Sudan University of Science and Technology
College of Graduate studies

DESIGN OF A TRACKED ROBOT FOR MINES SWEEPER

تصميم روبوت تتبعي لكاسحات الالغام

A thesis submitted to the College of Graduate studies of Sudan
University of Science and Technology in partial fulfillment of
the Requirements for the Degree of Master of Science in
Mechanical Engineering (Production)

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بسم الله الرحمن الرحيم

وقل رب زدني علما

صدق الله العظيم

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Abstract

The purpose of this research is to design a tracked robot which is capable to detecting buried landmines , while enabling the operator to control the robot wirelessly from a distance. The ideas and concepts from the theoretical stages are shaped into CAD model using SOLIDWORKS software .The detection of the buried mine is done by using metal detectors with Ground Penetration radar (GPR) ,Tension mechanism mounted in the middle of the chassis enables the track to have good tension in travelling over uneven terrains. Using this tension mechanism reduces energy consumption while crossing over obstacles. Lastly the research focused to present robot with ease of manufacturing and maintenance in Sudan.

المستخلص

الغرض من هذا البحث هو تصميم روبوت تتبعي قادر على إكتشاف الألغام الأرضية المدفونة ، مع تمكين المشغل من التحكم في الروبوت لاسلكيًا عن بُعد, تقوم الفكرة على تحويل كل مفاهيم التصميم النظرية للأجزاء المكونة للروبوت وتجميعها وتجسيدها في شكل تصميم نهائي بالحاسوب بإستخدام برنامج SOLIDWORKS. للقيام بعملية الكشف تم إستخدام كاشف معادن مزود بتقنية GPR مثبت في منتصف الهيكل. تم تصميم الية لشد السير تمكنه من الثبات الجيد أثناء الحركة عبر التضاريس غير المستوية مما يقلل من إستهلاك الطاقة.أخيرًا ركز البحث على تقديم روبوت يمتاز بسهولة التصنيع والصيانة في السودان.

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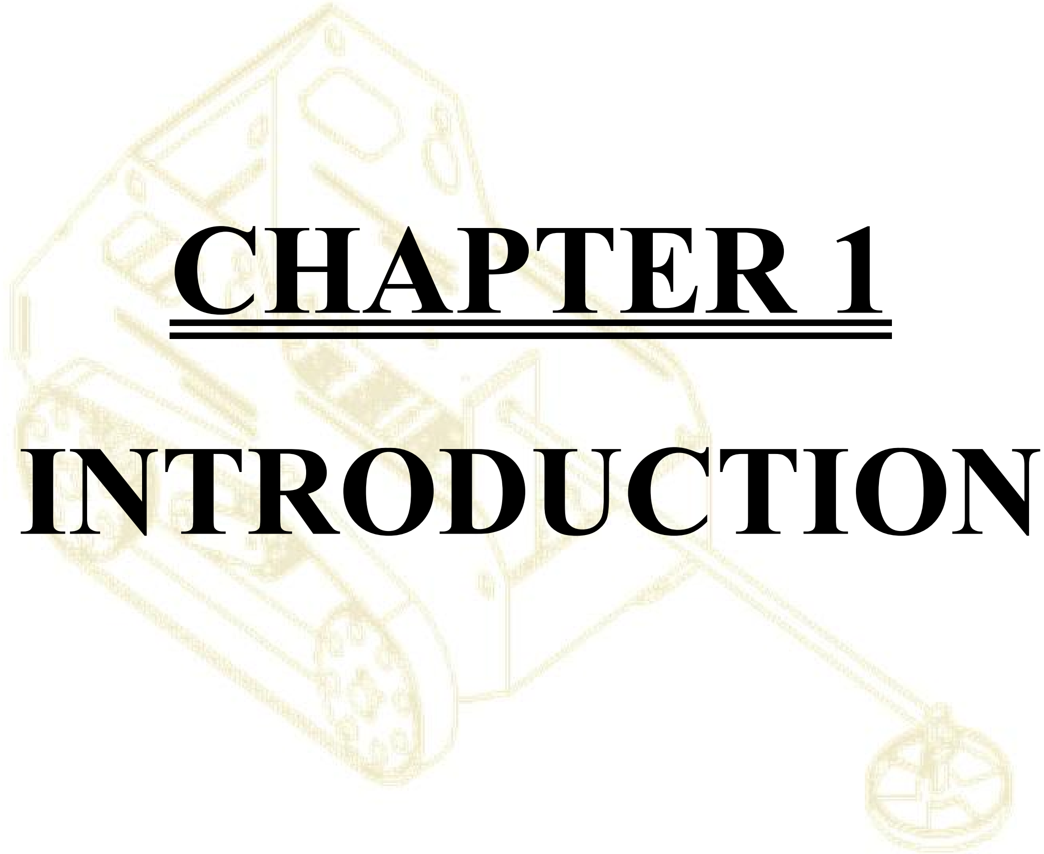
List of Abbreviations

Abb	
GPR	Ground penetration radar
ALIS	Advanced Landmine Imaging System
E	Education Uses
A	application
R	research
I	infrared sensor
U	ultrasonic sensor
O	odometer
GR	grippers
Pt	pan tilt camera
Pack Bot	mobile robot platform used for explosive disposal
UXO	ferromagnetic mine
ALIS	Advanced Landmine Imaging System
MD	metal detector
PVC	Polyvinyl chloride -pipe
PPR	Polypropylene random copolymer -pipe
SLA	Lead Acid Battery type
SP	SIDE PIECE
FP	FRONT PIECE
BP	BACK PIECE
SHAFT	WHEEL SHAFT
MWL	MAIN WHEEL
WS	WHEL SCREW
NT	NUT
TMB	TENSION MECHANISM BODY
TMSH	TENSION MECHANISM SHAFT
TMW	TENSION MECHANISM WHEEL
TS	180 DEGREE TORSION SPRING
PF	PLATE FIXER
PL	PLATE
PS	PLATE SCREW
TC	TOP COVER
HS	HUB SCREW
HUB	HUB
BNG	BEARING
MC	MANIPULATOR CARRIER
PA	PLASTIC ARM
WA	WOOD ARM
PJ	PLASTIC JOINT
MD	METAL DETECTOR



CHAPTER 1

INTRODUCTION

1. Introduction

1.1. General introduction

The increasing capabilities of tracked robots indicate the possible benefits in various fields of applications, such as transportation, industrial or agricultural purposes. Nevertheless, in order to be efficient, such automatic devices must be accurate, whatever the ground conditions (nature and geometry) and the path they must follow. Effectively, when a tracked robot moves in off-road conditions, some undesirable phenomena, such as noisy measurements, slip, vibrations, among others, lead to inaccurate robot location and influence negatively the controllability of the tracked robot. In this research, an application of this kind of tracked robots within the military context will be present.

1.2. Problem statement:

There was a problem with the balance in the previous version of the robot because it consists of three wheels (Wheeled robot) and did not satisfy the requirements of some experiments and has a low speed and low maneuverability. To ensure the high maneuverability is more expedient to design the track platform in this research because ease of maneuvering in the clay and sand earth and able to drive safely from point A to point B. The control of the tracked robot is much easier than wheeled robot. Low speed of the tracked robot in comparison with the wheeled robot is not a significant disadvantage. So the problem is fixing problem with the balance in the previous version and satisfying all mentioned needs above in addition to light weight and ease of manufacturing here in Sudan.

1.3. Objectives:

- Design and draw Chassis
- Determine the grooved plate specifications and design it
- Determine the Track configuration
- Design Track drive wheel
- Design Tension mechanism
- Determine the Scanning manipulator components
- Specify Motor and Battery types according to the availability in Sudan and equipments requirements
- Make assembly for all designed components in one unit using SOLIDWORKS

1.4. Thesis overview:

This Thesis is organized as follows: chapter 1 describes the literature review problem statement ,objectives, Methodology, and Thesis overview , while chapter 2 shows all theoretical background of component which needed in design ,also chapter 3 shows the mechanical design of robot components , development and the applied methods. More specifically, CAD drawings have been carried out in chapter 4.

1.5 Literature review

As mentioned in abstract and the problem statement sections there is need to know what researchers and designers said about research topic.

In this section of research light focused on some published papers about tracked robot in other uses to specify what methods of chassis design and tension suspension systems, types of manipulators, and other components to determine the gaps and try to fulfill some of them.

Radian and his colleagues made a development of a lightweight chassis and drivetrain of an Explosive Ordnance Disposal Robot. They defined design methodology of selecting the correct specification of a robot by using welded pipes to make the robot chassis; also they used brush DC motors assembled to planetary gearboxes. But they assume the climbing angle 15 degrees to determine the motor torque.[6]

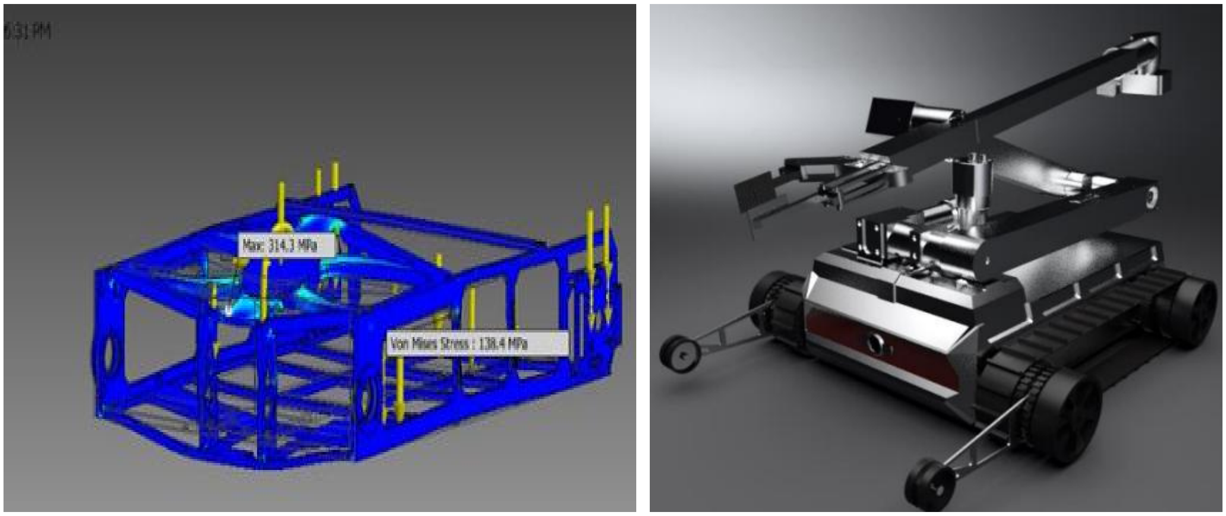


Figure (1.2) Radian`s platform

Christian Ducros and Gerard Hauser designed a robot platform contain tracks and wheels with suitable dimensions 570mm (length)*420(width)*330(high), speed was more convenient with nuclear environment and named it (RICA), but the weight is heavy and it exceeded 90Kg because they used stainless steel as a material.[10]

Figure (1.3) RICA platform

Suyang Yu designed a self-adaptive transformable tracked robot for cable tunnel inspection and added track-drive arms , five track wheel to be capable to change its shape according the obstacles situation and The tail wheel module to enhance the robot’s capability to prevent the tip-over during clearing obstacle. But the design hasn’t convenience of disassembly and maintenance.[11]

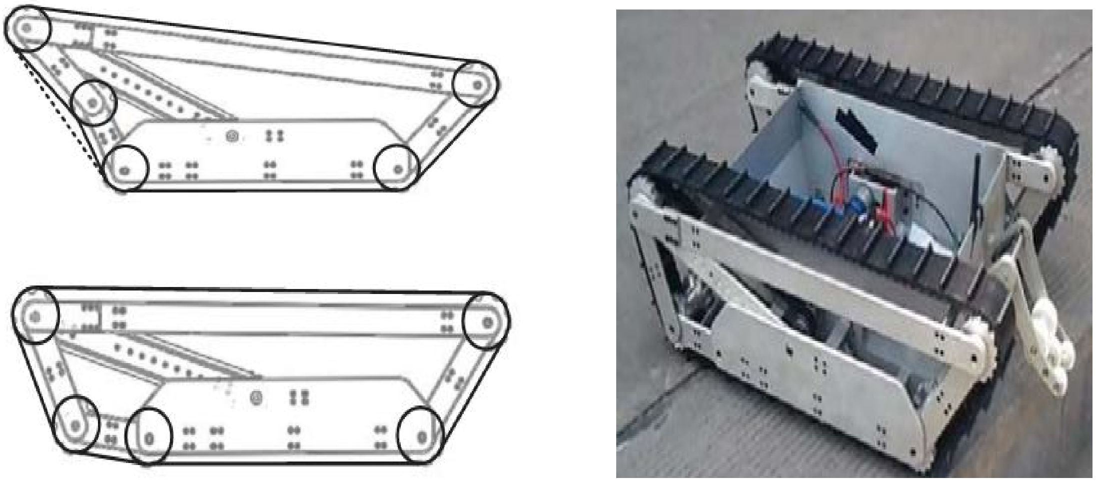


Figure (1.4) Suyang Yu`s tracked platform

Daniela D’Auria presented an application of tracked robots within the agricultural uses. They built a specific platform whose length is 35 cm and whose width is 60 cm based on a combined use of optical sensors aimed at performing an efficient and effective monitoring management of crops.

They also emulate the real settings in a field in order to carefully study the tracked robots behavior, by exploiting a specifically-built platform with several steps, allowing us to emulate the vibrations of a real field. [7]

Figure (1.5) Daniela D’Auria`s tracked platform

Also there was a paper addressed by Tracked Robot with Blade Arms to Enhance Crawling Capability and published by World Academy of Science, Engineering and Technology -International Journal of Mechanical and Mechatronics Engineering Vol:10,2016.it seems the paper that written by Daniela D'Auria above with the difference in weight .

A group from Fuji Heavy Industries Co. Ltd develop a mine-detecting robot with a ground penetrating radar and a metal detector for detection, a manipulator fitted with tools such as air hummer and hand for mine confirmation and track with these devices mounted which is capable to run on rough terrains, But the problem is the heavy weight (about 2 ton), too slow, and need to support vehicle.[14]

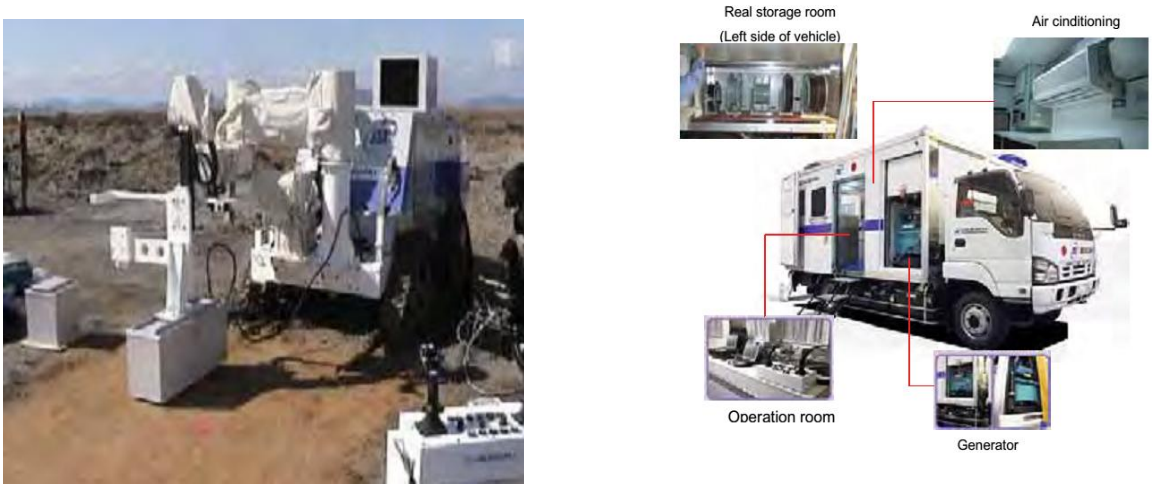


Figure (1.6) mine-detecting robot

Pinhas Ben-Tzvi and Andrew A. Goldenberg presented new mobile robot design based on hybridization of the mobile platform and manipulator arm as one entity for robot locomotion as well as manipulation. The approach is that the platform and manipulator are interchangeable in their roles in the sense that both can support locomotion and manipulation in several configuration modes.[3]

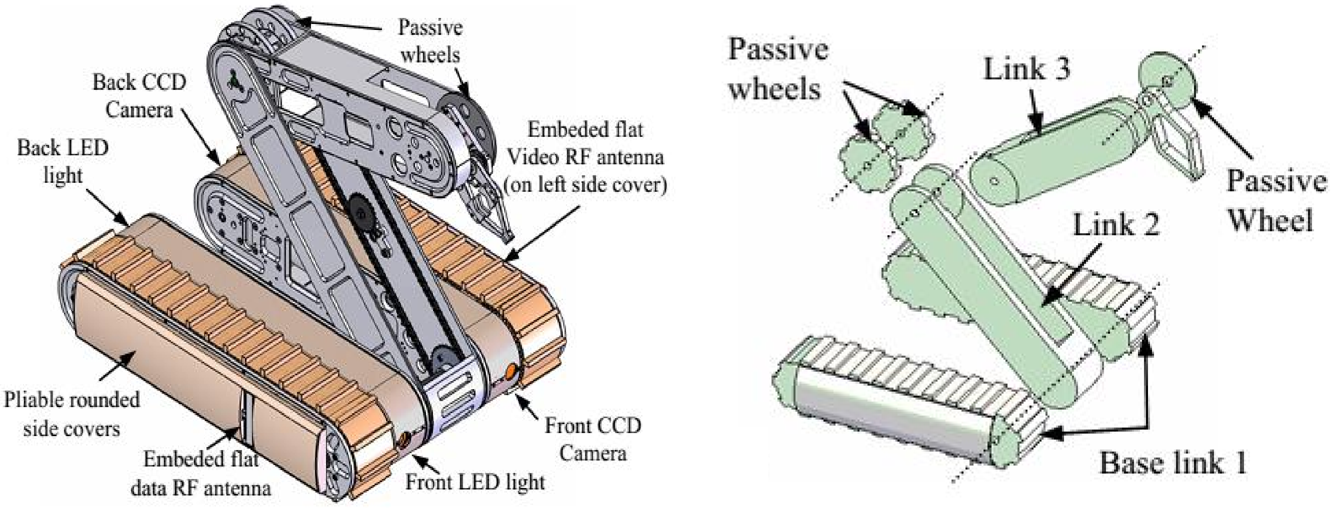


Figure (1.7) Pinhas Ben-Tzvi tracked robot

gokhan bayar, a. bugra koku designed a mobile robot referred to as CoMoRAT (Configurable Mobile Robot for All Terrain Applications) and manufactured at METU. CoMoRAT can be driven by wheels, tracks or both. Besides its ability to ride effectively on various terrains, robot body is designed in such a way that adding new hardware to the platform requires minimal manufacturing and installation efforts.[18]

Figure (1.8) Model and Manufactured CoMoRAT robot

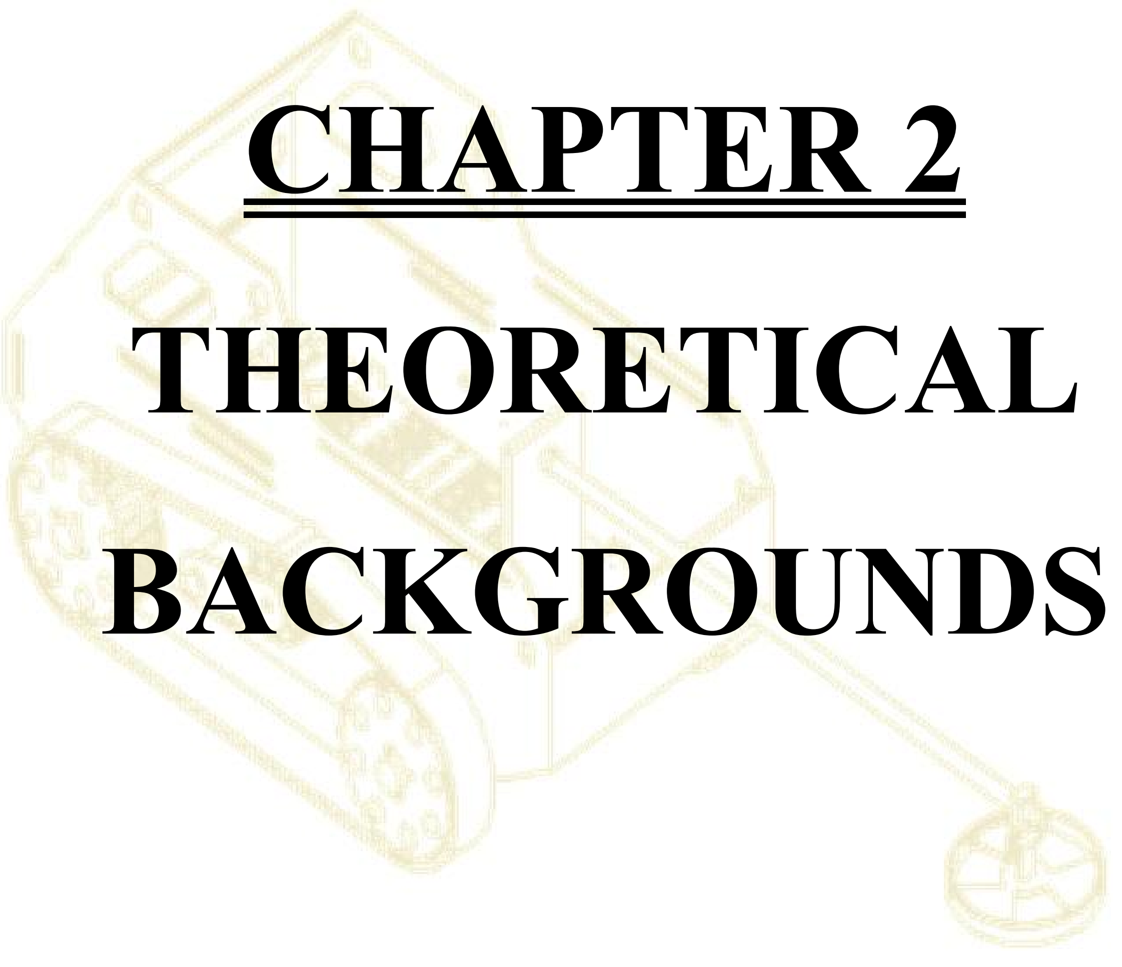
Khalid R. Asfar designed semi-autonomous three- wheels robot as shown in Figure(1.9) that can detect landmines using a metal detector, with a pneumatic system to remove these mines. This robot detects the mine location autonomously, and then the whole unit is moved by the operator manually for the removal stage which, is powered by pneumatic actuators to pull the mine out of the ground without triggering the mine. But the main problem which faced Khalid R. Asfar et al was the balance of the robot because he used three wheels.

Figure (1.9) Khalid R. Asfar robot

From the papers that mentioned above some design techniques of tracked robot in deferent uses were observed and some gaps were noticed. those gaps bridged by providing a new approach of tracked robot design that provides locomotion , manipulation capabilities , fully symmetric, simpler and robust design, significant weight reduction and lower production cost.

CHAPTER 2

THEORETICAL BACKGROUNDS



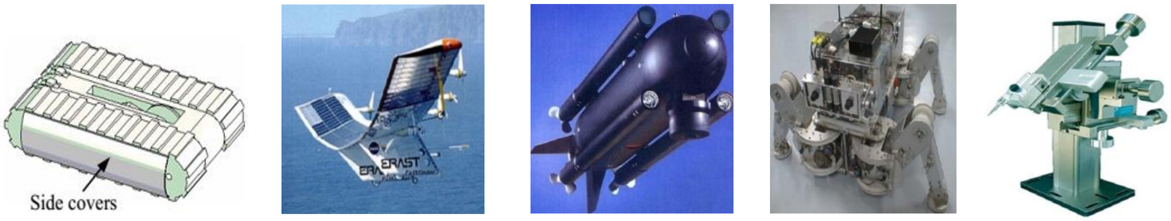
2. Theoretical background

Demand for mobile robot applications has significantly increased in the past couple of decades and mobile robotics has become a rapidly developing field of interdisciplinary research within robotics. This promising field has attracted the attention of academic, industry, as well as several government agencies. Currently from security to personal service, mobile robots are being used in a variety of tasks. Yet the use of such robots is expected to only increase in the near future. The demand for consumer robots for various applications being on the rise , and the availability of various funds in addition to big stake competitions, both industry and academy have shown great interest in developing robotic hardware and applications. With the ultimate purpose of creating fully autonomous robots that can outsmart humans, wide range of applications for mobile platforms have been developed, in this section of research take a look on mobile robots and its general components because the track robot used in this research is one of them, and the metal detectors used is one of them also.

2.1.1. Definition:

A robot is a reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks: Robot Institute of America, 1979.

2.1.2. Types of Robots:



Tracked robot

Unmanned Aerial Robot

Autonomous Underwater Robot

Legged Robot

Manipulator Robot

Fig (2.1) Types of Robots

2.1.3. Knowledgebase for Robotics:

– Dynamic system modeling and analysis
– Feedback control
– Sensors and signal conditioning
– Actuators (muscles) and power electronics
– Hardware/computer interfacing
– Computer programming

2.2. Key Components:

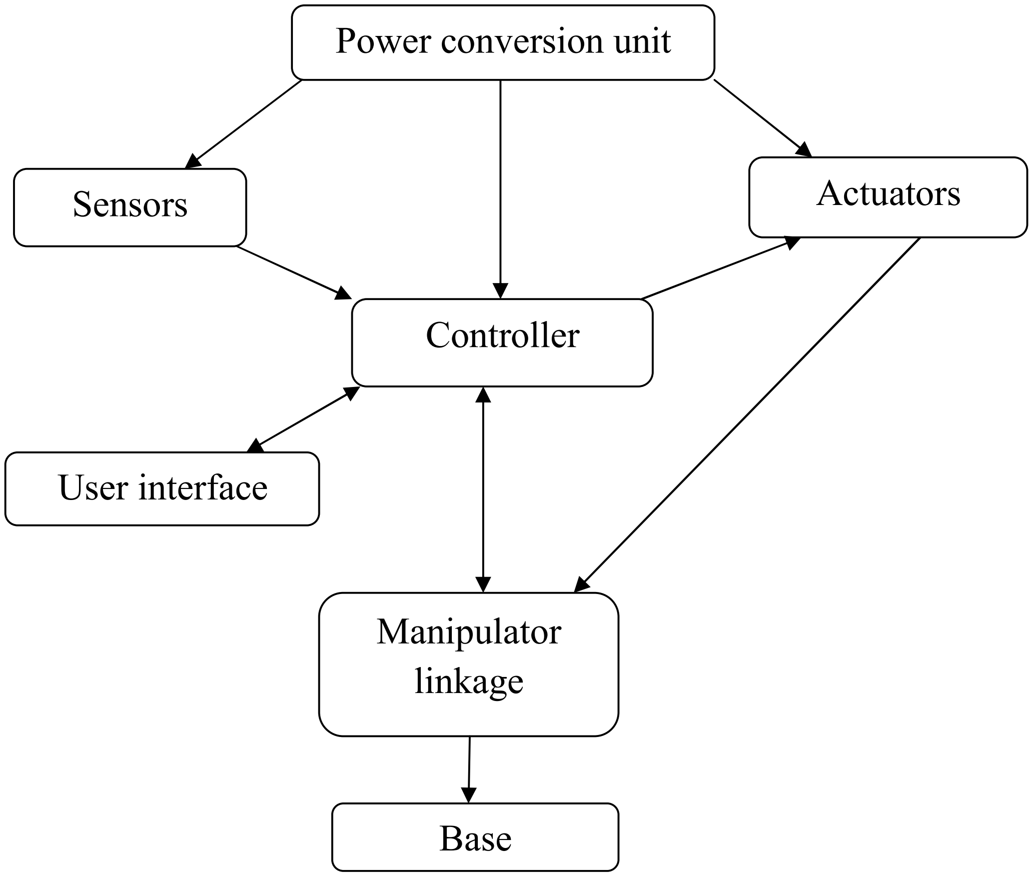


Fig (2.2) key components

2.3. Mechanical Elements:

All mechanical elements used in this research defined and explained as below:

2.3.1. Sensors:

Measure robot configuration/condition and its environment and send such information to robot controller as electronic signals (e.g., arm position, presence of toxic gas).

2.3.1.1. Types of sensors:

1. Vision Sensors: e.g., to pick bins ,perform inspection, etc
2. Force Sensors: e.g., parts fitting and insertion, force feedback in robotic surgery.
3. Proximity Sensors: e.g., Infrared Ranging Sensor.
4. Tilt Sensors: e.g., balance a robot.

2.3.2. Actuators/Muscles:

a device which moves a component, such as a manipulator, in response to signals from the controller. Such a device may be electric, hydraulic ,mechanical, or pneumatic

2.3.2.1. Types of Actuators:

1. Synchronous motor
2.Stepper motor: rotates a precise angle according the number of pulses of electricity sent to it.
3. AC servo motor: mainly used for producing large power outputs at a fixed speed.

4. Brushed DC servo motor: uses of a permanent-magnet field to replace the wound field.
5. Brushless DC servo motor: exhibits the same linear speed–torque characteristics as the brush-type PM DC motors, but they are electronically commutated.

2.3.3. Bogey Wheel:

One of a number of modern tank-tread double-wheels used as an Idler/Tension Wheel.

2.3.4. Idler (Tension Wheel):

It is a component that transmits power to guides, or tensions a track, belt, or rope.

2.3.5. Track:

It is a system of vehicle propulsion in which a continuous band of treads or track plates is driven by two or more wheels. This band is typically made of modular steel plates in the case of military vehicles and heavy equipment, or synthetic rubber reinforced with steel wires in the case of lighter agricultural or construction vehicles or robots .

2.3.6. Tread:

It is one of series of connected components that make up a track.

2.3.7 Bearings:

A bearing is a machine element that constrains relative motion to only the desired motion, and reduces friction between moving parts. The design of the bearing may, for example, provide for free linear movement of the moving part or for free rotation around a fixed axis; or, it may prevent a motion by controlling the vectors of normal forces that bear on the moving parts. Most bearings facilitate the desired motion by minimizing friction. Bearings are classified broadly according to the type of operation, the motions allowed, or to the directions of the loads (forces) applied to the parts.

With highly choreographed, programmed movement on two or more axes, bearings play a major role in the motion control aspect of this technology. The use of high-precision bearings is an integral consideration for those tasked with designing and maintaining these applications. Bearing life and performance demand that the correct type, material and lubrication are specified.

Using bearings in robots:

- Single-row deep groove ball bearings, with sizes ranging from miniature to extra-large, are generally the go-to bearing choice for the majority of robotic and automation applications. Thin section bearings are often designed into robot arm joints due to their low mass, space-saving construction and high-speed capability.
- Roller bearings are usually the first choice for heavy-duty requirements. Slewing rings are a common selection for the main rotation and associated lift equipment. Hybrid (ceramic balls with stainless steel rings) and full-ceramic bearings are an excellent alternative for operation in a vacuum or other inhospitable environments.

The hazardous environments to which robotic applications are often subjected demand proper contamination protection in order to prevent debris of all types, shapes and sizes from entering the bearing and causing irreparable damage or premature failure.

2.3.8. Sprockets:

A sprocket or sprocket-wheel is a profiled wheel with teeth, or cogs, that mesh with a chain, track or other perforated or indented material. The name 'sprocket' applies generally to any wheel upon which radial projections engage a chain passing over it. It is distinguished from a gear in that sprockets are never meshed together directly, and differs from a pulley in that sprockets have teeth and pulleys are smooth.

2.3.9. Raw Materials:

Robots chassis are mostly built of common materials. Some specialized robots for clean room applications, the space program, or other "high tech" projects may use titanium metal and structural composites of carbon fibers. The operating environment and strength required are major factors in material selection. Steel, cast iron, and aluminum are most often used for the arms and bases of robots.

2.4. Mobile robot:

Despite the rich spectrum of applications, mobile platforms available for research have been very few in number such as (ATRV, Pioneer series robots and Jackboot). First of all these robots are not economically feasible, second, they are designed to operate on a specific environment, hence developing diverse applications that require installing additional hardware, and drive system manipulations cannot be easily and effectively done on these robots. Purchasing a new robot for every different application being developed is not feasible both in terms of money and time. Different applications require the mobile robots to operate on different environments. Some robots are designed to operate indoors, some outdoors, and some have to be able to operate in both. Robots operating outdoors may stay on the road or navigate off-road. For effective traversing diverse terrain, it is important to have a driving system that can easily be configured to suit the needs of navigation task at hand. Indoor environments are generally smooth and well structured, whereas outdoors, especially off-road sections, are rough and pose challenges for wheeled robots. Various types of locomotion methods such as legs, wheels and tracks are used on mobile robots with various configurations. For instance, (Plunstech) walking robot, which has been designed for the forest applications, provides automatic leg coordination while the operator selects a travel direction. Six-wheeled mobile robot, (Sojourner), was designed for the mission of exploring Mars surface. Both of these robots have excellent rough terrain navigation capability, yet they are neither available to researchers nor versatile for diverse applications. Pioneer mobile robot is one of the mobile robot bases that are commonly used in research. Magellan mobile robot is another platform preferred by researchers. It is designed for indoor operation and commonly used in indoor navigation applications. Being decorated with various sensors, Magellan is not suitable for outdoor applications. Pack Bot is a mobile robot platform used for the applications of explosive ordnance disposal, search and rescue, surveillance, bomb squad, swat teams, and other vital tasks. Pack Bot is a tough, light weight and quickly configurable platform. It also allows integrating flippers, a camera and a robotic arm on its frame. All the assembling and disassembling stages take only a short period of time and hence, it can be adapted to different situations very quickly. However, the price tag of this robot is quite a burden on a limited research budget. MR-5 is a remotely controlled mobile robot base. It is ideally suited for explosive ordnance disposal, swat, harmful material search, surveillance and other hazardous environment and material tasks. It has been designed for operating with wheel and/or tracks [8]. It has two motion modes: wheels tracks on wheels. Being able to move on either wheels or tracks, MR-5 can be effectively operated in diverse environments and situations. Another well-known mobile robot platform which is commonly used by U.S. military is Talon. It has been designed for the missions ranging from exploration of the working environments to weapons delivery [9]. Even though integrating some equipment to its base can be done very easily and quickly, its track based driving system cannot be modified. Besides its legendry success in military applications, Talon is not suitable for research and it is even more expensive than other platforms. As a result, commercially available robots mentioned so far fall short in terms of being the ideal mid-size research platform .COMORAT is designed to be a modular, easy to reconfigure, on and off road capable mobile platform. CoMoRAT is compared to some well-known robots on the market in Table (2.1). Payload that robot can carry, velocity, dimensions, type of the motors that drive the robots, computational platform, development tools, sensors and equipments that can be attached, types of communication, application areas, and actuation types are compared in this table. During research, developers often need to add and remove hardware when deploying new applications to a platform. Hence, physically adding new hardware (i.e. sensors, actuators, computational units) to the robotic platform should be practical. Diverse applications require the robot to move on various types of terrain. To increase the efficiency of the robot on different terrain, it is important if the robot can be configured to drive on wheels, tracks or both. CoMoRAT is designed with the expectations that traction system can be easily changed (to be wheeled, tracked and wheeled + tracked) to suit a wide range of terrain, and allow additional hardware to be installed with minimal manufacturing and effort. In terms of size, it is aimed to create a robot that can be backpacked by the user (end user, or the grad-student) if needed. This study does not attempt to individually address any specific robotic application, indeed it is aimed to shape up a robotic module that can be used in a wide range of applications on different terrain with proper modifications

Table (2.1) Comparison chart about the features of the mobile robots

MOBILE ROBOT FEATURE	Sojourney	Magellan	Pioneer	PackBot	MR-5	Talon	CoMoRAT
PAYLOAD (KG)	4	9.1	22.7	25	80	150	15
Velocity (m/s)	2	2.5	1.6	1	1.5	2	1
Dimensions (mm)	225x400x130	368 h:198	440x380x220	525 h:1060	600x480x465	1025x680x400	300x500x80
Motors	2x12V	2x24V	2x12V	4x24V	2x48V	2x48V	2x24V
Comp. Platform	Siemens	-	Siemens C166	Embedded PC	MPC555	MPC555	Embedded PC
Development Tools	VB, C++ Matlab	C++	C++	C++	C	C	Matlab,C
Sensors and Equipments	I-U	G-L O-I	U-I-T LS-V GPS-C Gr-Pt	U-I-T LS-C-V GPS-Gr Pt	U-I-T LS-C-V GPS-Gr Pt	U-LS-C V-Gr-Pt	LS-G A-G-O
Communication	RS232 RF	RS232 Wireless RF	RS232 Wireless Ethernet	RS232 Wireless RF Ethernet	RS232 Wireless RF Ethernet	RS232 Wireless RF Ethernet	RS232 Wireless RF Bluetooth
Application	E	E	A,E,R	A,E,R	A,E,R	A,E,R	A,E,R
Permission for Reconfiguration of Platform	No	No	No	Yes	Yes	Yes	Yes
Permission for Actuation Configuration	No	No	No	No	Yes	No	Yes

The annotations are: **E, A, R** are education, application, and research, respectively. **I, U, O, G** are infrared sensor, ultrasonic sensor, odometer, and gyro, respectively. **A, L, T, LS** are accelerometer, light captor, tactile sensor, and laser scanner, respectively. **V, Pt, C, GR** are vision system, pan tilt camera, navigation compass, and grippers, respectively

2.5. Tracked robots:

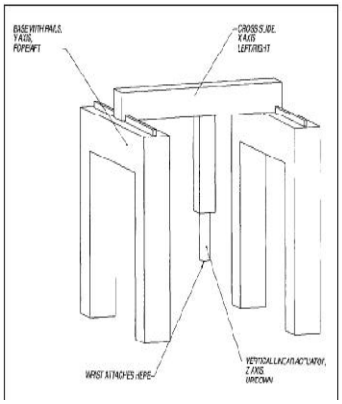
Primarily use Skid steer drive which is a modified concept of differential drive. A tracked robot has two tracks attached at either side of the chassis driven by two separate motors. They are steered by moving those tracks at different speeds in the same/opposite direction. Most of the time these tracked robots skid to change their direction. This makes the threads/tracks to wear off quickly and also they require larger area to turn as they slide their entire body against the ground.

2.6. **ARM GEOMETRICAL CONFIGURATIONS**

The three general layouts for three-DOF arms are the cartesian, cylindrical, and polar (or spherical) geometrical configurations. They are named for the shape of the volume that the manipulator can reach and orient the gripper into any position within the work envelope. They all have their uses, but as will become apparent, some are better for use on robots than others. Some use all sliding motions, some use only revolute joints, some use both. Revolute joints are usually more robust than sliding joints but, with careful design, sliding or extending can be used effectively for some types of tasks. Revolute joints have the drawback of preventing the manipulator from reaching every cubic centimeter in the work envelope because the elbow cannot fold back completely on itself. This creates dead spaces—places where the arm cannot reach that are inside the gross work volume. On a robot, it is frequently required for the manipulator to fold very compactly.[9]

2.6.1. CARTESIAN MANIPULATORS

There are two basic layouts of Cartesian manipulators, based on how the arm segments are supported, namely; gantry and cantilevered. The geometry of a gantry manipulator looks like a three dimensional XYZ coordinate system. the Gantry, using simply supported slides that can work outside the work envelope.[9]



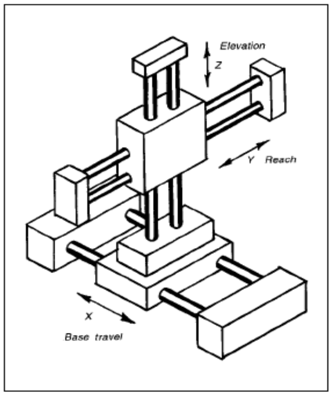


Figure (2.2) Gantry manipulator **Figure (2.3) Cartesian manipulator**

2.6.2. CYLINDRICAL MANIPULATORS:

The second type of manipulator work envelope is cylindrical. Cylindrical types usually incorporate a rotating base with the first segment able to slide up and down, carrying a horizontally telescoping segment

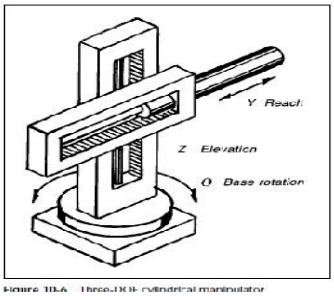


Figure (2.4) Cylindrical manipulator

2.6.3. **POLAR OR SPHERICAL MANIPULATORS:**

The third, and most versatile, geometry is the spherical type. In this layout, the work envelope can be thought of as being all around. In reality, though, it is difficult to reach everywhere. There are several ways to layout an arm with this work envelope. The most basic has a rotating base that carries an arm segment that can pitch up and down, and extend in and out raising the shoulder up changes the envelope somewhat and is worth considering in some cases.

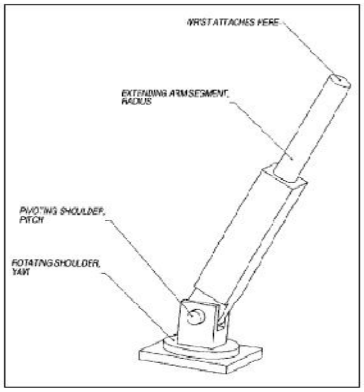


Figure (2.5) Basic polar coordinate manipulator

2.7. Anti person mines detectors:

According to official figures, more than 100 million landmines lie buried around the world. Although intended for warfare, these mines remain active after warfare ends. Each day these mines are triggered accidentally by civilian activities, ravaging the land and killing or maiming innocent people. To help stop this destruction of the environment and humanity, the scientific community must develop effective humanitarian demining. Mine detection is especially vital to humanitarian demining. The goal of military demining is to clear enough mines quickly to allow troops through a land area. Military demining usually requires mine destruction rates of80%. The goal of humanitarian demining, in contrast, is to clear enough mines to permit normal civilian use of the land (e.g., construction or agriculture). Humanitarian demining thus demands a destruction rate approaching perfection: UN specifications require a rate better than 99.6%. Of course, a critical aspect of mine clearance is mine detection. Before one can remove mines, one must locate them. To aid scientific inquiry into mine detection, this paper reviews the major current and developing technologies for mine detection. We do not claim to include every technology. Often the details of research intended for specific military applications are difficult to attain..

So the current technologies for anti person mines detectors are mentioned as follows:

2.7.1.Prodders

At present, the most common techniques for mine detection are manual, using either prodders or metal detectors. The most basic approach to mine detection is prodding. Using prodders, rigid sticks of metal about 25 cm long; the deminer scans the soil at a shallow angle of typically 30°. Each time he detects an unusual object, he assesses the contour, which indicates whether the object is a mine. Though effective, this technique is slow and dangerous. The deminer might encounter mines that have moved or have been placed so that they are triggered by prodding (Nicoud, 1996).[12]

2.7. 2. Metal Detectors

another current technology used for mine detection is the metal detector. The basic metal detector used for mine detection measures the disturbance of an emitted electromagnetic field caused by the presence of metallic objects in the soil (JASON, 96) (Tsipis, 1996). Magnetometers also are employed but almost exclusively for ferromagnetic objects (e.g. UXO), the magnetometers measure only the disturbance of the earth’s natural electromagnetic field (Jet Propulsion Laboratory, 1995) Metal detectors pose problems for mine detection. Both types of detectors identify all metallic objects; They cannot differentiate a mine or UXO from other debris. The large quantities of shrapnel, metal scraps, cartridge cases, and other metal debris in most battlefields lead to false alarms. Another problem is that many mines contain little metal. Many modern mines have almost no metal parts except for the small striker pin. Although metal detectors can be tuned to be sensitive enough to detect these small items (current detectors can track a tenth of a gram of metal at a depth of10 cm), such sensitivity detects more metal debris and increases considerably the rate of false alarms. Increasing the sensitivity of metal detectors, therefore, does not solve the problem of nonmetal mines satisfactorily.12]

2.7.2.1.Advanced Applications of Metal Detectors

Some interesting studies investigated whether metal detectors can discriminate mines and UXO from metallic debris, reducing the false alarm rate. For example, (Sower and Cave, 1995) used an impulse metal detector (MD) looking for a characteristic decay curve and compared it to the curves stored in a library. The study highlighted some problems. Capturing the response curve depends on several factors, e.g. the orientation of the metallic object, the exact metal type. Also, the approach is effective only with objects whose decay curves are known already. Nevertheless, this approach holds promise for specific situations. For earlier work in this area, see (Defense Research Establishment, 1991). Similarly, (Trag, Czipott, and Waldron, 1997) studied the possibility of characterizing objects through measurement of the eddy current frequency response over a large frequency range. Also being developed is an advanced Active/Passive Magnetic Gradiometer, which combines sensitive magnetic sensors (e.g. magneto resistive sensors capable of working over a broad frequency range, starting from DC) with advanced techniques of applied field rejection, as described in (Czipott and Iwanowski, 1996)

2.7.3. Ground Penetrating Radar (GPR)

GPR emits into the ground, through a wideband antenna, an electromagnetic wave covering a large frequency band. Reflections from the soil caused by dielectric variations (such as the presence of an object) are measured. Moving the wideband antenna reconstructs an image that represents a vertical slice of the soil, further data processing allows the display of horizontal slices or three-dimensional representations (Daniels, 1996).

2.7.4.Nuclear Methods

Nuclear methods include thermal neutron activation, neutron backscatter, and X ray backscatter. They are reviewed in (Gozani, 1996) and, with emphasis on military applications and the detection of AT mines, in (Department of the Army, 1985) and

(Department of the Army, 1991). (Defense Research Establishment, 1991) also provides thorough information about nuclear methods. Thermal neutron activation (TNA) (Bach et al., 1996) relies on the activation, via neutrons emitted by a radio isotopic source or an accelerator of the nitrogen nuclei abundantly contained in most explosives. The activated nitrogen nuclei emit specific gamma rays, which can be detected quickly. The SAIC company has developed, using a Californium252 source, a confirmatory device for the Canadian Improved Landmine Detection System (ILDS) (MacAfee, 1996) and for the VMDT vehicle already described (Brown, 1996).

2.7.5. Infrared (IR) Imaging

Mines emit heat at a various rate than their ambient, and it can measure the variation in temperature between the soil and the mine using infrared cameras. However, this method has some defects that's because imaging depends on the environmental conditions, in the evenings and in the mornings. The landmine is impossible to detect when the thermal variation is very little also canopy places an additional problem. [13]

2.7.6. Advanced Landmine Imaging System (ALIS)

ALIS development was financed by JST (Japan Science and Technology Agency). It is a hand-held sensor combined metal detector (MD) and (GPR) system for Anti-Personnel landmine detection, which can visualize their signals for the benefit of deminers. The visualized MD signal image provides direct data on the whereabouts of metal objects, and then GPR gives the radar image of the buried objects, which is used in landmines detection application. The visualization system results in developing the reliability of mine clearing process. The location of the sensor head scanned by the deminer can also be enrolled in real time. This record can be used for the quality control of the operation, and also for the training of operator.[13]

Figure (2.6) Advanced Landmine Imaging System

2.7.7. VMR1-MINEHOUN

The MINEHOUND sensor is financed by Vallon GmbH. It is a combined metal detector (MD) and (GPR) system in order to reduce the false alarm rate by metal detectors. This leads to increase productivity of mine purification operation. It is designed specifically for detection of anti-personnel landmines. [13]

Figure (2.7): VMR1-MINEHOUN

2.7.8. US Army Hand-held Standoff Mine Detection System (HSTAMIDS)

CyTerra describes the HSTAMIDS (AN/PSS-14) as it revolutionizes landmine detection by combining ground penetrating radar (GPR) and highly sensitive metal detector (MD) technology using advanced data integration algorithms. This unique combination enables the system to reliably and consistently detect antipersonnel (AP) and antitank (AT) mines and to reject the detection of metallic clutter, increasing deminer's assurance and efficiency. [13]

Figure (2.8): HSTAMIDS (AN/PSS-14)

Many sensors and different techniques used in mine detection are listed below. Table (2.2) shows these techniques with a comparison of cost, complexity and maturity. **[14]**

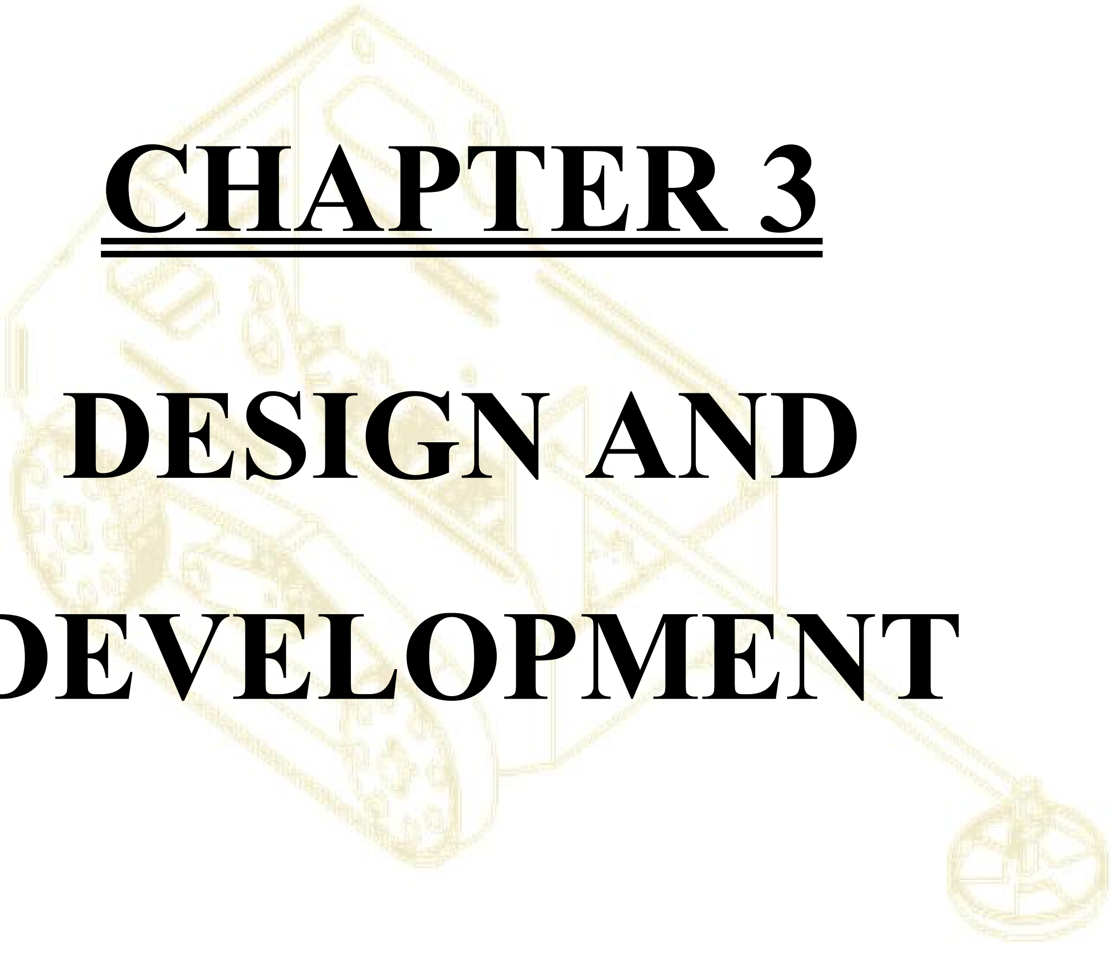
Table (2.2) several potential sensing technologies

Sensor Technology	**Maturity**	**Cost and Efficiency**	**Non-metal mine detection**
Metal detection	Available	Low	+
Infrared	Near	Medium	+++

Electro-optical	Near	Medium	+++
Multi/hyper spectral	Far	High	++
Passive mm-wave	Far	High	++
Mm- wave radar	Near	High	++
Ground Penetrating Radar	Near	Medium	++
Ultra-wide-band radar	Far	High	++
Active acoustic	Mid	Medium	++
Active seismic	Mid	Medium	+++
Magnetic field sensing	Near	Medium	+
Neutron activation analysis	Near	High	+++
Charged particle detection	Far	High	++
Nuclear quadrupole	Far	High	+
Resonance	Mid	High	+
Chemical	Far	High	+++
Bio-sensors	Available	Medium	+++
Dogs / rats	Available	Low	+++
Prodding	Available	Low	+++

+++ (good)   + (poor)

Humanitarian demining continues to be a world problem far from being solved. This means that there is no single technical achievement for detection of all mine types, since every approach has good results within limited conditions, so researchers turned to integrate more than one technology as one sensor, after the literature and benchmarks survey , one of these sensors (ALIS, VMR1-MINEHOUN or AN/PSS-14) was preferred to use in proposed design.



CHAPTER 3

DESIGN AND DEVELOPMENT

3.1. Concept

3.1.1 Design requirements

A robotic researcher often feels the need for a mobile platform; that can effectively move on different terrain conditions and to which addition of new hardware is practical. Since purchasing a new robot for every different application is neither economically nor time-wise practical. Hence, after noticed the need to develop easily manufactured tracked platform that can be used wide range of applications with minimal effort[9]. At the beginning of this study, the design requirements of the tracked robot platform are determined as follows:

Table(3.1) Design requirements

Chassis		**Wheeldrive**		**Manipulator**	
Dimension (L)	650 mm	Motor voltage	12 V	Degree of Freedom	1
Dimension (W)	400 mm	Speed	100 RPM	Join Rotation	180°
Dimension (H)	250 mm	Drive model	2motors	Vertical Reach	0cm
Weight	15 kg	Climb Elevation	30°	HorizontalReach	80cm
Protection	yes	Rotation	continuous	Weight	3kg
Track	1363 mm			Lift Capacity	4kg
Safety Factor	1.5				

3.1.2 Design procedure

In order to select (MTR-PW-R&L) actuators, a simple model of the platform as illustrated in Figure() is derived. Note that the model has been developed for an ideal flat surface condition in order to have an idea about the general requirements of the motion. In the mathematical model the forces coming from ground has been taken into account. The applied tracks traction forces, which are needed to give the motion to the robot base, have been modeled as given in Equations (1-6). The abbreviations used in Figure (3.0) are specified as:

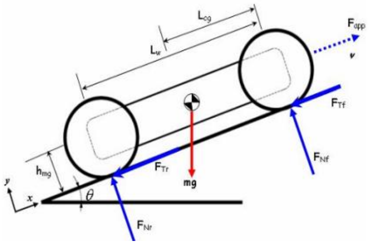


Figure (3.1) tracks traction forces

$$\sum F_x = \mu_w \gamma_r F_{Nr} + \mu_w \gamma_f F_{Nf} - mg\sin\theta \qquad (1)$$

$$\sum F_y = F_{Nr} + F_{Nf} - mg\cos\theta \qquad (2)$$

$$\sum M = F_{Nr} L_w - mg(L_{cg}\cos\theta + h\sin\theta) \qquad (3$$

$$F_{Nr} = \frac{mg(L_{cg}\cos\theta + h\sin\theta)}{L_w} \qquad (4)$$

$$F_{Nf} = \frac{mg((L_w - L_{cg})\cos\theta - h\sin\theta)}{L_w} \qquad (5)$$

$$F_{app} = F_{Nr}\mu + F_{Nf}\mu + mg\sin\theta \qquad (6)$$

m denotes the mass of the platform. g denotes the gravitational acceleration. H_{mg} denotes height of the center of mass. F_{Nr} and F_{Nf} denote the normal forces acting on rear and front wheel, respectively. F_{Tr} and F_{Tf} denote the total tractive effort for rear and front wheel, respectively. γf and γr equal 1 for the four wheel drive. θ is the slope angle of the terrain. The details of the model are given in [11]

Finally, although configurable locomotion and hardware are necessary conditions for a tracked research platform, hardware integration to the overall control system is an issue that has to be handled via software. Hence, the base should not restrict the user to a specific operating system. CAD models of the tracked version are given appendix. In the design process, SolidWorks 2010 is used. The dimensions of the parts have been optimized using the AutoCAD 2016 software, finite element analysis (FEA) done by Catia v5 software. Frame of the mobile robot has been manufactured from 6061 series of Aluminum, internal space of the platform can be rearranged and used effectively whenever it is required. pulley wheels have been connected to the frame by shaft. Dimensions of the shaft, shaft hole of the pulley wheels have been chosen in a way that they get along well with each other. The stages of the assembly are given also in appendix.

So the procedure is to design platform then the groove plate in which all inside components will be attach, then design the track, wheels and shafts, tension mechanism and finally design the manipulator

3.2. General dimensions and robot shape:

According to the design requirements mentioned in table (3.1) The minimum dimensions are stated below:

-The minimum length L_{min} is 650 mm.

-The minimum width W_{min} is 400mm.

-The minimum height H_{min} is 250mm.

The shape of a mobile robot is of great importance and can have an impact on the robots performance. Since the robot has different tasks and the robot will run autonomously, a rectangle shaped robot with a climb angle is the best solution.

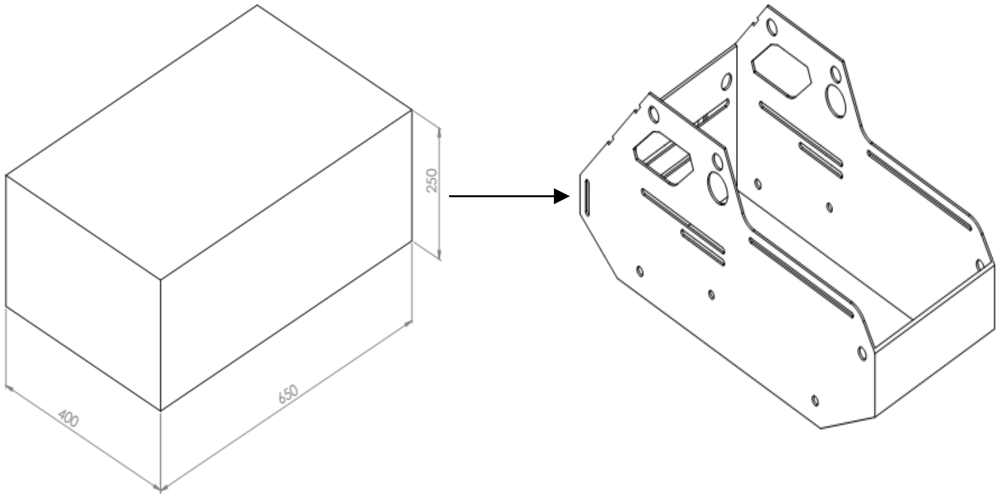


Fig.(3.1) general dimensions and shape.

3.3 Mechanical designs

3.3.1 Chassis:

In this research, according to the problem statement and design requirements which mentioned in table (3.1) A tracked platform sees ideal in this case, especially since tank tracks considered far cooler than wheels.

In order to keep the costs down, have taken into consideration the fact that there are not many tracks available, and to keep things simple, a single drive wheel and single tension wheel system have been considered, this should not be a problem since the robot will be very light weight.

-The chassis took a rectangular shape with these dimensions:

- 645 mm length.
- 300 mm width.
- 250 mm high.

-There are two extensions in the back and two on the top of chassis for picking and lifting, pulling and pushing.

-the chassis consisted from five sheets welded to give the platform more rigid.

- There are some holes for air conditioning.

-the material which used to build the platform is aluminum alloy 60-61 series because it was satisfied design requirements as specifications below:

Table (3.2) Aluminum alloy 60-61 Properties

Physical Properties	**Metric**
Density	2.70 g/cc
Mechanical Properties	**Metric**
Hardness, Brinell	30
Tensile Strength, Ultimate	124 MPa
Tensile Strength, Yield	55.2 MPa
Modulus of Elasticity	68.9 GPa
Ultimate Bearing Strength	228 MPa
Bearing Yield Strength	103 MPa
Poissons Ratio	0.33

Fatigue Strength	62.1 MPa of Cycles 5.00e+8
Machinability	30 %
Shear Modulus	26.0 GPa
Shear Strength	82.7 MPa
Electrical Properties	**Metric**
Electrical Resistivity	0.00000366 ohm-cm at Temperature 20.0 °C
Thermal Properties	**Metric**
Specific Heat Capacity	0.896 J/g-°C
Thermal Conductivity	180 W/m-K
Melting Point	582 - 651.7 °C
Solidus	582 °C
Liquidity	651.7 °C

-The sheets thickness 4mm.

-The front and back took an angled shape with 33° to climb obstacles.

-After applying material the weight of the platform 7000grams.

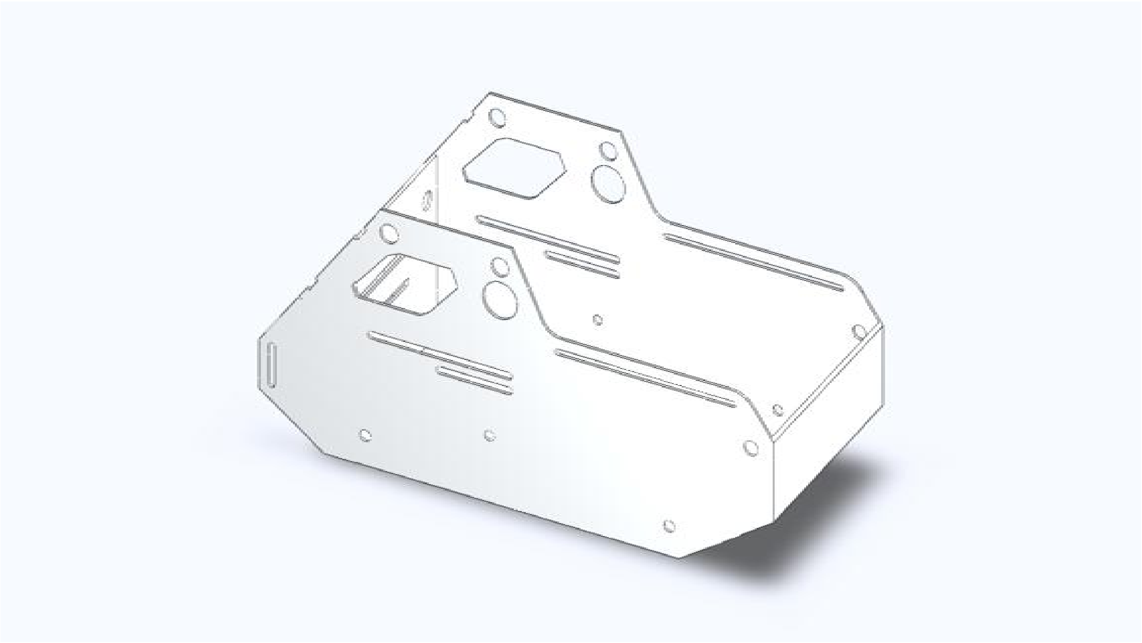


Fig. (3.2) 3D model of the chassis

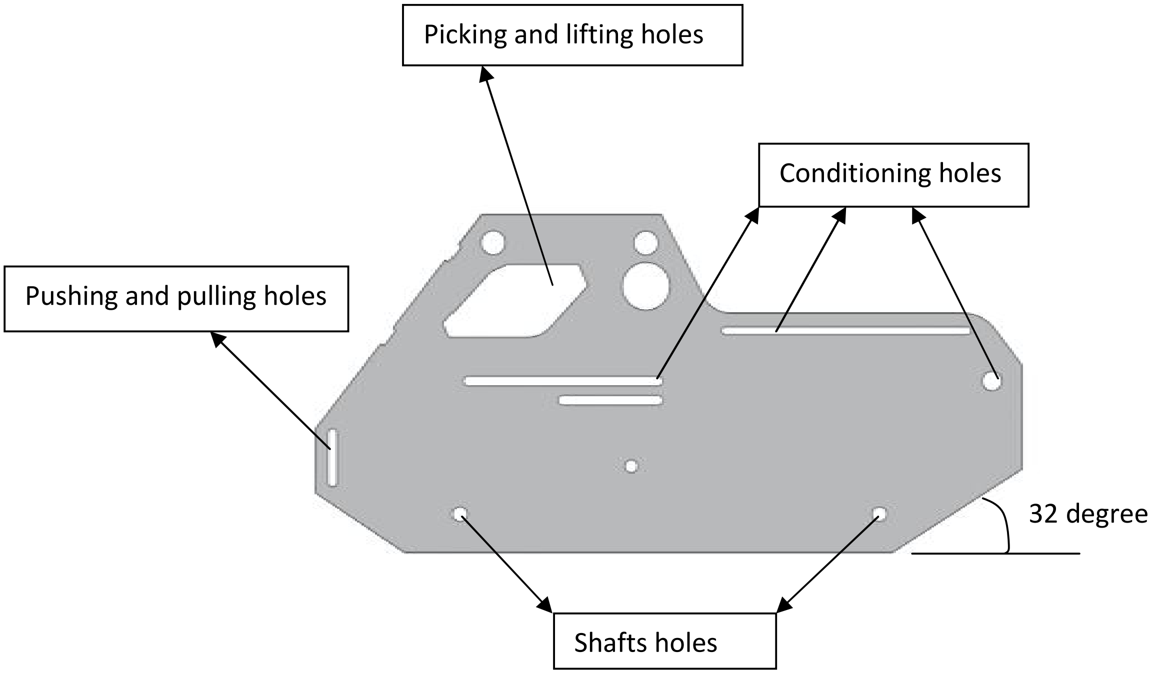


Fig (3.3) Illustration of the idea

- The detailed drawings will illustrate in the appendix.

3.3.2 Grooved plate:

As shown in the Figure (3.4), the grooved plate is constructed from extruded aluminum alloy 60-61, and fixed to the robot chassis by 4 welded L shape steel piece and 2 mm screws .This frame structure enables to design simple adaptor plates for individual hardware components and locate the hardware inside the robot with the same adapter. It is also practical to move the hardware once it is installed on a groove to open up some space for additional hardware. Another advantage of the grooved plate structure is that, by moving the hardware (including the batteries) within and around the robot, the center of gravity of the robot can be adjusted as needed.

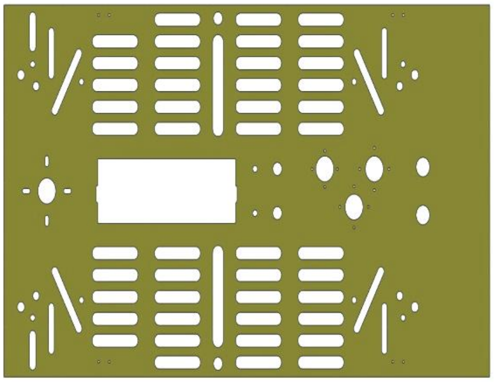


Fig. (3.4) grooved plate

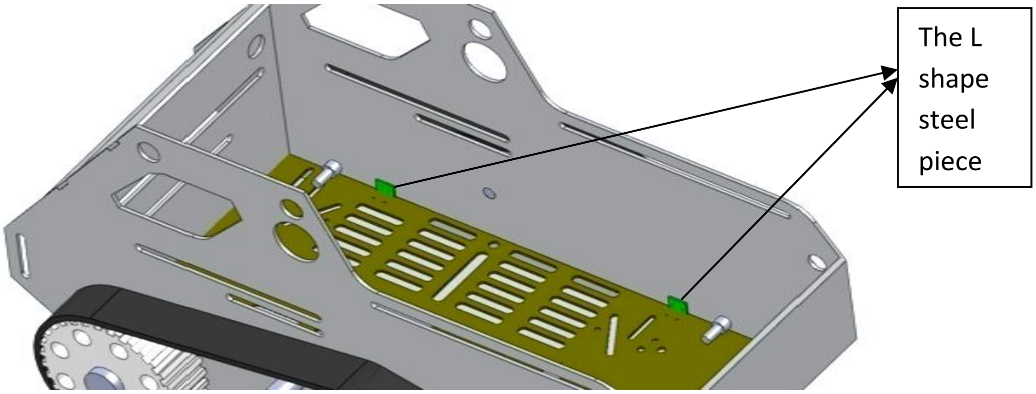


Fig. (3.5) fixing the grooved plate to the robot chassis

- The detailed drawings will be illustrated in the appendix .

3.3.3 Track configuration:

- The number of tracks needed to this robot is tow each one is actuated by two motors placed at the back and front of the robot.
- The material used to make the track : polyurethane

Polyurethane: it is kind of rubber and one of the common materials that used to make tracks for robots because it has the advantages bellow:

1-Abrasion resistant

Parts made of polyurethane will often outwear other materials by a margin of 5 to 50/one when severe abrasion is a factor. It has been proven to be vastly superior to rubber plastics and metal in many applications.

2-solvent resistant

Polyurethane has excellent resistance to oils, solvents, fats, greases and gasoline.

3-Load bearing capacity

Polyurethane has a higher load-bearing capacity than any conventional rubber. Because of this characteristic, it is an ideal material for load wheels, heavy duty couplings, metal-forming pads, shock pads, expansion joints and machine mounts.

4-Tear resistant

Tear-strength ranges between 500-100 Ibs./linear inch, which is far superior to rubbers. As a result, urethane is often used as drive belts, diaphragms, roll covers, cutting pads, gaskets and chute liners.

5-Weather resistant

Polyurethane has outstanding resistance to oxygen, ozone, sunlight and general weather conditions.

6-Heat and cold resistant

Continuous use above 225°F is not recommended nor is urethane recommended in hot water over 175°F. At low temperatures, polyurethane will remain flexible down to -90°F. Gradual stiffening will occur at 0°F, but will not become pronounced until much lower temperatures are obtained.

- The track width: 50 mm.
- The track pitch: 8.75 mm.
- Track length: 1363mm.
- Track weight: 1360 gram.

Fig.(3.6) Model of the continuous rubber

- The detailed drawings will be illustrated in the appendix.

3.3.4 Track drive wheel:

Drive wheels are rotating parts with teeth that are used in conjunction with a track and transmit torque. In order for the Drive wheels and track to work effectively, all of the Drive wheels should be on parallel shafts with their corresponding teeth on the same plane.

In this research the drive wheel designed according the properties below:

Material: cast carbon steel.

Width: 50 mm.

Outer diameter: 152mm.

Pitch: 5.95 mm.

But the design faced weight problem because the mass for one wheel exceeded 3697.48 grams after mass test done by SOLIDWORKS, so it was too heavy for four wheels.

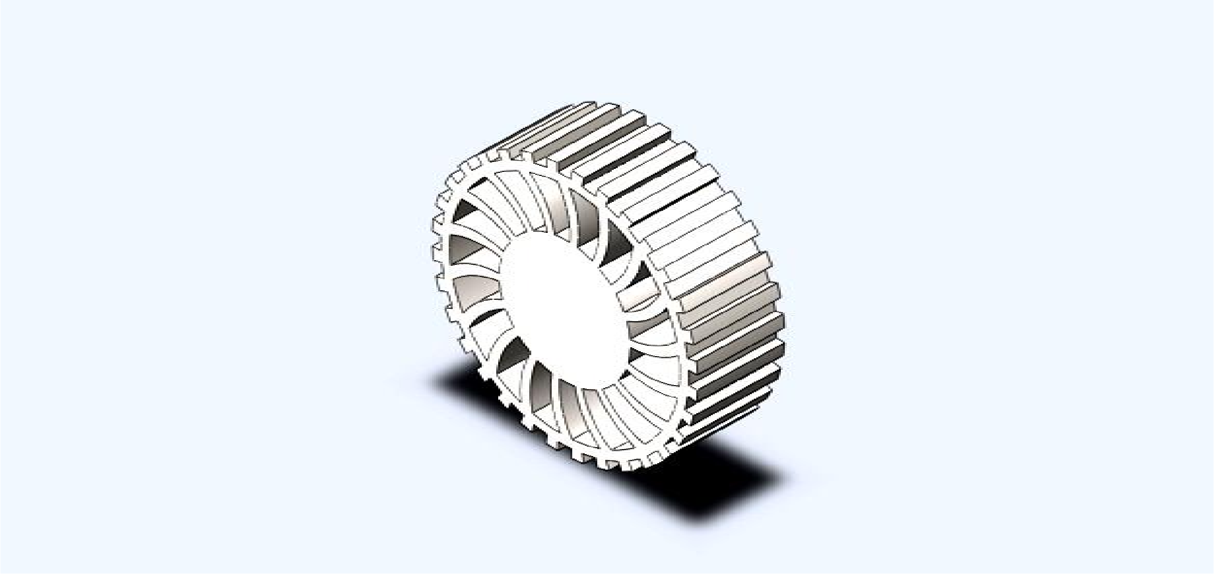


Fig (3.7) first drive wheel model

So the need to improve this design and solve the weight problem lead to change the previous material (carbon steel) to the plastic because it is light material and made holes around the shaft hole to dumping great quantity of unnecessary material .

Choosing plastic done according the specifications bellow:

Table (3.3) Plastic specifications

Sheer modulus	$3189*10^5$ N/m^2
Tensile strength	$3*10^7$ N/m^2
Thermal conductivity	0.2256 W/(m.K)
Specific heat	1386 J/(Kg. K)

- The width, pitch, and outer diameter were as same as the previous model.
- The new mass: 676.17 grams for one wheel.

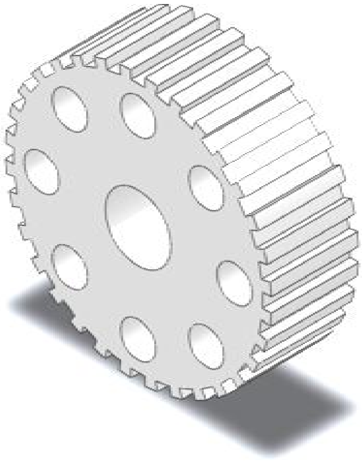


Fig (3.8) the improved drive wheel model

- The detailed drawings will be illustrated in the appendix.

3.3.5. Tension mechanism:

This mechanism designed to keep the track tensioned all time because the robot movement depends on track tension .

in this design a torsion spring with arm angle 180° used to connect the tension mechanism and robot platform .

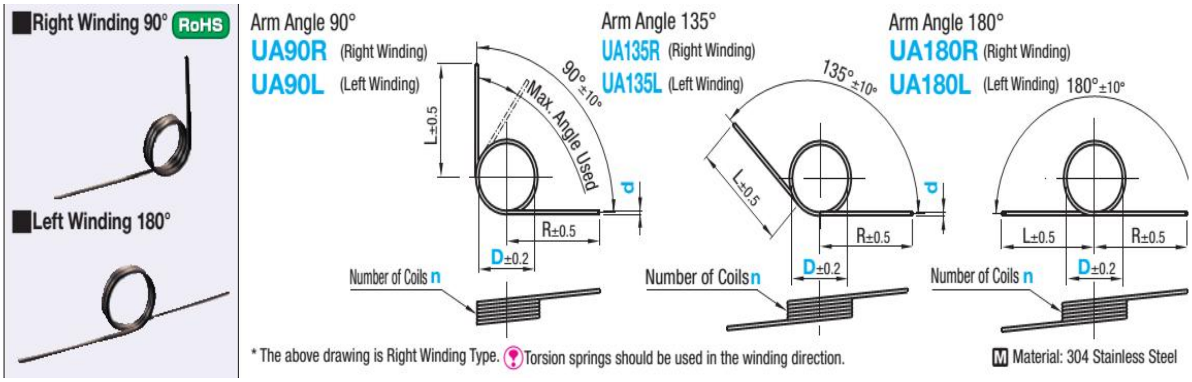
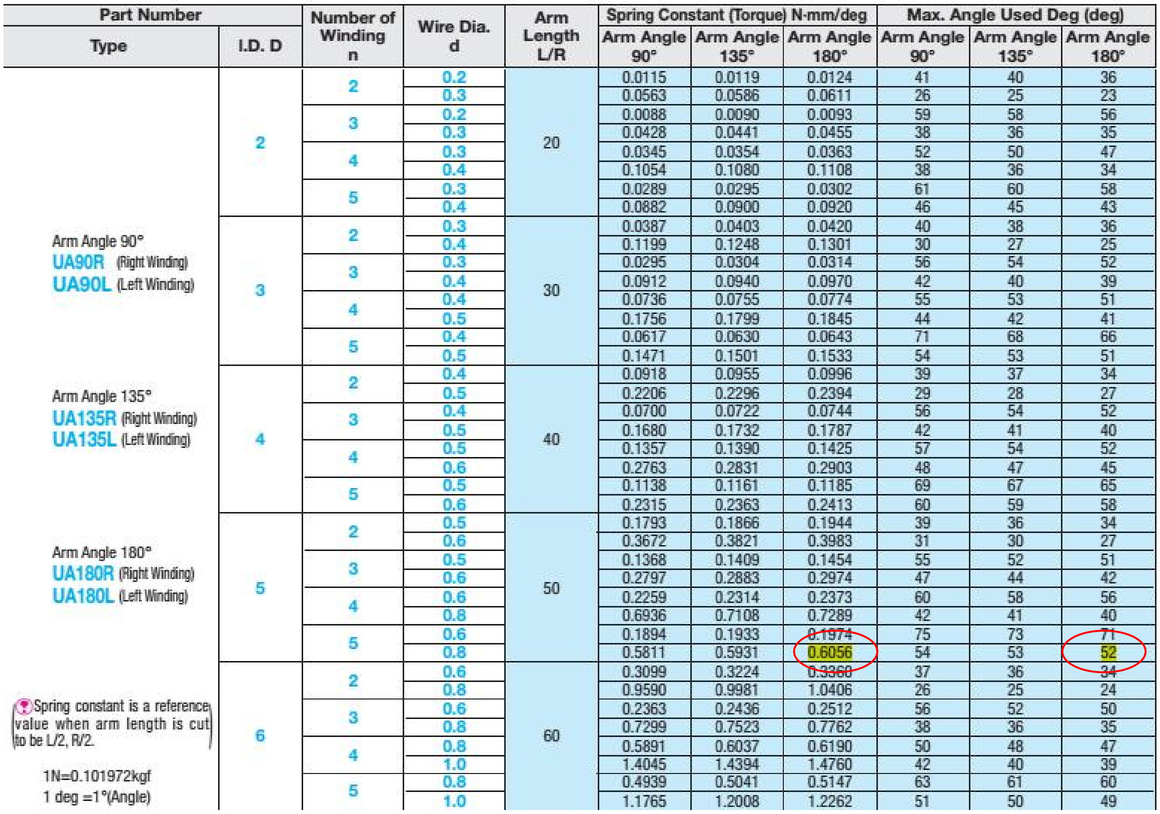


Fig (3.9) types of torsion spring

Table (3.4) Torsion spring specifications



Part Number		Number of Winding n	Wire Dia. d	Arm Length L/R	Spring Constant (Torque) N·mm/deg			Max. Angle Used Deg (deg)		
Type	I.D. D				Arm Angle 90°	Arm Angle 135°	Arm Angle 180°	Arm Angle 90°	Arm Angle 135°	Arm Angle 180°
Arm Angle 90° UA90R (Right Winding) UA90L (Left Winding) Arm Angle 135° UA135R (Right Winding) UA135L (Left Winding) Arm Angle 180° UA180R (Right Winding) UA180L (Left Winding)	2	2	0.2	20	0.0115	0.0119	0.0124	41	40	36
			0.3		0.0563	0.0586	0.0611	26	25	23
		3	0.2		0.0088	0.0090	0.0093	59	58	56
			0.3		0.0428	0.0441	0.0455	38	36	35
		4	0.3		0.0345	0.0354	0.0363	52	50	47
			0.4		0.1054	0.1080	0.1108	38	36	34
		5	0.3		0.0289	0.0295	0.0302	61	60	58
			0.4		0.0882	0.0900	0.0920	46	45	43
	3	2	0.3	30	0.0387	0.0403	0.0420	40	38	36
			0.4		0.1199	0.1248	0.1301	30	27	25
		3	0.3		0.0295	0.0304	0.0314	56	54	52
			0.4		0.0912	0.0940	0.0970	42	40	39
		4	0.4		0.0736	0.0755	0.0774	55	53	51
			0.5		0.1756	0.1799	0.1845	44	42	41
		5	0.4		0.0617	0.0630	0.0643	71	68	66
			0.5		0.1471	0.1501	0.1533	54	53	51
	4	2	0.4	40	0.0918	0.0955	0.0996	39	37	34
			0.5		0.2206	0.2296	0.2394	29	28	27
		3	0.4		0.0700	0.0722	0.0744	56	54	52
			0.5		0.1680	0.1732	0.1787	42	41	40
		4	0.5		0.1357	0.1390	0.1425	57	54	52
			0.6		0.2763	0.2831	0.2903	48	47	45
		5	0.5		0.1138	0.1161	0.1185	69	67	65
			0.6		0.2315	0.2363	0.2413	60	59	58
	5	2	0.5	50	0.1793	0.1866	0.1944	39	36	34
			0.6		0.3672	0.3821	0.3983	31	30	27
		3	0.5		0.1368	0.1409	0.1454	55	52	51
			0.6		0.2797	0.2883	0.2974	47	44	42
		4	0.6		0.2259	0.2314	0.2373	60	58	56
			0.8		0.6936	0.7108	0.7289	42	41	40
		5	0.6		0.1894	0.1933	0.1974	75	73	71
			0.8		0.5811	0.5931	0.6056	54	53	52
	6	2	0.6	60	0.3099	0.3224	0.3360	37	36	34
			0.8		0.9590	0.9981	1.0406	26	25	24
		3	0.6		0.2363	0.2436	0.2512	56	52	50
			0.8		0.7299	0.7523	0.7762	38	36	35
		4	0.8		0.5891	0.6037	0.6190	50	48	47
			1.0		1.4045	1.4394	1.4760	42	40	39
		5	0.8		0.4939	0.5041	0.5147	63	61	60
			1.0		1.1765	1.2008	1.2262	51	50	49

Spring constant is a reference value when arm length is cut to be L/2, R/2.

1N=0.101972kgf
1 deg =1°(Angle)

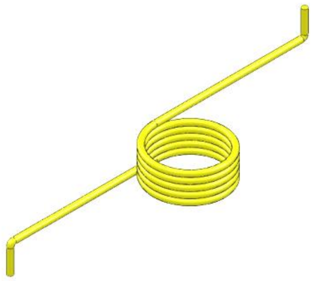


Fig (3.10) the chosen torsion spring

The body of tension mechanism consisted of:

1- Shaft: to connect the mechanism and robot platform and allow the mechanism to rotate around.
2- Hollow pipe: this pipe is welded to two slot steel pieces in one side.
3- Slot steel piece: the mechanism body has two pieces welded together to the hollow pipe in the first side and connected to the small wheel shaft in the other side.

4-The small wheel: this part was designed from the same material of the drive wheel to be light weight with same pitch of the track.

- The position of the tension mechanism is located in the center of robot platform to give good and stable tension to the track.

All these parts mentioned above and the mechanism assembly will be illustrated in figures (3.11):

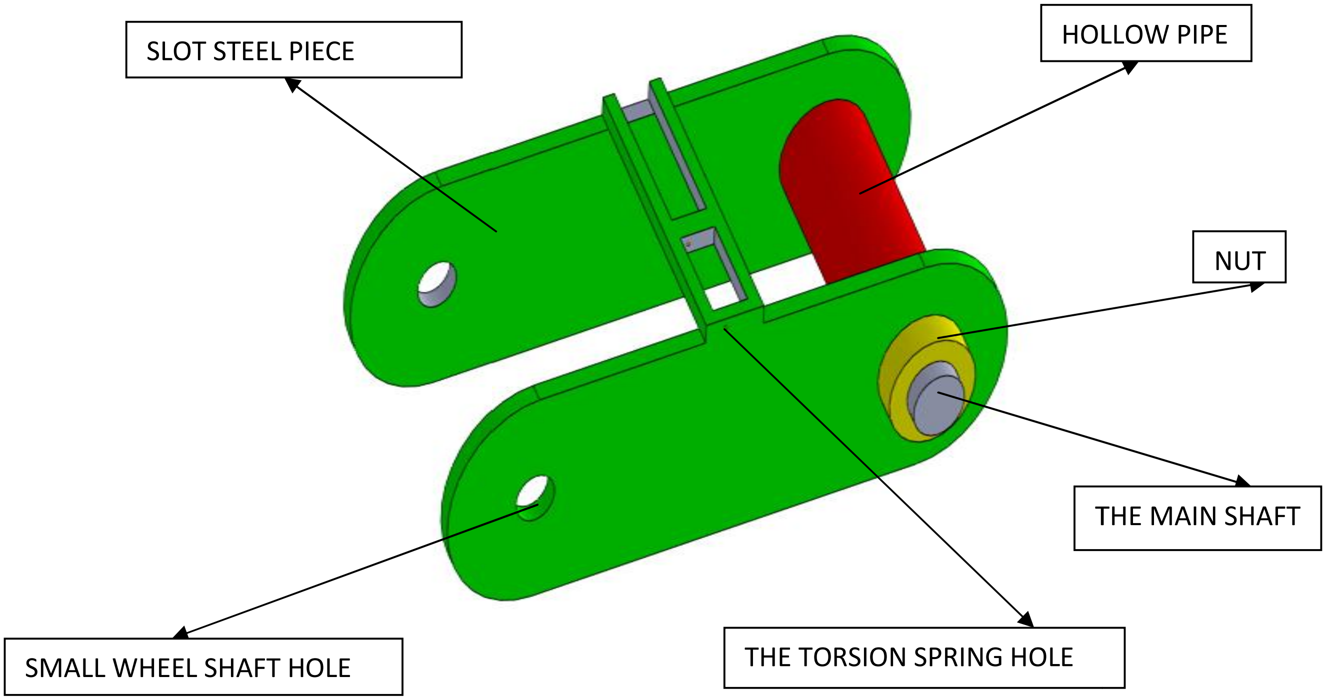


Fig (3.11) tension mechanism assembly

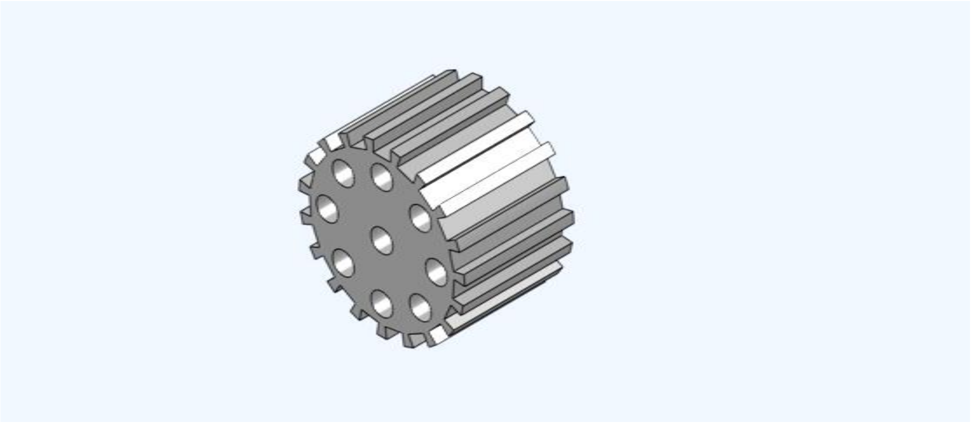


Fig (3.12) tension wheel

- The detailed design will be illustrated in the appendix.

3.3.6. Scanning manipulator

A sensor head based on a metal detector used, which is a device that senses a single point or very small areas. A scanning device is therefore needed that can sweep the sensor across large areas. The easiest system would be a manipulator tailor-made for this task. Such a manipulator would require one DOF for positioning the sensor in a 2D area; assuming that the system is scanning flat area, motions in the x and y components would be required. Also, the detector would have to be adapted to small terrain inclinations; hence a shape like wrist designed to pick metal detector when it faces an obstacle. The manipulator is designed to carry the sensor head, so the design is optimized to carry just this load. First, the load is balanced to move the detector 180º to scan the front, left and right sides. Another key design point is the tapered roller bearing which used to fix radial and axial loads while scanning and movement of the tracked robot. Figure (3.23) shows a model of the scanning manipulator taking into account the aforementioned design requirements. Table (3.5) lists the manipulator's features.

Table (3.5) Main scanning manipulator features

Number of joints	1
DOF	1
Metal detector type	Vmr1-minehoun
Motor power (watt)	DC motor
Mass	kg
Link material	Wood +PVC plasticized
Link length	60 cm
Link holder material	PVC rigid
Fixing with motor	By coupling
bearing	30202(tapered roller bearing)

3.3.6.1Manipulator components:

1- The main holder :

The design for this component done according to properties below:

-Material: PVC rigid to be light for the aluminum plate to carry without deformation.

-Height: 240 mm to give the link good tolerance from platform top side to move and scan.

The holder diameter: 100mm to be in the center of robot and to distribute the load in wide area.

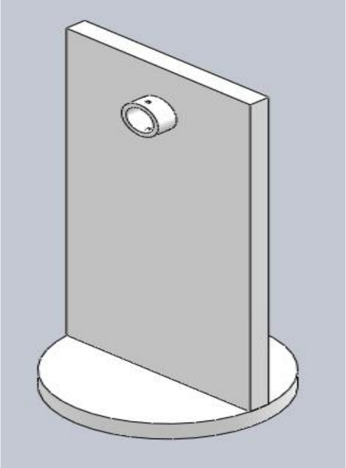


Figure (3.13) The main holder

-After designing the main holder the research process faced a problem because axial and radial forces while moving and scanning, so the holder needs to attach bearing to load and distribute these forces.

The bearing selection procedure:

According to the manipulator holder axle with 15mm diameter and 10mm thickness , bearing selector web site for fersa company used by assuming parameters below to give mutable options to select the most suitable one :

Inner diameter: 15-20 mm

Outer diameter: 25 -30 mm

Thickness: 10-15 mm.

The website gave deferent alternatives as mentioned in table (3.6).[15] below :

Table (3.6) fersa bearings

Fersa	Bore diameter(mm)	Out diameter(mm)	T Size(mm)	Weight (Kg)
30202 F	15.000	35.000	11.750	0.053
30203 F	17.000	40.000	13.250	0.074
30204 F	20.000	47.000	15.250	0.120
30205 F	25.000	52.000	16.250	0.150
30205 FR	25.000	52.000	16.250	0.150
30206 F	30.000	62.000	17.250	0.220
30207 F	35.000	72.000	18.250	0.320
30207/37 F	37.000	72.000	18.250	0.320

30207/80 F	35.000	80.000	18.250	0.427
30208 F	40.000	80.000	19.750	0.410
30209 F	45.000	85.000	20.750	0.460
30210 F	50.000	90.000	21.750	0.529
30211 F	55.000	100.000	22.750	0.687
30212 F	60.000	110.000	23.750	0.869
30213 F	65.000	120.000	24.750	1.103
30214 F	70.000	125.000	26.250	1.222
30215 F	75.000	130.000	27.250	1.347
30216 F	80.000	140.000	28.250	1.600
30217 F	85.000	150.000	30.500	2.050
30218 F	90.000	160.000	32.500	2.550

30202 match the requirements, so it had been selected. The technical and Dimensional Specifications mentioned in table (3.7). [16] as follows:

Table (3.7) Technical and Dimensional Specifications

Technical Specifications	
Type	Tapered Roller Bearing
Bore Type	Round
Material	Hardened Steel
Limiting Speed - Oil	13000 RPM
Limiting Speed - Grease	9900 RPM
Style	Cone & Cup
Precision Rating	Class 0
Configuration	One
Lubrication	w/o Oil Hole
e (Axial Load Factor)	0.35
Y2 (Axial Load Factor)	1.73
Static Load Rating	12.30 kN
Dynamic Load Rating	13.40 kN
Enclosure	Open
Weight	0.053 kg
Operating Temperature	-40 to 120 ºC

Range	

Dimensional Specifications

d	15.000 mm
D	35.000 mm
C	10.000 mm
B	11.000 mm
a (Effective Load Center)	-3.250 mm
T	11.750 mm
r	0.600 mm
R	0.6 mm
da	19.5 mm
db	20.5 mm
Db	28.5 mm

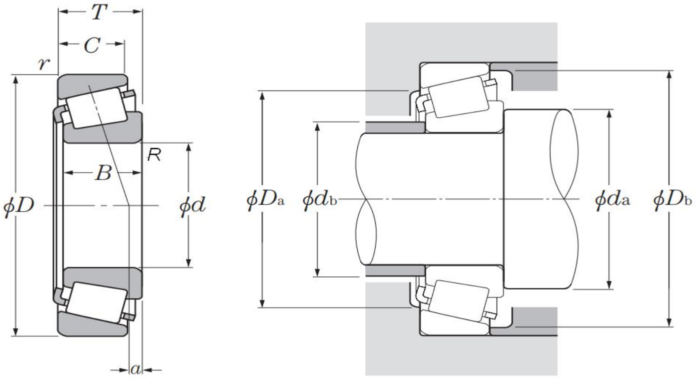


Figure (3.14) tapered roller bearing dimensional specifications

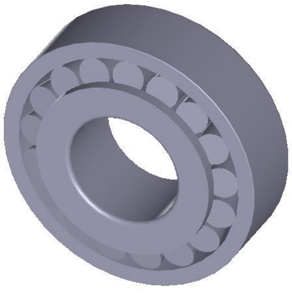


Figure (3.15) 30202 model

Figure (3.16) 30202 bearing

- After choosing the bearing a piece of steel designed to fix the bearing with the plate as illustrated in figure (3.17) and (3.18).

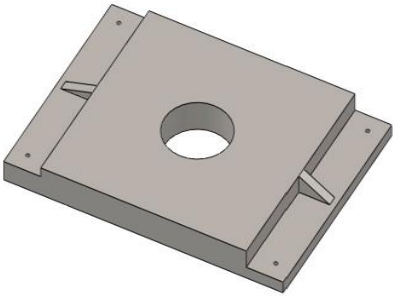


Figure (3.17) Bearing housing

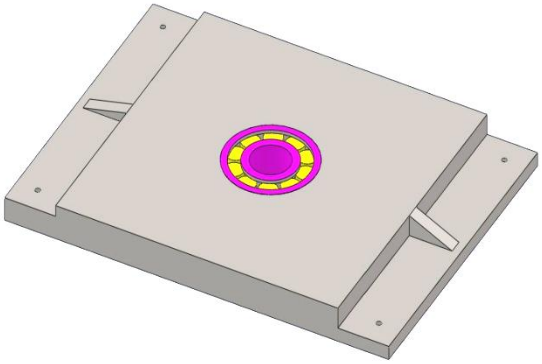


Figure (3.18) Bearing and housing assembly

- The housing fixed to the plate with 2mm diameter screws.

2-The wood link:

The purpose to choose wood as material to design the link is the confusion of metal detector if a metal material is selected and also the stiffness and rigidity of the type of wood (mahogany) which selected.

-Diameter: 13mm.

-Length: 700mm.

Figure (3.19) Wood link

3-The hollow PPR link:

The hollow PPR link with diameter 15mm and 2 mm thickness is used to give more stiffness and also to protect the wood link

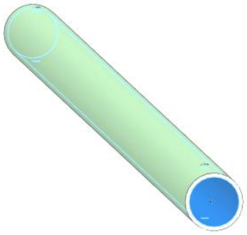


Fig (3.20) Hollow PPR link

4-The PVC joint:

This joint designed to connect the assembled wood /PVC link with the metal detector .The mechanism of the joint designed to avoid the obstacles which faced the metal detector while scanning by adding a screw that restrict movement in one axis.

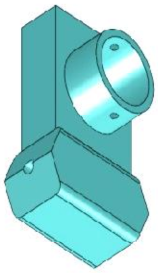


Figure (3.21) The PVC joint

5-Scanning sensor:

-Type: Vmr1-minehoun

Dual-sensor-metal detector For detection of metal and metal-free mines , search head with metal detector , and ground penetrating radar (GPR), handheld unit approx. 4 kg only.

Power supply: Lithium polymer cells, rechargeable, or 4 batteries, D-size.

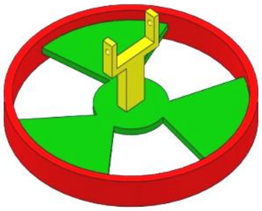


Figure (3.22) Scanning sensor

After assembling all above components the last shape of the manipulator was given in figure (3.23) below:

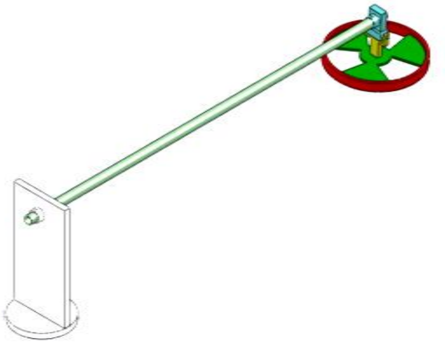


Fig (3.23) the assembled manipulator

3.4. Motor:

Many motors founded in www.mybotic.com but according to the robot mass and other specifications the window motor was considered as below:

1-Power car Window DC Motor (Wira) – Right and left :

Specifications:

- For Right side of car door
- Voltage Rating: 12VDC
- Speed (No Load): ~ 85RPM
- Current (No Load): <3A
- Current (Load): <7A
- Current (Lock): ~20A at 12V
- Torque: 30Kg.cm
    - Mass: 560 grams
    - REF: MTR-PW-R
    - REF: MTR-PW-L
    - Retail Price: RM40.28
    - http://www.mybotic.com.my/products/Power-Window-Motor-(Wira)-Right/871

2-Power car Window DC Motor with Coupling (Left) and (right) :

Specifications:

REF: MO-PW-CL

- For left side of car door
- Voltage Rating: 12V-DC
- No load Speed: 85 ± 15RPM
- Rated Speed: 60 ± 15RPM
- Current (No Load): <5A
- Rated Current (Load): <15A
- Stall Current (Locked): <28a at= 12v
- Rated Torque: 30Kg.cm (2.9N.m)
- Stall Torque (Locked): 100 ± 15Kg.cm (~10N.m)
- Packing list:
    - Power Window Motor with Custom Coupling/Hub
    - http://www.mybotic.com.my/products/Power-Window-Motor-With-Coupling-(Left)/993
    - 3 x round head M5 screw

- Retail Price: RM86.92
- Mass: 750 grams

-So according to type of fixing and the god features Power Window Motor with Coupling (Left) and (right) is chosen in the robot design.

3.5 Battery (power supply):

Many batteries founded in [17] but according to the center of gravity and robot weight and other specifications some types were considered as below:

1-12V 7.2Ah Lead Acid Battery (SLA)

Description:
Seal Lead Acid (SLA) Rechargeable battery is the most common general purpose battery. Low cost, robust and less maintenance required are the advantages of SLA. But it is considered heavy weight for certain robotic application. To charge SLA batteries, you can use any general DC power supply as long as it provides the correct voltage to your battery.

Features:
Rechargeable

Recyclable

No Memory Effect

Able to use for most of the 12V controllers

, motors or any other appliances

Specifications:
Voltage: 12V

Capacity: 7.2Ah

Size: 150mm x 63mm x 94 mm

Mass: 1.8 kg,

2-Switching Power Supply 24V 4.5A:

DESCRIPTION:

Metal enclosure type AC-DC switching power supply that suitable for most machinery application. Protects over short circuit. Overload and over voltage.

Specifications:

Output voltage: 24VDC; single output

Output current: 4.2A

Output power: 108W

Input voltage: 85~132VAC/ 176~264VAC

Selection by switch

Origin: China

3-Ni-Cd Battery 6V 700mah

Specifications:
Size: 50mm x 70mm x 14mm

Normal capacity: 700mah

Normal voltage: 6V

Cell: 1.2V battery

No of cell: 5

Suitable: Ni-Cd Battery Charger 6V

Charging time:4-5 hours

MASS: 100 grams

3- LiPo Rechargeable Battery 30C 11.1V 5200mAh:

DESCRIPTION

Lithium Polymer (LiPo) rechargeable battery is frequently used in robotic sector due to its small-size and lightweight.
Specification:

Specification:

Ordinary Voltage: 11.1V

Capacity: 5200mAh

Able to use for most of the 12V controllers, motors or any other appliances

Must charge with designated LiPo Battery Charger

Dimension: 135*28*42mm

30C

Mass:0.4kg

4-Li-Ion Rechargeable Battery 12V 2200mAh:

Description

This is Li-Ion Rechargeable Battery 12V 2200mAh.

Size: 55mm x 66mm x 20mm

Max Output Ampere: 2A

Over charge and over discharge protection

DC 12.6V 1A Adapter (11.1V Lion Battery Charger)

Lastly Switching Power Supply 24V 4.5A battery type chosen to the design.

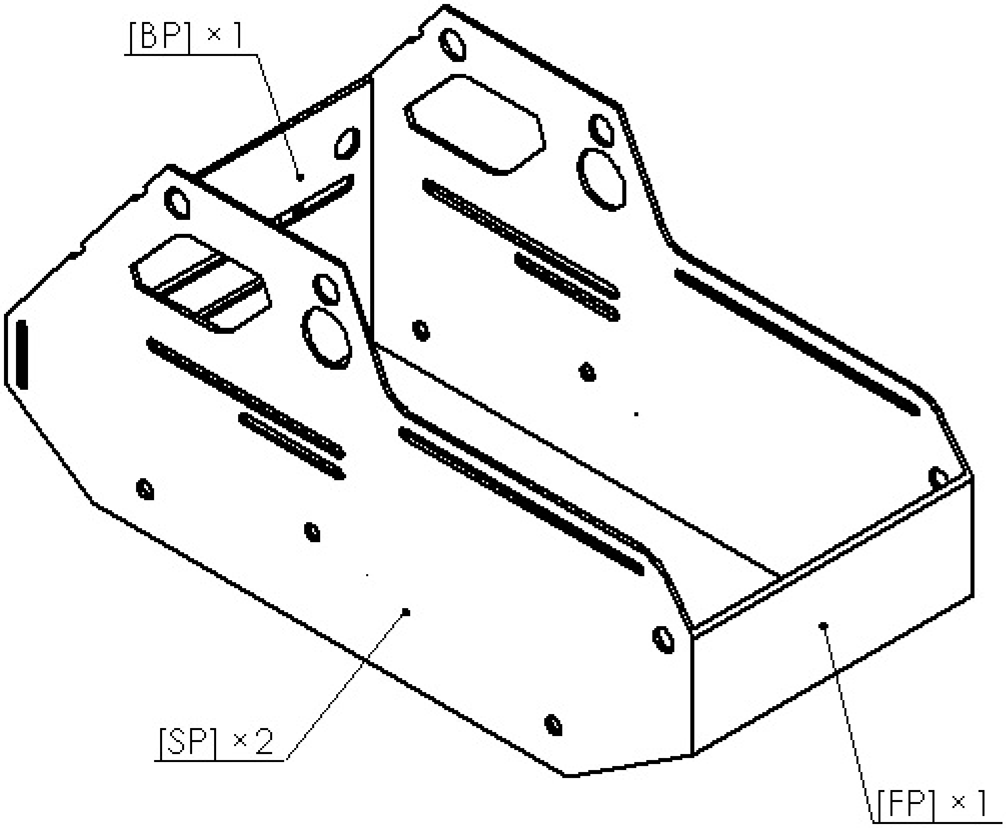
3.6. Build (assembly) phase:

The following parts are used in this phase:

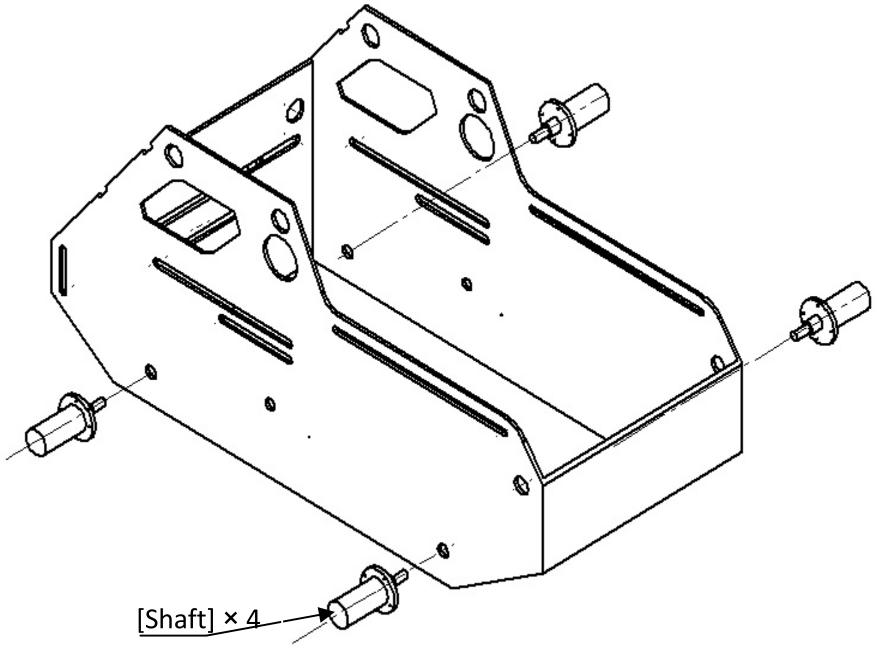
Table(3.8)give the parts which are used in assembly phase and abbreviations

NO	NAME	Quantity	Abbreviations
1	SIDE PIECE	2	SP
2	FRONT PIECE	1	FP
3	BACK PIECE	1	BP
4	WHEEL SHAFT	4	SHAFT
5	MAIN WHEEL	4	MWL
6	WHEL SCREW	16	WS
7	NUT	16	NT
8	TENSION MECHANISM BODY	2	TMB
9	TENSION MECHANISM SHAFT	2	TMSH
10	TENSION MECHANISM WHEEL	2	TMW
11	180 DEGREE TORSION SPRING	2	TS
12	PLATE FIXER	4	PF
13	PLATE	1	PL
14	PLATE SCREW	10	PS
15	TOP COVER	1	TC
16	HUB SCREW	4	HS
17	HUB	1	HUB
18	BEARING	1	BNG
19	MANIPULATOR CARRIER	1	MC
20	PLASTIC ARM	1	PA
21	WOOD ARM	1	WA
22	PLASTIC JOINT	1	PJ
23	METAL DETECTOR	1	MD

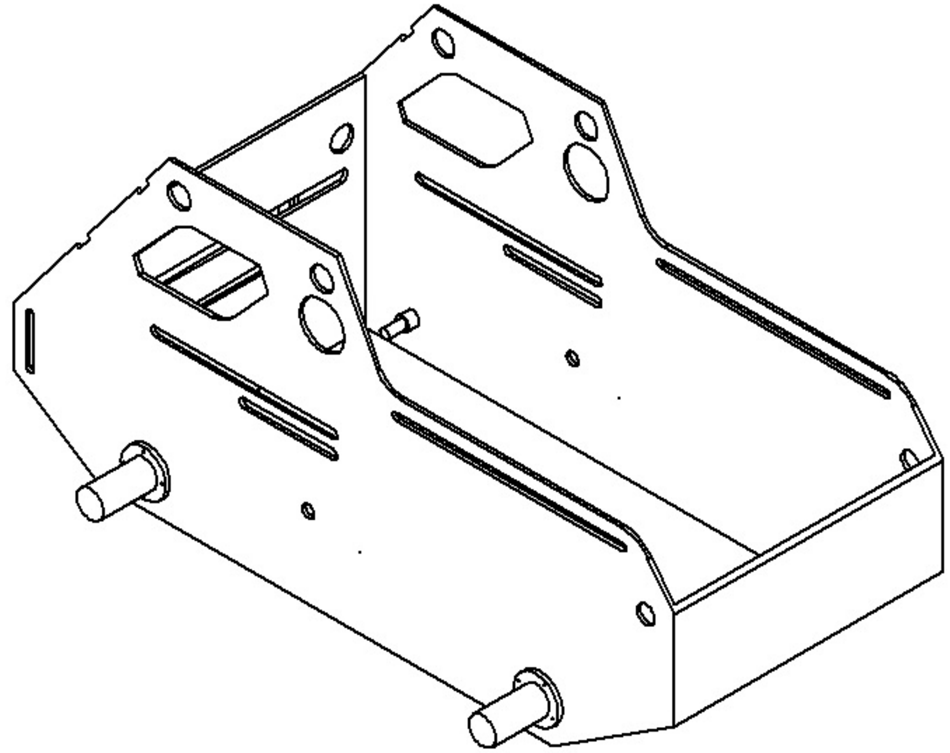
The assembly phase step by step:

1.	**Weld together two side pieces[SP] with front [FP]and back piece[BP]** 

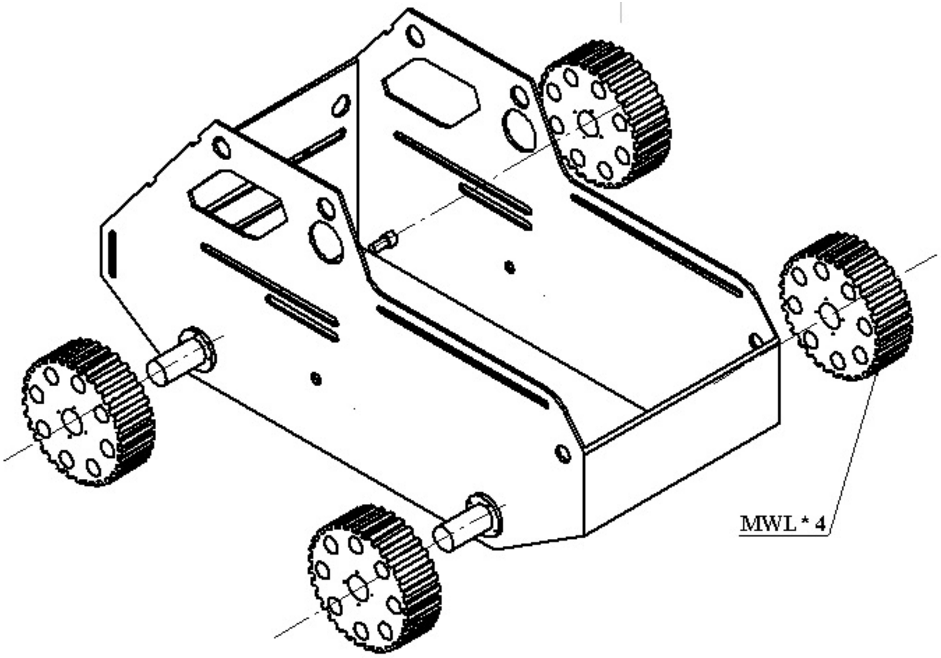
2. **Attach the four wheel shaft to the main robot body through the 15mm hole.**



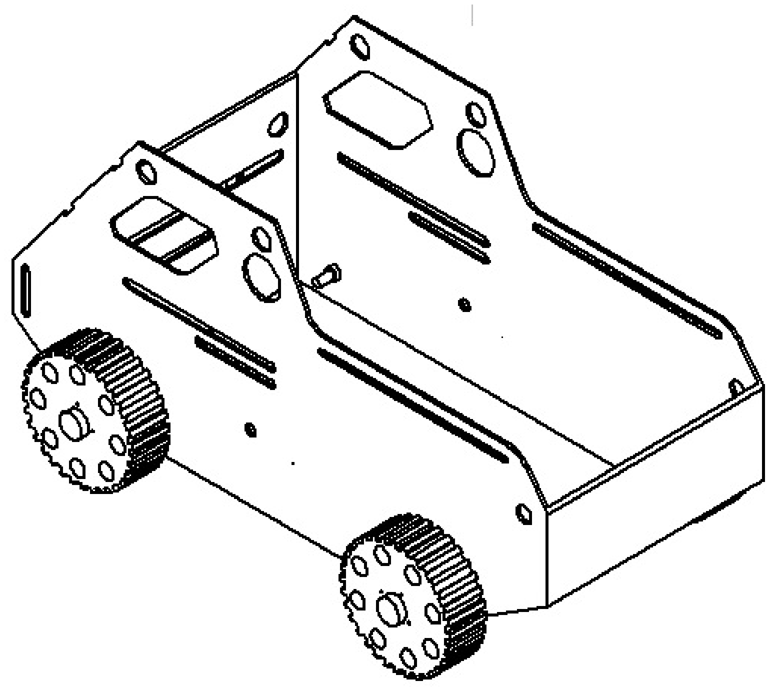
The completed model is as shown:



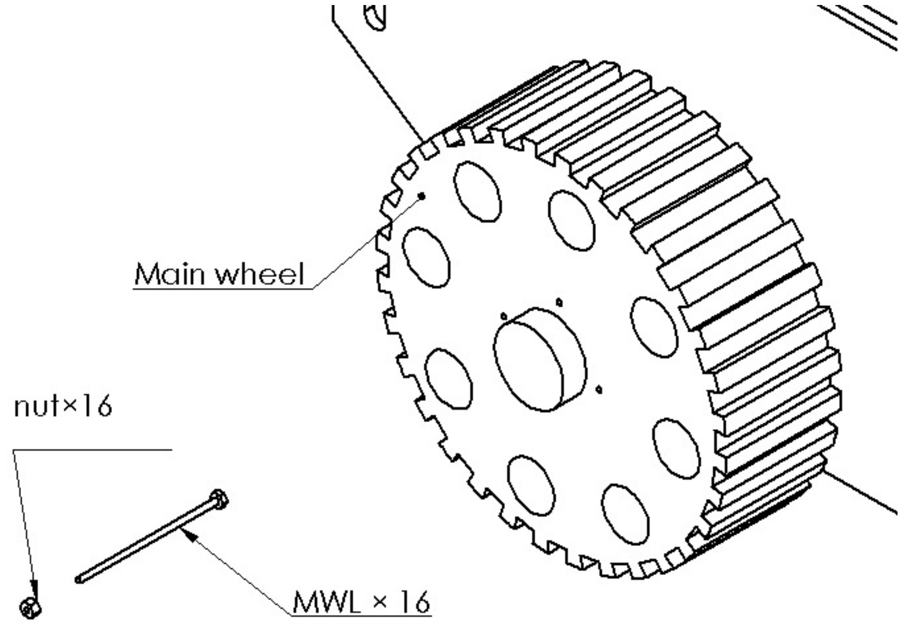
3. **Bolt four wheels [MWL] to the wheel shaft [shaft].**



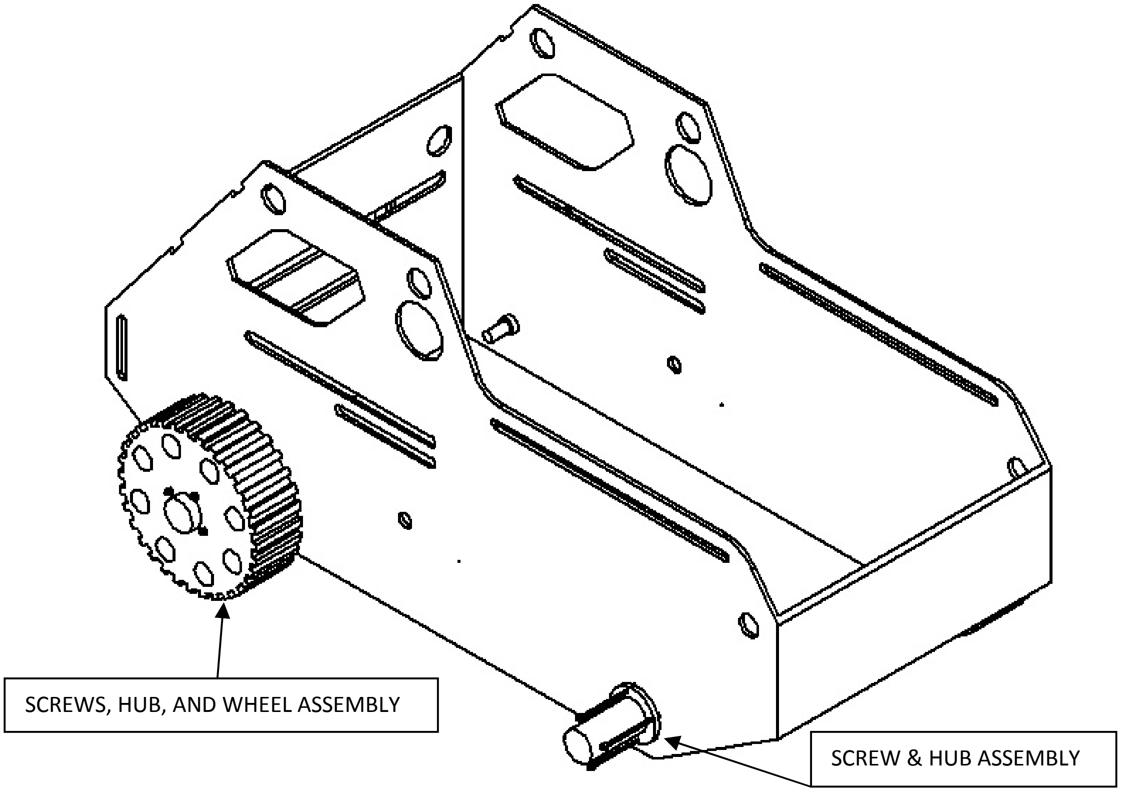
The completed model is as shown:



4. Bolt 16 screw [WS] and 16 nut [NT]to the wheel hub for fixing the wheel shaft [SHAFT] and wheel [MWL] together.

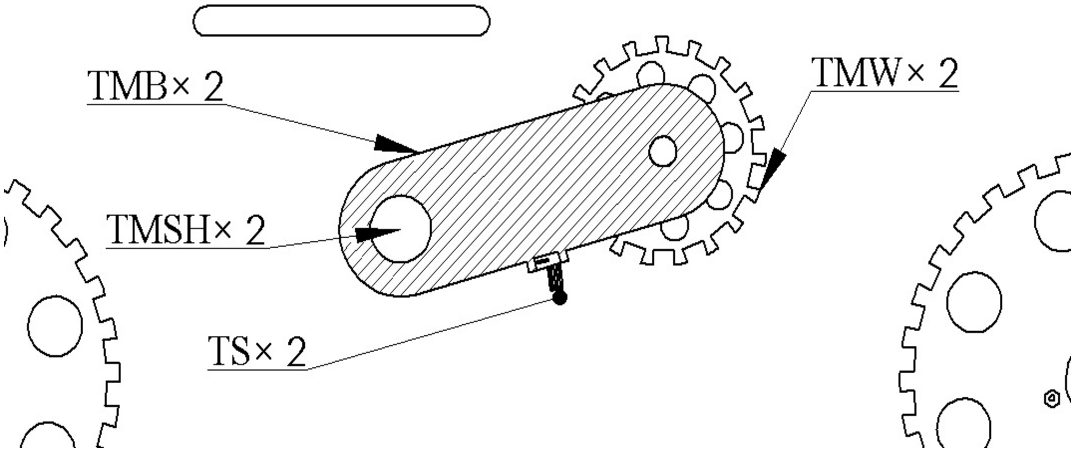


The completed model is as shown:

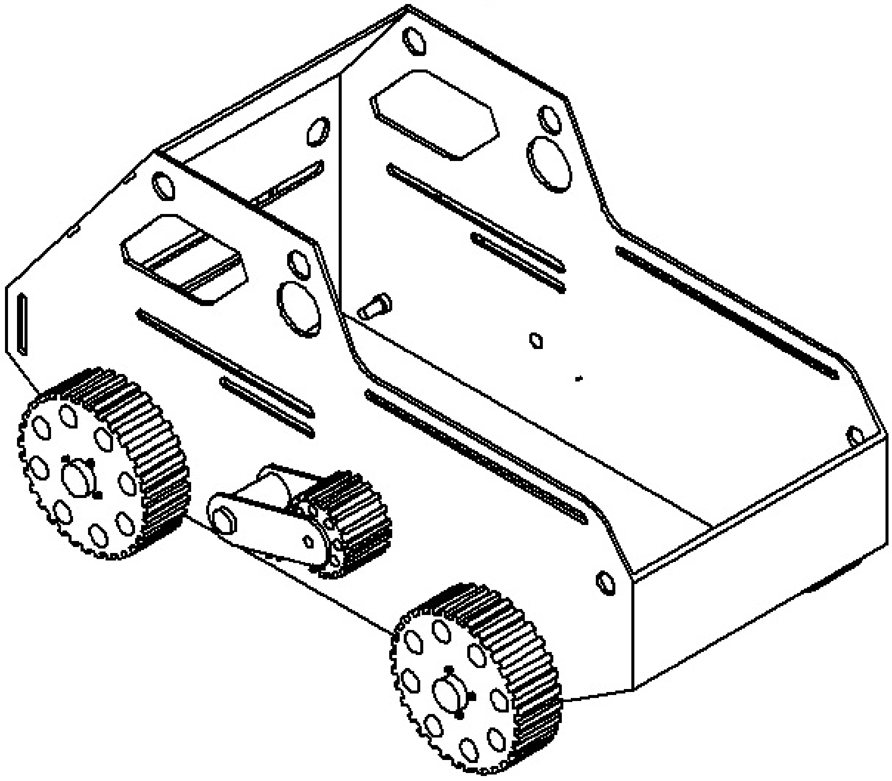


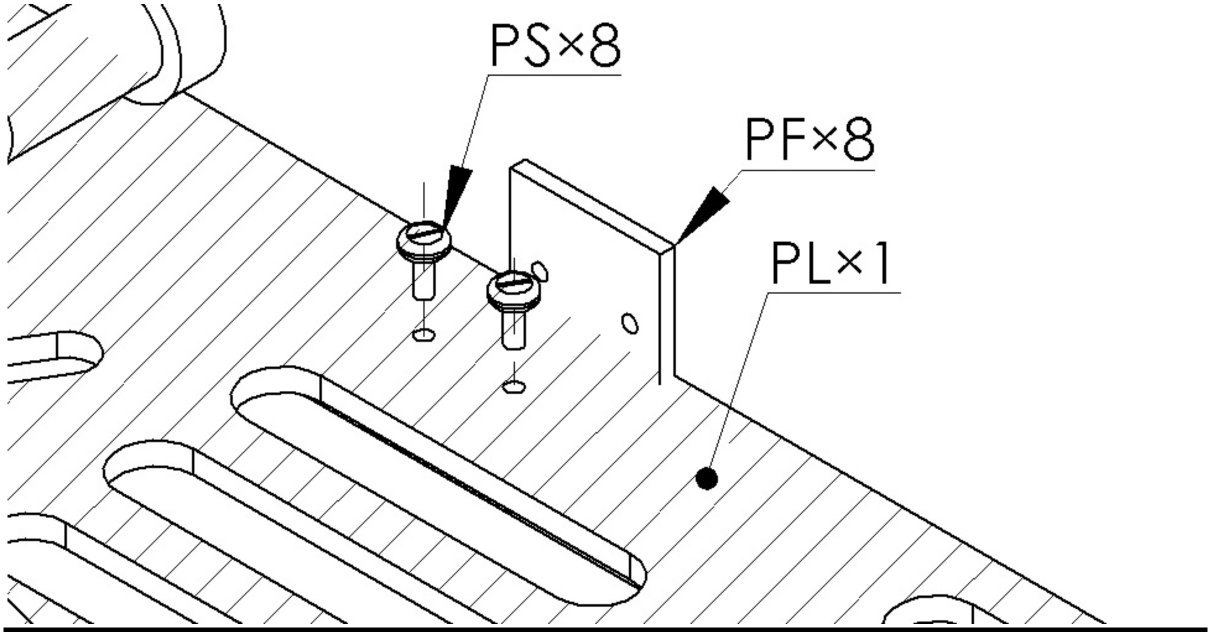
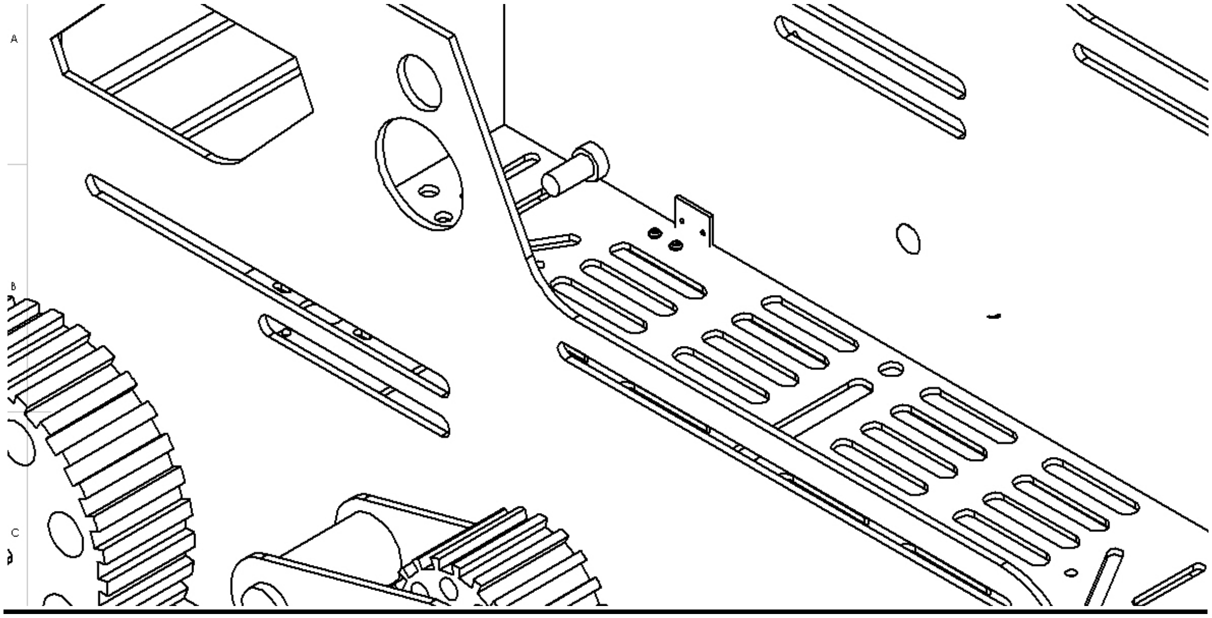
5. **<u>Tension mechanism assembly:</u>**

1. Attach the torsion spring in its specific hole.
2. Attach the tension mechanism shaft and wheel.
3. Attach the tension mechanism body.



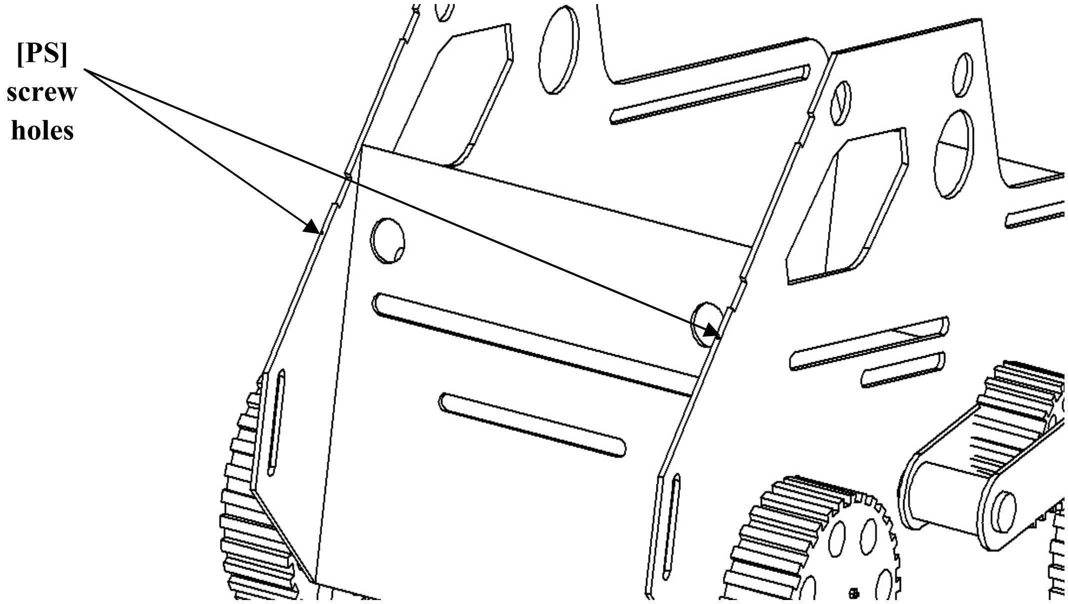
The completed model is as shown:



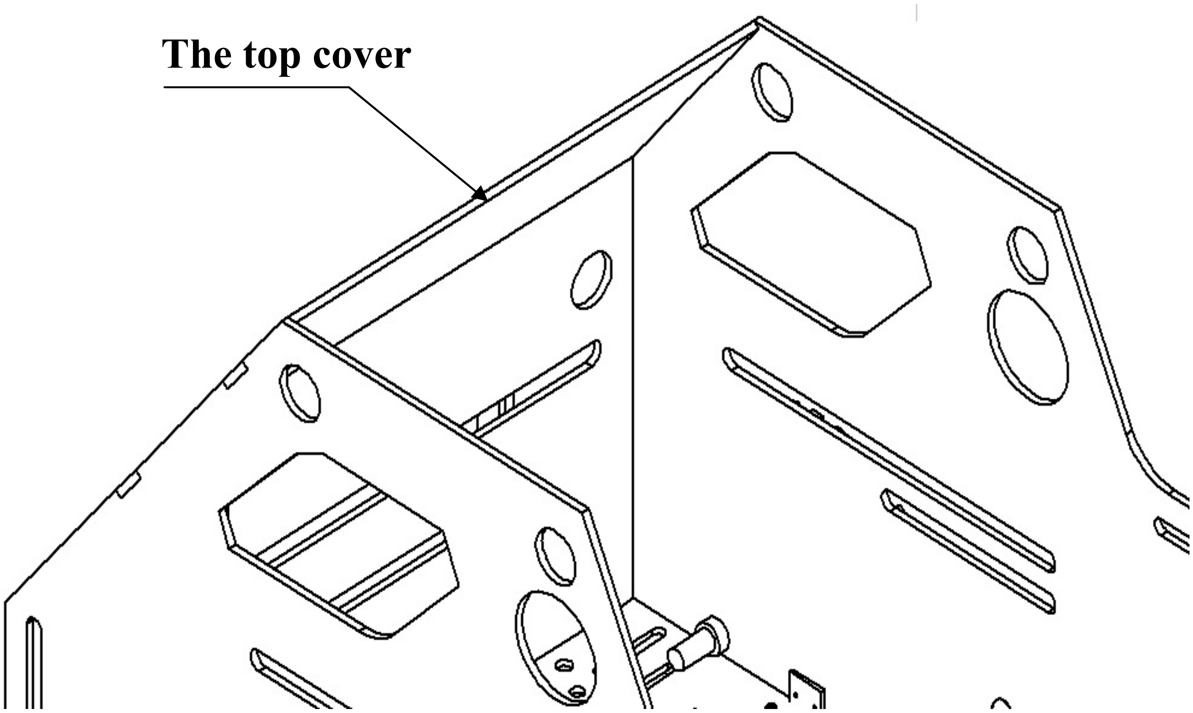
6.	**Weld the four plate fixer and then attach the plate using 8 [PS] screws.**  **The completed model is as shown:** 

7. Attach the top cover [TC] using 2[PS] screws.

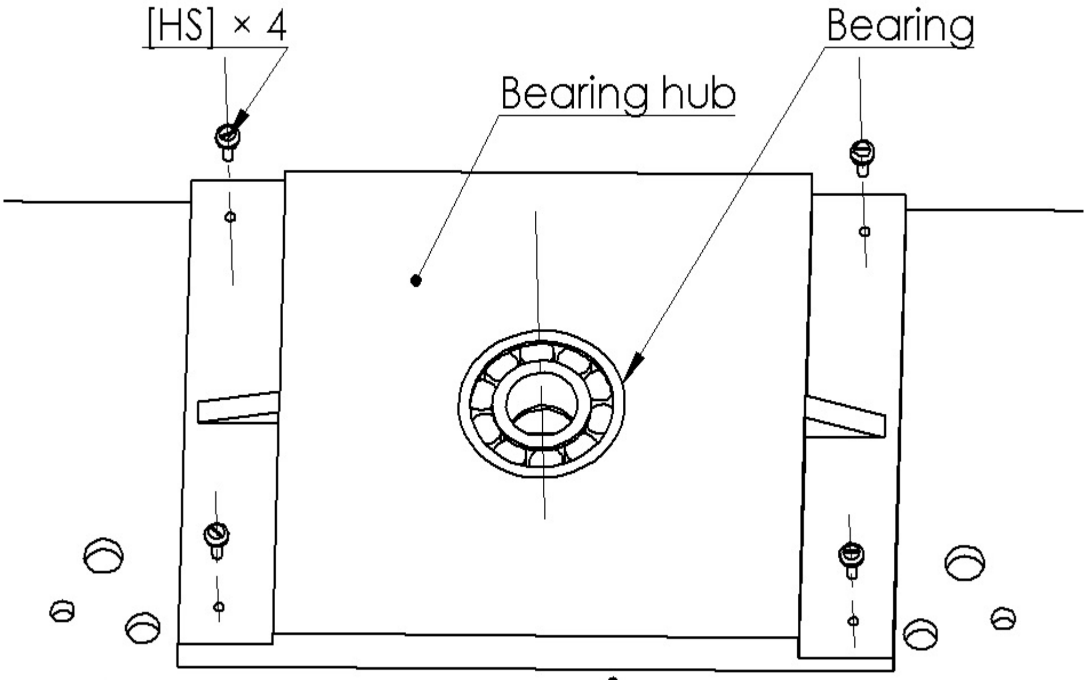
***The top of the robot before attach the top cover**



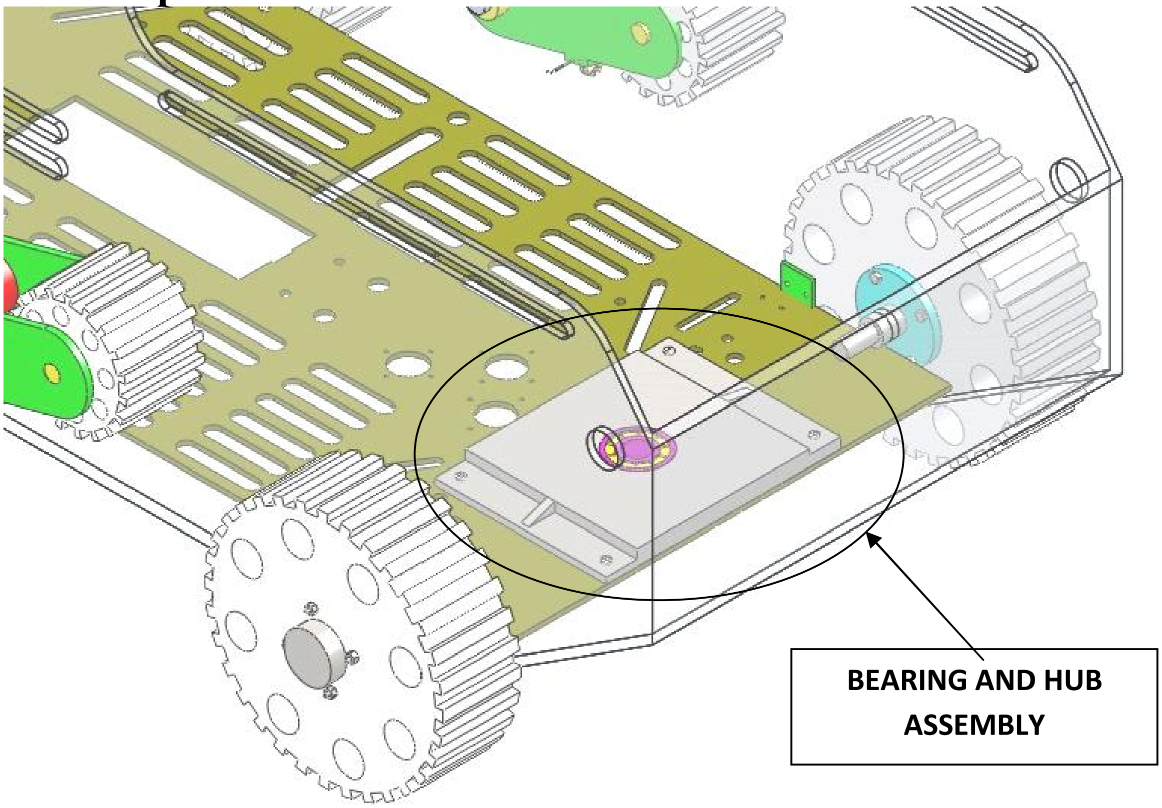
The completed model is as shown:



8. **Attach the manipulator bearing hub using 4 [HS](D=2mm) and bearing.**



The completed model is as shown:



9

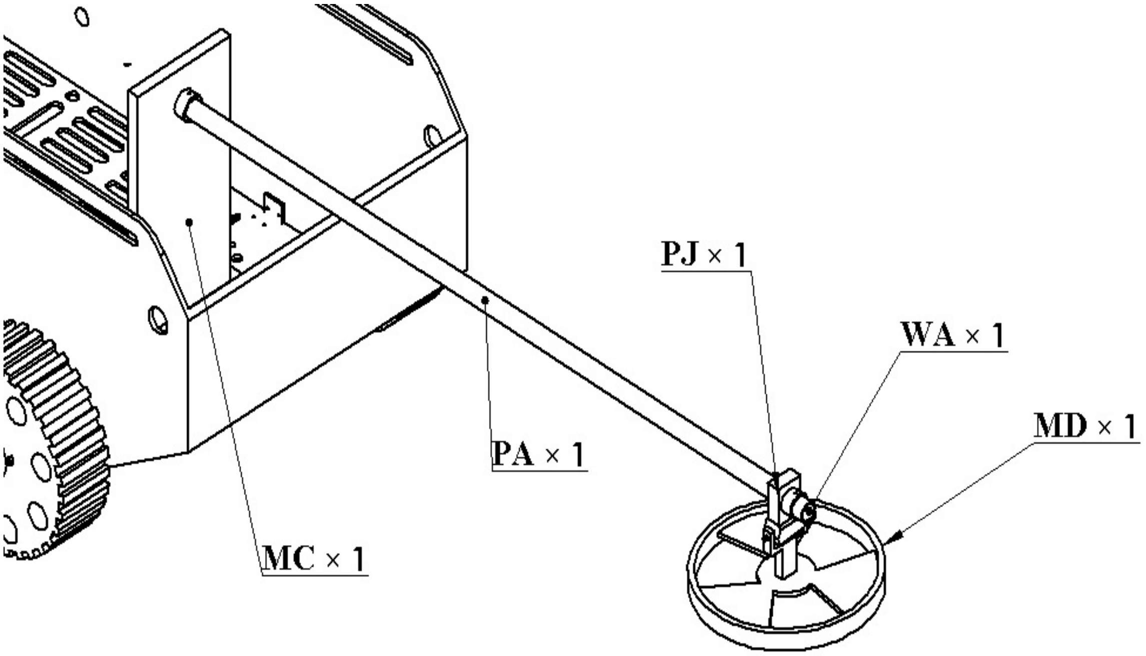
MANIPULATOR ASSEMBLY

1. Attach the manipulator carrier [MC].

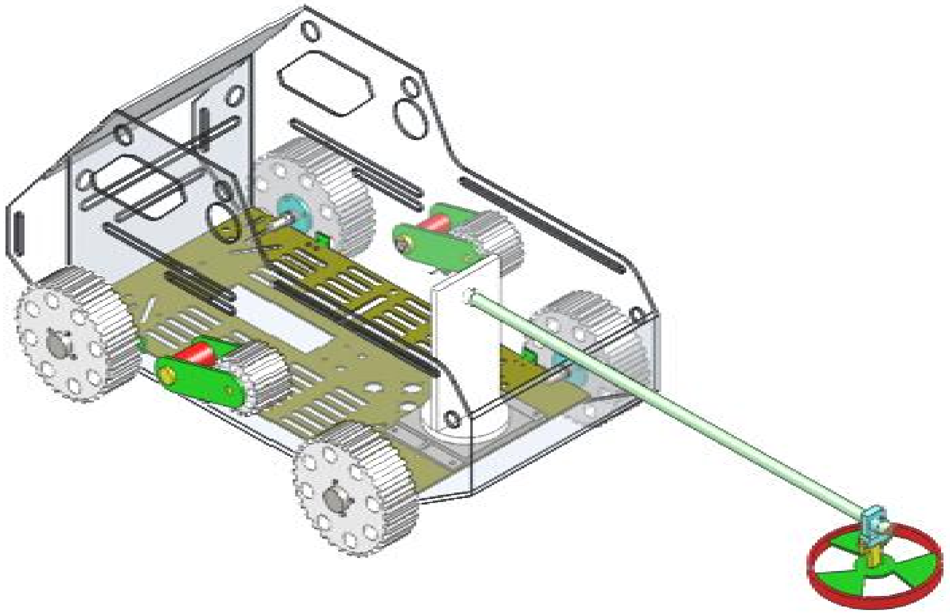
2. Attach the wood [WA] and plastic arm [PA].

3. Attach the plastic joint [PJ].

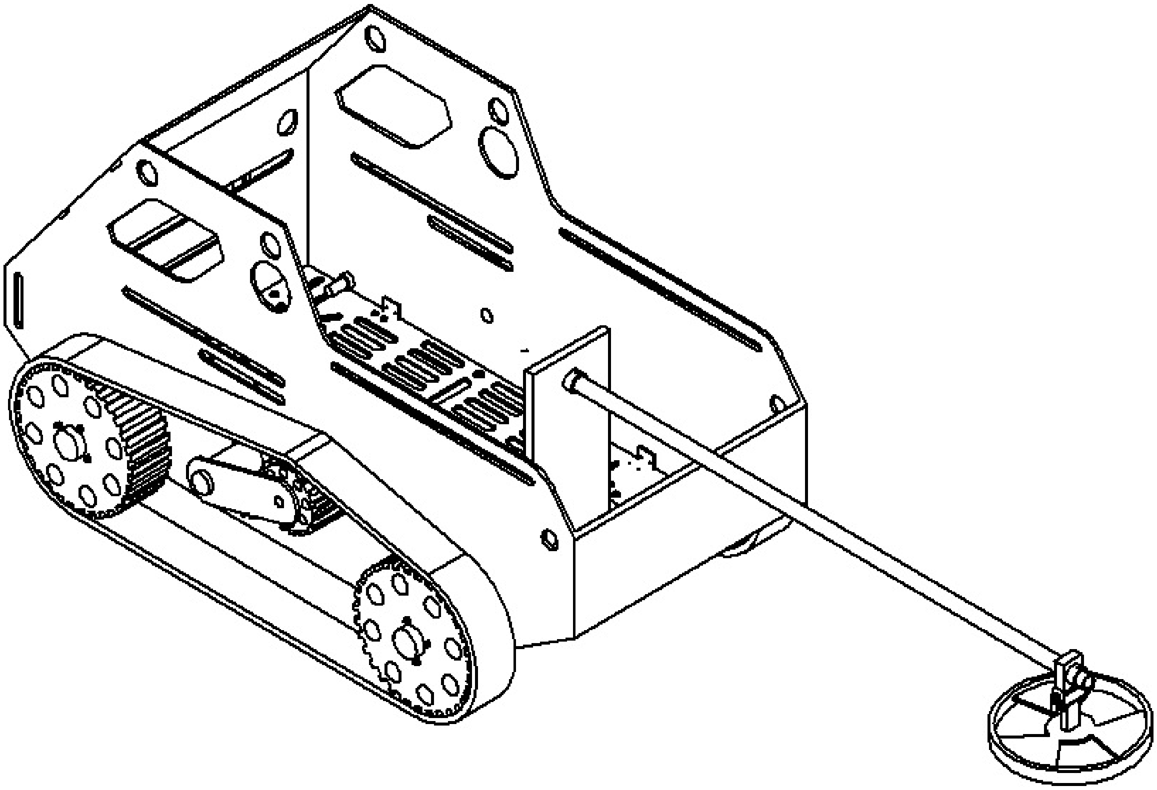
4. Attach the metal detector [MD].



The completed model is as shown:

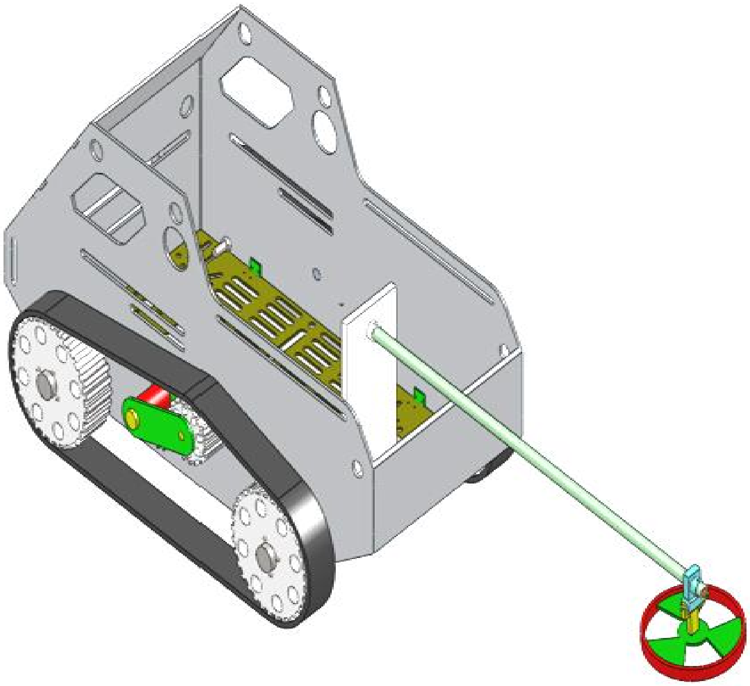


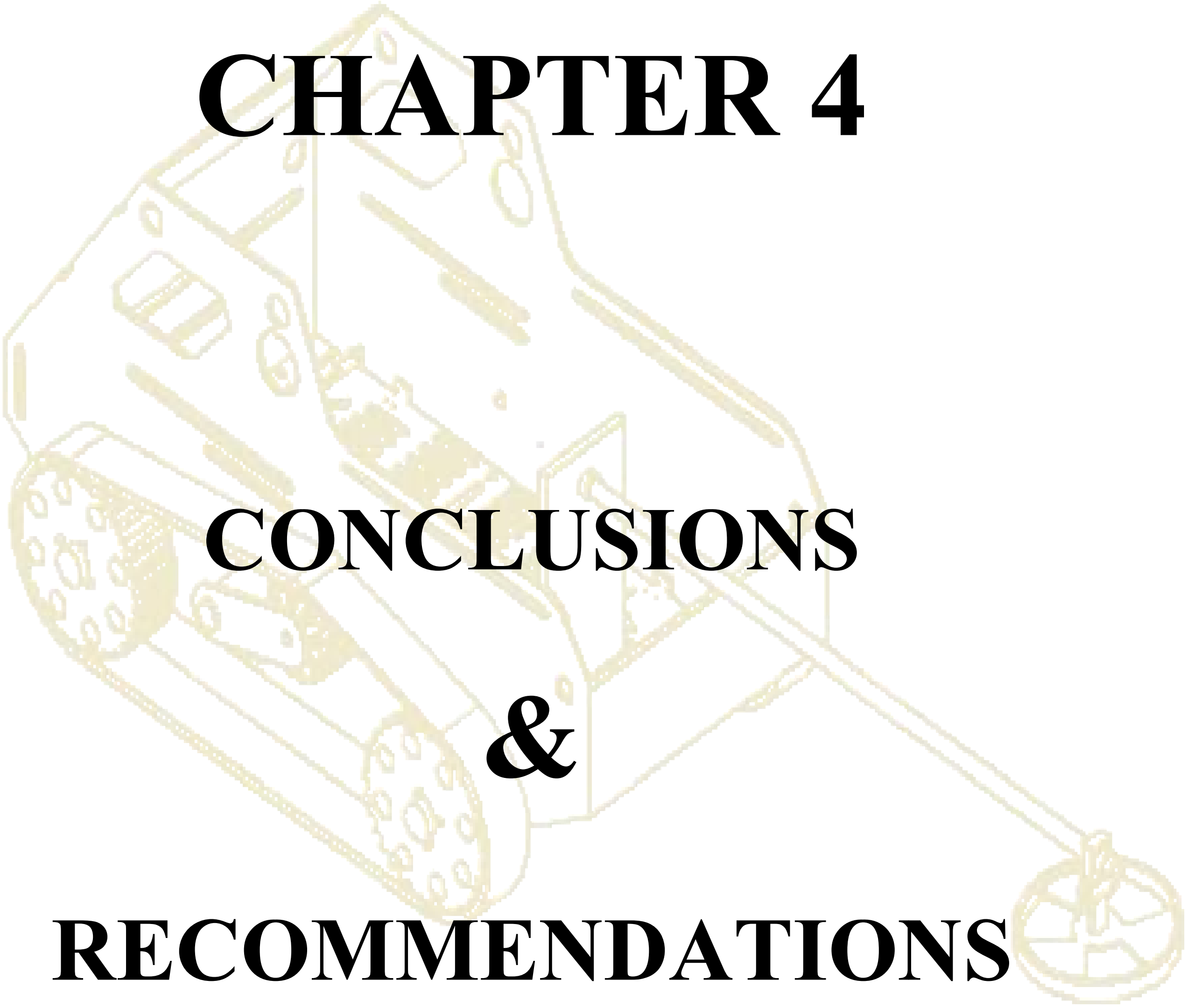
10 **Install tracks**



…

The final assembly





CHAPTER 4

CONCLUSIONS

&

RECOMMENDATIONS

4.1. CONCLUSION

In this research a new tracked robot chassis and manipulator arm were designed and developed. Chapter three and four presented an illustrative description of different phases of the project components mechanical design, so the main specifications were set. After a conceptual and preliminary design, the detailed design of the robot and each part was developed. In order to evaluate the robot's mobility many simplified simulation of robot operation were created by solidworks software. With the results of simulation, the design was improved and finally the platform was successfully assembled and disassembled without backlash by solidworks 2010 software. The mechanical platform is also equipped with a microcontroller and specific motor electronics, tracks and wheels. Interface electronics allows controlling the motors with the microcontroller. That way the mechanical platform, with its own energy supply, more specific a battery pack, can be used individually for different applications.

4.2. RECOMMENDATIONS:

Most of the major parts needed for the desired tracked robot were worked out. However some more tests, the combining of the different components and the last parts still have to be worked out before the robot can actually be built to perform all its desired tasks. Applied to the locomotion mechanism described in this work, some dynamic experiments should be done to tune the mechanical platform even further and to describe its dynamics. Unfortunately the time for this project was limited and these data could not yet be obtained. Also the upper platform still has to be worked out in more detail. It is clear that there is still work to do and that all the efforts made in the different fields will have to be combined to achieve the main aim: building Sudanese tracked robot. Hence it becomes clear once again that robotics really is a challenging and interdisciplinary field.

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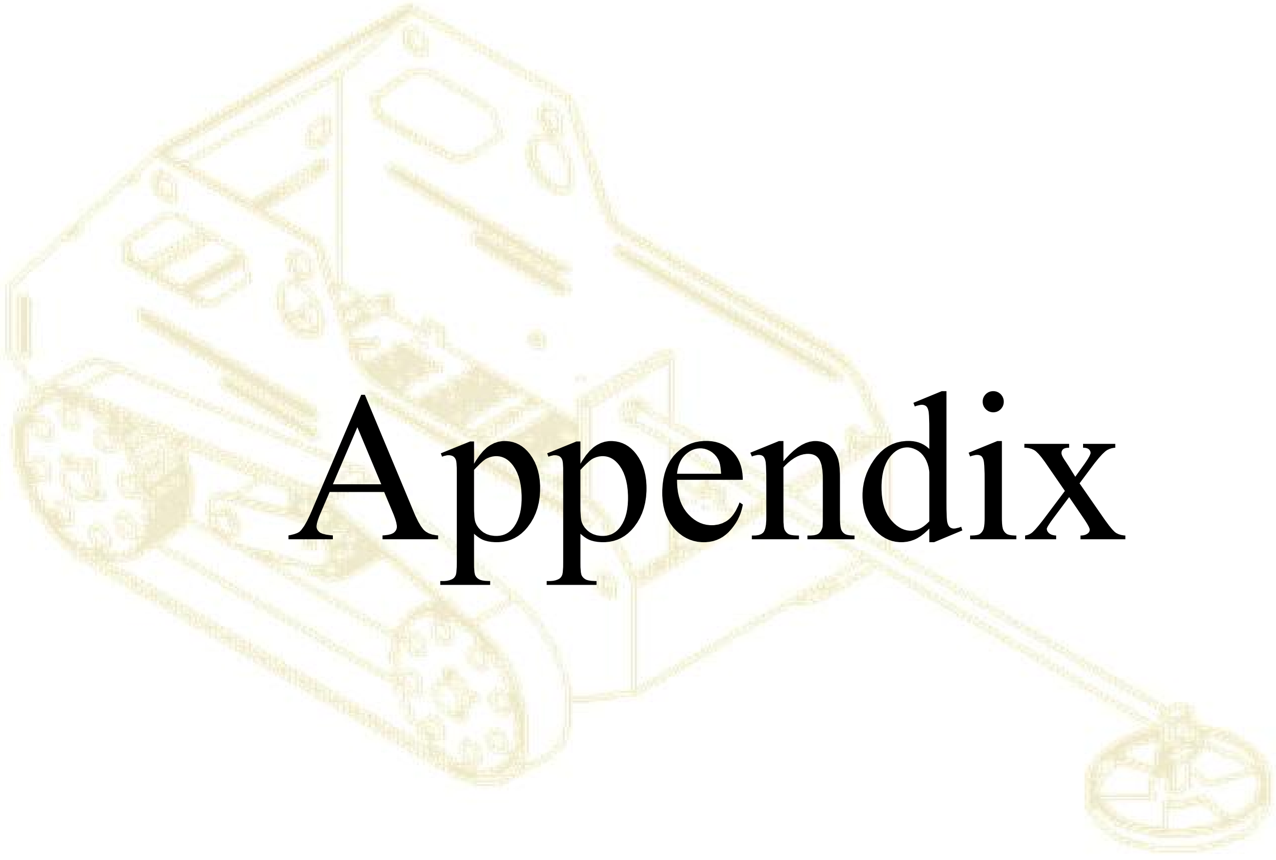
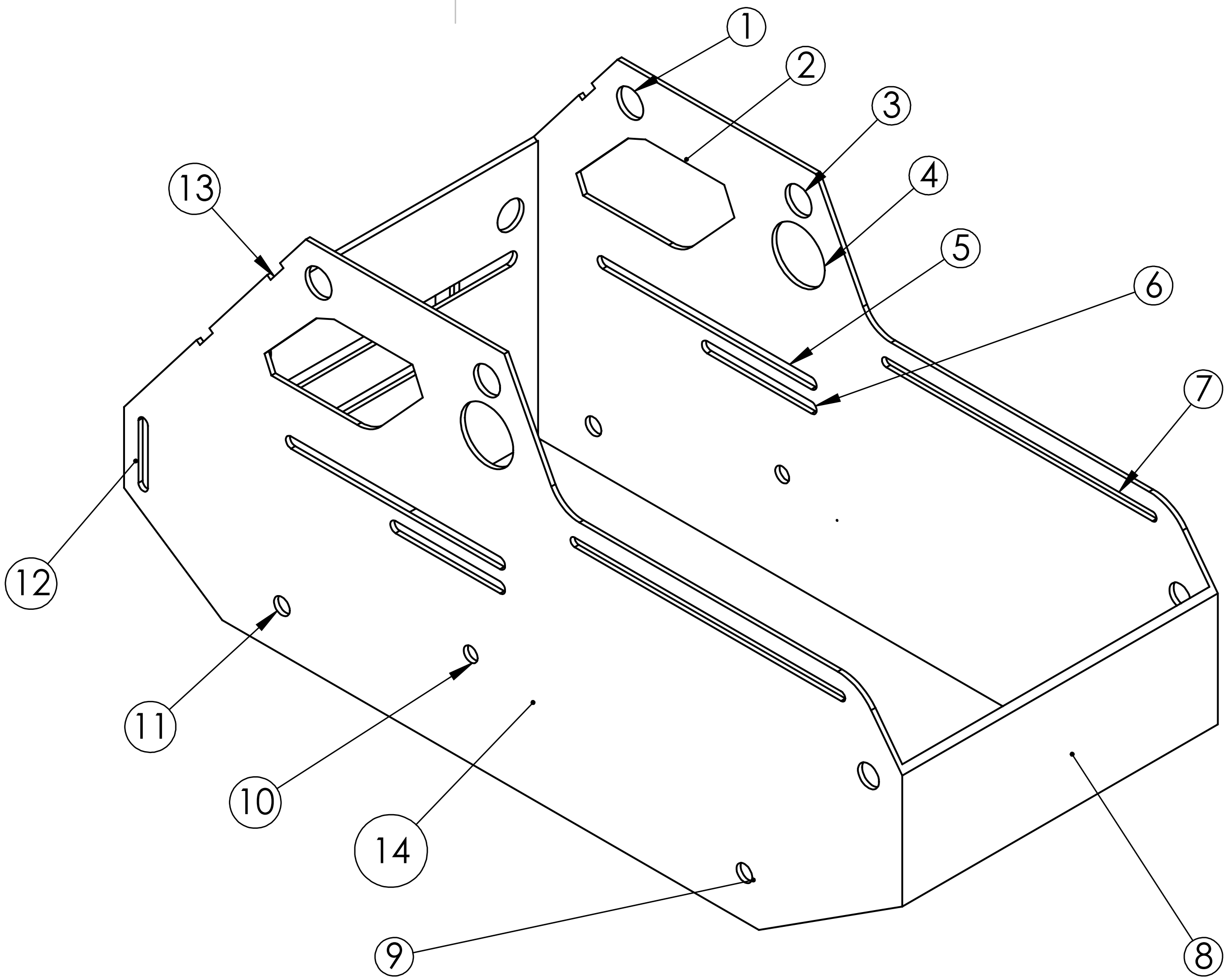
Appendix



1	chain lifting hole
2	manual lifting hole
3	chain lifting hole
4	conditioning hole
5	conditioning hole
6	conditioning hole
7	conditioning hole
8	front of the robot
9	front axle hole
10	tension mechanism hole
11	back axle hole
12	pushing hole
13	cover fixing unit
14	torsion spring hole



SUDAN UNIVERSITY FOR SCIENCE AND TECHNOLOGY

	NAME	SIGNATURE	DATE
DRAWN	MUAAZ MOHAMMED ALI		/ /2018
CHK'D	Dr. Abd El fattah Bilal		/ /2018

TITLE: body of the robot (general)

paper A4 Landscape

Dimensions: mm

MATERIAL: 6061 alloy

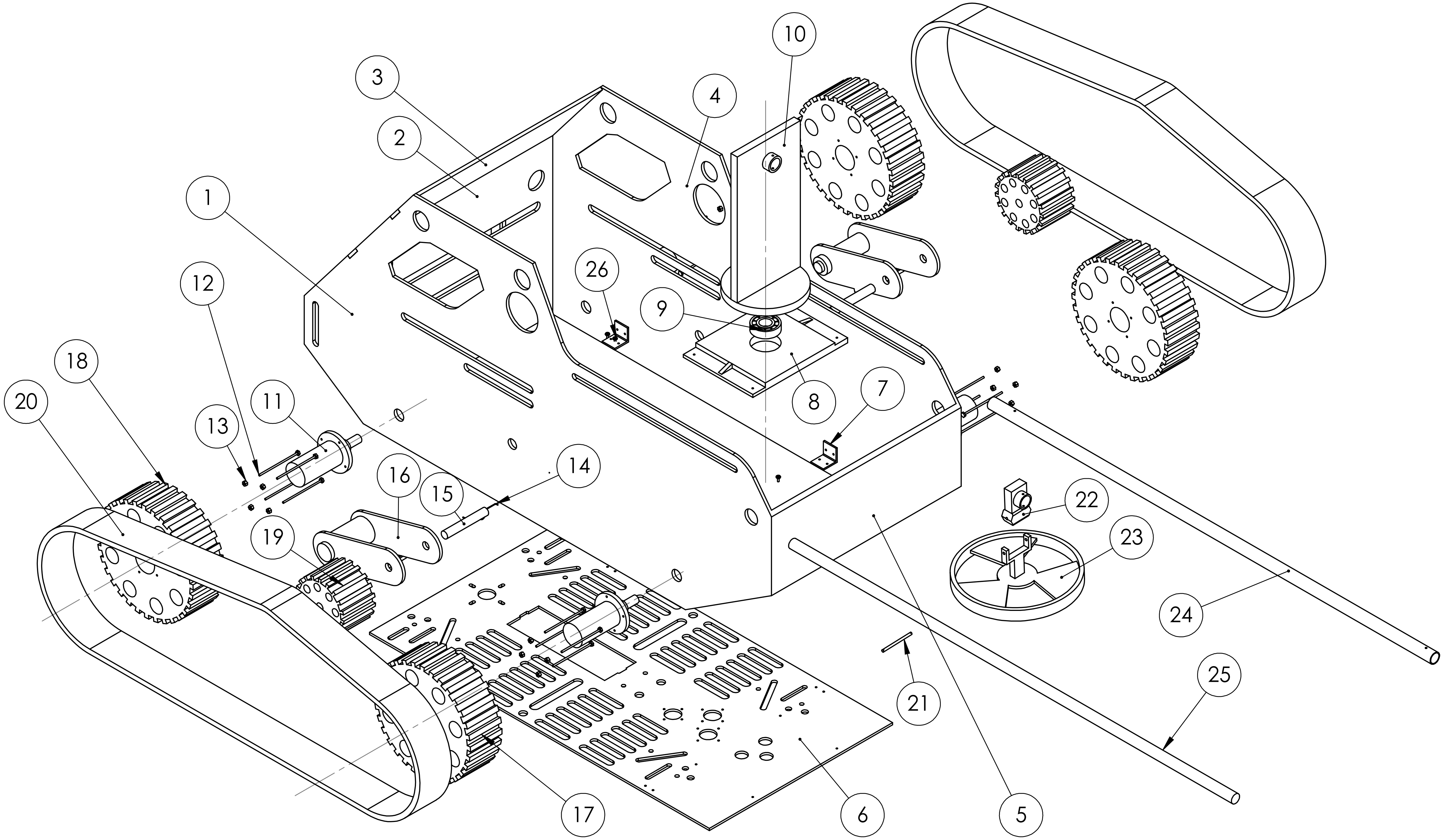
DWG NO. 2

NO OF VIWES: 1

WEIGHT:

SCALE:1:10

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND
BREAK SHARP
EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

WEIGHT:

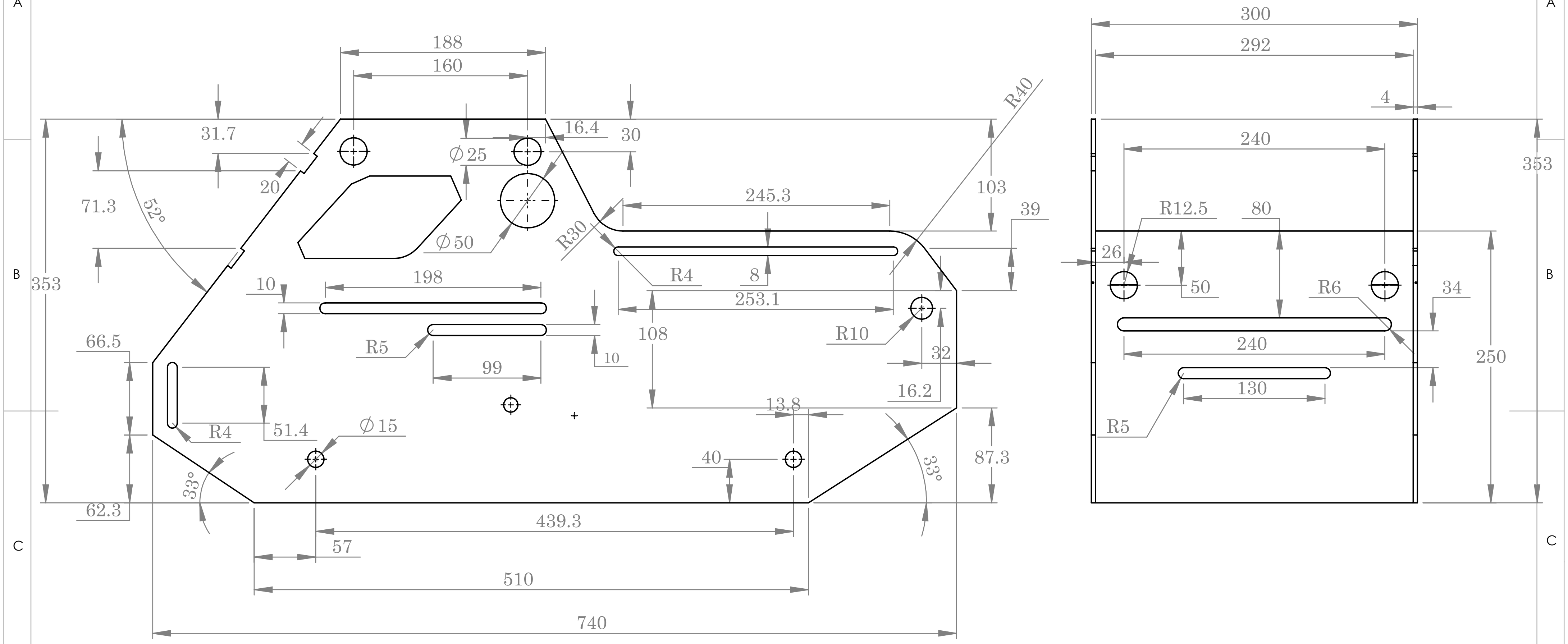
DWG NO. exploded

A3

SCALE:1:20

SHEET 1 OF 1

NO	**PIECE NAME**	**NO**	**PIECE NAME**
1	ROBOT SIDE SHEET	14	TORSION SPRING
2	ROBOT SIDE SHEET	15	TENSION MECHAMISM SHAFT
3	ROBOT SIDE SHEET	16	TENSION MECHAMISM BODY
4	ROBOT SIDE SHEET	17	FRONT WHEEL
5	ROBOT SIDE SHEET	18	BACK WHEEL
6	PLATE	19	TENSION WHEEL
7	PLATE FIXER	20	TRACK
8	BEARING HUB	21	SENSOR AND PVC JOINTCONNECTOR
9	DEARING	22	PVC JOINT
10	LINK HOLDER	23	METAL DETECTOR
11	WHEEL SHAFT	24	PPR LINK
12	WHEEL CSREW	25	PLATE FIXER SCREW
13	NUT	26	…..



SUDAN UNIVERSITY FOR SCIENCE AND TECHNOLOGY

	NAME	SIGNATURE	DATE
DRAWN	MUAAZ MOHAMMED ALI		/ /2018
CHK'D	Dr. Abd El fattah Bilal		/ /2018

TITLE: Body of the robot

paper: A4 Landscape

Dimensions : mm

MATERIAL: Aluminum 6061 aloy

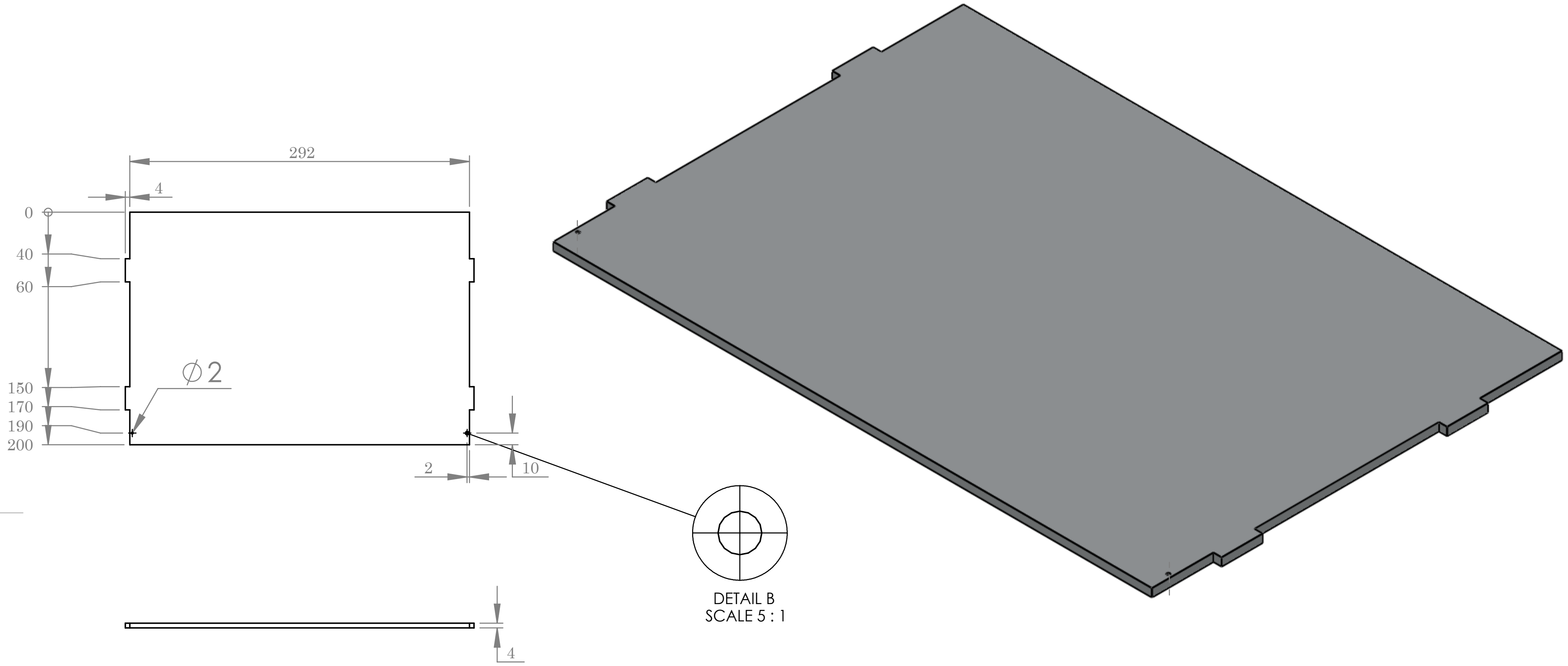
WEIGHT: 7006.22 grams

DWG NO. 1

NO OF VIWES: 2

SCALE: 1:10

SHEET 1 OF 1



DETAIL B
SCALE 5 : 1

SUDAN UNIVERSITY FOR SCIENCE AND TECHNOLOGY

	NAME	SIGNATURE	DATE
DRAWN	MUAAZ MOHAMMED ALI		/ /2018
CHK'D	Dr. Abd El fattah Bilal		/ /2018

TITLE: body cover

Paper: A4 Landscape

Dimensions mm

MATERIAL: aluminium 6061 alloy

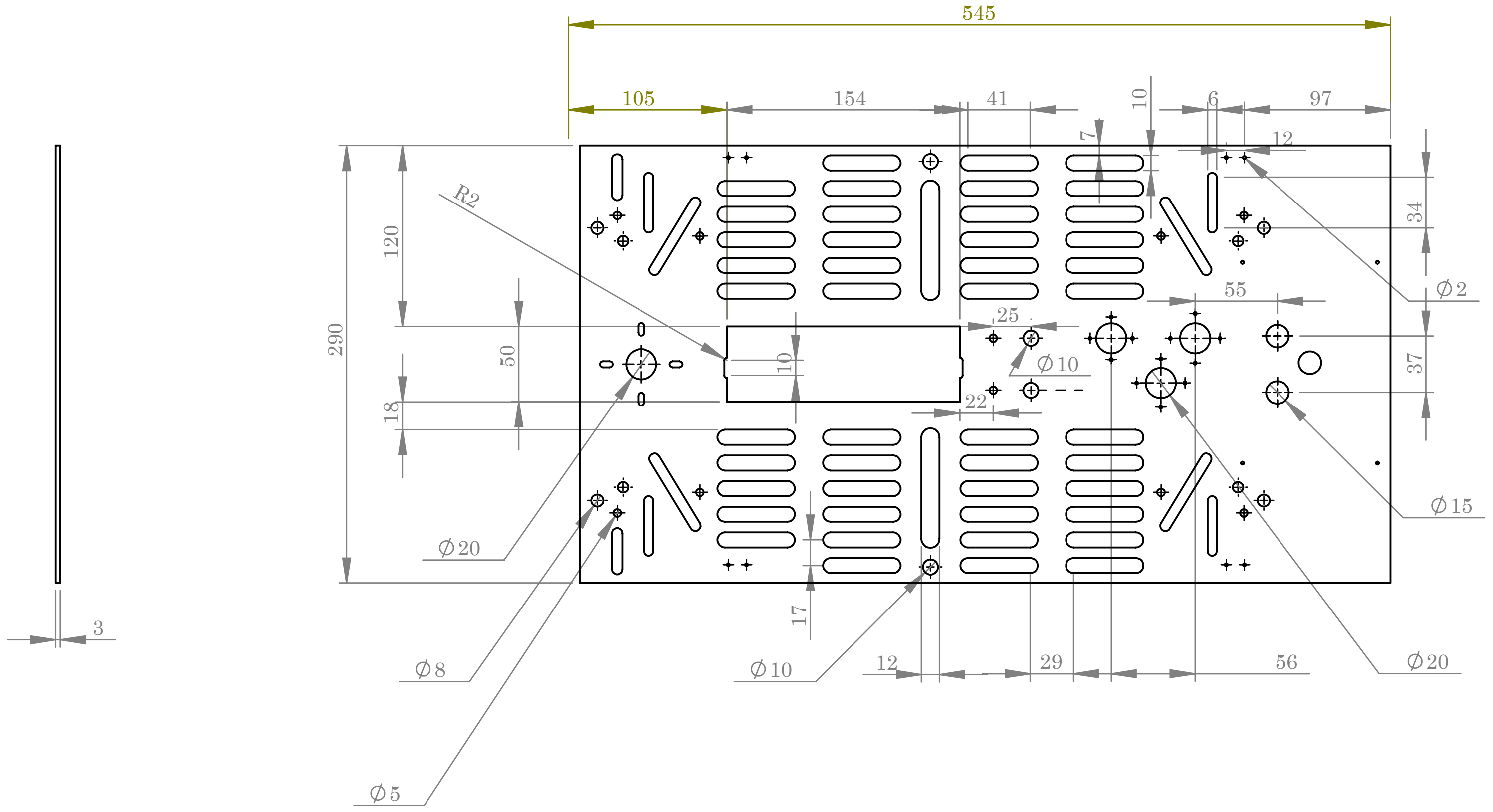
DWG NO. 3

NO of viwes 3

WEIGHT:

SCALE: 1:5

SHEET 1 OF 1



SUDAN UNIVERSITY FOR SCIENCE AND TECHNOLOGY

	NAME	SIGNATURE	DATE
DRAWN	MUAAZ MOHAMMED ALI		/ /2018
CHK'D	Dr. Abd El fattah Bilal		/ /2018

TITLE: component fixing plate

paper A4 LAND SCAPE

DAIMENSIONS: mm

MATERIAL: 6061 Alloy

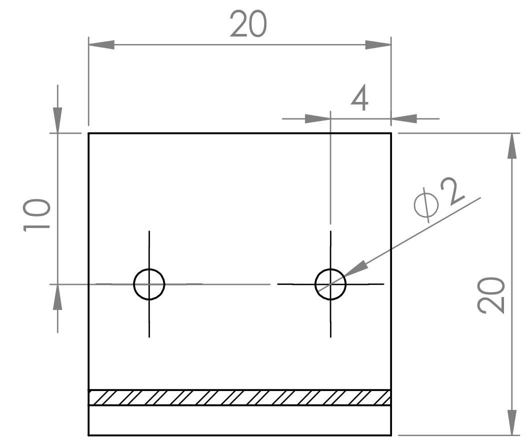
DWG NO. 4

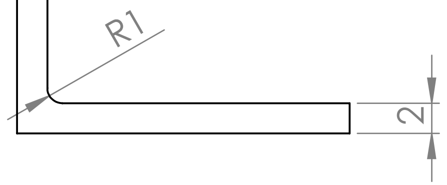
NO OF VIWES : 2

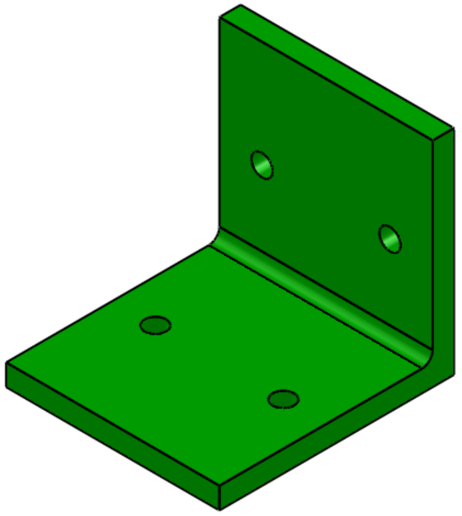
WEIGHT: 973.75 gram

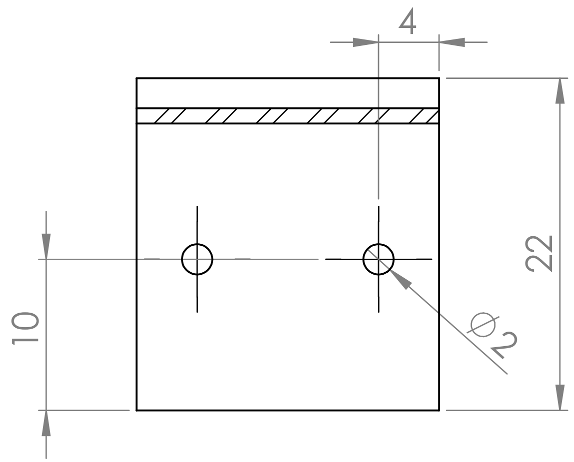
SCALE: 1:10

SHEET 1 OF 1









SUDAN UNIVERSITY FOR SCIENCE AND TECHNOLOGY

	NAME	SIGNATURE	DATE
DRAWN	MUAAZ MOHAMMED ALI		/ /2018
CHK'D	Dr. Abd El fattah Bilal		/ /2018

TITLE: plate / body fixing unit

paper: A4 land scape

Dimensions : mm

MATERIAL: cast carbon steel

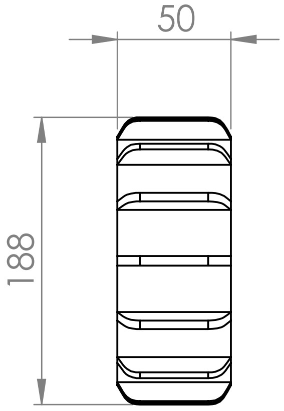
DWG NO. 5

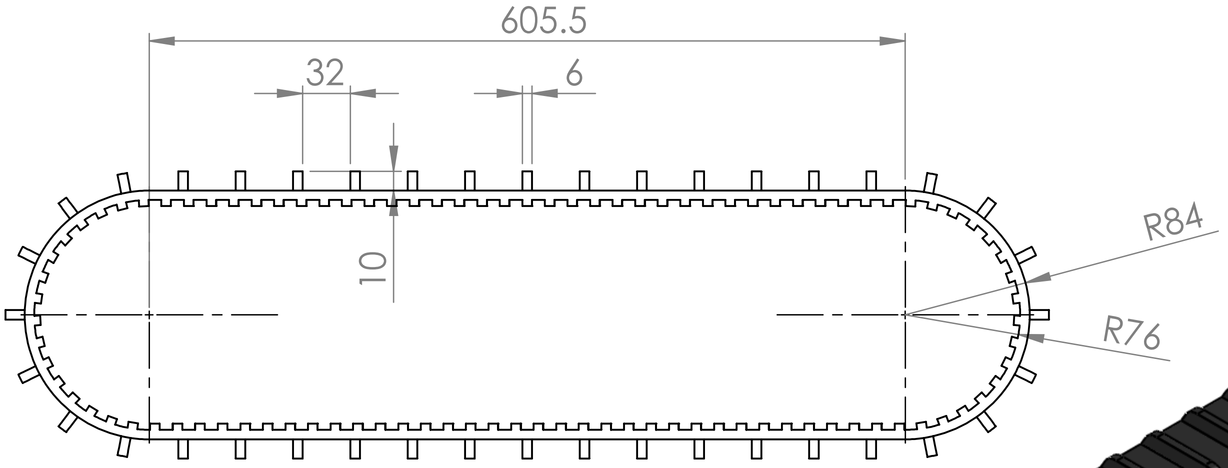
No of viwes : 4

WEIGHT: 33 gram

SCALE: 2:1

SHEET 1 OF 1





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	NAME	SIGNATURE	DATE
DRAWN	MUAAZ MOHAMMED ALI		/ /2018
CHK'D	Dr. Abd El fattah Bilal		/ /2018

TITLE: Track of the robot

paper: A4 Landscape

Dimensions : mm

MATERIAL: Polyurethane(11671)

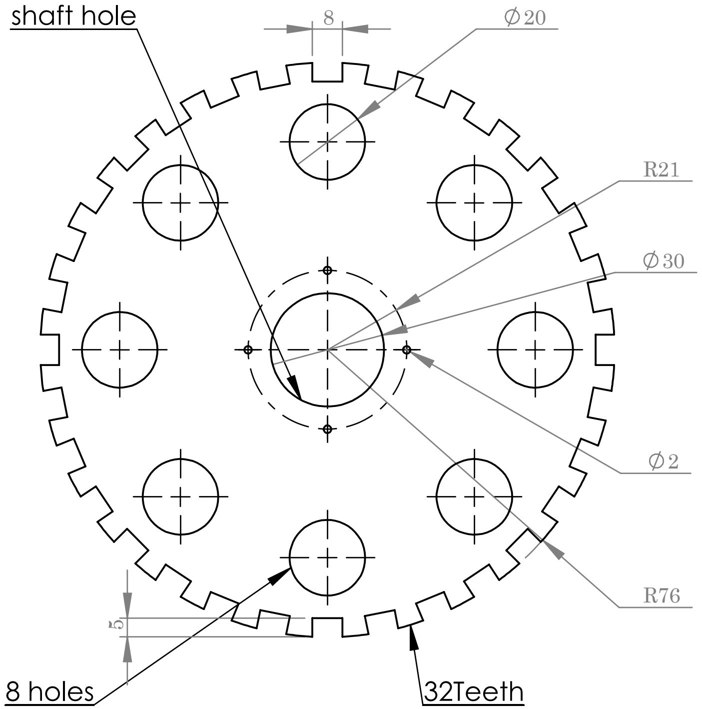
DWG NO. 10

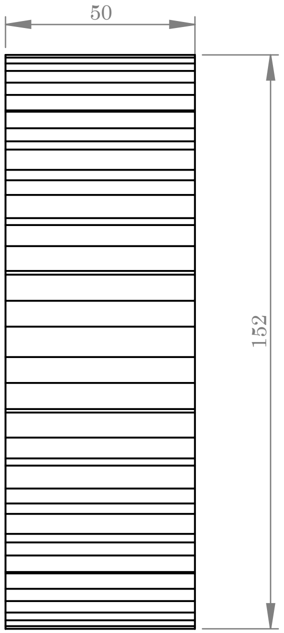
NO OF VIWES: 3

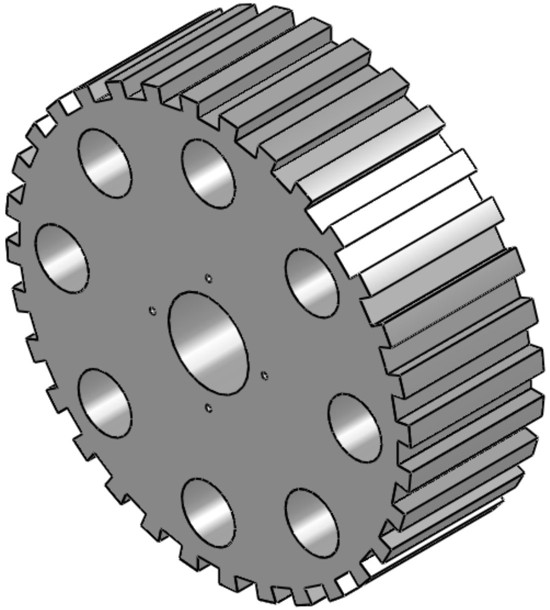
WEIGHT: 650 grams

SCALE: 1:10

SHEET 10 OF 1







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	NAME	SIGNATURE	DATE
DRAWN	MUAAZ MOHAMMED ALI		/ /2018
CHK'D	Dr. Abd El fattah Bilal		/ /2018

TITLE: Main wheel

paper: A4 Landscape

Dimensions : mm

MATERIAL: CUSTOM PLASTIC

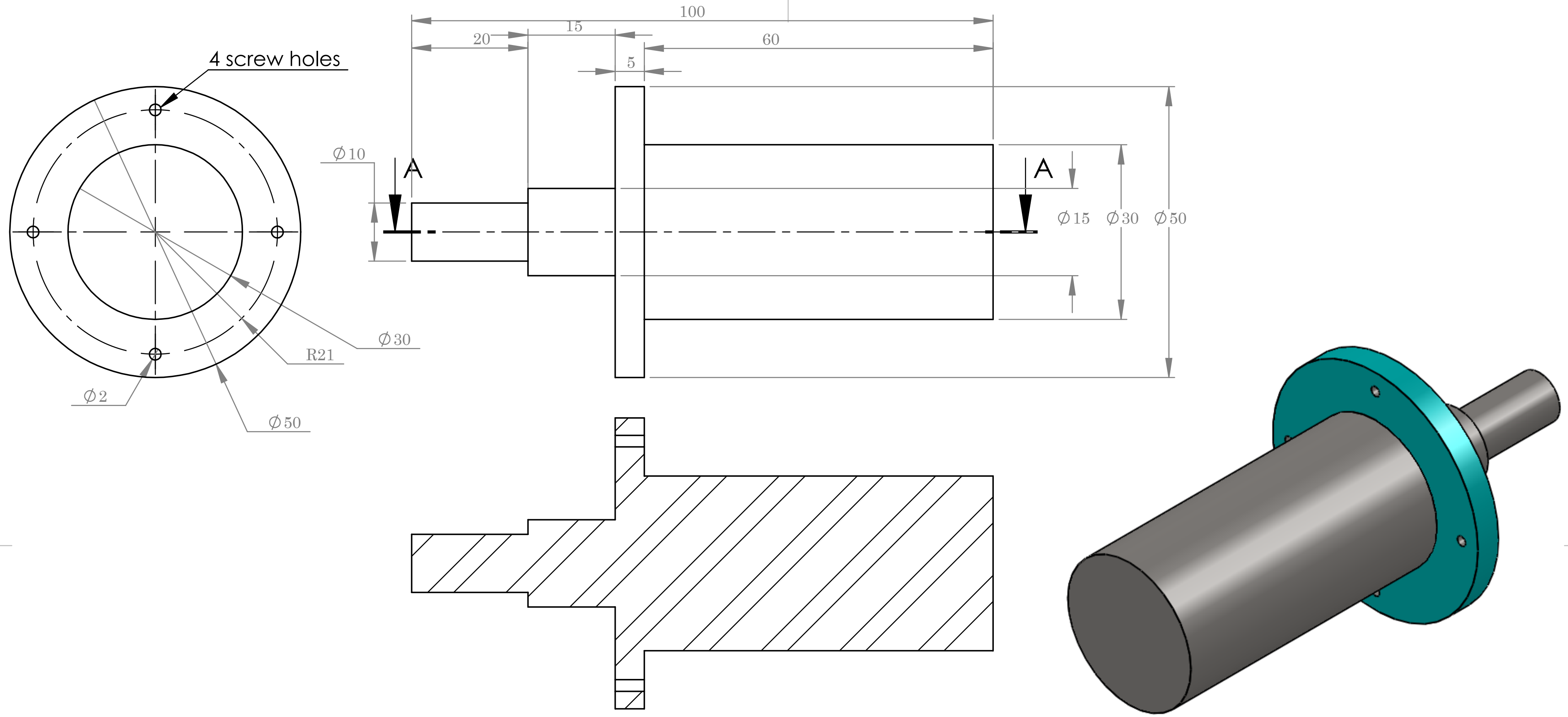
DWG NO. 12

NO OF VIWES: 3

WEIGHT: 696 grams

SCALE: 1:2

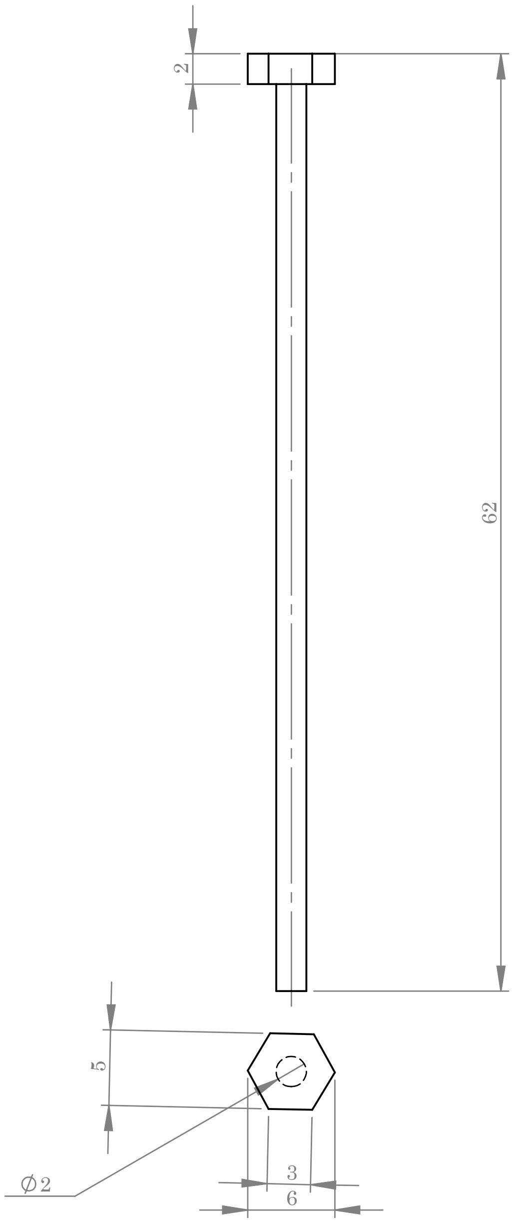
SHEET 12 OF 1

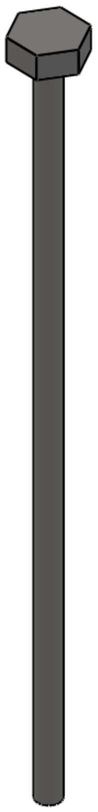


SECTION A-A
SCALE 1 : 1

SUDAN UNIVERSITY FOR SCIENCE AND TECHNOLOGY

	NAME	SIGNATURE	DATE	TITLE:	robot wheel shaft
DRAWN	MUAAZ MOHAMMED ALI		/ /2018		
CHK'D	Dr. Abd El fattah Bilal		/ /2018	paper:	A4 Landscape
Dimensions : mm		MATERIAL: cast carbon steel		DWG NO. 11	NO OF VIWES: 4
		WEIGHT: 440 grams		SCALE: 1:2	SHEET 11 OF 1





SUDAN UNIVERSITY FOR SCIENCE AND TECHNOLOGY

	NAME	SIGNATURE	DATE
DRAWN	MUAAZ MOHAMMED ALI		/ /2018
CHK'D	Dr. Abd El fattah Bilal		/ /2018

TITLE: SCREW

paper: A4 Landscape

Dimensions : mm

MATERIAL: CAST CARBON STEEL

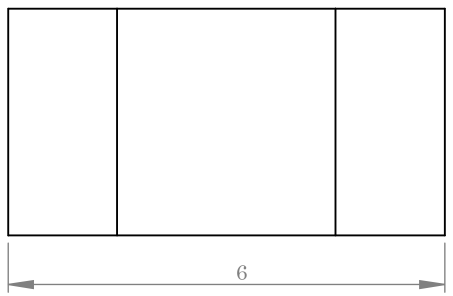
DWG NO. 13

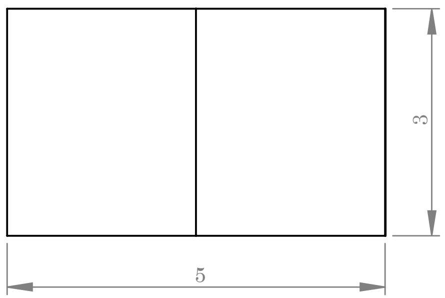
NO OF VIWES: 3

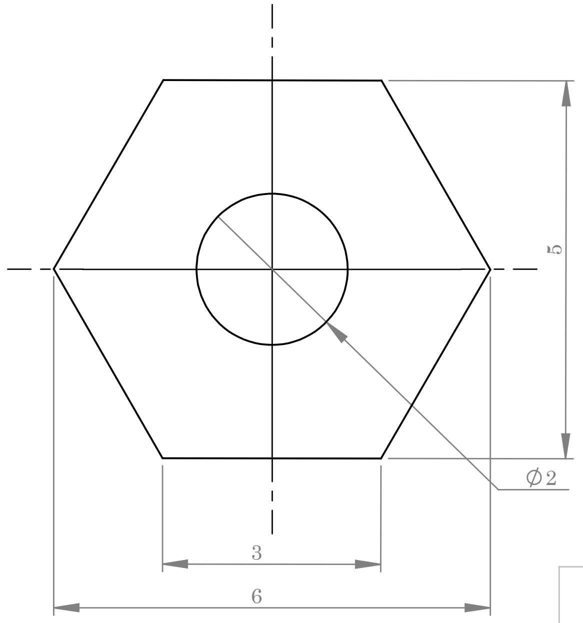
WEIGHT: 4 grams

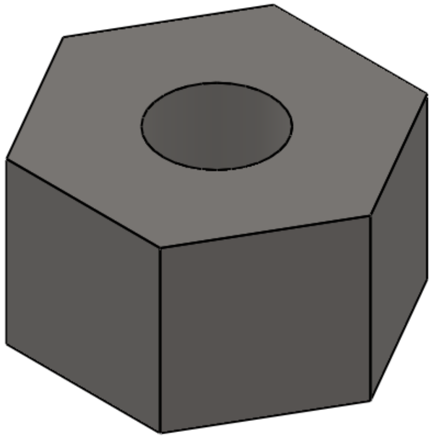
SCALE: 1:1

SHEET 13 OF 1



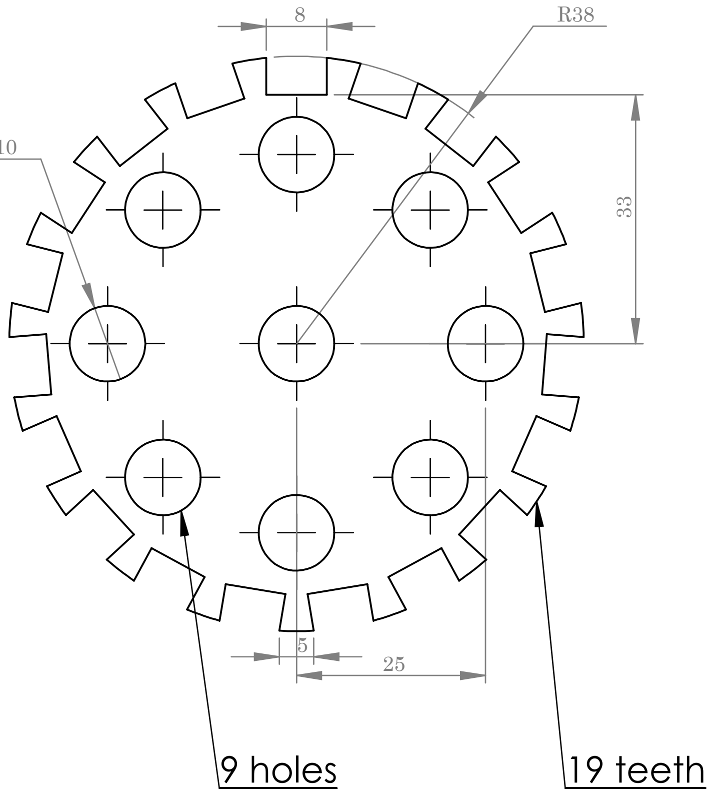


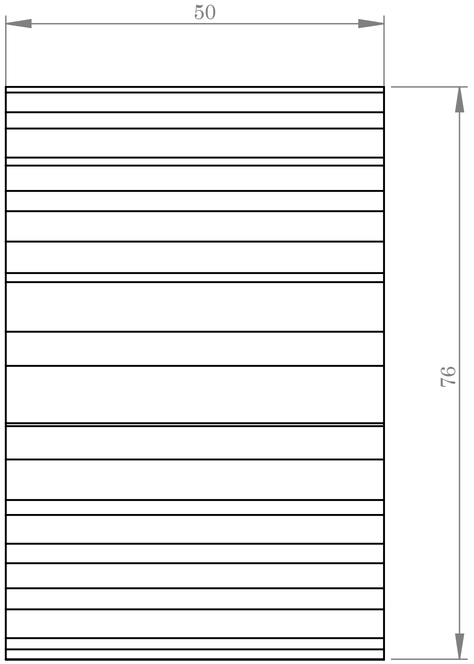


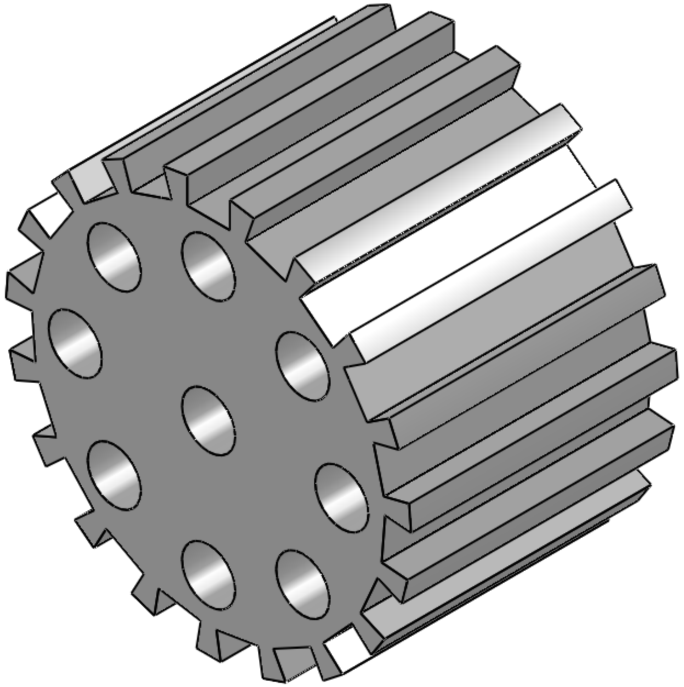


SUDAN UNIVERSITY FOR SCIENCE AND TECHNOLOGY

	NAME	SIGNATURE	DATE	TITLE: Nut
DRAWN	MUAAZ MOHAMMED ALI		/ /2018	
CHK'D	Dr. Abd El fattah Bilal		/ /2018	paper: A4 Landscape
Dimensions : mm		MATERIAL: cast carbon steel		DWG NO. 14 / NO OF VIWES: 4
		WEIGHT: 0.8 grams		SCALE: 10:1 / SHEET 14 OF 1





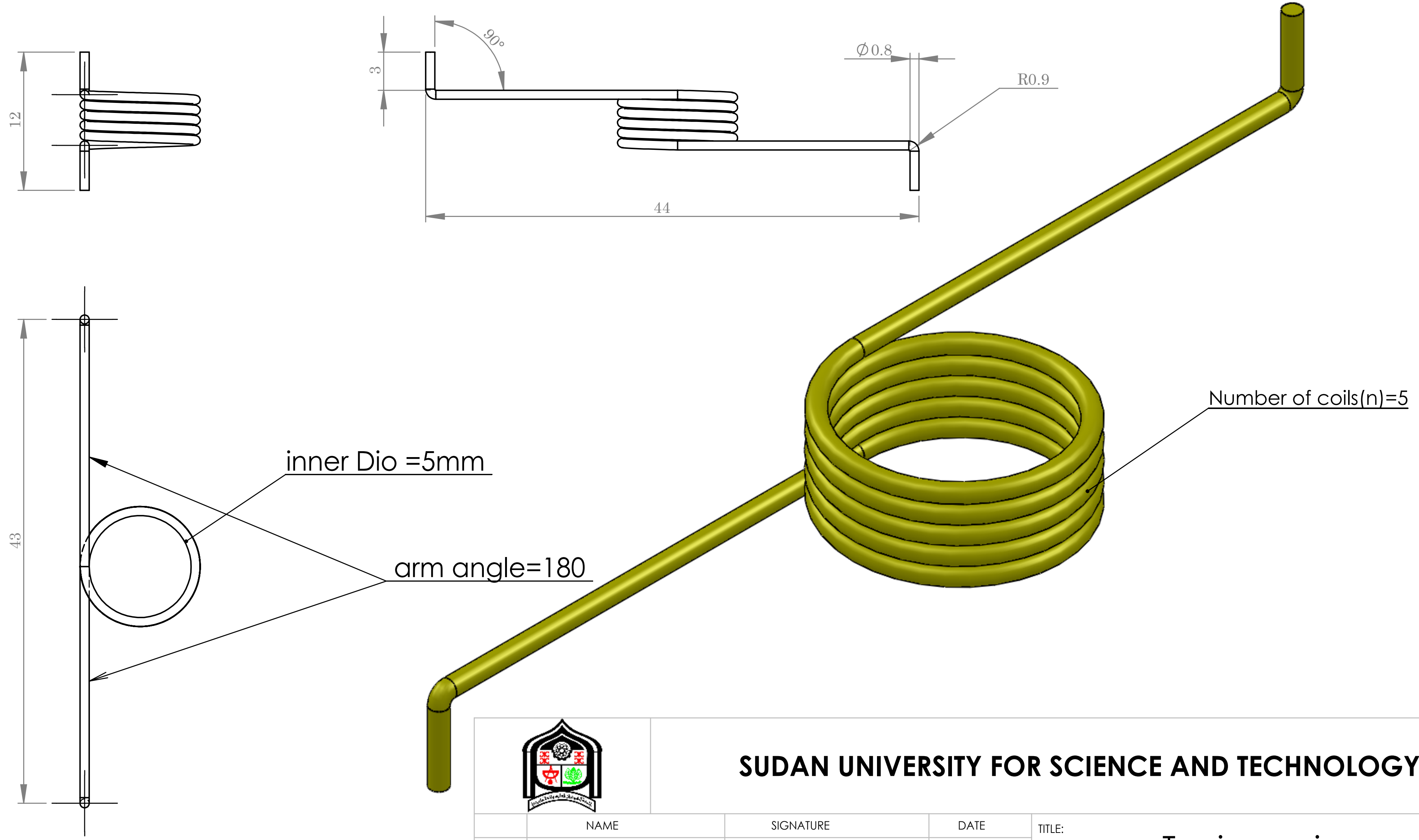


SUDAN UNIVERSITY FOR SCIENCE AND TECHNOLOGY

	NAME	SIGNATURE	DATE	TITLE: Tension wheel
DRAWN	MUAAZ MOHAMMED ALI		/ /2018	
CHK'D	Dr. Abd El fattah Bilal		/ /2018	paper: A4 Landscape
Dimensions : mm		MATERIAL: custom plastic		DWG NO. 9
		WEIGHT: 156.4 grams		SCALE: 1:2

NO OF VIWES: 3

SHEET 9 OF 1



SUDAN UNIVERSITY FOR SCIENCE AND TECHNOLOGY

	NAME	SIGNATURE	DATE
DRAWN	MUAAZ MOHAMMED ALI		/ /2018
CHK'D	Dr. Abd El fattah Bilal		/ /2018

TITLE: Torsion spring

paper A4 Landscape

Dimensions: mm

MATERIAL: AISI 304

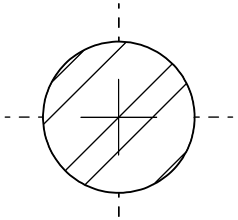
DWG NO. 6

No of viwes 4

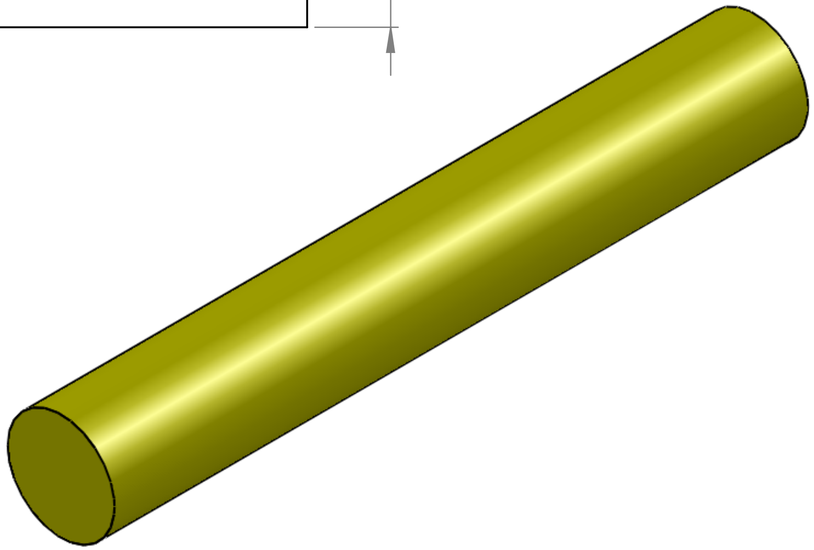
WEIGHT: 2 gram

SCALE: 2:1

SHEET 6 OF 1



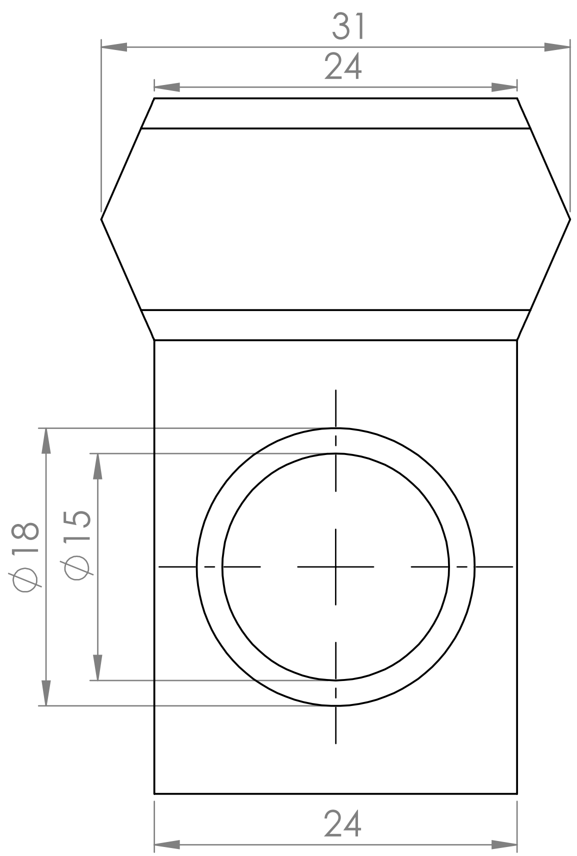
SECTION B-B
SCALE 2 : 1

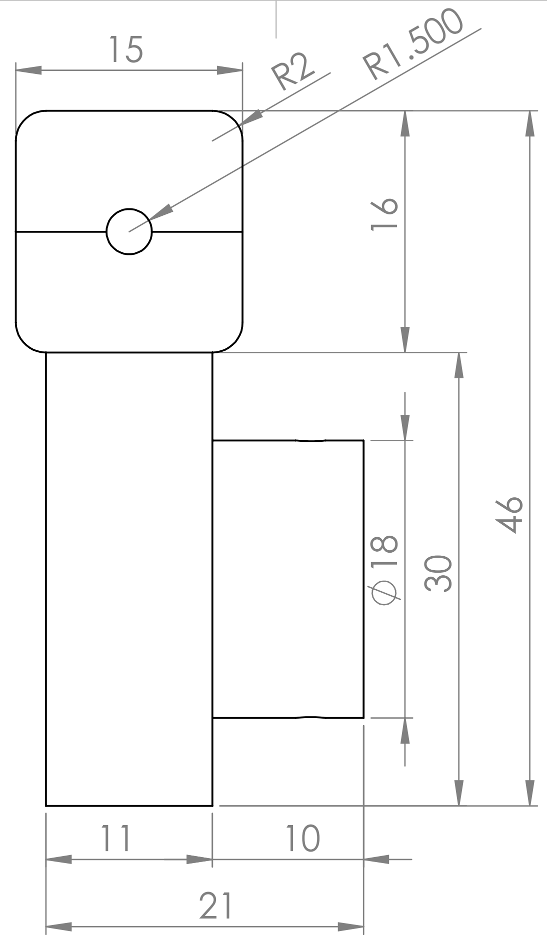


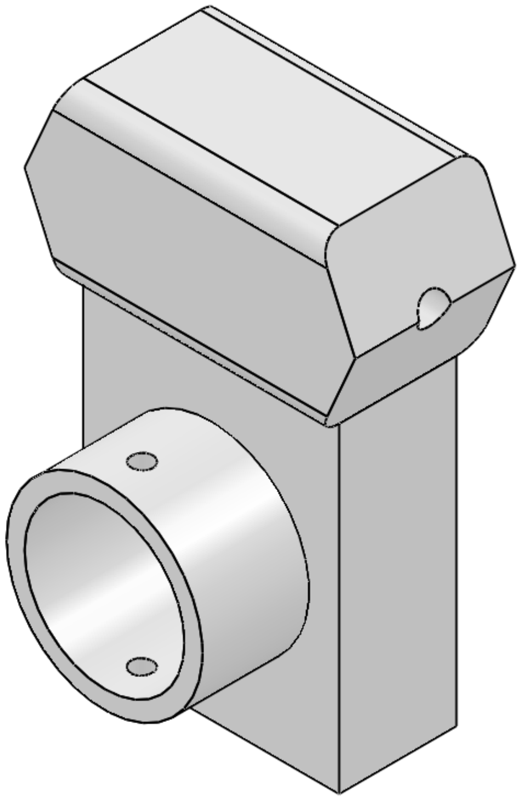
SUDAN UNIVERSITY FOR SCIENCE AND TECHNOLOGY

	NAME	SIGNATURE	DATE	
DRAWN	MUAAZ MOHAMMED ALI		/ /2018	TITLE: Tension mechanism shaft
CHK'D	Dr. Abd El fattah Bilal		/ /2018	paper: A4 Landscape

Dimensions : mm	MATERIAL: cast carbon steel	DWG NO. 8	NO OF VIWES: 3
	WEIGHT: 39.32 grams	SCALE: 1:1	SHEET 8 OF 1

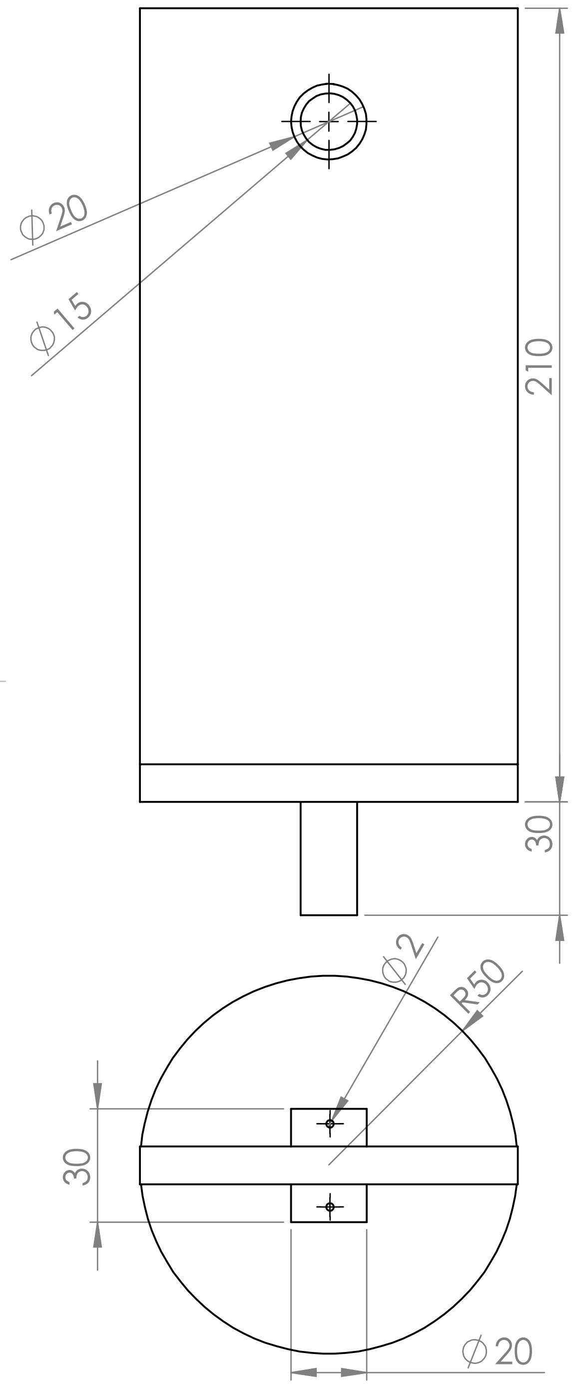


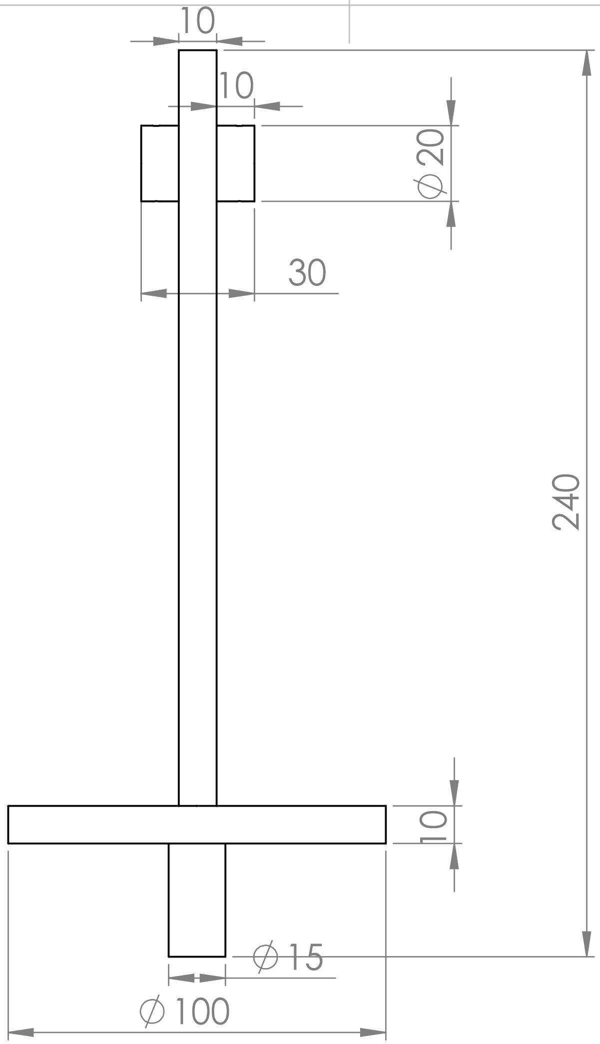


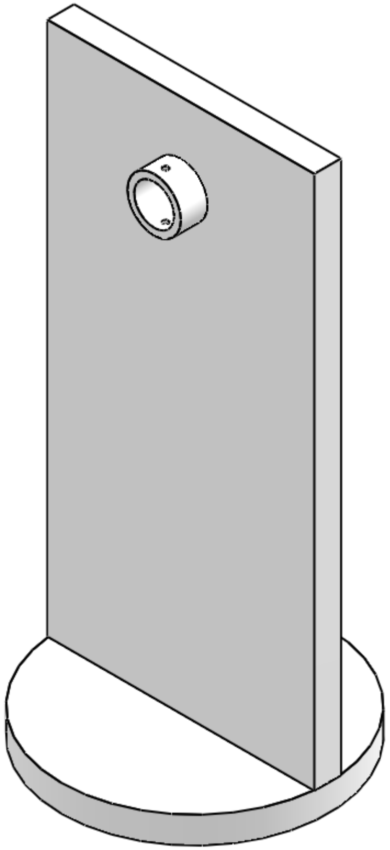


SUDAN UNIVERSITY FOR SCIENCE AND TECHNOLOGY

	NAME	SIGNATURE	DATE	TITLE: PVC JOINT
DRAWN	MUAAZ MOHAMMED ALI		/ /2018	
CHK'D	Dr. Abd El fattah Bilal		/ /2018	paper: A4 Landscape
Dimensions : mm		MATERIAL: PVC RIGID	DWG NO. 22	NO OF VIWES: 2
		WEIGHT: 18 grams	SCALE: 1:1	SHEET 1 OF 1







SUDAN UNIVERSITY FOR SCIENCE AND TECHNOLOGY

	NAME	SIGNATURE	DATE
DRAWN	MUAAZ MOHAMMED ALI		/ /2018
CHK'D	Dr. Abd El fattah Bilal		/ /2018

TITLE: LINK HOLDER

paper: A4 Landscape

Dimensions : mm

MATERIAL: Aluminum 6061 aloy

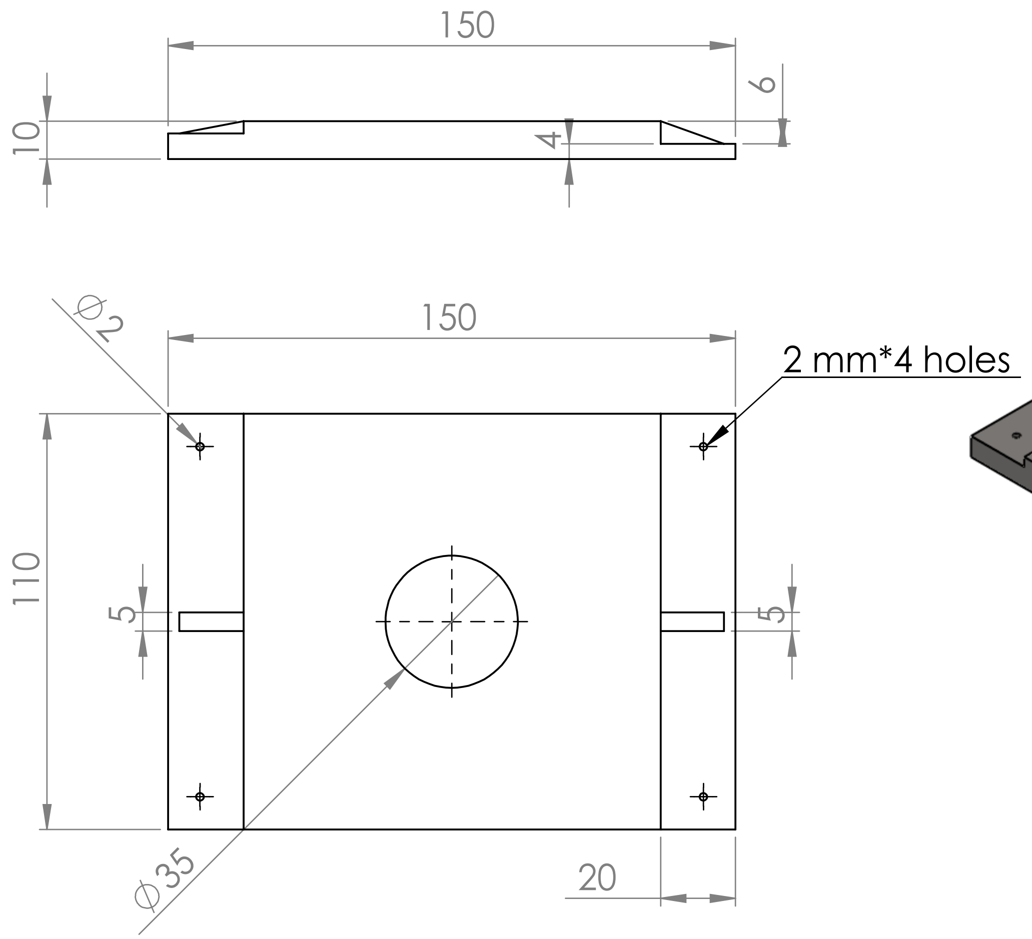
DWG NO. 10

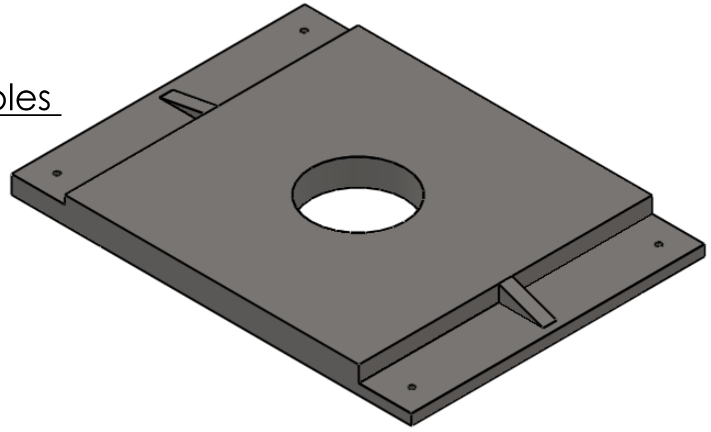
NO OF VIWES: 2

WEIGHT: 370 GRAMS

SCALE: 1:5

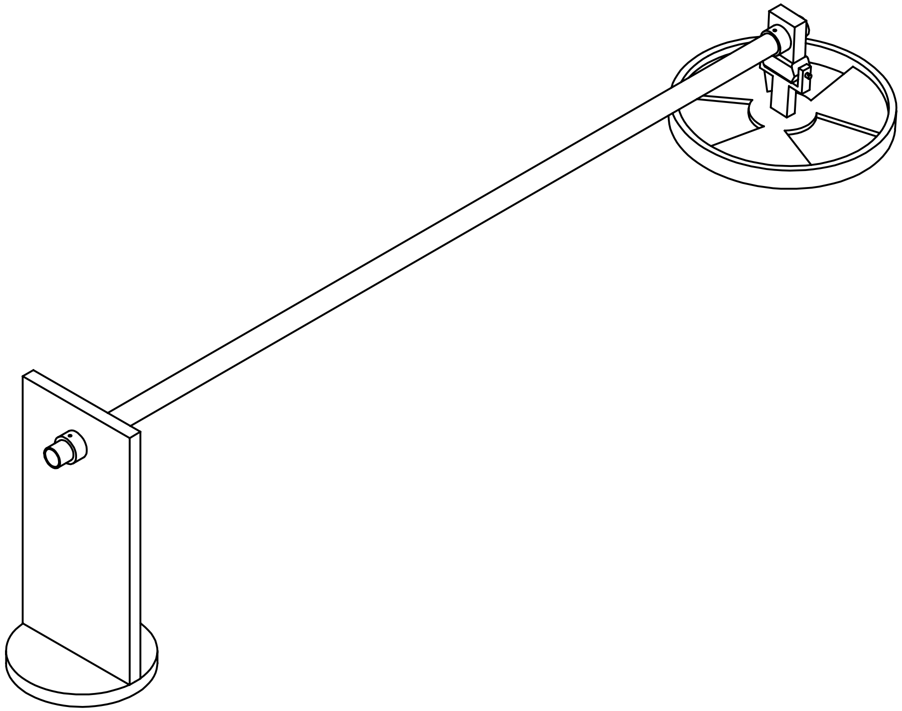
SHEET 1 OF 1





SUDAN UNIVERSITY FOR SCIENCE AND TECHNOLOGY

	NAME	SIGNATURE	DATE	TITLE: bearing fixer
DRAWN	MUAAZ MOHAMMED ALI		/ /2018	
CHK'D	Dr. Abd El fattah Bilal		/ /2018	paper: A4 Landscape
Dimensions : mm		MATERIAL: cast carbon steel	DWG NO. 23	NO OF VIWES: 2
		WEIGHT: 1058 grams	SCALE: 1:2	SHEET 1 OF 1



SUDAN UNIVERSITY FOR SCIENCE AND TECHNOLOGY

	NAME	SIGNATURE	DATE	TITLE: MANIPULATOR
DRAWN	MUAAZ MOHAMMED ALI		/ /2018	paper: A4 Landscape
CHK'D	Dr. Abd El fattah Bilal		/ /2018	

Dimensions : mm	MATERIAL:	DWG NO.	NO OF VIWES: 1
	WEIGHT: grams	SCALE: 1:10	SHEET 1 OF 1