جامعة الأمير محمد بن فهد
PRINCE MOHAMMAD BIN FAHD UNIVERSITY

College of Engineering

Department of Mechanical Engineering

Spring 2021

Senior Design Project Report

Robot for pipeline inspection
Degree of Bachelor of Science in Mechanical Engineering

Team 01

Team Members

	Student Name	Student ID
1	Abdullah Alsaleh*	201900193
2	Ahmed Alabbas	201601497
3	Mohammad Alyousif	201403591
4	Mustafa Aljubarah	201900656
5	Mytham Alasker	201701719

Project Advisors:

Advisor Name: Dr. Mohamed Saleh

Abstract

Pipelines are found in each and every power plant and, as such are fundamental components of modern worlds. Current industry requires more secure, dependable and productive machines and specifically these working at high paces and under high pressure. This has prompted an expansion interest in observing the wellbeing of all types of pipelines. In any case, due to the dangerous nature of pipelines and the size it's difficult for people to inspect them and give a proper diagnosis without putting their lives at risk. It would be significantly better to figure out how to diagnose those pipelines without utilizing physical work.

This project aim is to plan and deliver a basic robot, where the robot can be installed and research pipelines. The robot is furnished with a few sensors and a camera to get live film of the planned pipeline and use that to decide if there was an issue with it or not.

Acknowledgments

We are truly appreciative on the grounds that we designed a robot that can assist with examining pipelines within the time given by our educator DR. Mohamed Saleh. This project couldn't be finished without the effort and help of our advisor Dr. Mohamed Saleh, so we would like to thank him for the direction and support in completing this project and furthermore for teaching us in this course. To wrap things up, we would like to offer our thanks to Dr. Faramarz Djavanroodi, chair of the Mechanical Engineering Department at PMU. Finally, we would like to thank our family members for this continue support

List of Figures:

List of Tables:

Table of Contents

Chapter 1: Introduction

1.1 Project Definition

This project is intended to design and produce a straightforward robot, where the robot can be embedded and investigate pipelines. The robot is equipped with two or three sensors and a camera to get live footage of the intended pipeline and utilize that to determine whether there was an issue with it or not. The project is vital to influence power plants as through understanding the attributes and issues of pipelines, time and cash will be saved also operators lives.

1.2 Project Objectives

1. Examine tight regions that people cannot reach.
2. To build up a technique where the client can expedite the inspection.
3. Clients can examine nearly anything remotely.
4. Shielding individuals lives from any sort of risk.

1.3 Project Specifications

Table 1.3.1: Arduino Uno (Microcontroller Board)

Controller	ATmega328
Voltage	5V
Input voltage (recommended)	7-12V
Input voltage (limits)	6-20V
Digital entrances and exits	14
Processor speed	16MHz
Input and output current	40 mA

Table 1.3.2: TT Gear Motor (4x)

Voltage	4.5V
Speed	140 rpm
Parameter	190 mAh
Torque	800gf.min
Dimensions	20 x 20 x 64 cm

Table 1.3.3: Ultrasonic Sensor

Working voltage	5V (DC)
Output signal	Electric frequency signal, high level 5V, low level 0V
Sensor Angle	Not more than 15 degrees
Detection distance	2cm-450cm
Input trigger signal	10us TTL impulse
Echo signal	Output TTL PWL signal

Table 1.3.4: Servo Motor

Dimensions	40 x 19 x 43 mm
Weight	55g
Operating speed	0.13sec / 60 degrees (6.0V no load)
Operation voltage	4.8-7.2V
Gear type	Metal Gear

Table 1.3.5: Camera

Brand	EZVIZ
Connection	Wi-fi
Special features	130-degree wide angle, infrared night vision
Power source	100-240V

Table 1.3.6: Wheels

Operating voltage	3V to 6V DC
No-load current	250mA (6V)
Maximum torque	4500mg x cm(6V)
Weight of motor	29g
Wheel diameter	65mm
Wheel width	27mm
Weight of wheel	33g

Table 1.3.7: 18650 Li-on Battery

The 18650 Cell	18mm in diameter and 65mm tall
Voltage	3.7V

Table 1.3.8: L298N Motor Driver

Driver	L298N Dual H Bridge DC Motor Driver IC
Driver part of peak current Io	2A
Maximum power consumption	20W (when the temperature T = 75 ℃)
Storage temperature	-25 ℃ ~ +130 ℃
Driver board size	55 x 60 x 30 mm
Driver plate weight	33g

Table 1.3.9: Infrared Sensor

VCC	External 3.3V-5V voltage (can be directly connected to 5v MCU and 3.3v MCU)
GND	GND External
Output	Small board digital output interfaces (0 and 1)
Board size	3.1cm x 1.5cm

1.4 Applications

The main applications for the projects are:

- To inspect any corrosion in the pipeline.
- Visual and measurement inspection for any corrosion and wall thickness losses.
- To find any coating failure that may occur.
- To identify any kind of dent that may happen on the pipeline.
- To find any type of gouges that could hurt the pipeline.

Chapter 2: Literature Review

2.1 Project background

Pipelines play a major role in our modern life; more importantly most types of energies are delivered using this method, such as (Oil & Gas). The purpose of choosing and using the pipeline system over other transportation methods is because of the cut of cost and time that pipelines provide.

In the current time more than 100 countries uses pipelines for many purposes, which shows us the importance of developing this transportation method.

By this project we are aiming to solve many problems that could appear in pipelines, and detecting all problems faster and quicker, such as Leaking, Corrosions and Cavities. There are also small pipes that cannot fit a human being, or it may cause harm to human beings. Also, it can be used to resolve problems inside a long-distance pipeline. therefore, reducing the amount of manpower used and avoiding hazardous issues can save lives and cut the cost by large amount

2.2 Previous Work

It is very important and helpful to us that we take a look for some previous works related to our project, so that we can get solid feedback that can help us to make our project to become advanced. The followings are some works that had same purpose as ours.

2.2.1 X5-HW Pipeline Robot

In the past years, many robots were developed to inspect pipes in such a way they overcome a lot of defects that were not considered while the old techniques were designed. This robot was designed to help the industries to inspect and detect any defects, failures, leakages, corrosion, … etc. in large long distance drainage pipelines. This robot is appropriate for pipes with a breadth scope of 800mm to 4000mm and a discovery distance of up to 2000 meters [1]. X5-HW2 comprises of four sections: crawler, Camera, link reel, and expert control. The crawler can be furnished with various particulars of the Camera (like the turning Camera, direct view Camera, fisheye Camera), through the association of link reel and expert control regulator, the crawler reacts to the working orders of the expert control regulator. For instance, the forward, in reverse, controlling, pause and speed change of crawler; the Camera seat is raised, brought down, and lit; the flat or vertical turn, center, and zoom of the Camera, and so on, front and rearview exchanging, etc. [1]. It enjoys a few benefits that are not engaged with the customary ones, for example, having lightweight parts, and proficient recognition which implies speedy gathering nearby, efficient and effective, and quick information transmission with no compelling reason to associate link. It is likewise portrayed by stable execution; the entire machine is waterproof and blast verification, little exertion without any concerns, simple to dismantle, and dominate control has zero disappointment [1].

Figure 2.2.1: X5-HW Pipeline Robot

2.2.2 Advanced Pipe Inspection Robot Using Rotating Probe

New investigation robots utilizing remote radio correspondence frameworks are considered valuable for long complex lines and significant distance pipes including straight, vertical, and twist lines. However, conveying remote radio messages isn't reasonable on the grounds that the properties of the radio wave are influenced by the shape and material of the lines. Therefore, we estimated the properties of remote radio signs with steel lines and fired lines and we built up a useful remote radio correspondence framework. Then again, the Indian Establishment of Innovation Kanpur has explored a turning test utilizing a piezo component for reviewing within pipes with a touch sensor framework. This time, we created and tried another examination robot that had incorporated both the review framework utilizing remote radio correspondence and picture transmission created by Waseda College and the investigation framework utilizing the pivoting test created by the Indian Establishment of Innovation. It was affirmed that it is feasible to drive the robot by a remote radio correspondence framework in within test line and gather the picture and a few signs from the turning test [2].

2.3 Comparative Study

2.3.1: 3D Printing of a Quadruped:

This paper is focused on a very popular legged robot, the quadruped robot.

A vary common legged robot, the quadruped robot, is the subject of this project. The first thought of constructing legged robots was inspired by different existing organisms in the environment, like millipedes, centipedes, etc.

There are two main hardware and software used in this project. Beginning with Computer Aided Design software, the computer systems are used for the optimization, architecture and study of a given product. The robot components were designed using CAD software. Moving to 3-D printing software, accurate and high-quality 3D printed models have been produced by this printer. The robust metal frame seen in the device improves the stability of moving parts. Also, precise rotation on the Z-axis is possible with metal platform support. The construction plate is made of aluminum alloy.

Regarding the fabrication and design, on each limb, the robot to be built will have 3 servomotors, thereby giving it 3 degrees of freedom. The legs will also have sub-parts like higher and lower legs as it is shown in the figure below. It will then connect these legs to the body. The following sections in the figure below were designed using CAD software. [3]

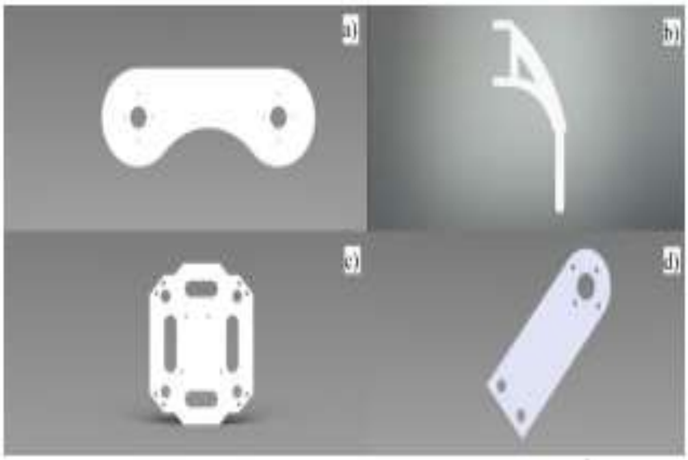

Figure 2.3.1: Part by part 3-D model designed in CAD software. a) Femur b) Tibia c) Body d) Extension Hand

Figure 2.3.2: Complete 3-D constrained assembly in CAD Software

2.3.2: Low cost two-wheels self-balancing robot for control education.

This paper presents the discoveries of an undertaking planned at College of Seville determined to build up a minimal effort two wheels self-adjusting robot that con be planned and worked in a course by understudies streaming PBL approach, displaying programing control and sign preparing. This robot endeavors to adjust on 2 wheels, as it was a rearranged pendulum. The primary thought is to hold the robot in balance by applying the voltage to the engine that move the wheel to arrive at the necessary speed.

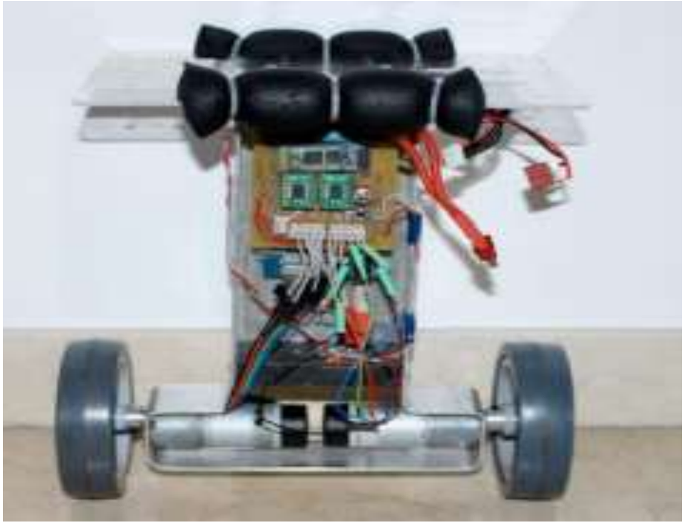

Figure 2.3.3: Low cost two-wheels self-balancing robot for control education.

The following hardware components are used in building the robot:

- Inertial measurement unit (IMU).
- Microcontroller Arduino Mega.
- Engine controllers.
- Motors.
- Bluetooth unit.
- Body
- Connections.

There are different ways of constructing the control mechanism for the constructed robot. The design selected for the prototype on the basis of two nested controls, one controls the motion of the wheels and another to stabilize the robot. [4]

2.3.3: Legend 3D Printed Mobile Robot:

Figure 2.3.4: Legend 3D Printed Mobile Robot

Adaptation and modification of the current robotic platform built at Cornell University is the main objective of the project. The facets of design, electrical circuitry, increased autonomy, generation of gait and reduction of mass are improved. The platform initially weighted 1.29 kg and was printed out of 11 components. It has been succeeded in minimizing its bulk; at about 200 g. Mass reduction is achieved with the use of lower-density components and optimized architecture. In the shape of a wider leg width, the current style is distinct from the past. Considering electronics, substantial improvements have been made in order to gain greater autonomy and performance. Lower nominal voltage servomotor selection permitted two serial connected batteries to be applied instead of three, leading to space savings, when using lower torque servomotor, the robot’s output is not reduced because the robot is smaller. Batter power is also substantially improved, thereby guaranteeing a longer lifetime of 74 percent. The key distinctions between the original Arcana platform and the updated version introduce in the paper are demonstrated in the table below.

Table 2.3: Comparison between original and enhanced robot

Characteristic	Original robot	Enhanced robot
Actuators	AX 18-A	TowerPro MG995
Power supply	3S 11.1 V 2000 mAh LiPo	2S 8.4 V 3500 mAh Li-Ion
Controller	ArbotiX Robocontroller	Arduino Uno
Weight	1.29 kg	1.09 kg
Leg span	48 cm	52 cm
Printed parts	11	19
Lifespan	6.82 min	26.25 min

FEM analysis is used to achieve an optimal design, which is large enough to sustain exerted force on its legs and minimizes mass as well. The lower legs of this robot are vital spots because they are subject to the greatest tension. Optimal thickness of the lower legs was obtained following iterative simulations of sufficient material properties. Constant fields and linear displacement of stress and strain will characterize the finite elements. FEM results revealed a median elongation of just 1 mm under a peak VON Mises stress equivalent of 5 N/mm2, which tends to be attributed to the mass of the robot. That is more than enough for the stuff from VeroBlue. For such conditions, this material is very suitable, due to the fact that its break elongation is around 20 percent. The figure below illustrates the lower leg FEM study, noting that the stress legend is seen in N/m3. [5]

Figure 2.3.5: the lower leg FEM study

The main difference between our project and the projects, which have been discussed above, is the live footage. Our main objective is to design a small vehicle that can travel between oil pipes to investigate what is happening in the damaged pipe. In order to achieve this, there will be a camera located in the front of the car, which takes pictures and videos and send them to us via Bluetooth. Another difference is the design. By using Computer Aided Design software, we have designed four wheels car, which looks very different from the other projects.

Chapter 3: System Design

3.1 Design Constraints and Design Methodology

3.1.1: Geometrical Constraints

At the point when the team began planning and designing for the task, the group confronted recognizable challenge to most engineers, which is the absence of parts that are required for the project like engine motor and 18650 li-on battery. In the nearby market, the team couldn't track down the appropriate motor driver for the project rather the team discovered different sorts of motor drive, which may not do the required job. The team should plan the framework with enough rooftop space, so the necessary supplies can be attached and work appropriately. In the event that the team had the option to plan the framework with a greater rooftop territory then the framework will have additional features, for example, utilizing sunlight-based boards rather than batteries. The subsequent boundary is the weight of the robot. At the point when the team planned the robot; it was seen that load of the robot ought to be in considerations due to the fact the heavier it is the more force it needs to be moved. Nevertheless, the team planned the robot with an insignificant weight, so it tends to be utilized in many pipelines without damaging them.

3.1.2: Sustainability

We may deal with an issue as far as sustainability because of the possibility of draining batteries, which will affect the performance. Since the force requires some energy, the batteries are getting drained to keep good performance. To evade this issue, the team decided to go with rechargeable batteries.

3.1.3: Environmental

Most nations like to utilize eco-accommodating fuel sources to produce power. Australia and Chile are two of the greatest nations in lithium producing batteries. Our framework relies upon batteries to produce power. Lithium batteries are rechargeable, which means in the future less batteries are going to be needed due the rechargeability feature.

3.1.4: Social

Our robot can be utilized by multi platforms for various reasons. A few groups can utilize it to examine pipelines while others can utilize it to infiltrate an unwanted structure. Accordingly, the robot will have social effect.

3.1.5: Economic

In financial side, our robot assists saving with timing and individuals' lives with regards to investigating pipelines that is on the grounds that it very well may be utilized in little territories and it is quicker than individuals. In addition, it will lessen maintenance costs because most of its parts are cheap.

3.1.6: Safety

Perhaps the main factor of our design is security of people. The robot can be utilized whenever in any spot because of its long reach while sitting at the workplace away from any sort of threat.

3.1.7: Ethical

This project is new in terms of being used mostly in pipeline with live-cam footage, but when it comes to the structure of the robot and how it works it has comparative past works. Subsequently, the team took some broad thoughts from them and enhances the work by creating new plans to improve the design regarding security, financially, and sustainability.

3.1.8: Risk

Fortunately, since the project is equipped with live-cam and works wirelessly it does not cause any type of danger to the user meaning there are no risks whatsoever.

3.2 Engineering Design standards

Engineering design standards were considered in designing our project when it comes to select the components used in our system. This part of this chapter will describe the technical details and specifications of each component that has been selected in our project. The that we selected were as follow; Arduino uno (Microcontroller Board), TT gear motor (4x), ultrasonic sensor, motor driver, servo motor, battery holder, camera, Bluetooth chip, 18650 Li-on battery, wheels, and infrared sensor. The following table shows the engineering standards for the main components of the design:

Table 3.2: Engineering Standards

Components	Engineering standards
Arduino Uno	ATmega328
Ultrasonic sensor	HC-SR04
Servo Motor	ISO 16092-2
Bluetooth Ship	IEEE 802.15
Driver Motor	L298N
18650 Li-on Battery	UL2054
Infrared Sensor	ASTM F3238
Camera	ISO/IEC 29151

3.2.1: Arduino Uno (Microcontroller Board)

Voltage: 5V

Input voltage (suggested): 7-12V

Input voltage (limits): 6-20V

Computerized passages and ways out: 14

Total memory: 32 KB

Static Memory: 2 KB

Memory EEPROM: 1 KB

Processor speed: 16 MHz

Info and yield current: 40 mA.

3.2.2: TT Gear Motor (4x)

Voltage: 4,5 volts.

Speed: 140 rpm

Parameter: 190 mAh.

Torque: 800gf.min

Dimensions: 20 * 20 * 64cm.

3.2.3: Ultrasonic Sensor

Working Voltage: 5V (DC)

Static current: Under 2mA.

Yield signal: Electric recurrence signal, significant level 5V, low level 0V.

Sensor point: Not in excess of 15 degrees.

Identification distance: 2cm-450cm.

High exactness: Up to 0.3cm

Information trigger sign: 10us TTL impulse

Echo signal: output TTL PWL signal

3.2.4: Servo Motor

Dimension: 40mm x 19mm x 43mm

Weight: 55g

Working Velocity: 0.17sec/60 degrees (4.8V no load)

Working Velocity: 0.13sec/60 degrees (6.0V no load)

Activity Voltage: 4.8 - 7.2Volts

Gear Type: Metal Gear

3.2.5: Camera

- Brand: EZVIZ

- Models are compatible with standard equipment

- Wi-Fi connectivity technology

- Compatible with Internet of Things (IoT)

- Special features tuk-tuk, 130-degree wide angle, infrared night vision

- Smart monitor

- Power source: 100 to 240 volts

3.2.6: Bluetooth Chip

- High performance-price ratio

- Small volume, easily embedded to other products

- Strong function with support LWIP protocol, Freertos

- Supporting three modes: AP, STA, and AP+STA

- Supporting Lua program, easily to develop

3.2.7: Wheels

Operating voltage: 3V to 6V DC

No-load current: 250mA (6V)

Maximum torque: 4500mg x cm(6V)

Reduction ratio: 1:48

Weight of Motor: 29g

Wheel diameter: 65mm

Wheel width: 27mm

Weight of wheel: 33g

3.2.8: 18650 Li-on Battery

The 18650 cell is 18 mm in diameter and 65 mm tall

Voltage: 3.7v

3.2.9: L298N Motor Driver

- Driver: L298N Dual H Bridge DC Motor Driver IC

- Driven piece of the terminal stock region Versus: +5 V ~ +35 V; like the need to take power inside the board, the stockpile territory Versus: +7 V ~ +35 V

- Driven piece of the pinnacle current Io: 2A

- The coherent piece of the terminal stockpile territory Vss: +5 V ~ +7 V (can take power inside the board +5 V)

- The coherent piece of the working current reach: 0 ~ 36mA

- Control signal info voltage range:

Low: - 0.3V ≤ Vin ≤ 1.5V, High: 2.3V ≤ Vin ≤ Vss

- Empower signal input voltage range:

Low: - 0.3 ≤ Vin ≤ 1.5V (control signal is invalid), High: 2.3V ≤ Vin ≤ Vss (control signal dynamic)

- Greatest power utilization: 20W (when the temperature T = 75 ℃)

- Capacity temperature: - 25 ℃ ~ +130 ℃

- Different Augmentations: control of direction indicators, the logic part of the plate to take power interface.

- Driver Board Size: 55mm * 60mm * 30mm

- Drive plate Weight: 33g

3.2.10: Infrared Sensor

- VCC: external 3.3V-5V voltage (can be directly connected to 5v MCU and 3.3v MCU)

- GND: GND External

- OUT: small board digital output interfaces (0 and 1)

- Board size: 3.1CM * 1.5CM

3.3 Theory and Theoretical Calculations

Like any project or design there are steps that needed to be taken. Those steps can either make your design successful of not. It all depends on your knowledge, research and brainstorming as a team. One of those steps is your theory and theoretical calculations. Since we are working on this design lets discuss some of the calculations and the theory behind it. This design does not require a lot of calculations. However, there are a few things that we have to be careful when we calculate for our design, which is, a care for pipeline inspection. We calculated the horsepower and made sure that our car had enough horsepower to do the job, and if the motor had enough power to work with it. As well as the battery power needed to give the gear motor its full potential.

$$Hp = \frac{RPM * Torque}{63025}$$

Horsepower is very important and very delicate mater to be careful when calculating because if you have low hp then the design might face major difficulties.

$$P = IV$$

Where P is power, I is current, and V is voltage. It is important to calculate how much the motor power needs, so we can pick which battery that can support that.

$$E = Pt = IVt$$

Where E is energy, and t is time. Here we have to calculate the time our battery runs before needing to be charged again.

3.4 Product Subsystems and selection of Components

In the figure below it shows the exploded assembly of the project. And it shows each part specifically such as, both lower and upper chassis, line tracking module "infrared sensor", 4 DC motors "Gear", Motor driver panel, The core board "UNO Arduino", Multiple sensors, Battery holder, Servo Motor, Ultrasonic Sensor, Rubber Wheels, Bluetooth chip and a Camera. Also, the final shape of the Smart Robot Car can be seen below as well. Moreover, All the parts will be placed on top of both of the Chassis; the lower one will hold all the 4 motors along with Wheels, the line tracker sensor and the motor driver panel. We will place the other Chassis on the said parts and tighten them. The upper Chassis will hold the core board which is the UNO Arduino, multiple sensors on the front of the robot, the battery holder along with the servo motor, Ultrasonic sensor, the Bluetooth chip and the camera.

Figure 3.4: Exploded assembly of the system

3.5 Manufacturing and assembly (Implementation)

Beginning with the design, the structure was created using Computer Aided designed as it is shown in the figures below and was printed using 3d printer. Secondly, Arduino Uno, which can read inputs such as the light from a sensor or a finger on a switch and convert them into outputs. This will be needed in our robot for these several features. The third part is TT gear motor. It is a plastic gearbox motor, which is responsible of moving the robot. Moreover, in terms of the movement of the robot, a Motor driver is a necessity. It is a small current Amplifier transforms a low current control signal into higher ones. Fourthly, since the robot is designed for oil and gas pipelines, an ultrasonic sensor is needed to measure the distance of the aimed object. The fifth part is the Camera and the flashlight. The camera will be connected to a Bluetooth chip which can give us a live pictures and videos.

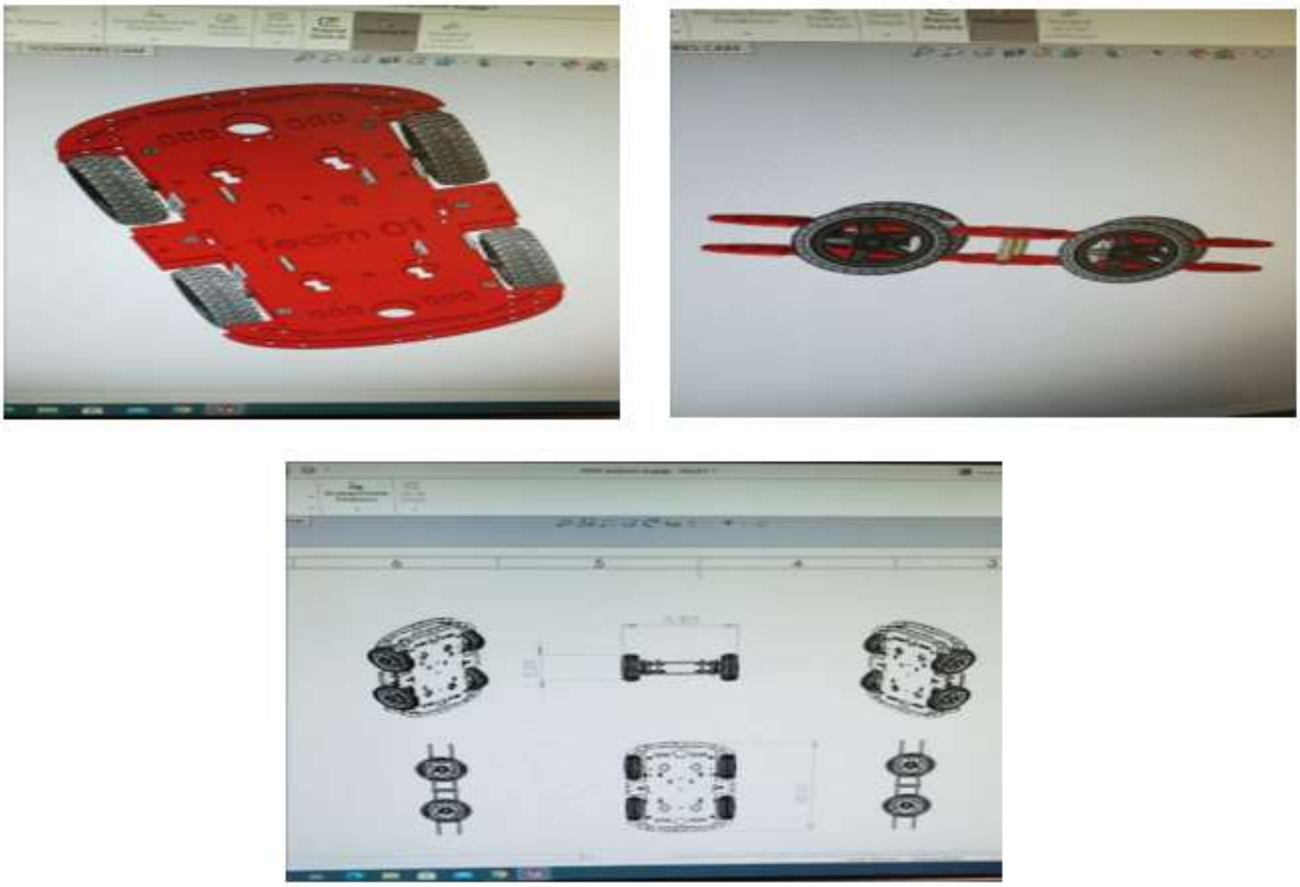

Figure 3.5: Drawings of the chassis

3.6 Economic Evaluation of Engineering Projects

Table 3.6: the economical aspect of the robot

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Capital Costs											
Equipment	159058	159058	159058	159058	159058	159058	159058	159058	159058	159058	159058
Construction	-	-	-	-	-	-	-	-	-	-	-
Total	-1749638										
Operating Cost											
Energy	-	-	-	-	-	-	-	-	-	-	-
Electricitiy	-	-	-	-	-	-	-	-	-	-	-
Labour	40150	40150	40150	40150	40150	40150	40150	40150	40150	40150	40150
Insurance	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Taxes	47552.5	47552.5	47552.5	47552.5	47552.5	47552.5	47552.5	47552.5	47552.5	47552.5	47552.5
Total	-979927.5										
Revenues											
Product 1	240000	252000	264600	277830	291721.5	306307.575	321622.954	337704.101	354589.307	372318.772	390934.71
Total	3409628.92										
Profits	682063.419										

Chapter 4: System Testing and analysis.

4.1 Experimental setup, sensors, and data acquisition system.

4.1.1: Ultrasonic sensor:

The ultrasonic sensor is located in the front of the car. We have done an experimental set up for calculating the distance that the ultrasonic sensor can get before it stops. There is also another experimental set up to calculate the time the sensor takes before it changes its direction. Since the phone can control the car, one of us was moving it and the others were calculating the distance and time as well.

Specification:

Working Voltage: 5V(DC)

Static current: Less than 2mA.

Output signal: Electric frequency signal, high level 5V, low level 0V.

Sensor angle: Not more than 15 degrees.

Detection distance: 2cm-450cm.

High precision: Up to 0.3cm

Input trigger signal: 10us TTL impulse

Echo signal: output TTL PWL signa

We choose the ultrasonic sensor over any other sensor because it a great option for the identification of objects. Ultrasonic sensors recognize objects paying little mind to shading, surface, or substance for presence identification, except if the material is unfathomably delicate like fleece, as it would ingest sound. Therefore, ultrasonic sensor would be best possible choice to use for inspecting pipeline.

Table 4.1.1: The testing Parameters.

Testing Parameters	**Objective**
Ultrasonic sensor	To detect objects.
Line tracking sensor	To follow a certain Path.

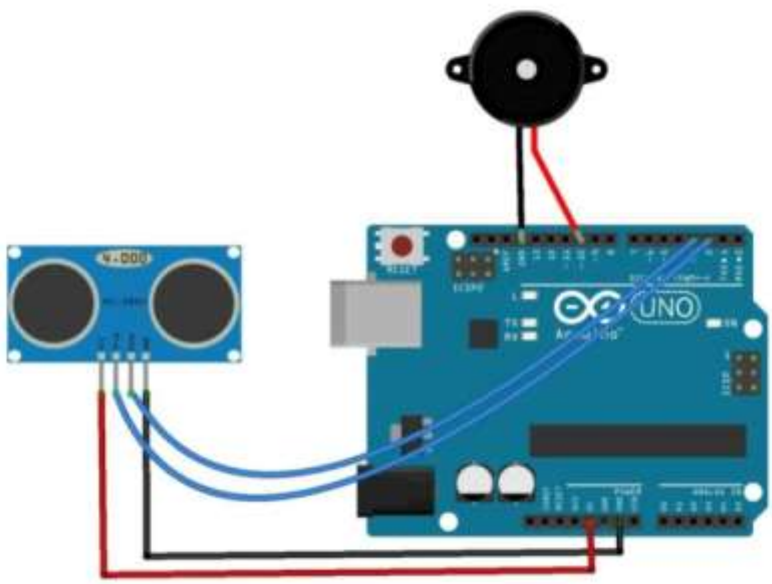

Figure 4.1.1: Ultrasonic Sensor assembly

The hardware of this project is not complicated to assemble. Making the contacts with the ultrasonic sensor with the Arduino first. The ultrasonic sensor is connected to the Arduino in the following steps. First, on the Arduino, VCC are connected on the Ultra sonic sensor to 5V pin. Second, we connected Trig pin-to-pin number 2 on the Arduino, and we also connected Echo pin-to-pin number 3 on the Arduino. The next step is we have connected the GND to GND on the Arduino. Finally, Making the contacts between the buzzer and the Arduino after that. Connect the buzzer's positive pin to pin 10 on the Arduino, and the buzzer's negative pin to the Arduino's GND pin.

4.1.2 Line tracking sensor:

The line-tracking sensor is located in the middle of the car as the most of the other parts.

There was no need to put it in the back or in the front of the robot like the ultrasonic sensor.

Figure 4.1.2: Line tracking sensor assembly

<u>Specifications</u>:

Working Voltage: 3.3V - 5V DC

Working Current: ≥ 20 mA

Operating Temperature: -10°C~+50°C

Detection distance: 2-40 cm

IO Interface: 4-Wire Interfaces (-/+/S/EN)

Output Signal: TTL Level (Low level when detecting objects/ high level when no objects/0 or 1 decides if objects exist)

Effective angle: 35°

Size: 28mm × 33mm

The particular reason why we choose The Digital Line Tracking Sensor is that it can lead your robot easily and reliably distinguishing white from black using a TTL signal. We would ensure much more accurate outcomes with a drawn path and effective programming than if the robot were merely told where to go without any context.

4.2 Results, Analysis and Discussion

Table 4.2: Data of the results

Time (s)	Distance (m)
0s	0m
2s	1m
4s	2m
6s	3m
8s	4m
10s	5m

Figure 4.2: Time vs Distance

As it is shown in the figure and the table above, we found out that the velocity of the car is 0.5 m/s. This velocity is more than enough for pipeline inspection. It is not awfully slow, and not extremely fast either where it is difficult see through the camera. Another calculation that has been done for the ultrasonic sensor stops the car 0.5m away from any object. It is a safe distance, which avoids the car from touching any liquids that might harm the car. We had an idea to make more the 0.5 m, but it leads to unclear vision and it will make difficult to the person who is seeing the live footage by the phone.

Chapter 5: Project Management

5.1 Project Plan

In our project, there are numerous tasks included. Each task is allotted to at least one individual. Here is the all data about the tasks, colleagues, and the term of each assignment to be finished. See table 5.1.1 for tasks and time to finish and table 5.1.2 for the tasks and the individuals who are responsible of.

Table 5.1.1: Tasks and their durations

#	Tasks		Start	End	Duration
1	Chapter 1: Introduction		31/1/2021	4/2/2021	4 days
2	Chapter 2: Literature Review	Project Background	7/2/2021	31/2/2021	6 days
		Previous Work			
		Comparative Study			
3	Chapter 3: System Design	Design Constraints & Design Methodology	14/2/2021	19/3/2021	34 days
		Engineering Design Standards			
		Theory & Theoretical Calculations			
		Product Subsystems & Selection of Components			
		Manufacturing and Assembly			
4	Chapter 4: System Testing & Analysis	Experimental Setup, Sensors and data			
		Results, Analysis and Discussion			
5	Chapter 5: Project Management	Project Plan	28/3/2021	7/4/2021	10 days
		Contribution of Team members			

		Project Execution Monitoring			
		Challenges & Decision Making			
		Project Bill of Material & Budget			
6	Chapter 6: Project Analysis	Life Long Learning	8/4/2021	13/4/2021	5 days
		Impact of Engineering Solution			
		Contemporary Issues Addressed			
7	Chapter 7: Conclusion & Recommendation	Conclusion	14/4/2021	17/4/2021	3 days
		Future Recommendation			
8	Design of Prototype	SolidWorks	14/2/2021	21/2/2021	7 days
9	Parts Purchase	Car Battery	9/2/2021	19/2/2021	10 days
		Sensors			
		Light			
		Wires			
		Motors			
10	Manufacturing	3D Printing	14/2/2021	17/2/2021	3 days
11	Testing	Changing Different Wires	20/3/2021	22/3/2021	2 days
		Adding More Sensors	23/3/2021	24/3/2021	1 day

		Retesting	25/3/2021	27/3/2021	2 days

Table 5.1.2: Tasks and assigned members

#	Tasks	Assigned Members
1	Chapter 1: Introduction	All
2	Chapter 2: Literature Review	All
3	Chapter 3: System Design	All
4	Chapter 4: System Testing & Analysis	Ahmed Alabbas
5	Chapter 5: Project Management	Abdullah Alsaleh
6	Chapter 6: Project Analysis	Mustafa Aljubarah
		Mohammed Alyousif
7	Chapter 7: Conclusion & Recommendation	Maytham Alasker
8	Design of Prototype	All
9	Parts Purchase	Abdullah Alsaleh
10	Manufacturing	Abdullah Alsaleh
11	Retesting	All

5.2 Contribution of Team Members

The team leader allocated the tasks in this project to the individuals. The tasks were assigned to each member keeping in mind their ability to perform them and deliver them in the specified time. Table 5.2 shows the assignments, the individuals who did them, and the percentage of contributions in every part from their side.

Table 5.2: Tasks the contribution of the members

<table>
<tr><th>#</th><th colspan="2">Tasks</th><th>Assigned Members</th><th>Cont. %</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Chapter 1: Introduction</td><td>Project Definition & Project Objectives</td><td>Abdullah Alsaleh</td><td>100%</td></tr>
<tr><td>Project Specifications Applications</td><td>Mytham Alasker</td><td>100%</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">Chapter 2: Literature Review</td><td>Project Background</td><td>Mohammad Alyousif</td><td>100%</td></tr>
<tr><td>Previous Work</td><td>Mustafa Aljubarah</td><td>100%</td></tr>
<tr><td>Comparative Study</td><td>Ahmed Alabbas</td><td>100%</td></tr>
<tr><td rowspan="5">3</td><td rowspan="5">Chapter 3: System Design</td><td>Design Constraints & Design Methodology</td><td>Abdullah Alsaleh</td><td>100%</td></tr>
<tr><td>Engineering Design Standards</td><td>Mustafa Aljubarah</td><td>100%</td></tr>
<tr><td>Theory & Theoretical Calculations</td><td>Mytham Alasker</td><td>100%</td></tr>
<tr><td>Product Subsystems & Selection of Components</td><td>Mohammad Alyousif</td><td>100%</td></tr>
<tr><td>Manufacturing and Assembly</td><td>Ahmad Alabbas</td><td>100%</td></tr>
<tr><td>4</td><td>Chapter 4: System Testing & Analysis</td><td>Experimental Setup, Sensors and data</td><td>Ahmad Alabbas</td><td>100%</td></tr>
</table>

		Results, Analysis and Discussion		
5	Chapter 5: Project Management	Project Plan	Abdullah Alsaleh	100%
		Contribution of Team members		
		Project Execution Monitoring		
		Challenges & Decision Making		
		Project Bill of Material & Budget		
6	Chapter 6: Project Analysis	Life Long Learning	Mustafa Aljubarah	100%
		Impact of Engineering Solution	Mohammad Alyousif	100%
		Contemporary Issues Addressed		
7	Chapter 7: Conclusion & Recommendation	Conclusion	Mytham Alasker	100%
		Future Recommendation		
8	Design of Prototype	SolidWorks	All	21/2/2021
9	Parts Purchase	Car Battery	Abdullah Alsaleh	100%
		Sensors		
		Light		
		Wires		

		Motors		
10	Manufacturing	3D Printing	Abdullah Alsaleh	100%
11	Testing	Changing Different Wires	All	100%
		Adding More Sensors		
		Retesting		

5.3 Project Execution Monitoring

During our task, we had numerous meetings, which identifies with improving our project. These meetings including the significant gathering and occasions that identified, which should be done regarding the project. In table 5.3 shows the rundown of meeting and different occasions for our project during spring semester 2021.

Table 5.3: Dates of the activates and events

Time / Date	**Activities / Events**
One time a week	Assessment Class
Weekly	Meeting with group members
Biweekly	Meeting with the advisor
March 24, 2021	Finishing 1st prototype
April 8, 2021	Midterm presentation
March 17, 2021	1st test of the system
April 17, 2021	Finishing final prototype
April 22, 2021	Test the system
April 22, 2021	Final submission of the report
April 22, 2021	Final presentation

5.4 Challenges and Decision Making

During the project stages, we confronted a few difficulties that influence the advancement of the project. The following difficulties are the main challenges we have confronted:

1- Device Problems

2- Testing

3- Design problems

5.4.1: Equipment and Devices Problems

In this project, we utilized different gadgets and sensors. Nevertheless, we had our share of difficulties with the sensors, but luckily, we prevail to tackle these issues, so the gadgets turned out great.

- **Sensors:**

In sensors, we have utilized two kinds of sensors. The first is an ultrasonic sensor, which is an electronic gadget that measures the distance of an objective article by radiating ultrasonic sound waves, and converts the reflected sound into an electrical sign. The second sort is a line follower sensor, which is a gadget that helps the robots to recognize lines or close by objects. The sensor works by recognizing mirrored light coming from its own infrared LED. In the ultrasonic sensor, evidently, we purchased a wrecked ultrasonic sensor from the web it didn't give any sort of reading, so we supplanted it with another one from a close by store and it turned out great. The second sensor is the line follower sensors. We got them from the web and they were not the ones we needed for our project, so we requested the college to provide us with a couple of them and we utilized them in our testing and they worked impeccably.

- **Testing and safety issues**

In testing, we did not have any problems with the body; however, we had few problems with the line follower sensor. We gathered some information regarding the sensor, and it seems like it was a coding issue. With that being said there was no risk in making neither the project nor the use of it.

❖ **Design Problems**

In our project, there was one main concern in the parts which are the wheels are set if they're going to be able to rotate without causing any issue or not. Nevertheless, our concern was for nothing. At the point when we printed the chassis we set the wheels, and they were a perfect fit and had enough room to rotate.

5.5 Project Bill of Materials and Budget

Table 5.5 shows the materials that we bought and their expenses in Saudi Riyals (SAR).

Table 5.5: Bill of materials

Materials	**Costs (SAR)**
Car chassis	349
Bluetooth ship	39
Smart car robot gear motor	44
Wheels	24
Car batteries	40
Arduino Uno	45
Micro Servo	28
Camera	119
Wires	40
Driver Motors	40
Ultrasonic Sensor	28
Line Tracking Sensor	44
Battery holder	7
Total	**847**

Chapter 6: Project Analysis

6.1 Life-long Learning

Like any project completed in life, it will end up with the acquisition of something new that will be added to our credit, whether it is knowledge, scientific, or even on the level of life thinking. In this project, we have a lot of experiences and skills that will definitely have an impact in the long run. And because there was a commitment to some basic skills in this project, such as working as a team and communicating between members of the team, we were able to succeed in achieving other skills, which are no less important than these two skills, in a wonderful way. In this section of the chapter, some of these experiences and skills will be explored in some detail.

6.1.1: Software Skills

Based on the fact that the nature of our project relied on designing a vehicle with specific specifications that would achieve the objectives of the project without obstacles, it was necessary to resort to some computer programs that were studied in previous semesters and which mainly contributed to the completion of the project as planned. For example, Solid-works program was used to design the vehicle's chassis according to the specified dimensions. Another software used in this project was the Arduino program which helped us in building a code that controls the speed of the motor, the ultrasonic sensor, and the Bluetooth technology. Among the programs that were used in this project is the Microsoft word that served us in writing the project report.

6.1.2: Hardware Skills

In this project, there are many components used to design the robotic vehicle. The main components were the Arduino Uno, the sensors, Bluetooth ship, and the Lithium battery. The ultrasonic sensor is used to detect objects. We used the line tracking sensor to make the vehicle following a certain path. The Bluetooth ship is used to enable us for remote controlling of the vehicle. The Lithium battery is used to supply power for the Arduino, Bluetooth ship, and the camera, which used to give live pictures during the inspection.

6.1.3: Time Management Skills

One of the most valuable skills that we were applying during our project was the time management. In our project, we were able to manage the tasks by using an important new mean which is the Gantt Chart that helped us in assigning proper needed time to fulfill each task. This Gantt chart helped us to finish the task on time. In the Gantt chart, we divided the large tasks to small tasks (subtasks) with its start and end time. This great tool helped to keep us in contact with the advisor about the weekly and monthly progress.

6.1.4: Project Management

To make sure that the project is going in the right path, we had to have a plan that mange the project. We started by assigning a leader for the project who is representing the team. We divided the tasks between the members of the team. Some of the tasks were to be done individually and some others as a team. Almost, we had a weekly meeting between the members and a monthly meeting with the advisor. This is in addition to the continuous weekly e-mail communication. All members were contributing in both the main tasks of the project, which were designing and manufacturing the prototype and researching and writing the report.

6.2 Impact of Engineering Solutions

In this section, we will target some of the most critical aspects of engineering solutions in terms of their effectiveness. Those aspects are mostly concerned with the safety of technicians, the general economy, and ensuring less harm to the environment.

6.2.1: Safety

Our project aims to reduce the risk of contamination on technicians and to avoid human error. For instance, nowadays we are relying on manpower and risking the lives of many people by exposing them to harmful chemical substances and other such materials. Where the robotic car will not have to face any of those obstacles.

6.2.2: Economy

When it comes to the economy, this project will save a huge amount of money by cutting the cost of labor by more than 50%. Not to mention that there will be a major cut in insurance costs and other compensation, along with their benefits. Another thing is that this robotic car only needs one operator, which will help minimize production costs. Furthermore, there will be a major increase in productivity and improvement in efficiency, since the robotic car has line-tracking sensors. The most prominent issue with the car is the maintenance of the wheels, which can cost about 40 SAR/Month. This project as a whole will cost around 900 SAR.

Table 6.2.2: Cost of the components

Components	**Costs (SAR)**
Car chassis	349
Bluetooth ship	39
Smart car robot gear motor	44
Wheels	24
Car batteries	40
Arduino Uno	45
Micro Servo	28

Camera	119
Wires	40
Driver Motors	40
Ultrasonic Sensor	28
Line Tracking Sensor	44
Battery holder	7
Total	**847**

6.2.3: Environmentally

In the case of the environmental properties, we assured that the battery is rechargeable, which will lessen the dependency on fuel. Therefore, no carbon footprint will be produced, instead most materials used are recyclable. In this prototype, it can operate for up to 4 hours, and cover a distance of 4 to 5Km. Yet, we can assure with the technology advancing everyday we can double the time and distance.

6.3 Contemporary Issues Addressed

Piping suffers a major issue due to chemical substance and other fluids running through them. Such as, corrosion, cracks, sediments and internal lining failure. In the long run of service and the exposure of the fluids. Specially, when most pipes are made of metal such cast iron and steel, the metal pipes will result to high rate of failure. For example, the case in Canada the failure rate of cast iron pipes can reach up to 39 bursts per 100km/year. While in Australia the failure rate of water mains is 20 bursts per 100km/year on average. Therefore, detecting the issue from its early stages is very important, which can reduce the loss of delivered material and save money significantly.

Chapter 7: Conclusion and Recommendation

7.1 Conclusion

Every design, project or business it is important that you learn from it. Learn from your mistakes and improve on your skills. We enjoyed working together on this project. We all improved on our teamwork and communication skills. At the beginning of this project, it was not easy to work together. However, as we moved on, we all were very comfortable on working together as a team. I believed we developed a very nice working project and we put a lot of work and effort into it. We used everything that we learnt throughout our engineering courses in this project. From electrical things to using SolidWorks to draw our design, and also to program coding into the design. We made sure that our robot has enough torque to work properly without any problems. To end, working as a team is really fun, and it will benefit all of us in the long run. It was nice to develop a fully working project from simple ideas to a very complex design. I am really proud of what we have achieved.

7.2 Future Recommendations

There are many ideas that we thought of to make our project advanced. However, most of these ideas require us to spend a lot of money which was the issue that we have faced. We wanted to make our robot work on wireless instead of Bluetooth because Bluetooth only travels short distance. However, we faced problems working on wireless because we did not have enough budget. From the start, we decided that we do not want a basic design and that is my recommendation to anyone who is going to work on their senior design. Never look for an easy design nor should you look for a very complex design. When starting on your project, always make the most effort to do a full research to put your ideas together. Always work on you project as a team and share ideas with your group. Before working on your actual hands-on work, make sure you have all your ideas written down in order. Make sure your 3D design is clear and nice looking. Finally, make sure that you work on everything and finishing it before the due time. So, you have enough time to do testing and more testing because it is very important to have a fully working project.

References

[1] Nishijima, K., Sun, Y., Srivastava, R., Ogai, H., & Bhattacharya, B. (2010, December 01). Advanced pipe inspection robot using rotating probe. Retrieved February 17, 2021, from https://waseda.pure.elsevier.com/ja/publications/advanced-pipe-inspection-robot-using-rotating-probe

[2] waterproof weatherproof robotic sewer camera x5-hw pipeline cctv inspection robot. (n.d.). Retrieved February 17, 2021, from https://m.made-in-china.com/product/Waterproof-Weatherproof-Robotic-Sewer-Camera-X5-Hw-Pipeline-CCTV-Inspection-Robot-941124205.html

[3] Maity, A., Roy, K., & Gupta, D. (2019, May 1). Designing, 3D Printing of a Quadruped Robot and Choice of Materials for Fabrication. Retrieved February 14, 2021, from https://www.researchgate.net/publication/333457421_Designing_3D_Printing_of_a_Quadruped_Robot_and_Choice_of_Materials_for_Fabrication

[4] Gonzalez, C., Alvarado, I., & Peña, D. (2017, October 18). Low cost Two-wheels SELF-BALANCING robot for control education. Retrieved February 17, 2021, from https://www.sciencedirect.com/science/article/pii/S2405896317323406

[5] Curkovic, P., Šarančić, D., & Miskovic, L. (2018, January 5). Legged 3D Printed Mobile Robot. Retrieved February 16, 2021, from https://www.researchgate.net/profile/David_Sarancic/publication/329461438_Legged_3D_Printed_Mobile_Robot/links/5c0e9a8b4585157ac1b90092/Legged-3D-Printed-Mobile-Robot.pdf