/25/2020	A.E	DRAWING NO 1-3-3
SCALE 1:2	Bottom			

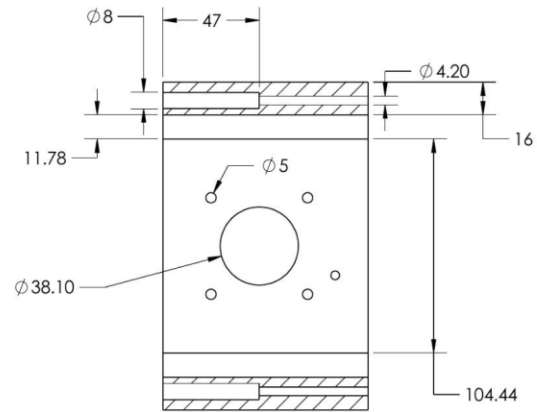
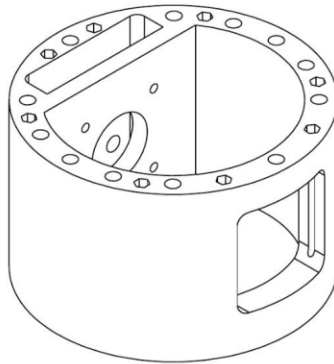
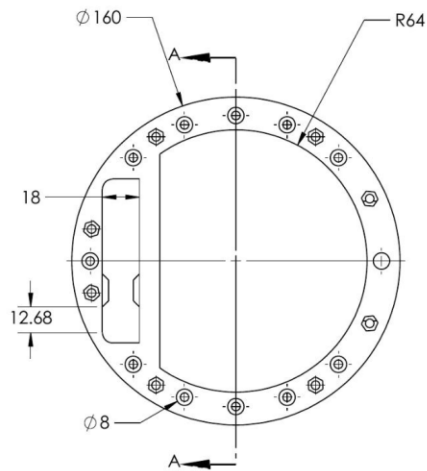


	NAME	DATE	SIGN	EMU
DRW. BY	Hatim	15-05-2019	H.S.	
CHK. BY	Sharif	15-05-2019	S.S.	
SCALE 1:2	First Axis Con.		DRAWINGNO 1-2-2	

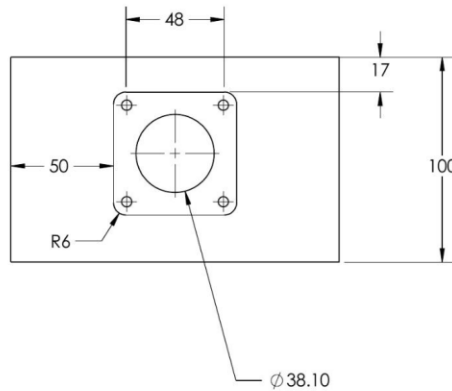
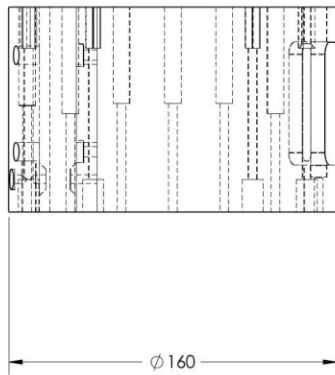
Item No.	Item Name
1	Nema 24 Housing
2	Shoulder Link
3	DIN625 Bearing
4	DIN912 M4 Bolt
5	DIN934 M4 Nut
6	M4 Spacer
7	3M TIMING PULLEY
8	DIN625 Bearing



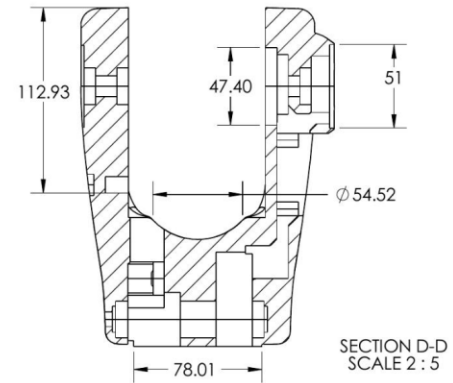
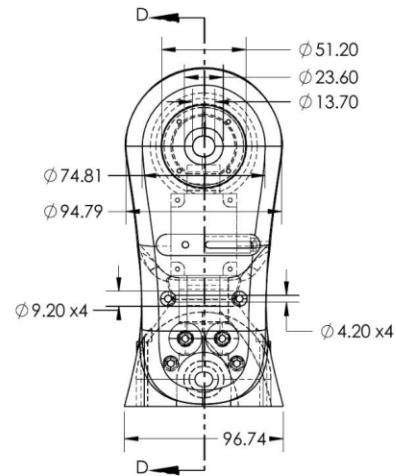
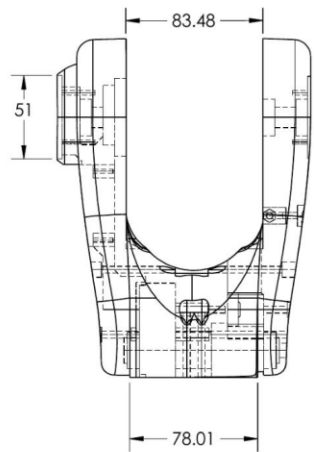
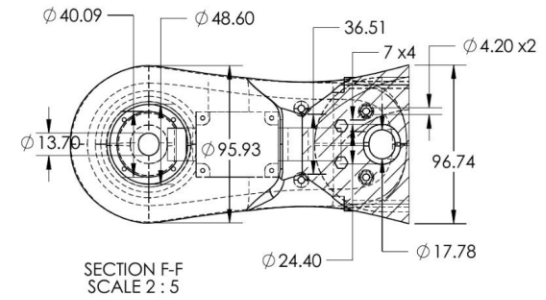
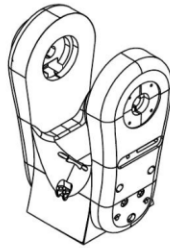
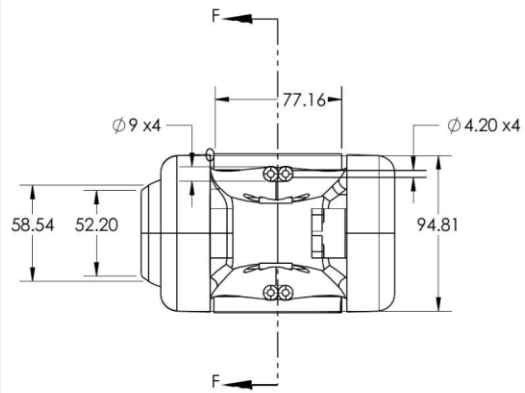
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DRW. BY	Hatim	15-05-2019	H.S.	
CHK. BY	Sharif	15-05-2019	S.S.	
SCALE 1:2	Shoulder Assembly		DRAWING NO 1-3	



SECTION A-A

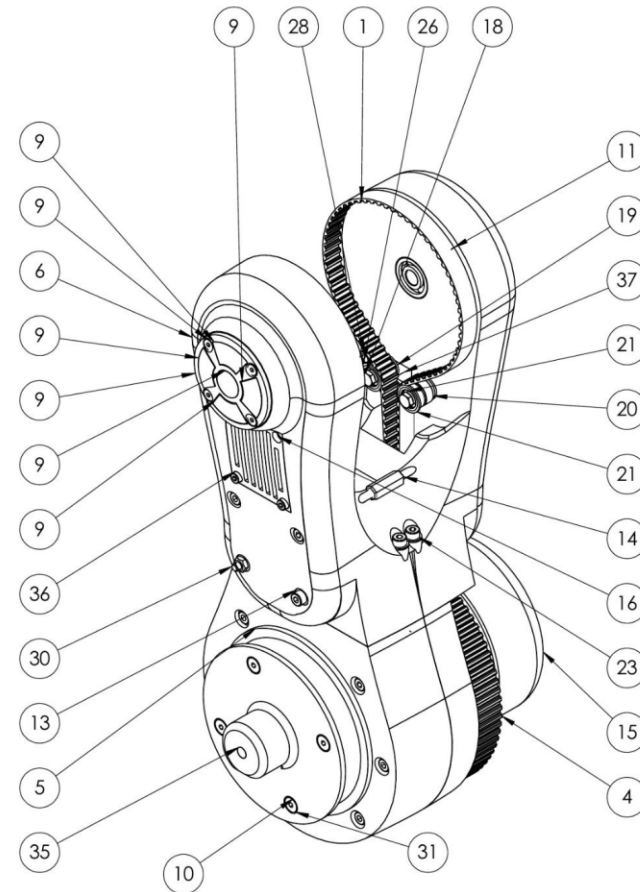


	NAME	DATE	SIGN	EMU
DRW. BY	Samer	17-05-2019	S.S.	
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SCALE 1:2	Nema24 Housing		DRAWING NO 1-3-1	



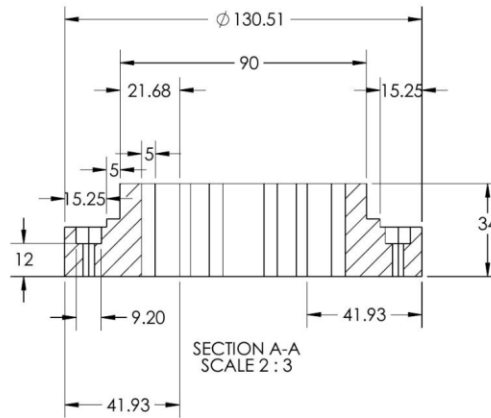
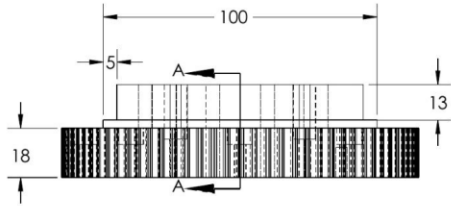
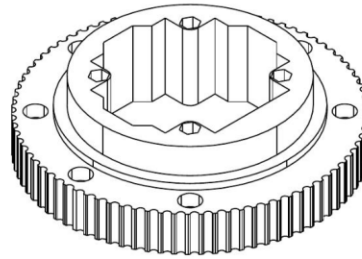
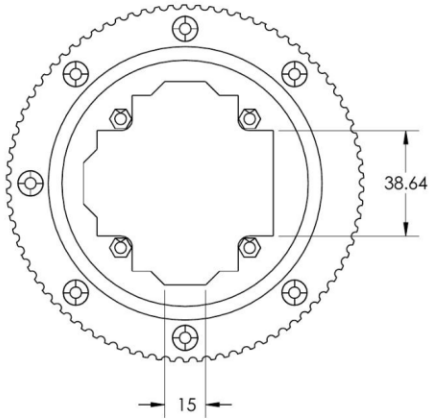
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CHK. BY	Hatim	18-05-2019	H.S.	
SCALE	Shoulder Link		DRAWING NO	1-3-2
2:5				

ITEM NO.	PART NUMBER	DESCRIPTION	AltPosition_Default_1/QTY.
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2	Nema24_3		1
3	X_DCbertragung des Zahnriemens2_3		1
4	OberArm_A_2		1
5	OberArm_B_3		1
6	OberArm_C_2		1
7	Cover_G2_2		1
8	Welle1_3_2		1
9	encoder_1_2		1
10	OberArmMagnet_3		1
11	DIN 625 SKF - SKF 608_3		6
12	DIN 912 - M4 x 0,7 x50_3		4
13	DIN 125 - A 4,3_3		39
14	Distanzhülse_M4x20mm_3		13
15	MotorCoverN24_3_3		1
16	DIN 912 - M3 x 0,5 x 10 x 8,75_3		8
17	DIN 912 - M4 x 0,7 x 35 x 20_3		4
18	DIN 933 - M4 x 40_3		2
19	DIN 9021 - 4,3_2		6
20	DIN 625 T1 - 624 - 4 x 13 x 5_2		7
21	DIN 625 SKF - SKF 624_flansch_2		3
22	DIN 625 SKF - SKF 61807_2		1
23	DIN 912 - M4 x 0,7 x55_2		10
24	16221600_3		2
25	Synchrone RiemenscheibeT5_z48_3		1
26	DIN 912 - M4 x 0,7 x 30 x 20_3		16
27	DIN 933 - M4 x 55_3		2
28	DIN 934 - M4 x 0,7_2		16
29	DIN 562 - M4 x 7_2		5
30	DIN 933 - M4 x 25_3		1
31	DIN 7991 - M4x30_2		4
32	Belt_T_Spacer_3		1
33	DIN 912 - M4 x 0,7 x 40 x 20_2		1
34	DIN 125 - A 8,4_3		3
35	EncoderMagnet_3		1
36	Cable_Cover_2		1
37	Alu_Belt_tens_2		1
38	DIN 913 - M4 x 16_3		1
39	DIN 913 - M4 x 4_2		3
40	ISO 13337 - 3 x 26BS EN ISO_3		1
41	ISO 13337 - 3 x 20BS EN ISO_2		1

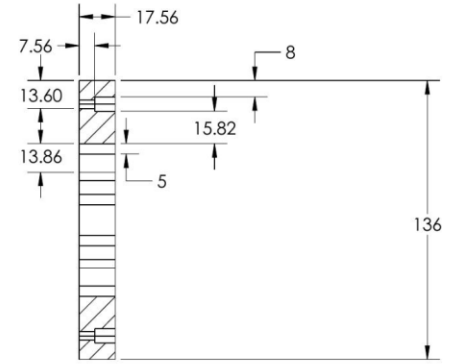
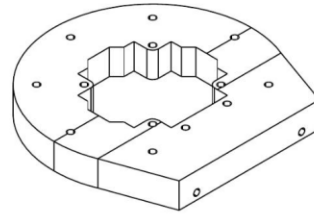
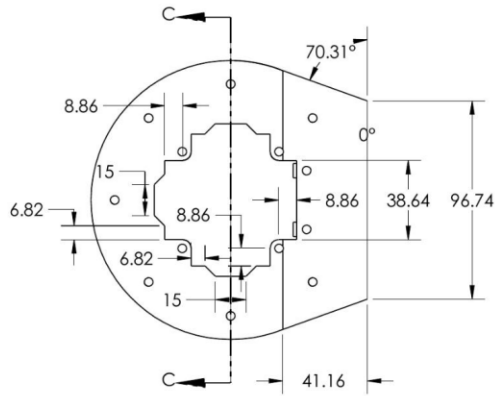


	NAME	DATE	SIGN	EMU
DRW. BY	Hatim	15-05-2019	H.S.	
CHK. BY	Sharif	15-05-2019	S.S.	
SCALE	Elbow Assembly		DRAWING NO	
1:2			1-4	

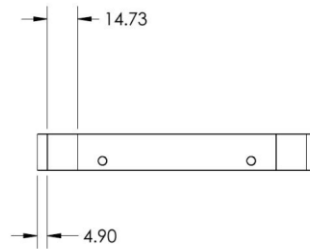
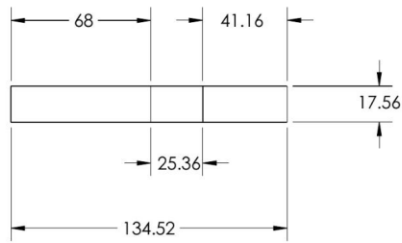




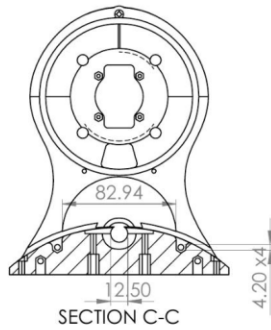
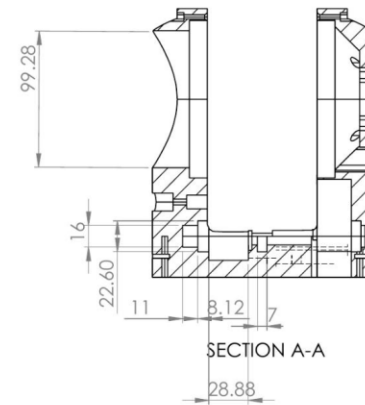
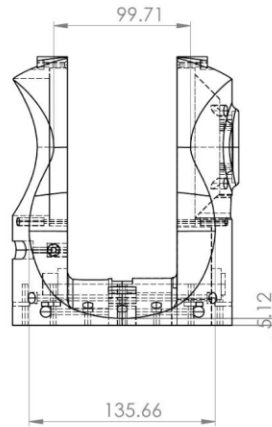
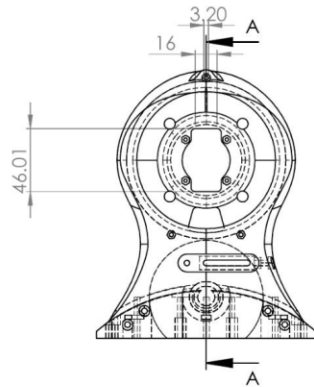
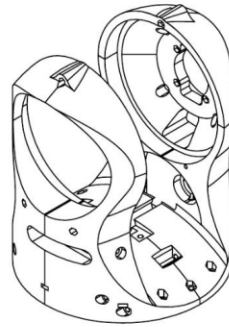
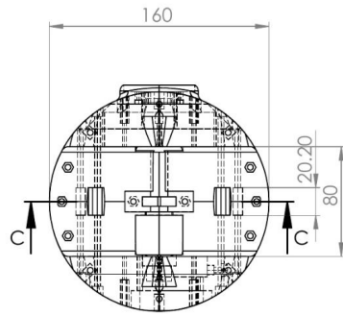
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DRW. BY	Samer	15-05-2019	S.S.	
CHK. BY	Hatim	18-05-2019	H.S.	DRAWING NO 1-41
SCALE 2:3	Part A			



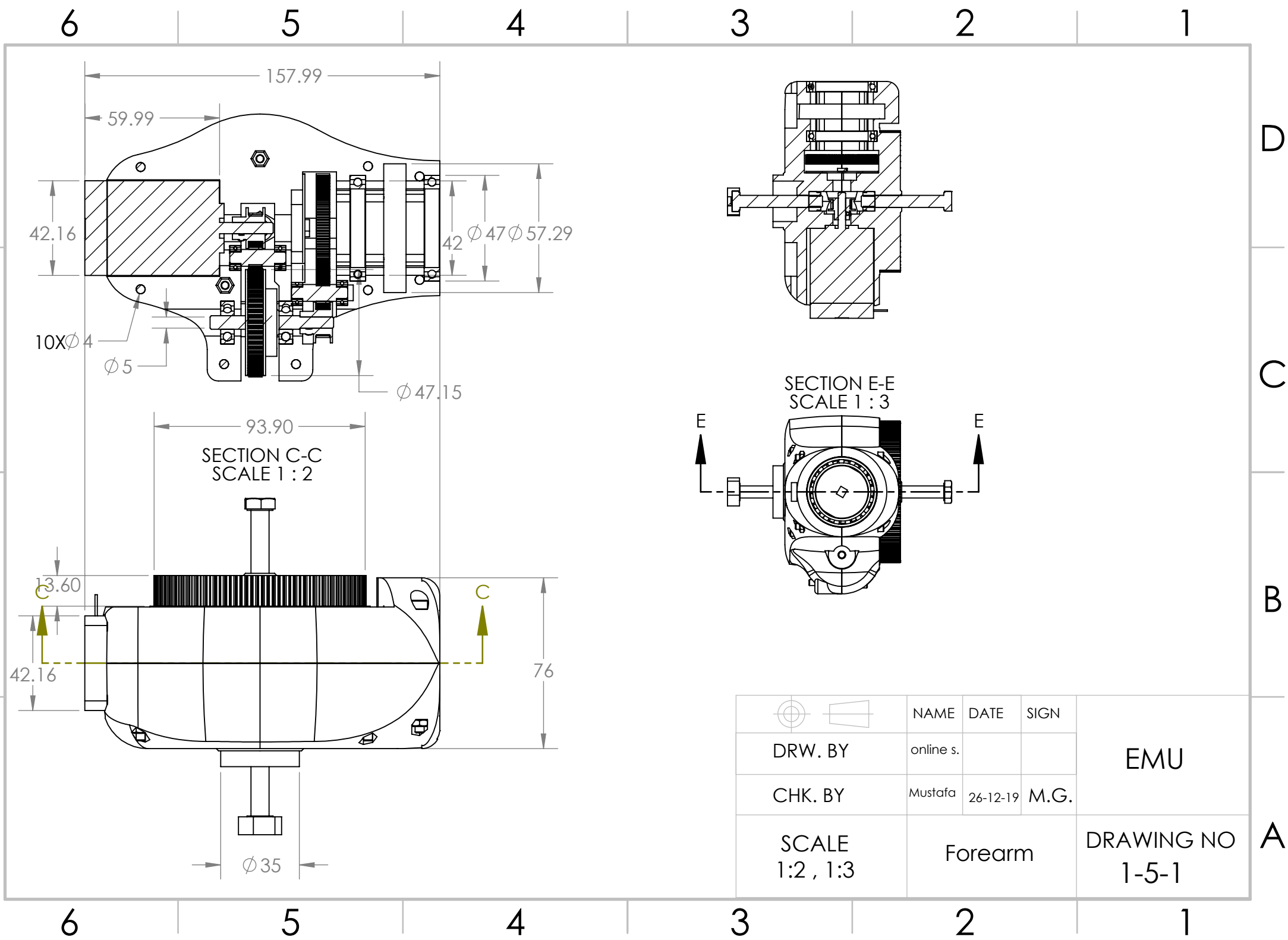
SECTION C-C

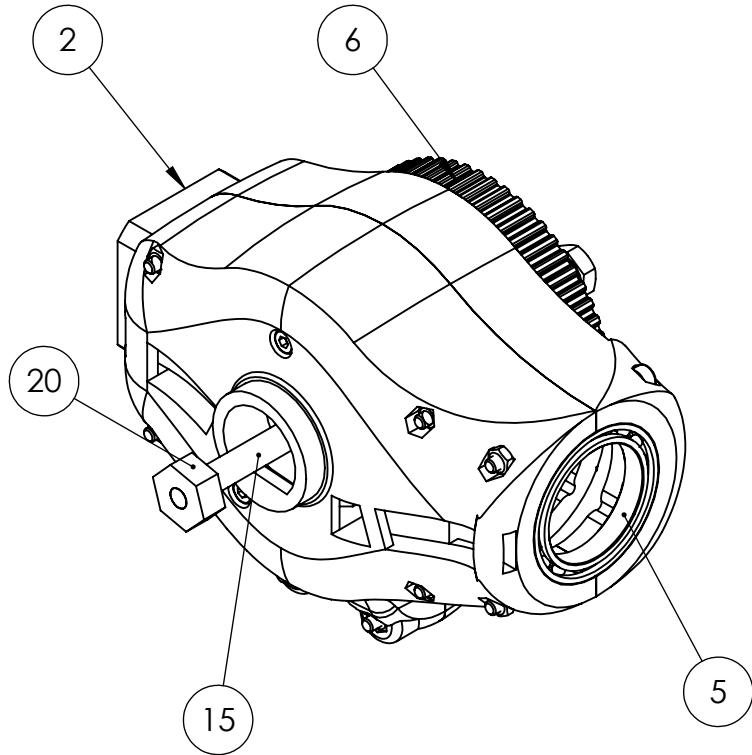


DRW. BY	NAME	DATE	SIGN	EMU
CHK. BY	Samer	15-05-2019	S.S.	
SCALE	Hatim	16-05-2019	H.S.	DRAWING NO 1-4-2
1:2	Part B			



		NAME	DATE	SIGN	EMU
DRW. BY	Hatim	15-05-2019	H.S.		
CHK. BY	Sharif	15-05-2019	S.S.		
SCALE	1:3	Shoulder Link		DRAWING NO	
				1-4-3	

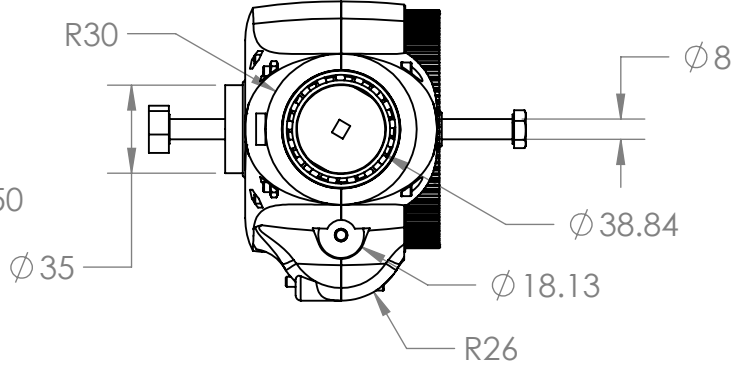
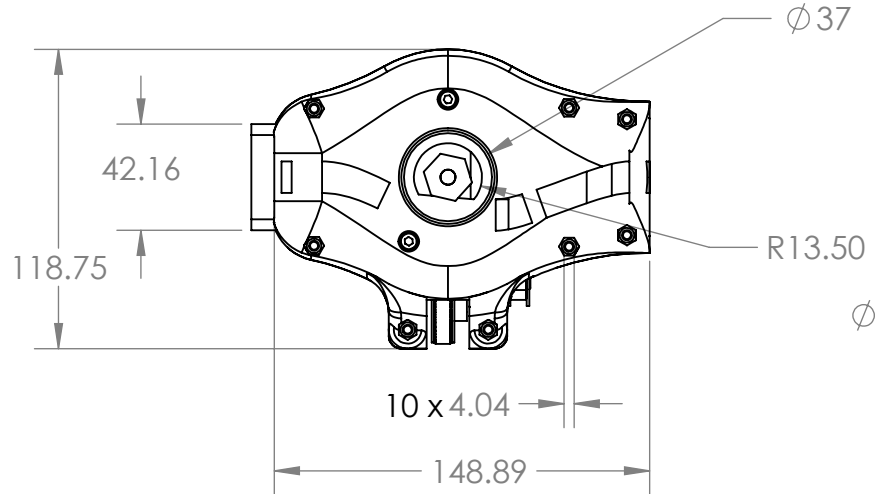
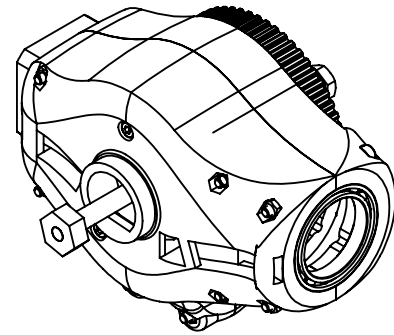
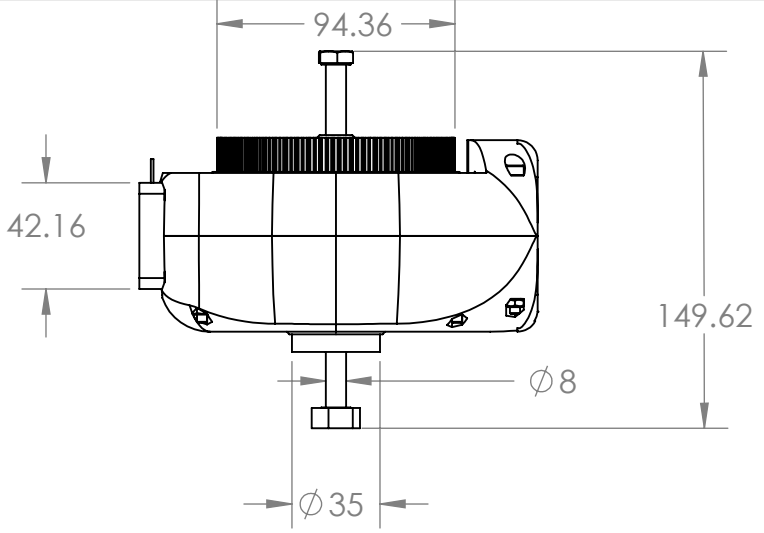




PART NO.	DESCRIPTION	QUANTITY
2	NEMA MOTOR	1
6	GERA	1
5	DIN 500 BEARING	2
15	SHAFT A	1
20	STANDARD NUTS	2

		NAME	DATE	SIGN	EMU
DRW. BY	online s.				
CHK. BY	Mustafa	26-12-19	M.G.		
SCALE	1:2	Forearm		DRAWING NO	
				1-5-2	A

6 5 4 3 2 1



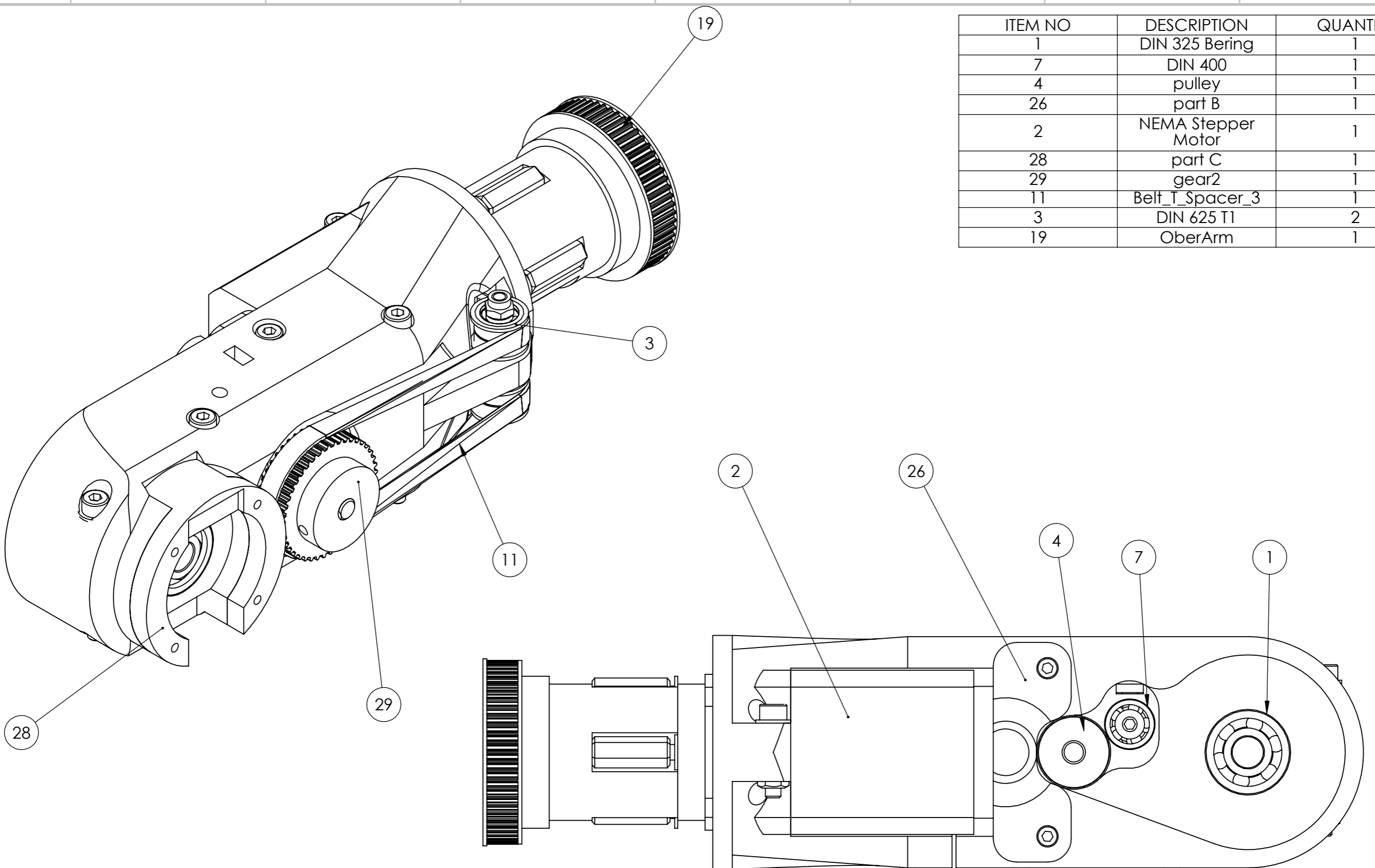
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DRW. BY	online s.				
CHK. BY	Mustafa	26-12-19	M.G.		
SCALE 1:3	Forearm		DRAWING NO 1-3-3		

6 5 4 3 2 1

D  
C  
B  
A

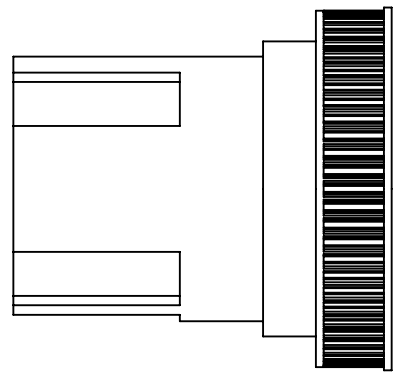
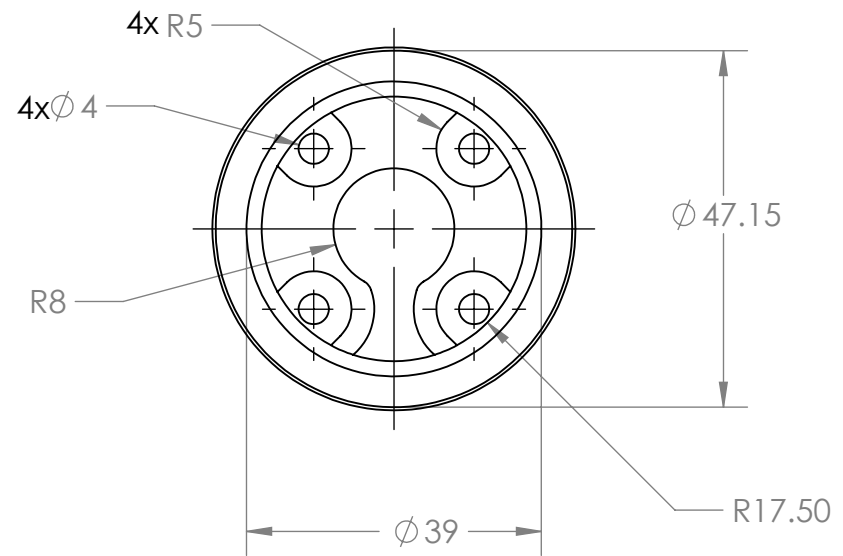
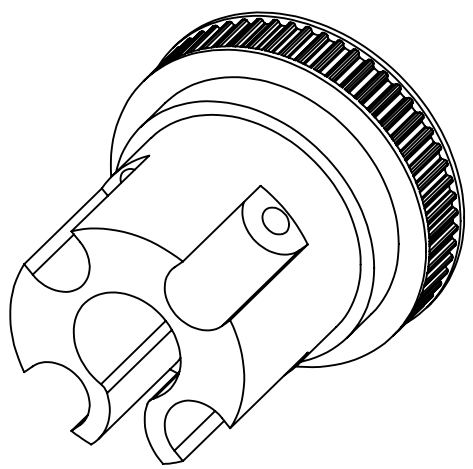
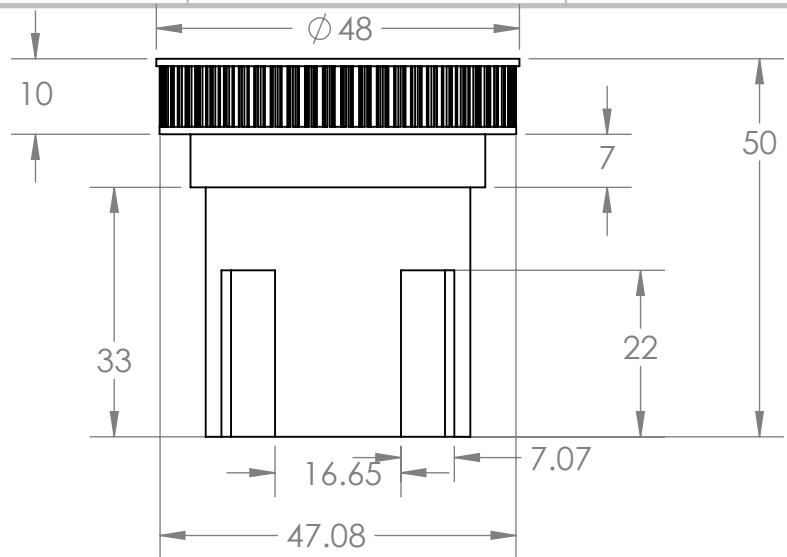
D  
C  
B  
A

ITEM NO	DESCRIPTION	QUANTITY
1	DIN 325 Bering	1
7	DIN 400	1
4	pulley	1
26	part B	1
2	NEMA Stepper Motor	1
28	part C	1
29	gear2	1
11	Belt_T_Spacer_3	1
3	DIN 625 T1	2
19	OberArm	1



		NAME	DATE	SIGN	EMU
DRW. BY	ONLINE S.				
CHK. BY	Mustafa	26-12-19	M.G.		
SCALE 1:1	Wrist		DRAWING NO 1-6		

6 5 4 3 2 1



		NAME	DATE	SIGN	EMU
DRW. BY	ONLINE S.				
CHK. BY	Mustafa	26-12-19	M.G.		
SCALE 1:1	OberArm		DRAWING NO 1-6-1		

D  
C  
B  
A

D  
C  
B  
A

6 5 4 3 2 1



6

5

4

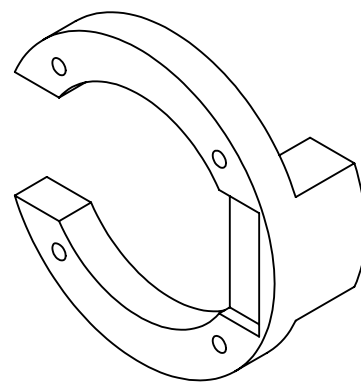
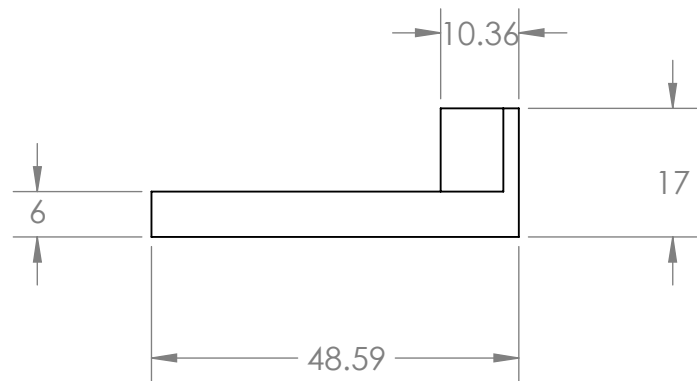
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2

1

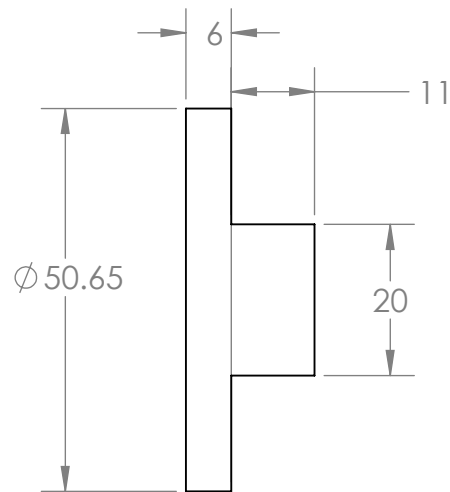
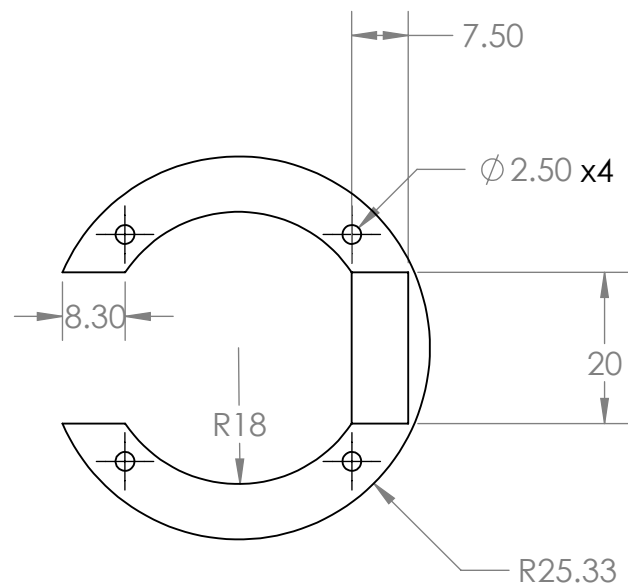
D

D



C

C



B

B

A

A

6

5

4

3

2

1

		NAME	DATE	SIGN	EMU
DRW. BY	ONLINE S.				
CHK. BY	Mustafa	26-12-19	M.G.		
SCALE 1:1	Part C		DRAWING NO 1-6-2		

6

5

4

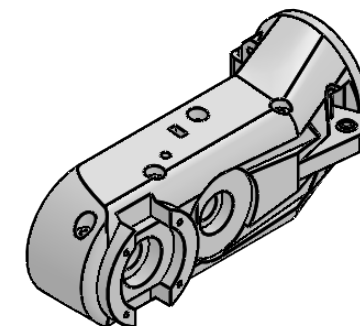
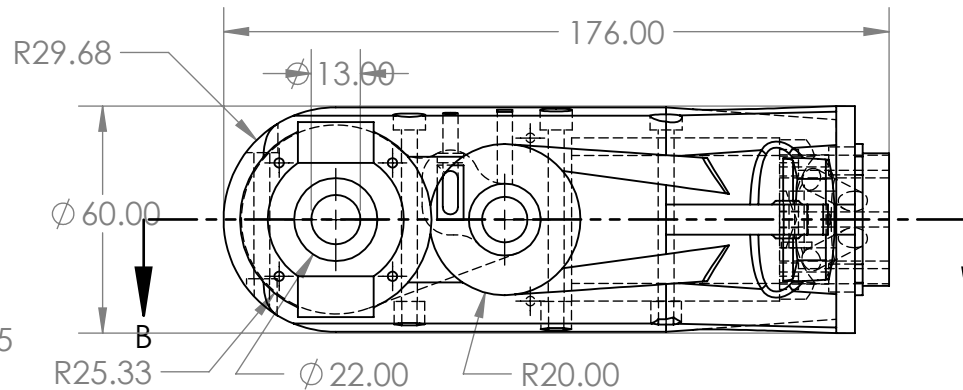
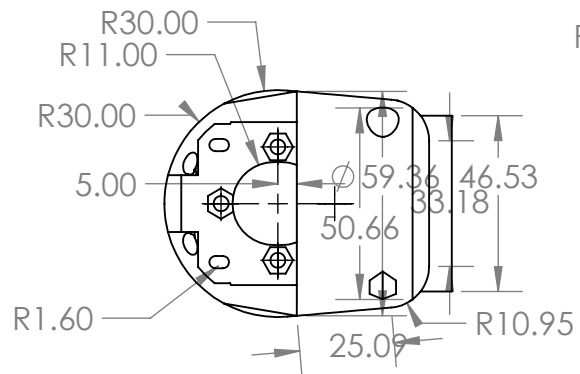
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2

1

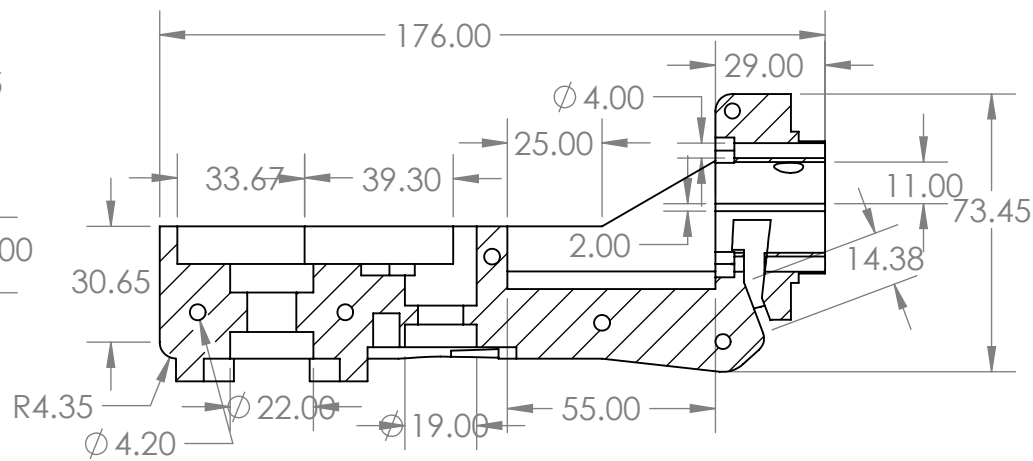
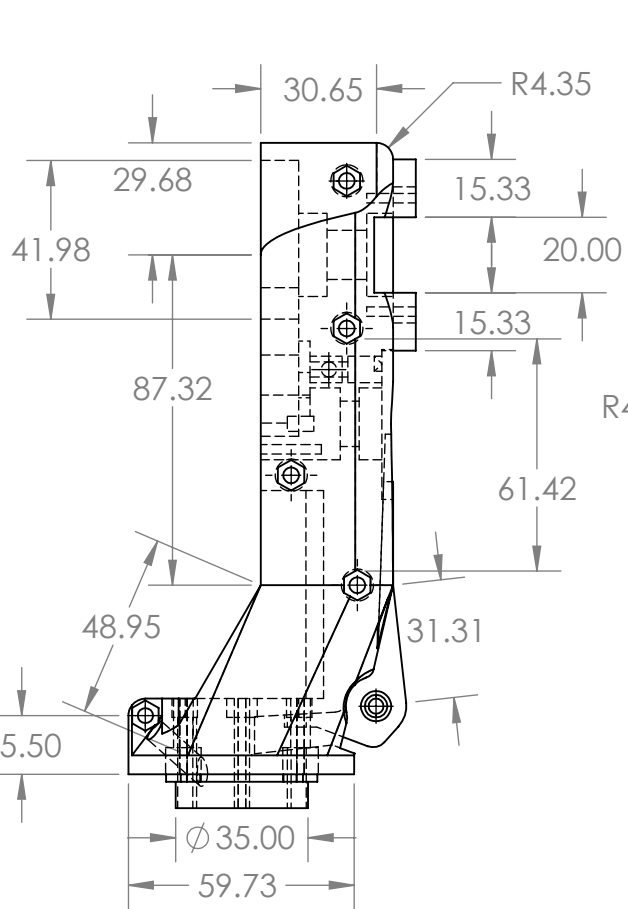
D

D



C

C



SECTION B-B

B

B

	NAME	DATE	SIGN	
DRW. BY	open source	-	-	EMU
CHK. BY	Mustafa	9-6-20	M.G.	
SCALE	Wrist		DRAWING NO	
1:2			1-6-3	

A

A

6

5

4

3

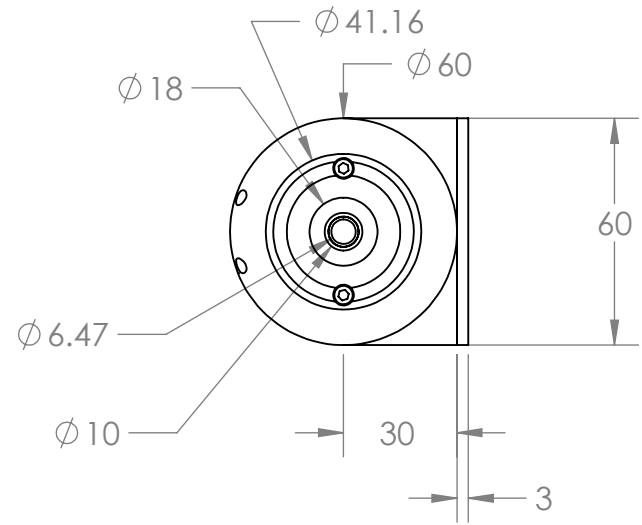
2

1

6 5 4 3 2 1

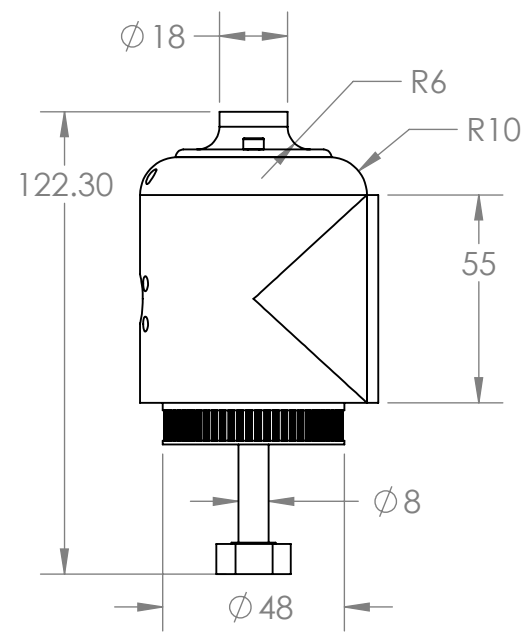
D

D



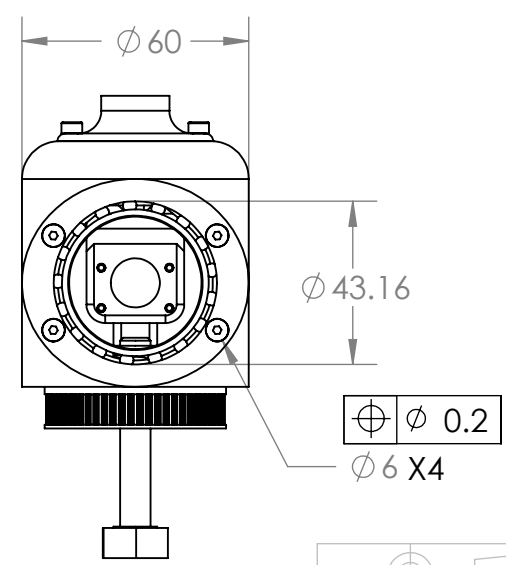
C

C



B

B

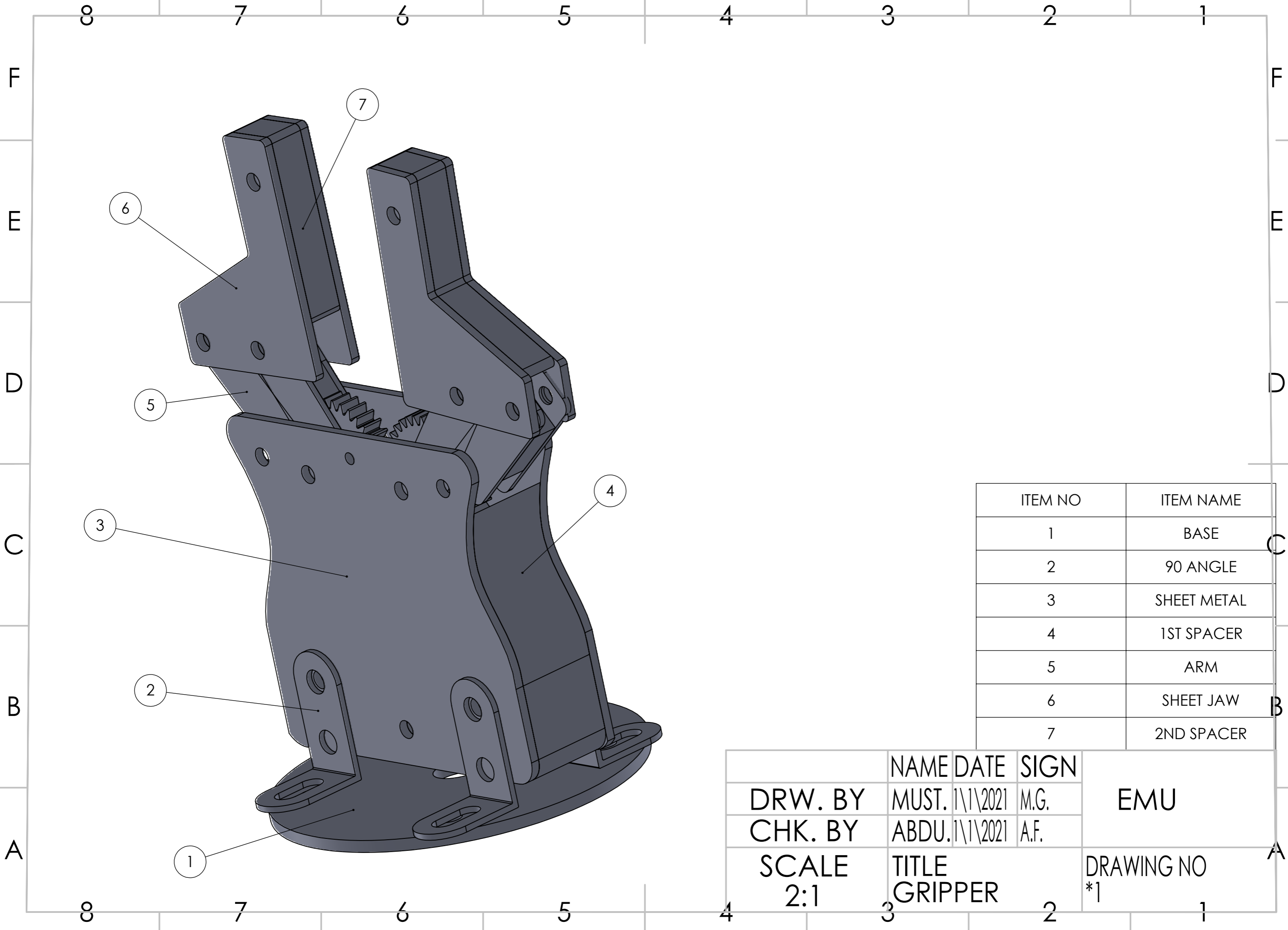


A

A

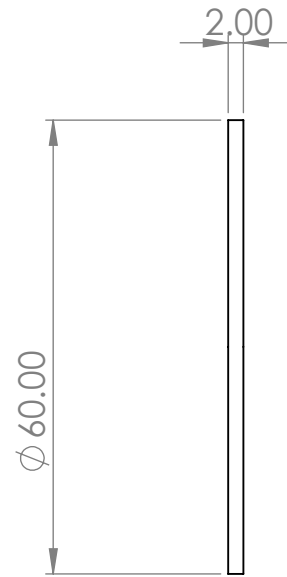
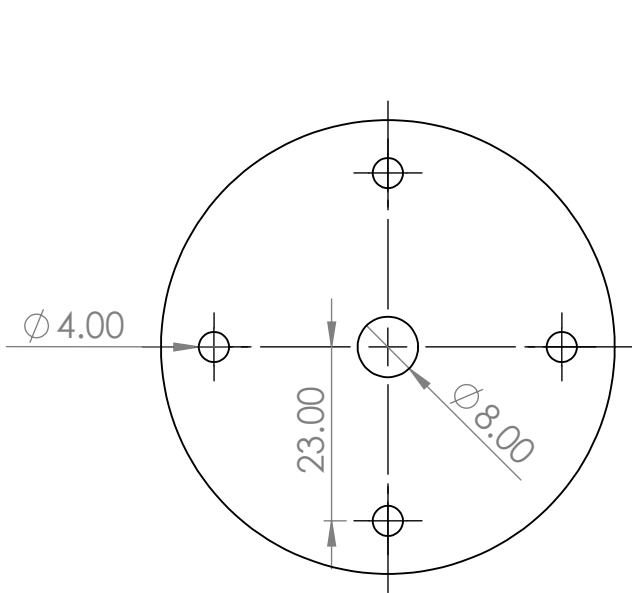
	NAME	DATE	SIGN	EMU
DRW. BY	ONLINE S.			
CHK. BY	Mustafa	26-12-19	M.G.	
SCALE 1:2	WRISTROT		DRAWING NO 1-7	

6 5 4 3 2 1

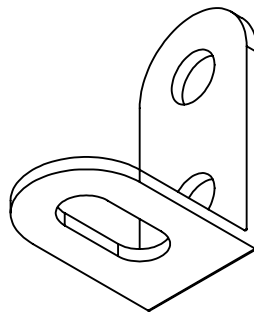
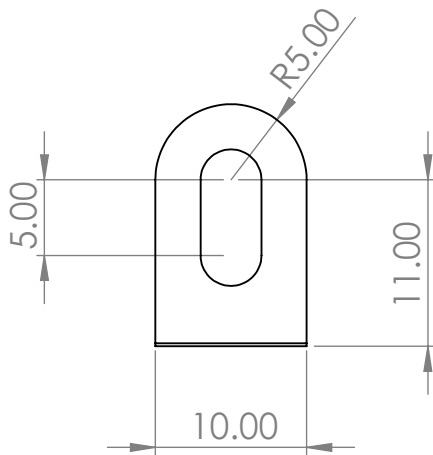
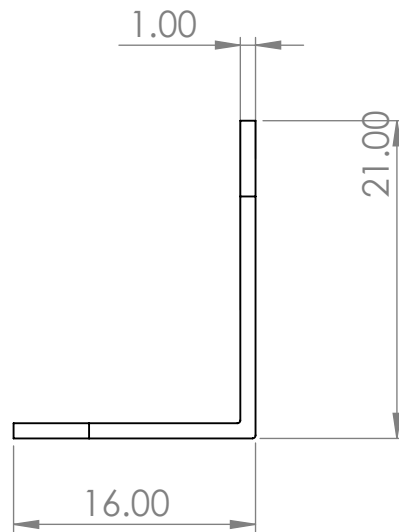
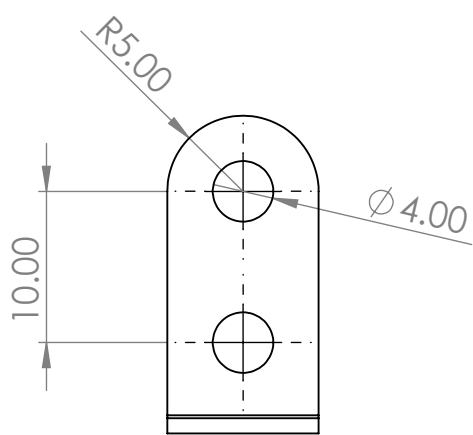


ITEM NO	ITEM NAME
1	BASE
2	90 ANGLE
3	SHEET METAL
4	1ST SPACER
5	ARM
6	SHEET JAW
7	2ND SPACER

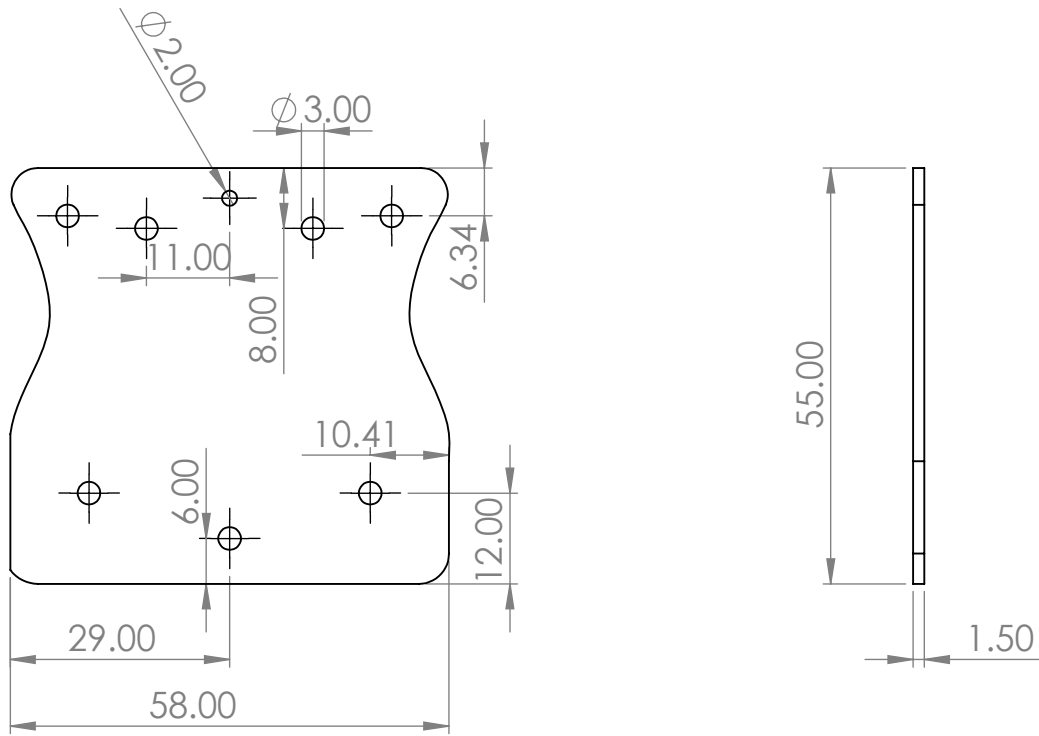
	NAME	DATE	SIGN	EMU
DRW. BY	MUST.	1\1\2021	M.G.	
CHK. BY	ABDU.	1\1\2021	A.F.	
SCALE	TITLE	DRAWING NO		
2:1	GRIPPER	*1	1	



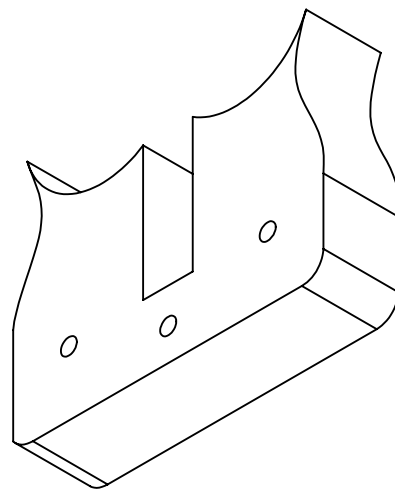
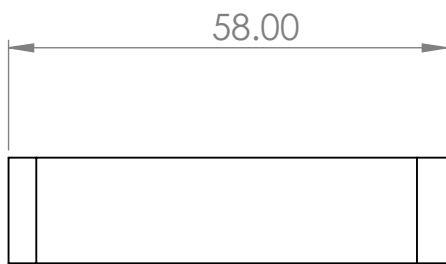
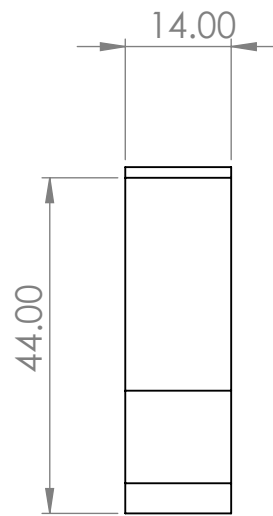
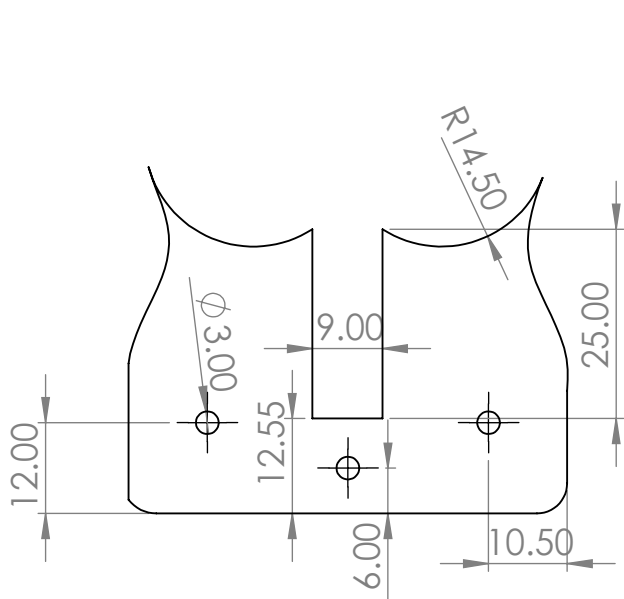
	NAME	DATE	SIGN	EMU
DRW. BY	MUST.	1-1-2021	M.G.	
CHK. BY	ABDU.	1-1-2021	A.F.	
SCALE 1:1	TITLE BASE			DRAWING NO *1-1



	NAME	DATE	SIGN	EMU
DRW. BY	MUST.	1-1-2021	M.G.	
CHK. BY	ABDU.	1-1-2021	A.F.	
SCALE 2:1	TITLE 90 ANGLE			DRAWING NO *1-2

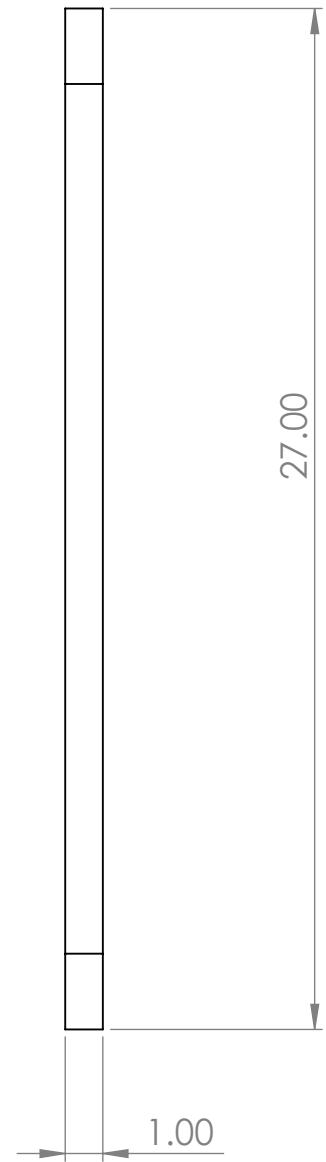
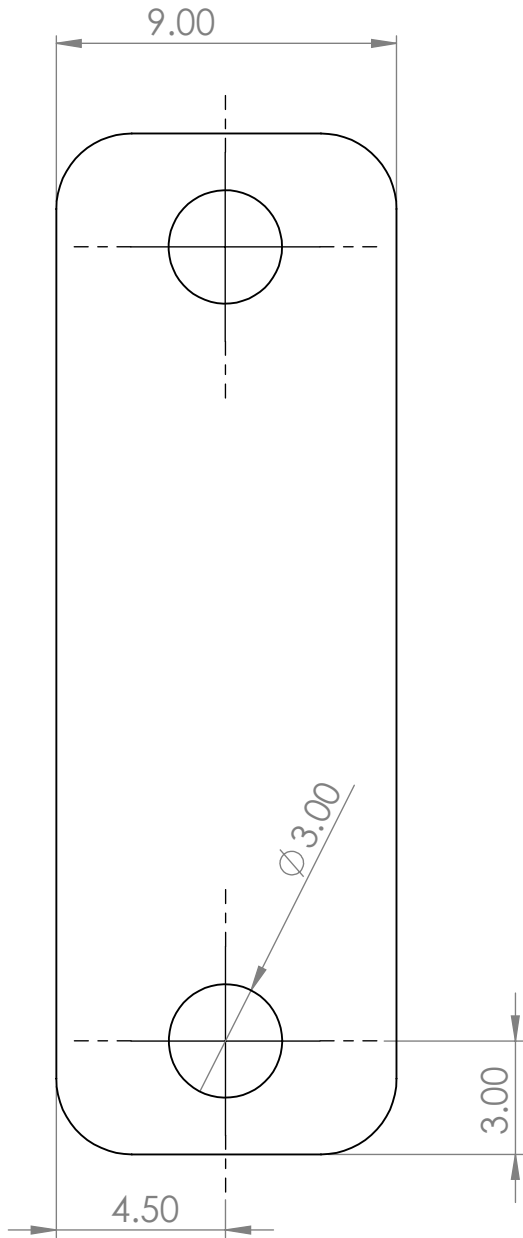


	NAME	DATE	SIGN	EMU
DRW. BY	MUST.	1-1-2021	M.G.	
CHK. BY	ABDU.	1-1-2021	A.F.	
SCALE 1:1	TITLE SHEET METAL			DRAWING NO *1-3

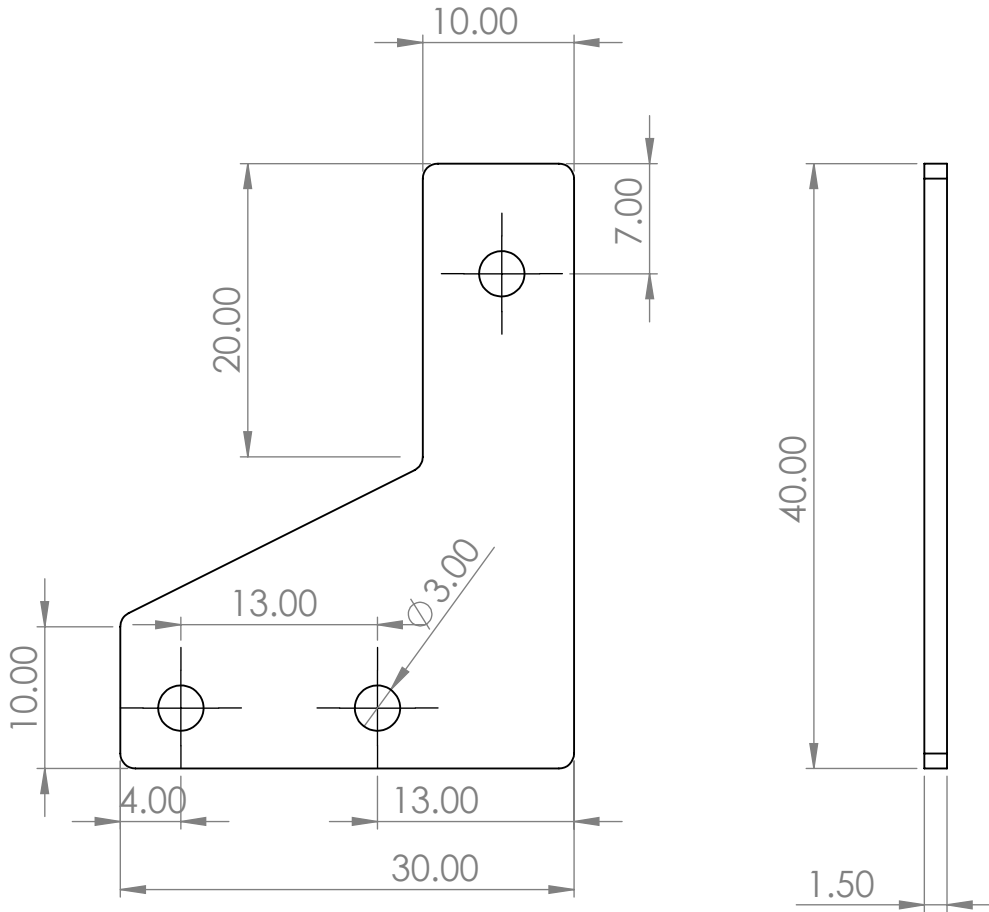


	NAME	DATE	SIGN	
DRW. BY	MUST.	1-1-2021	M.G.	EMU
CHK. BY	ABDU.	1-1-2021	A.F.	
SCALE 1:1	TITLE 1ST SPACER			DRAWING NO *1-4

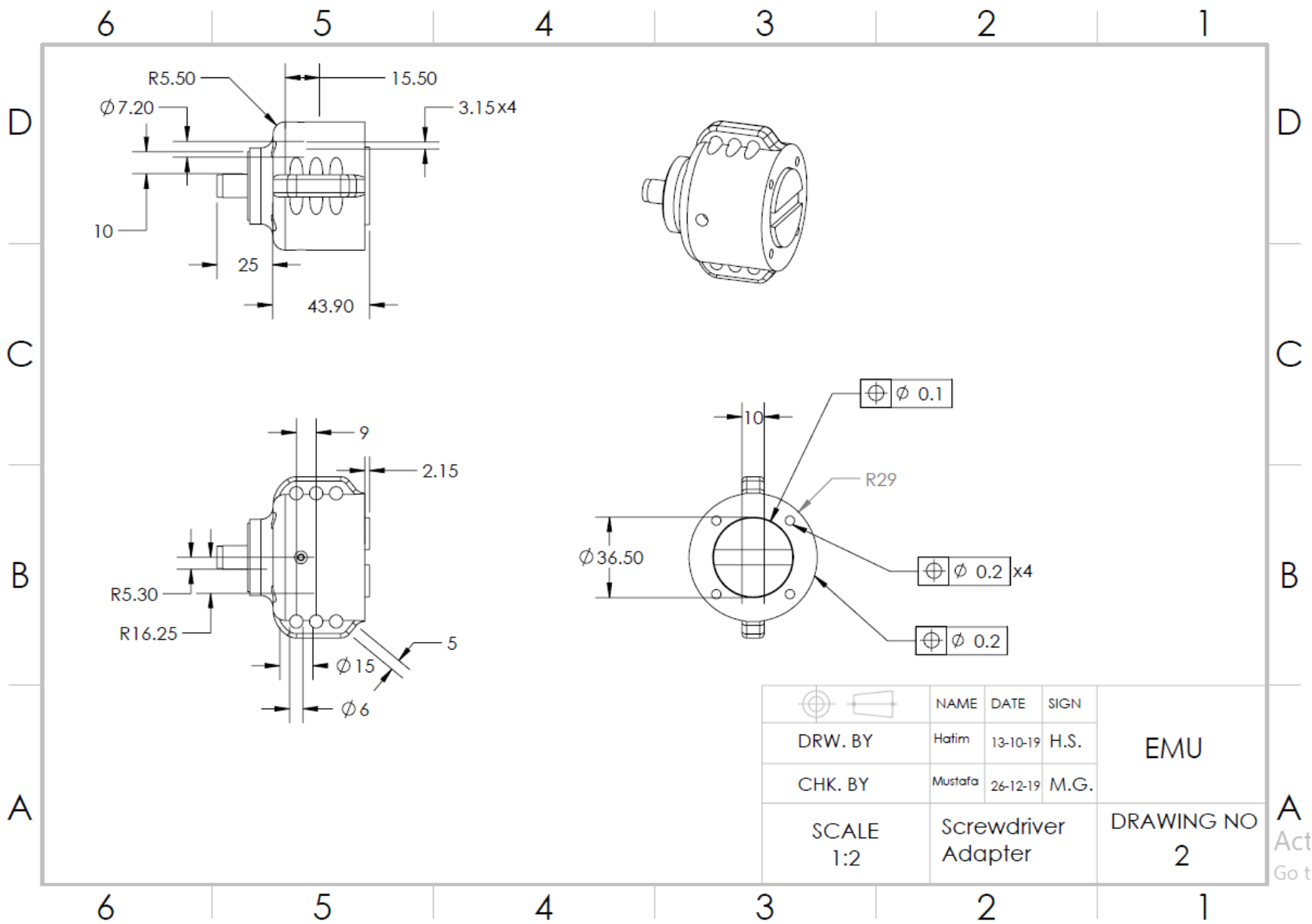


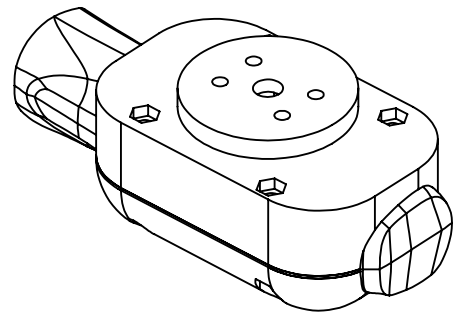
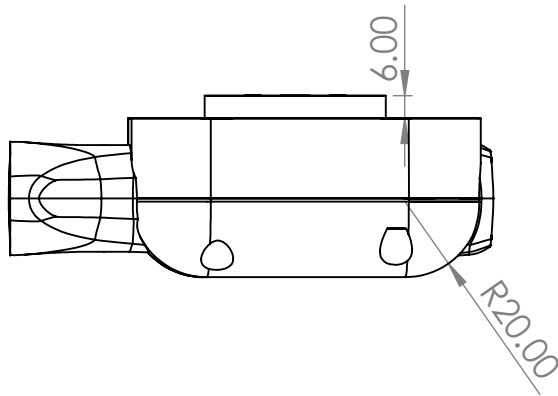
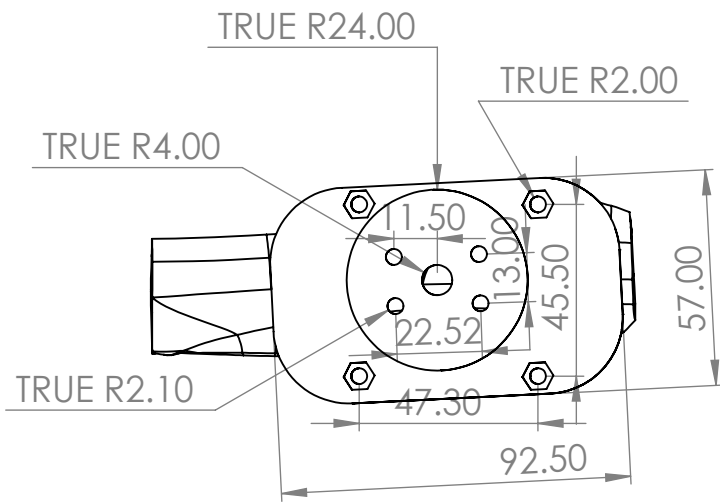


	NAME	DATE	SIGN	EMU
DRW. BY	MUST.	1-1-2021	M.G.	
CHK. BY	ABDU.	1-1-2021	A.F	
SCALE 5:1	TITLE ARM			DRAWING NO *1-5



	NAME	DATE	SIGN	
DRW. BY	MUST.	1-1-2021	M.G.	EMU
CHK. BY	ABDU.	1-1-2021	A.F.	
SCALE 2:1	TITLE SHEET JAW			DRAWING NO *1-6





	NAME	DATE	SIGN	EMU
DRW. BY	Hatim	25-12-2020	H.S.	
CHK. BY	MUST.	1-1-2021	M.G.	
SCALE 1:2	TITLE WELDING AD.			DRAWING NO *3