جامعة الأمير محمد بن فهد
PRINCE MOHAMMAD BIN FAHD UNIVERSITY

College of Engineering

Department of Mechanical Engineering

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Senior Design Project Report

Pipe Inspection and Cleaning Robot

In partial fulfillment of the requirements for the Degree of Bachelor of Science in Mechanical Engineering

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Abstract

The name of our project is pipe the pipe inspecting and cleaning robot (PIAC); in a nutshell it is a robot that will be used to clean the interior of the pipes using a brushing mechanism. One of the critical areas of the oil and gas industry is the transport of oil and other fluids through a network of pipes. Over time these pipes have accumulated amount of slug and other deposits; this leads to decrease in pipeline carrying capacity, reduced reliability, loss of power due to higher pumping pressure required and irregular flow.

In the light of the problems mentioned above we have decided to attempt to solve this problem using our PIAC project. This will not only clean the interior of the pipe but also be able to send live video feedback to the personnel on the ground depicting the kind of residues found in the pipes. The robot can also be added with additional sensors to relay any other critical information. During the course of the project we have faced multiple challenges, which were mitigated by the team accordingly using alternatives and prior knowledge through literature review.

There are many outcomes of this project. The first being that the set objectives of the project are achieved which in a nutshell was to build a prototype PIAC with the mobility, cleaning and video feedback functionality. The second outcome is that the project has worked effectively to clean the rust that was in a sample pipe. The amount of rust removed for the pipe was about 4 grams cleaning a surface area of 0.398 square meters the fourth outcome of the project is that the team was able to lean many new things about the pipe cleaning industry through the literature review and during building the prototype. The fourth and final outcome of the project is that there is scope of improvement for the project and new engineering standards such as ASME , NEC and IEEE can be incorporated in later builds

Acknowledgements

The final year project is a testament to the engineering mindset of the student and his capacity of problem solving and applying engineering principals. However the completion of the project can never be possible without the help of individual's whether be it at home or in university. We owe a lot to our advisors `Mr Nader Sawalhi and Dr Farmars Djavanroodi. It is they who have supported our project and believed in us. With their valuable advice and guidance we were able to make critical adjustments at specific junctures of the project.
We would also like to thank Dr Jamal Nayfeh for his excellent leadership in guiding all the students to the path of academic excellence. Our parents our are hidden strength and have supported us in very way. Not a leaf falls before his permission we express our gratitude to Allah the almighty

1 Table of Contents

1. Introduction

1.1 Project Definition

The name of our project is the pipe inspecting and cleaning robot (PIAC). As the name suggests the robot will be built to clean the residues that are built up inside the pipe. This is done through a brushing mechanism. Not only this robot will also be able to relay live video feedback from the ground to the controller that the user has. By this the users can verify the cleaning that is done by the robot

1.2 Project Objectives

During the execution of the projects we have had specific and transparent objectives. These include the following:

a. Increased pipeline carrying capacity: As the deposits are removed the volume inside the pipe increases
b. Improved product quality: Corrosion can cause catastrophic failure with a check in corrosion such a risk is avoided
c. Power savings by reducing pump pressure: As carrying capacity increases the pump requires less pressure to pump the fluid into the pipe
d. Confirmation of pipe and flow integrity
e. Live video streaming: To monitor the condition of the pipe and to make sure that the cleaning is done
f. Remote robot control

Product objectives:

a. Compact design
b. Light weight
c. Plastic structure

d. 3 motors (1 cleaning 2 mobility/crawling)

1.3 Project Specifications

The PIAC consists of several sub systems that have been integrated into one sophisticated robot. The specifications are stated below

I. Metrics

a. Power of the cleaning motor: 10 Watts (Depends on load)
b. Power of front mobility motor: 3 Watts (Depends on load)
c. Power of rear mobility motor (wider wheelbase); 6 Watts (Depends on load)
d. Voltage input for camera: 12 V
e. Voltage input for controller: 12V
f. Kind of battery: Lead acid 1.2 AH
g. Platform: Open source
h. Weight: 1250 g

II. Marketing

a. Easy to use
b. Easy to recharge
c. Long lasting battery
d. ROHS compliant
e. Compact and portable
f. Energy efficient

1.4 Product Architecture and Components

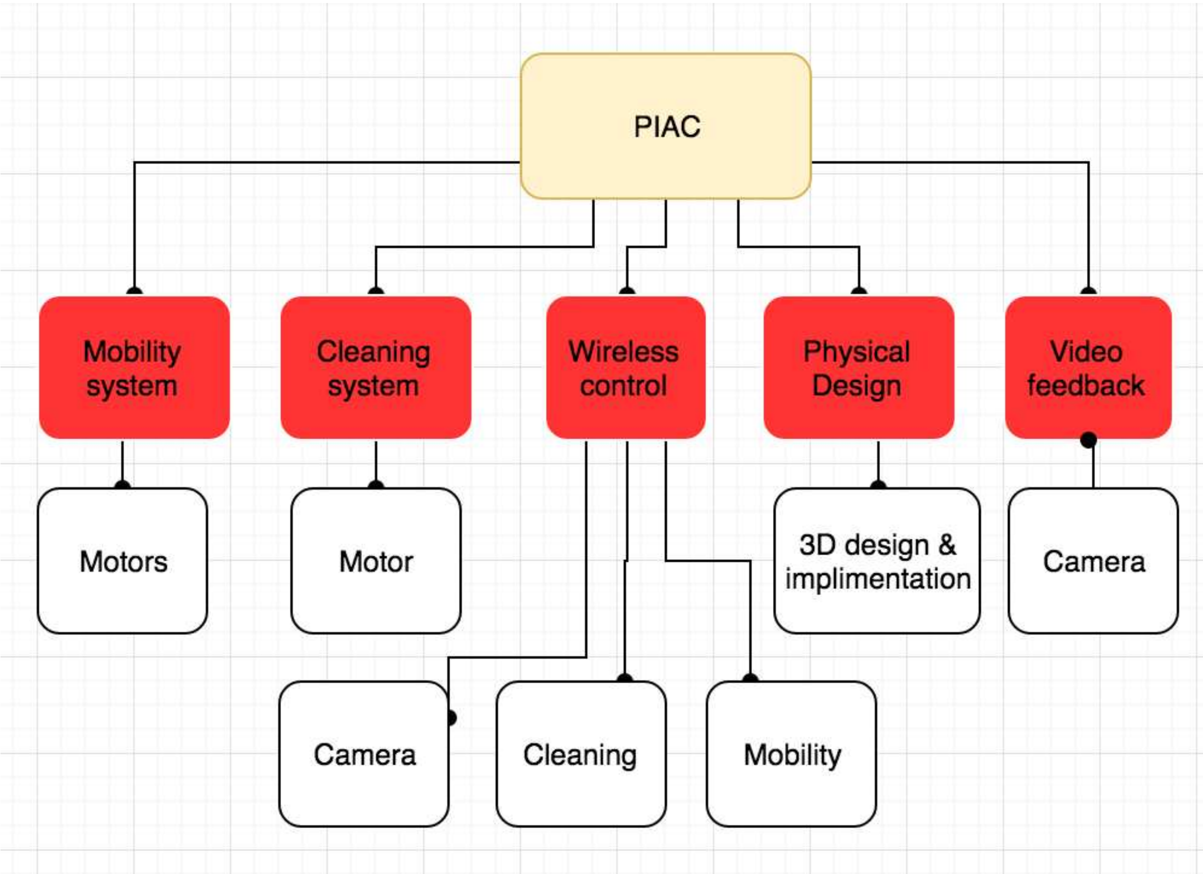

Figure 1.1: Functional diagram

This figure represents the functional system and sub-cross functional system. In the functional diagram it shows the system which we used to make our project and as shown there are five functions of our project (PIAC), and every function has functions to make the system integrated and complete.

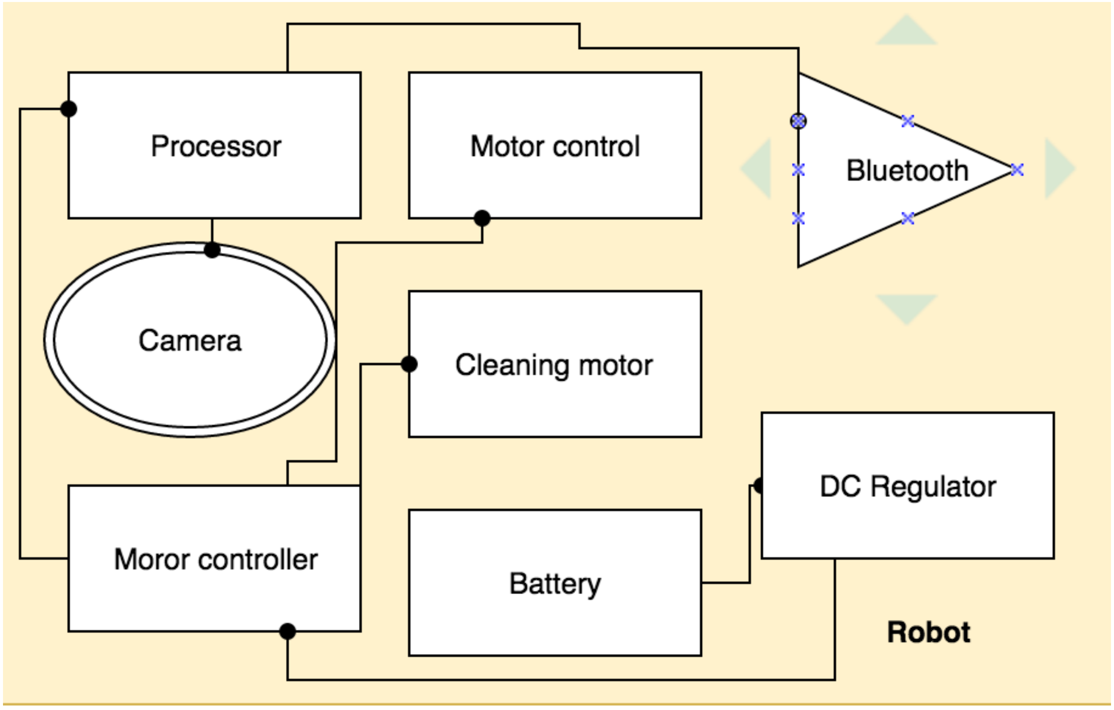

Figure 1.2: Sub system connection

The main sub systems of our project PIAC are as follows:

a. Mobility system: The mobility system consists of the motors that control the motion of the robot with the pipe. There are 2 motors that are connected to 4 wheels 2 in the front and 2 at the back.
b. Cleaning system: the cleaning system consist of the powerful cleaning motor that is connected to the from of the PIAC
c. Wireless control: Wireless control system is responsible for the wireless communication between the robot and the
d. Physical design: This sub sections studies the feasibility of the physical design of the project and if the project design is viable
e. Video feedback: This sub system connects the camera to the rest of the PIAC

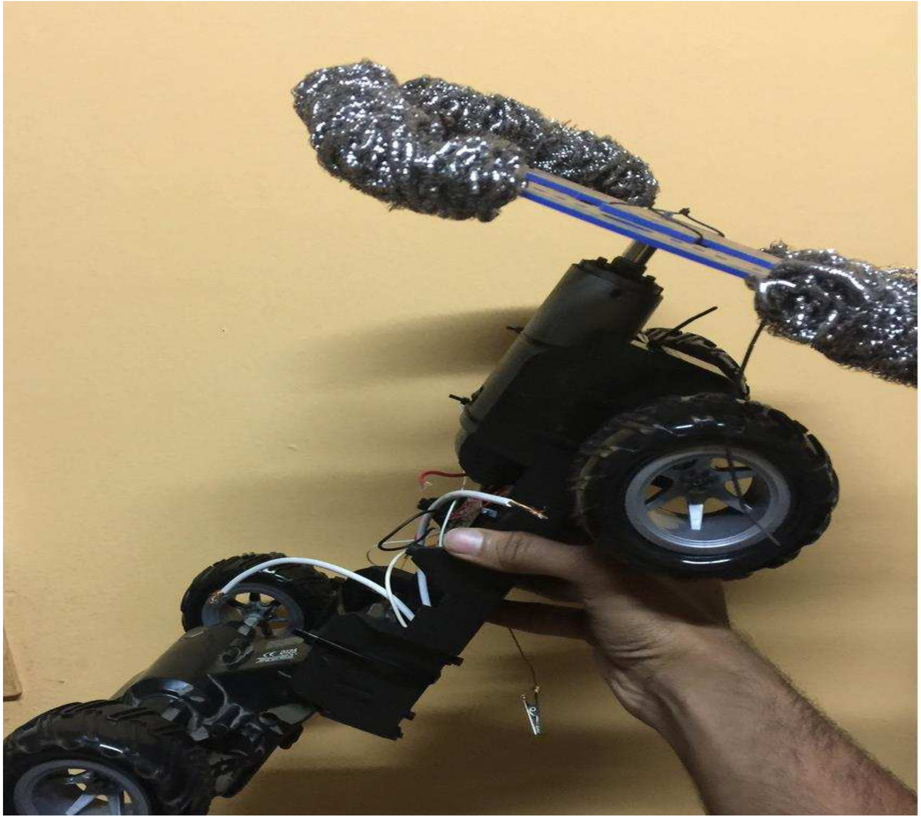

Figure 1.3: Final physical design

As can be seen in the figure the PIAC has 4 wheels and 1 cleaning brush. The cleaning brush is significantly large because it snugly fits into the pipe diameter and also can comprehensively clean the top and the bottom. This system has been finalized after 2 have the other design and implementation were canceled due to the improper designs.

After we finish the final physical design we have covered the wires and we improve the look of the project. The design of the wheels helps to avoid flipping or rotating inside the pipe which could cause damage to the robot.

1.5 Applications

The application of our system is very specific. It can be used in the following industries:

a. Oil and gas (To clean slug and other deposits formed in the pipes)
b. Water pipes (To detect leakage and save the water)
c. Survey (To relay video information)
d. Allow inspection of inaccessible and / or hazardous equipment or work areas.
e. Provide on-line inspection / maintenance without loss of equipment / plant availability & remove
f. humans from potentially hazardous work situations.
g. Provide information about the health and condition of critical plant components to Facilitate decision-
h. making regarding plant life management
i. Reduce equipment / plant downtime and improve maintenance and inspection procedure thorough better
j. coverage and documentation.
k. The robot has great application in accessing the regions of pipe in which human doesn't have reach. It could be mounted with a camera which would send us pictures of inside and would help in our inspection.
l. It could be fitted with ultrasonic sensors and can pin point us the location of a hole.
m. It even has an application in painting up the old installed pipe from the inside very easily.
n. It could be even used for the dosing purpose through a pipe as its pitch is fixed we could attach some material to be dosed and control the feeding of the material inside where we want.

2. Literature Review

2.1 Project background

A pipeline inspection gadget (PIG) is a device used to run through pipelines for cleaning, measurement and inspection operations. By-pass is the name for one or a set of orifices allowing flow from back to front of a PIG. It is used for speed control or to improve cleaning operations results. By-pass prevents speed excursions in gas pipelines thereby avoiding damage to the PIG or the pipe.

Studies and algorithms have been developed to simulate the dynamics of PIGs running inside pipes. Most studies have been for gas pipelines; these have helped to design some PIG models.

By optimizing the cylindrical shape of the pipes high efficiency is achieved. This reduces interaction force between the body and the fluid hence reduces internal loss.

Addressing the topic of corrosion it can be brought to account that it is very for failures to occur because of the pipe corrosion. The only way to avoid this is by preventive maintenance and cleaning. Below **table 2.1** summarizes the failure modes of the pipes

Table 2.1: Failure modes of pipes

2002-2009		2010-2013		Failure modes adopted in this study
Leak	Pinhole	Leak	Pinhole	Leak
			Crack	
	Connection failure		Connection failure	
			Seal or packing	
			Other leak type	
	Puncture	Mechanical puncture		Puncture
Rupture	Circumferential	Rupture	Circumferential	Rupture
	Longitudinal		Longitudinal	
			Other of rupture type	
Other		Other		Other

To avoid such kind of failures inspection of the pipes is very critical. In the industry the only proven device to carry out these inspection activities are the PIAC they are detailed below

The pipe inspecting and cleaning robot (PIAC) that we are making will have completely different dynamics to be taken into consideration for efficiency as it is not a PIG. However the robot will be more advanced as sensors and cameras can be fit in it.

Our project will be used to clean gas pipelines in the major industries. Moreover Saudi Arabia is an ideal market for an introduction of such a product because of the numerous refineries and the need for continuous cleaning.
The size of the pipe that is applicable for our robot is fixed at 12 inches diameter. In future modifications we shall make the robot more versatile

2.2 Previous Work

It is very critical for us to review the previous work before we deliver deeper into the development of the project. Below is a summary of the projects that have been done.

2.2.1: In-pipe Cleaning Mechanical System for DeWaLoP Robot - Developing Water Loss Prevention [1]

The work presented in **[1]** describes the design and development of a mechanism used for pipe-joint redevelopment from the Developing Water Loss Prevention (DeWaLoP) project. The project objective is to redevelop the cast-iron pipes of the over 100 years old fresh water supply systems of Vienna and Bratislava, by building a robot that crawls into water canals of about one meter in diameter and that is able to clean and apply a restoration material to repair the pipe-joint gaps.

This proposed redevelopment pipe-joint method is more complex than conventional ones, which superficially clean the in-pipe surface with a rotating tool located at the front of the robot without cleaning in detail the area of application.

The DeWaLoP redevelopment method removes the corrosion with a power tool, such as grinding tools, suck the debris with a wet and dry vacuum cleaner and then apply a restoration material to seal the pipe-joint, preventing it from water loss as well as from external contamination.

To do so, the proposed mechanism must be precise, due to the required pipe-joint gap dimension, in the range of 2 to 30mm and due that cast-iron is a fragile material and can be broken easily. Therefore, the mechanism developed is similar to a double ”flexible” cylindrical robot, able to cover the inner pipe surface for different pipe diameters, ranging from 800mm to 1000mm.

Figure 2.1 depicts a) Human operator partial cleaning. b) Cleaning result from human operator c) DeWaLoP robot with milling head. d) Drive wheel with suspension system. e) DeWaLoP robot with straight grinder - grinding head installed. f) DeWaLoP robot with angle grinder - brushes disk installed.

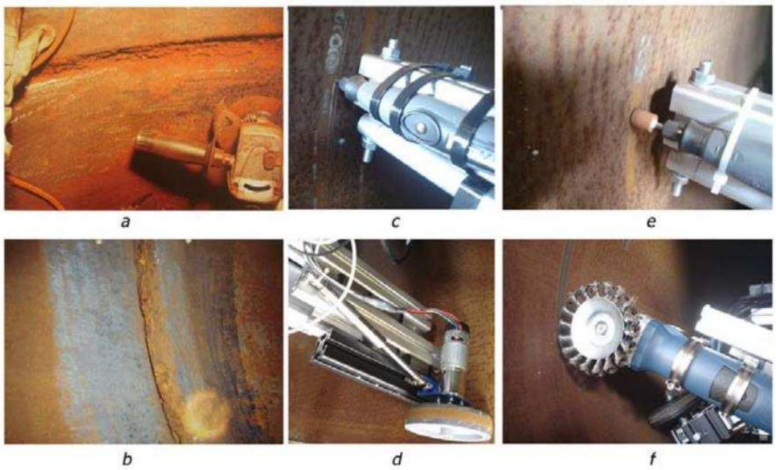

Figure 2.1: Human operator partial cleaning

2.2.2: Oil Pipelines/Water Pipeline Crawling Robot for Leakage [2]

Drive control system plays important roles in pipeline robot. In order to inspect the flaw and corrosion of seabed crude oil pipeline, an original mobile pipeline robot with crawler drive unit, power and monitor unit, central control unit, and ultrasonic wave inspection device is developed.

Considering the limited space, a compact hardware system is designed based on an ARM processor with controllers. With made-to-order protocol for the crawl robot, an intelligent drive control system is developed.

The implementation of the crawl robot demonstrates that the presented drive control scheme can meet the motion control requirements of the underwater pipeline crawl robot.

As shown in **Figure 2.2,** the in-pipe robot inspection system contains ten units, including crawler unit, drive unit, central controller unit, battery unit and ultrasonic inspect unit, etc.

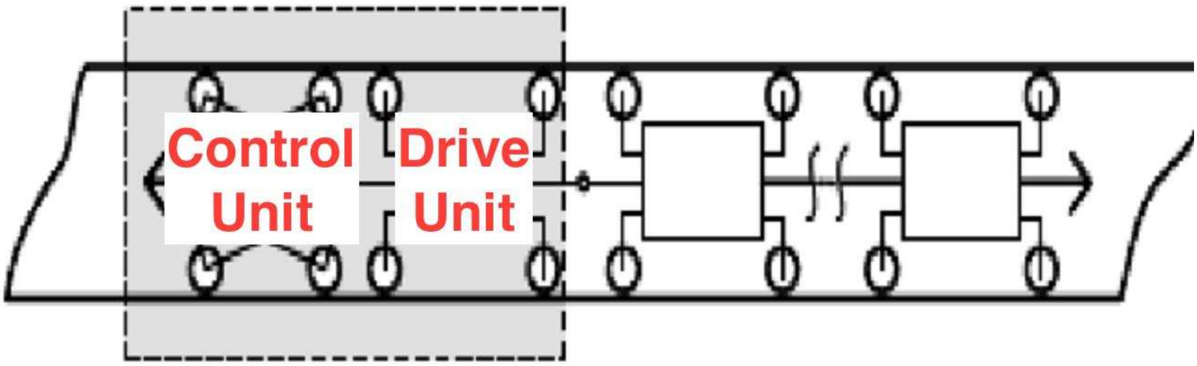

Figure 2.2: Overall structure

2.2.3: Fully Autonomous Pipeline Cleaning Robot [3]

Fully Autonomous Pipeline Cleaning Robot is used to clean the mud or dirt inside the pipe. The autonomous pipe cleaning robot has four tracks to make a smooth mobility inside the pipe. The track was attached with foldable linkage. The foldable linkages give the ability to the robot to move horizontally or vertically inside the pipe.

The compress and track design was combined together to maximize the efficiency of the robot. Furthermore, the track wheel will give more friction between robot and the pipe. Thus it can prevent the robot from slipping or spinning inside the pipe. The wire brushes are an effective way to remove the mud inside the pipe. This gives the idea of combining the robot technology with the wire brushes cleaning technology.

The brushes are attached behind the robot. The brushes will rotate to clean the mud .The cleaning process will start if the sensors detect the mud. If the sensors do not detect the mud, the cleaning process will not happen. By using this method the life span of battery can last longer due to power saving. The dsPIC30F4011 is used as the microcontroller for the robot to control the movement of the robot. The sensor used in this project is infra red sensor.

Infra-red sensor is used to detect the obstacle in front of the robot. If there are any obstacles the robot will reverse automatically until the robot come up from the pipe. **[3]**

2.2.4: Design of a Fully Autonomous Mobile Pipeline Exploration Robot (Famper) [4]

This thesis presents the design and implementation of a robot based on novel idea we call "caterpillar navigational mechanism". A Fully Autonomous Mobile Pipeline Exploration Robot (FAMPER), for exploring pipeline structures autonomously has been built and its performance has been evaluated.

We present the design of a robot based on wall-pressed caterpillar type for not only horizontal, but also vertical mobility in pipeline elements such as straight pipelines, elbows and branches, and its autonomous navigational system providing useful information for pipeline maintenance.

FAMPER has been designed for 6 inch sewer pipes, which are predominantly used in urban constructions. The proposed design enables FAMPER to display formidable mobility and controllability in most of the existing structure of pipeline, and provides a spacious body for housing various electronic devices. Specifically, FAMPER is equipped with several sensors, and a high performance processor for autonomous navigation.

We have performed experiments to evaluate the effectiveness of our architecture and we present here a discussion of the performed results. As we can see **Figure 2.3** shows the robots operational architecture **[4]**

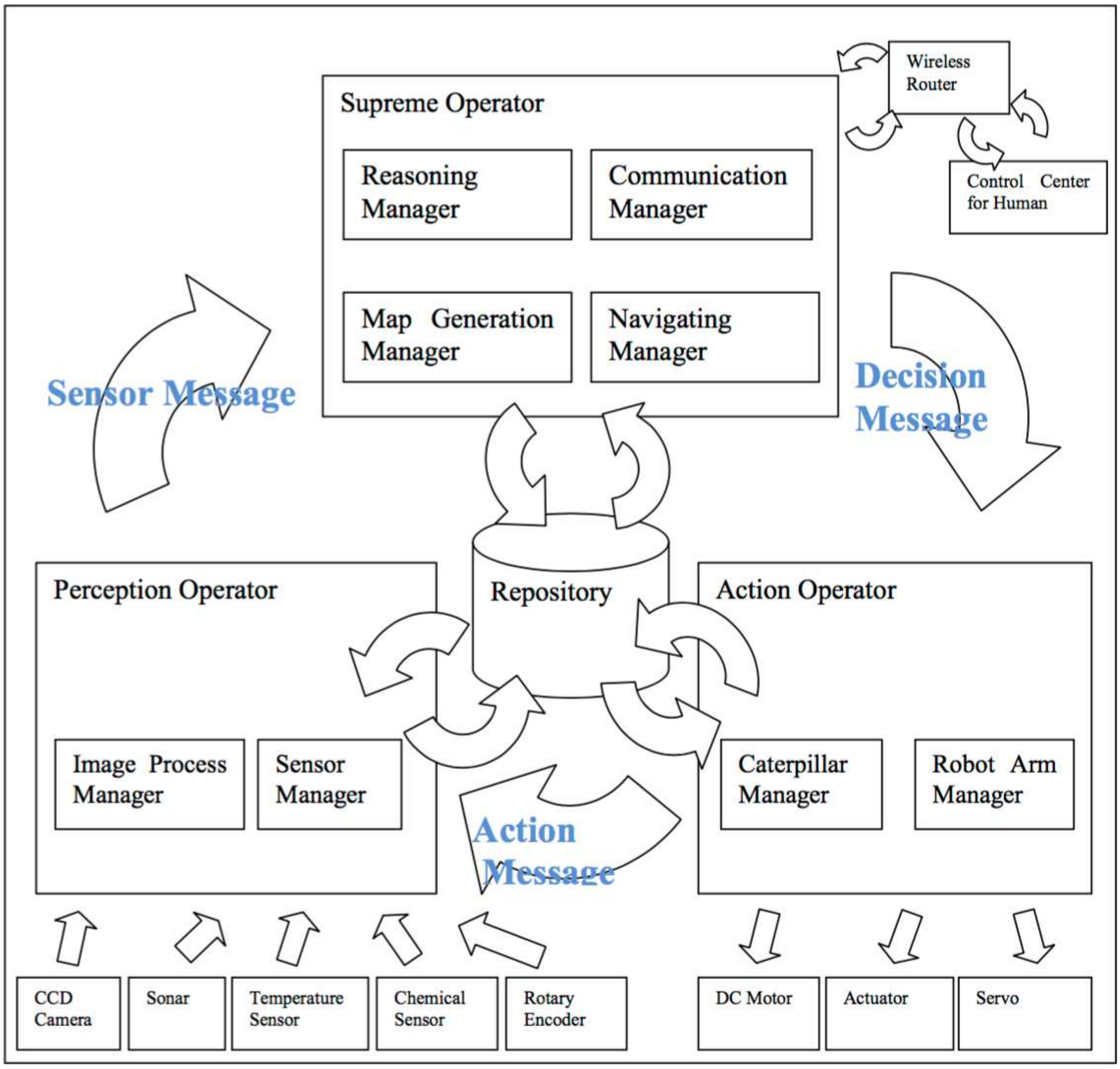

Figure 2.3: Flow diagram for operational architecture [4]

2.2.5 Advanced pipe inspection robot [8]

Recently many plants' pipes and drains became old and many robots to inspect these pipes were developed in the past. Wired robots were put to practical use, but they had a heavy power supply and a signal wire.

Therefore, new inspection robots using wireless radio communication system are considered useful for long complex pipes and long distance pipes including straight, vertical and bend line. But sending wireless radio signals isn't practical because the properties of the radio wave are affected by the shape and material of the pipes.

For these reasons, it measured the properties of wireless radio signal with steel pipes and ceramic pipes and it developed a practical wireless radio communication system. On the other hand, the Indian Institute of Technology Kanpur has researched a rotating probe using piezo element for inspecting the inside of pipes with a touch sensor system. This time, we developed and tested a new inspection robot that had integrated both the inspection system using wireless radio communication and image transmission developed by Waseca University and the inspection system using the rotating probe developed by the Indian Institute of Technology.

In this experiment, it was confirmed that it could drive the robot by wireless radio communication system in the inside test pipe and collect the image and some signals from the rotating probe.

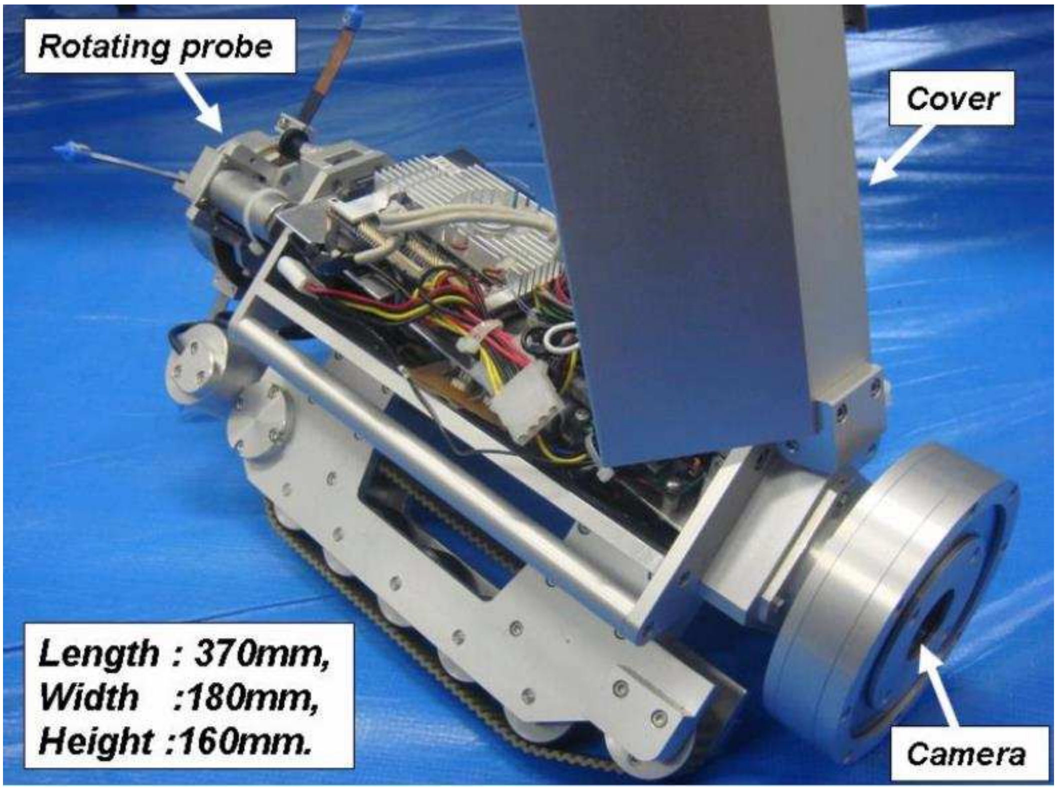

Figure 2.4: Final prototype [8]

2.3 Comparative Study

There has been significant amount of research that has been done in the field of gas pipe cleaning. After going through the literature review we have decided to divide the project deliverability and features into categories. Reading the literature review has enabled us to understand better how the project can be implemented

Table 2.2: literature review of the project

	Autonomous Cleaning	Video Feedback	PIG (Pipeline inspection gadget)	Jet Cleaning (Other than mechanical brushing)	Cleaning (with metal brush)	Remote control	Inspection
Literature review 1[1]	NO	NO	NO	NO	NO	YES	NO
Literature review 2 [2]	SEMI	NO	NO	NO	YES	YES	YES
Literature review 3 [3]	YES	NO	NO	NO	YES	YES	Sensors
Literature review 4 [4]	YES	NO	NO	YES	YES	YES	YES
Our project: <u>The pipe inspecting and cleaning robot</u>	**NO**	**YES**	**NO**	**NO**	**YES**	**YES**	**Manual**

As can be seen in table 2 the literature review findings show that robots that have been made by the institutions concerned have not included all the features that are ideal such as video feedback. Only our PIAC will have such a feature however the other robots have some other features such as sensory feedback which will be absent from the PIAC

3. System Design

3.1 Design Constraints

3.1.1 Specifications

To complete the project it is very critical to have the project specifications before the commencement of development. This will ensure the conformity with the standards set. Below are the specifications of the PIAC:

- Video streaming 480p
- Vertical movement within the pipe (Max crawl 2km/h)
- Wireless control (up to 200 m)
- Cleaning metal bristles
- Plastic body
- 7 Megapixels Camera
- Integrated joystick for comprehensive control of the robot
- Rechargeable Lead acid battery to power the cleaning motor
- Rechargeable NiCad battery to run the movement

3.1.2 Design Requirements

The application of this project is industrial. With use of the PIAC in the industrial oil pipes cleaning and monitoring can easily be performed with utmost ease and professionalism. To be able to achieve this following critical design requirements must be achieved:

1. In pipe crawling: To navigate within the pipe
2. Cleaning motor with bristles: To clean any built up or slug inside the pipe
3. Long battery life: To ensure practicality of use; for this to be achieved the power management of the system has to be efficient
4. Wireless control: long range wireless control is critical for the success of the project as pipelines are made of steel and obstruct the transmission of electro magnetic waves
5. Video streaming: video streaming is critical to check the condition of the pipe before and after the completion of cleaning

3.1.3 Constraints

Several designs constrains have been implicated in the project they are as follows:

Time: there is a severe time constraint for this project, as it has to be completed within the duration of the course and be submitted for grading. Due to this many processes need to be cut short and extensive testing also must be avoided.

Pipe size: Initially the main challenge that was faced by the group was to determine the size of the pipe. This is because one device cannot be developed to fit all sizes. Hence this robot can only be used to clean pipes of a fixed size.

Range of operation & battery: This robot will have limited distance at which it can operate and the battery life. These are 2 critical factors that determine the duration and distance it can be used for

3.1.4 Standards

Since this is a first prototype we will not be implementing any engineering standards. However in the subsequent implementations we have suggested to have the following standards:

1. ROHS: (Restriction Of Hazardous Substances) it is environmental certification.
2. CE: (Certified Electronics) with this certification we can be sure it is safe to use.
3. IP 67: water and dust protection.

3.2 Design Methodology

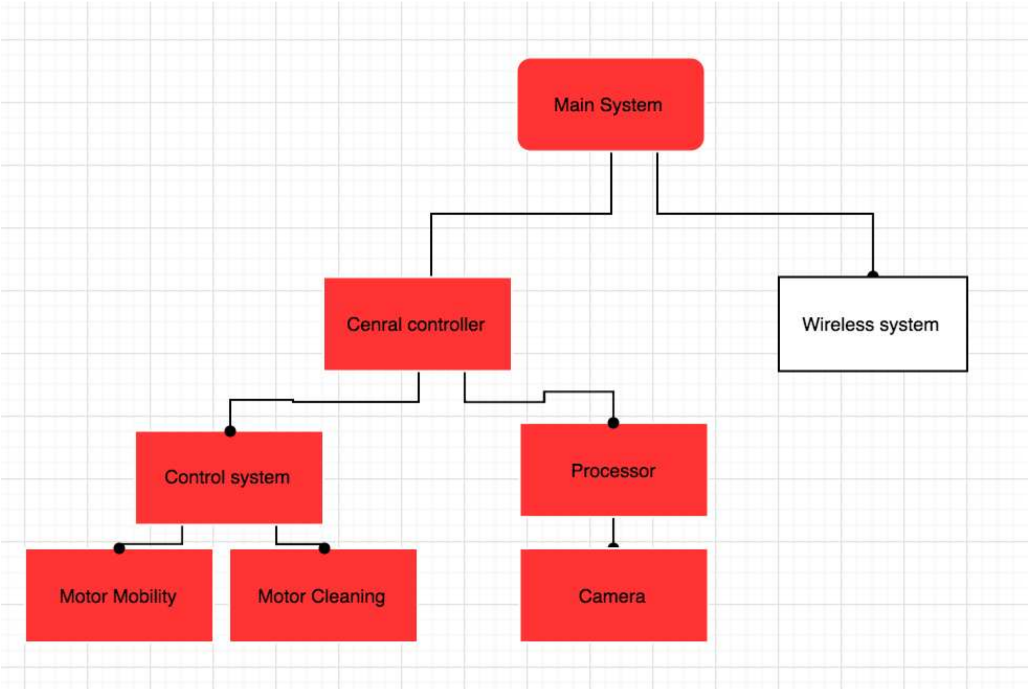

Figure 3.1 System architecture

Figure 3.1 shows the system architecture and the relation of the various sub-systems in the project.

Due to the complexity of the project it has been divided into multiple sub section the figure 3.2 Below summaries it

Figure 3.2: Project Sub Sections

Broadly the project has been divided into the flowing sub sections:

1. **Video monitoring**
2. **Mobility system**
3. **Cleaning system**
4. **Structural design**
5. **Wireless commination control**
6. **Wireless video streaming control**

The methodology we used for the project development was to first brainstorm the way of implementation. Later several literatures were reviewed to put the objectives of the project into perspective. We have then simulated and tested the proposed design to study the feasibility of the project. Below is the first prototype design; this was rejected due to being ineffective inside the pipe. **Figure 3.3** shows the first design simulation made by AutoCAD.

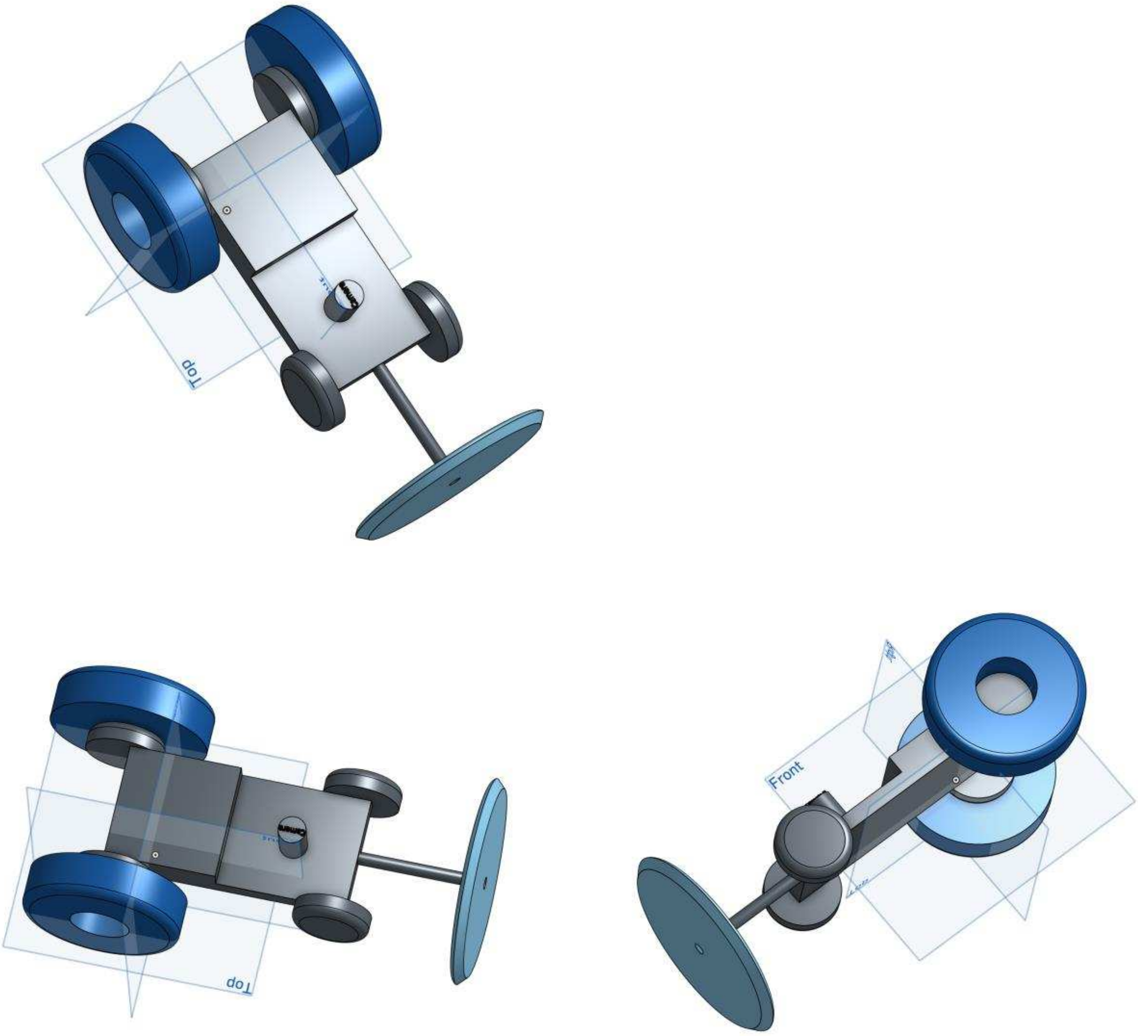

Figure 3.3: First design simulation

On subsequent it was decided that 8 wheels would be used to provide better stability within the pipe **(figure 3.3).** However even this design was revised to a better version as seen in **figure 3.4**

Design parameters

The following design parameters are taken into consideration during the design and implementation phase of this project

Rotational Speed

The rotational speed of the cleaning motor has to be at least as much as that of the mobility motor. The expected RPM of the mobility motor should be around 4000 RPM and that of the cleaning motor to be around 7000 RPM

Delivery date

The project is to be completed before 1 Jan 2017

Battery life

The product should be able to clean a I km long pipe on a single charge

Weight

The product shall not be more than 5 Kg

Product cost

The product should not cost more that 10,000 Sr fro development as a prototype

Operating costs

There should be zero operating costs associated with the product except for regular maintenance

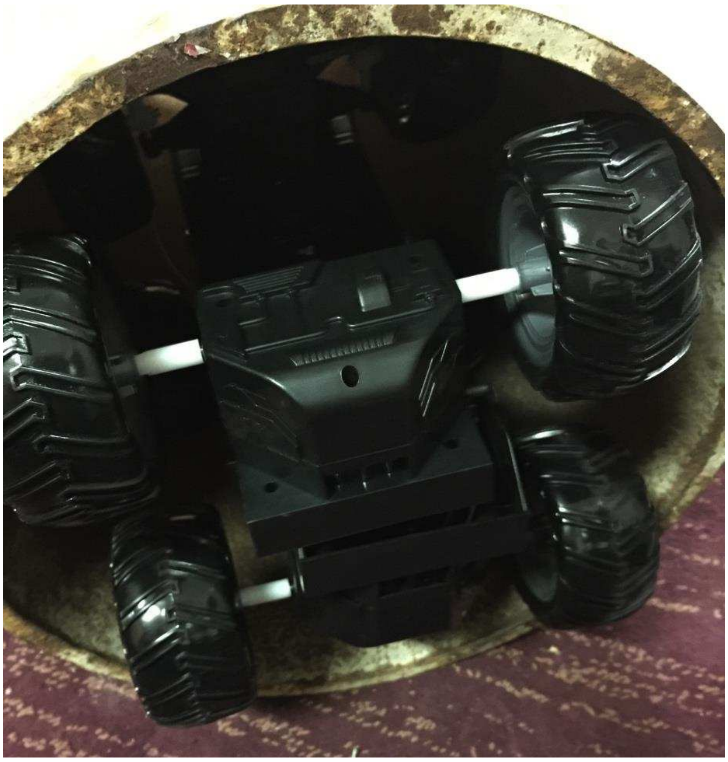

Figure 3.4 wheel design proved to be more effective

Figure 3.5 Final physical design

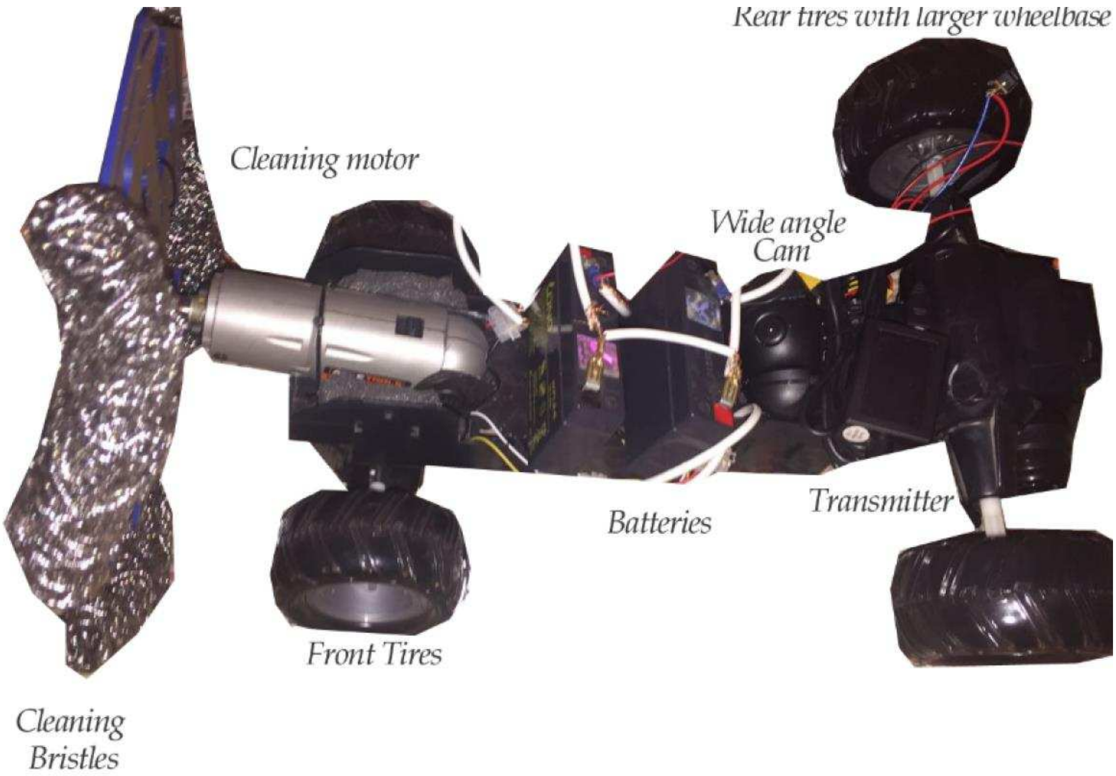

Figure 3.6: Breakdown of components

Figures 3.4 shows the initial rejected design; Figures 3.5 and 3.6 show the final project design

3.3 Product Subsystems and Components

1. **Video monitoring**

   Components used:

   - Raspberry pi

     The Raspberry Pi 3 is the third generation Raspberry Pi. It replaced the Raspberry Pi 2 Model B in February 2016. Compared to the Raspberry Pi 2 it has:

     1. A 1.2GHz 64-bit quad-core ARMv8 CPU
     2. 802.11n Wireless LAN
     3. Bluetooth 4.1
     4. Bluetooth Low Energy (BLE)
     5. Like the Pi 2, it also has:

6. 1GB RAM
7. 4 USB ports
8. 40 GPIO pins
9. Full HDMI port
10. Ethernet port
11. Combined 3.5mm audio jack and composite video
12. Camera interface (CSI)
13. Display interface (DSI)
14. Micro SD card slot (now push-pull rather than push-push)
15. VideoCore IV 3D graphics core
16. The Raspberry Pi 3 has an identical form factor to the previous Pi 2 (and Pi 1 Model B+) and has complete compatibility with Raspberry Pi 1 and 2.

- Camera

  12V Wireless Camera System. Water-resistant Wide, 110-degree viewing angle; Wireless transmitter; LCD screen has Standby and Auto-On; Adjustable arm with suction cup.
- LED illumination
- Radio TX RX

  This module is used for the wireless transmission and reception of signals mainly used for controlling the PIAC
- Wi-Fi streaming (Optional)

  Wifi stream has the application of streaming the video

2. Mobility system

Components used:

- Atmel 328

  Arduino/Genuino Uno is a microcontroller board based on the ATmega328P (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller;

- Motor controller

  The Arduino Motor Shield is based on the L298. Which is a dual full-bridge driver designed to drive inductive loads such as relays, solenoids, DC and stepping motors. It lets you drive two DC motors with your Arduino board, controlling the speed and direction of each one independently. You can also measure the motor current absorption of each motor, among other features. The shield is TinkerKit compatible, which means you can quickly create projects by plugging TinkerKit modules to the board.

- DC motor
  1. RF-1220 electrical dc motor
  2. Round shape and plastic end cap
  3. Lower noise and high speed
  4. Dia12*L20mm
  5. Long lifetime

- Switching protection (TIP 120)

The switching protection system is used to save the controller from being burnt. Using the system high power is isolated from the controller.

3. Cleaning system

Components used:

- Atmel 328

  Arduino/Genuino Uno is a microcontroller board based on the ATmega328P (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller;

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- DC motor
  1. RS-360/365H motor:
  2. Dia27.7*L32.6mm
  3. High quality and the best service
  4. 3/5 slots armature
  5. Metal end cap
  6. Switching protection (TIP 120) (Optional)

4. Structural design

Components used:

- Solid works :

  Solid works was used for the simulation of the structure before actual building of the prototype.

- Laser printing

  For making the cleaning brush as seen in image 3.6 precise lasers cutting was used. Plastic was laser cut taking into consideration the diameter of the pipe

5. **Wireless commination control**

Components used:

- Wifi protocol

  IEEE 802.11 is a set of media access control (MAC) and physical layer (PHY) specifications for implementing wireless local area network (WLAN) computer communication in the 900 MHz and 2.4, 3.6, 5, and 60 GHz frequency bands. They are created and maintained by the Institute of Electrical and Electronics Engineers (IEEE) LAN/MAN Standards Committee (IEEE 802). The base version of the standard was released in 1997, and has had subsequent amendments. The standard and amendments provide the basis for wireless network products using the Wi-Fi brand. While each amendment is officially revoked when it is incorporated in the latest version of the standard, the corporate world tends to market to the revisions because they concisely denote capabilities of their products. As a result, in the marketplace, each revision tends to become its own standard.

- Bluetooth HC 06 (Optional)

  Bluetooth is a wireless technology standard for exchanging data over short distances (using short-wavelength UHF radio waves in the ISM band from 2.4 to 2.485 GHz) from fixed and mobile devices, and building personal area networks (PANs). Invented by telecom vendor Ericsson in 1994,it was originally conceived as a wireless alternative to RS-232 data cables.

- Zigbee RX TX

  ZigBee is an IEEE 802.15.4-based specification for a suite of high-level communication protocols used to create personal area networks with small, low-power digital radios, such as for home automation, medical device data collection, and other low-power low-bandwidth needs, designed for small scale projects which need wireless connection.

  The technology defined by the ZigBee specification is intended to be simpler and less expensive than other wireless personal area networks (WPANs), such as Bluetooth or Wi-Fi. Applications include wireless light switches, electrical meters with in-home-displays, traffic management systems, and other consumer and industrial equipment that requires short-range low-rate wireless data transfer.

- Zigbee explorer dongle

3.4 Implementation

This project is divided into the following sub-systems

1. Video monitoring
2. Mobility system
3. Cleaning system
4. Structural design
5. Wireless commination control
6. Wireless video streaming control
7. Mechanical design

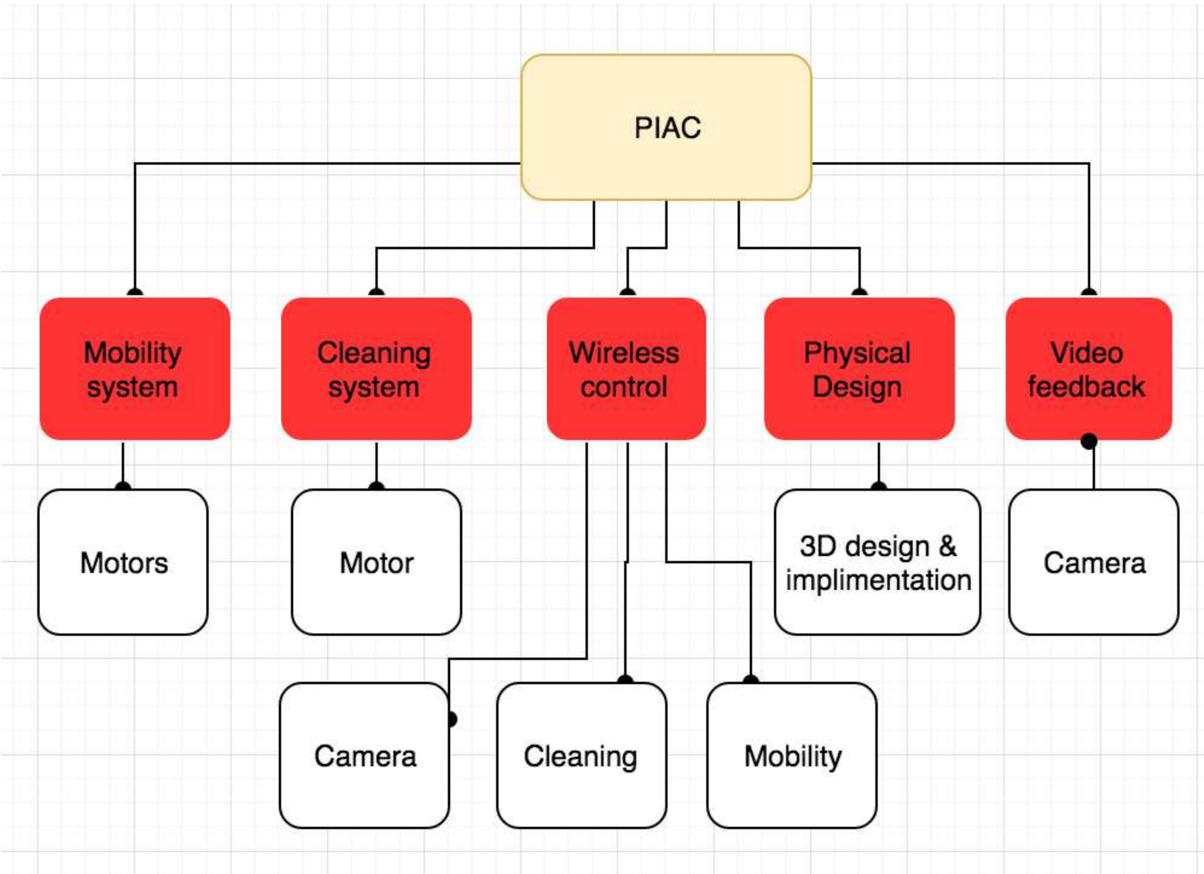

Figure 3.7 Sub systems of PIAC

3.4.1 System integration

During system integration we had the challenge of integrating the different sub systems into one final product. Overcoming several challenges did this. We will look onto each sub system in detail:

1. Mobility system

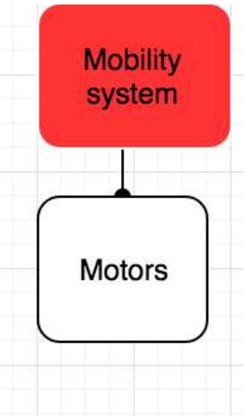

Figure 3.8 Mobility system

Figure 3.8 represents the parent system of the motors sub- system

The motor connections on the Ardiuno board can be seen below. As can be seen the motors are connected to the TIP 120 Darlington pain transistors to protect the Arduino controller. The Arduino uses a PWM pulse to operate the motors. This is represented in figure 3.9

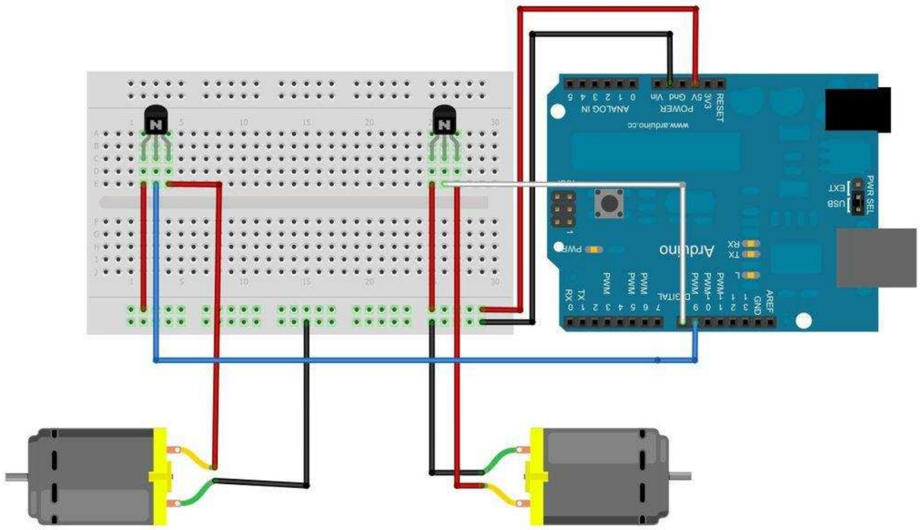

Figure 3.9 Motor connections to controller

2. Cleaning system

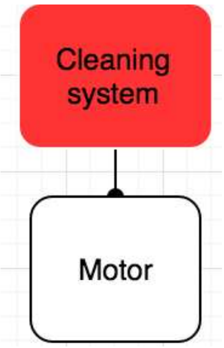

Figure 3.10 Cleaning system

Figure 3.10 represents the parent system of the cleaning motors sub- system. In this system the brush was custom designed to fit the mouth of the pipe. The motor is controlled in a very similar way like the mobility motors

Laser cutting:

Laser cutting was employed to cut the frame for the cleaning brush

Figure 3.11 Laser cutting of plastic sheet

A large plastic sheet is cut as seen in figure 3.8 and this is used to make the cleaning brush. At the end of the cleaning brush structure the bristles are attached to create friction

3. Mechanical design

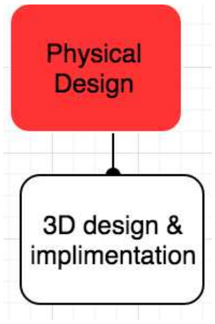

Figure 3.12 **3D** design and implementation

Figure 3.12 represents the parent system of the 3D design and implementation sub-system

Central Frame

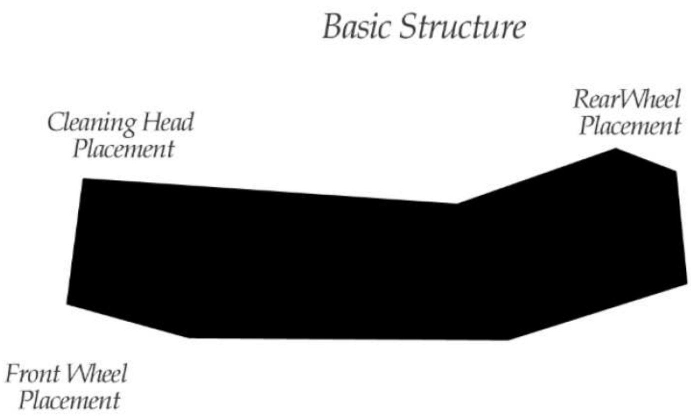

Figure 3.13

As seen in figure 3.13 the three transitional elements in the PIAC and their placement is depicted.

Translational Elements

The translational parts of the project are the ones that move. in the PIAC the following parts move.

i. **Mobility motor front**

   The mobility front motor has a smaller wheelbase (12cm) this makes the robot more structurally stable and reduces the friction.

ii. **Mobility motor rear**

   The mobility rear motor is more powerful and has a wider wheelbase (22 cm). The wider wheelbase prevents tilting of the PIAC.

iii. **Cleaning motor**

   The cleaning motor is centrally located and as the PIAC enters the pipe makes an even contact at the top and bottom of the pipe.

Calculations and formulas

i. **Static analysis**

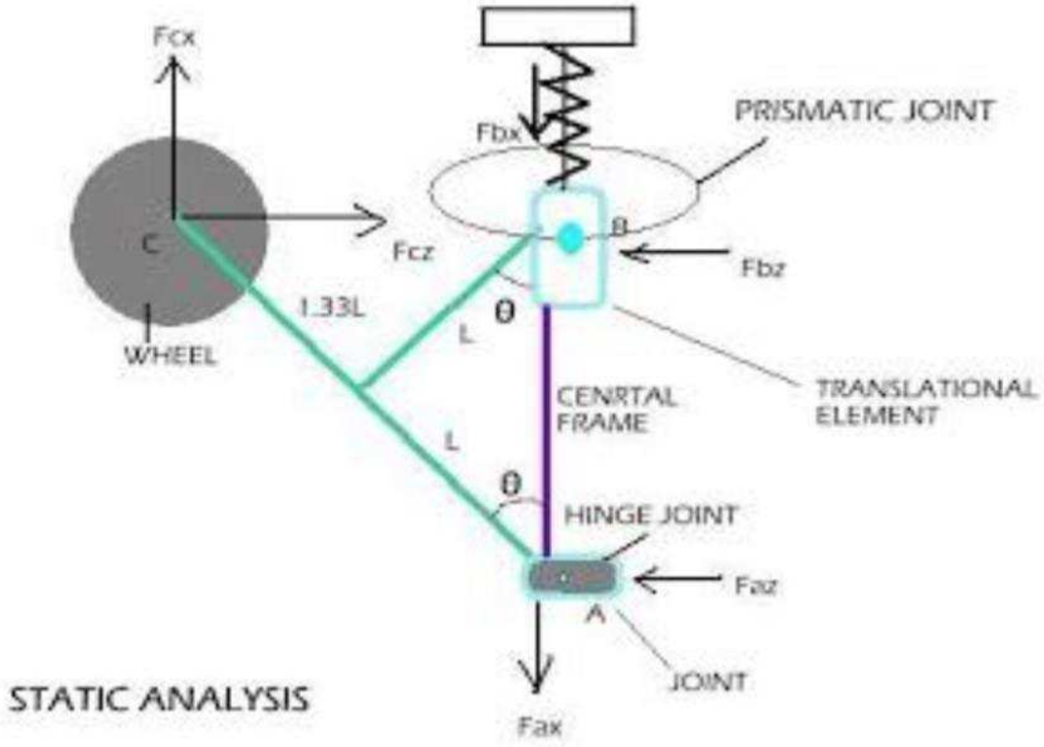

Figure 3.14 Static analysis

Figure 3.14 explains the statics of the wheels. The translational elements are 3 in the PIAC as explained above. As the wheels are incident on the pipe forces act in 2 directions perpendicular to each other Fcx and Fcz (as seen in the figure)

ii. **Calculation on torque required to turn the cleaning brush**

The applied torque is normal moment multiplied with the friction factor, seen in Eq 3.1 and is valid for both the 2D and the 3D model.

$$T = \mu r w \Delta s \sin\alpha$$

Eq 3.1

From Eq., a vertical bend (equal to zero) would give no torque, while a horizontal section (equal to 90 degree) applies the maximum torque. For the case with only rotation, axial friction has no effect, and the direction of the motion plays no role on the torque.

Please note we only consider torque in straight sections. In curved sections it is not calculated as the robot will only operate in straight pipes. The PIAC can later be modified to operate in curved sections

iii. Friction factor

$$\mu = \frac{F_F}{F_N}$$

Eq. 3.2

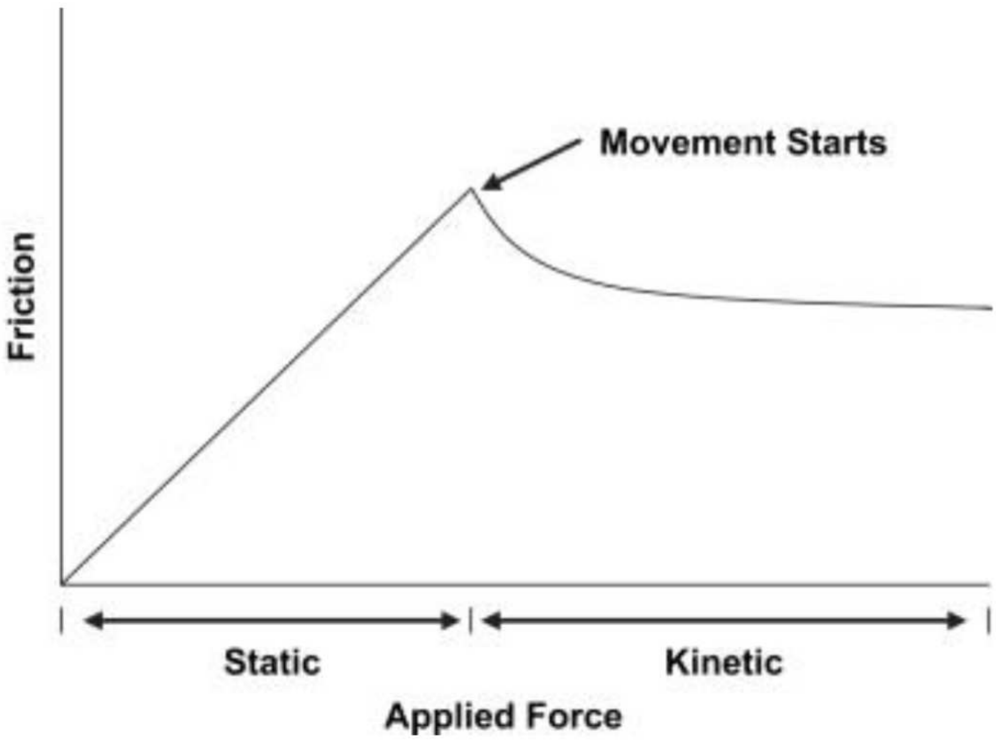

Figure 3.15 Friction vs applied force

Figure 3.15 shows that as in the beginning the brush requires a lot more torque as opposed to when the movement has already started. The frictional losses reduce as the motion begins

As a force is applied to an object, the region for static friction last until the force is great enough to overcome the initial resistance to move the object. Kinetic friction is on the other hand valid for objects in movement, and is the one used in torque & drag models. Static friction on the other hand can be associated with differential sticking environment

Table 3.1 Experienced friction factors from over 100 wells drilled by conventional down hole assemblies

Mud System	Actual Casing F.F.	Planning Casing F.F.	Actual Open Hole F.F.	Planning Open Hole F.F.
Water Based				
Generic	0.18	0.24	0.24	0.32
Polyseal / Barasilc	0.25	0.34	0.30	0.40
Thixal	0.22	0.29	0.27	0.36
Pure Oil Based				
Generic	0.10	0.13	0.12	0.16
Pseudo Oil Based				
Generic	0.15	0.20	0.17	0.23
XP07	0.17	0.23	0.17	0.23
Petrofree	0.14	0.19	0.18	0.24
Ecomul	0.16	0.21	0.20	0.27

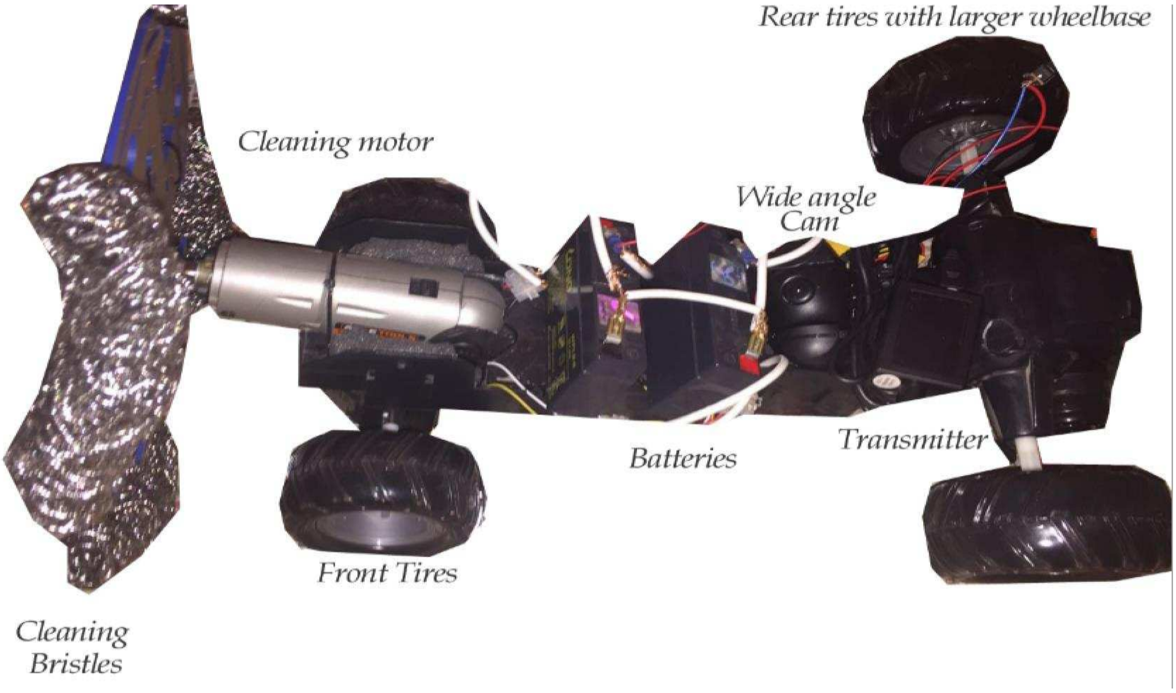

Figure 3.16

Figure 3.16 represents the project complete with components

4. Wireless commination control

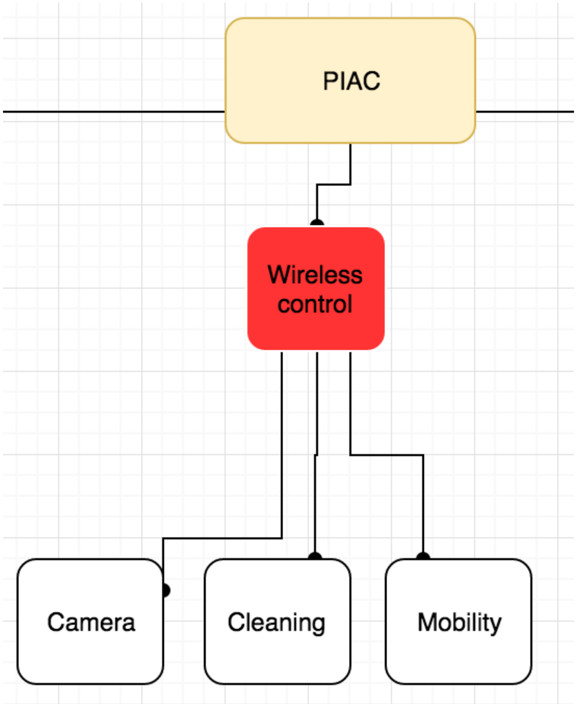

Figure 3.17 Wireless communication control

The wireless communication of the PIAC has been divided into 3 sub-divisions namely the camera wireless cleaning, the cleaning wireless sub system and the mobility wireless sub-system this is represented in figure 3.17

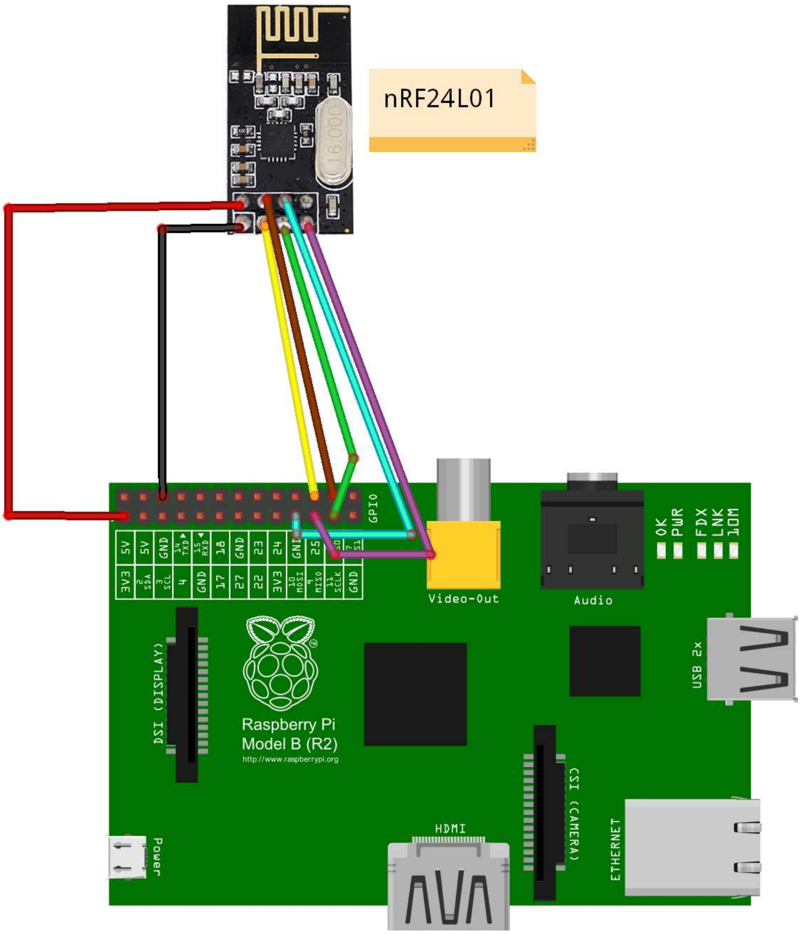

Figure 3.18

Figure 3.18 shows the connection of the Bluetooth and the raspberry pi. From this it is clear that the Bluetooth module is connected with the GPIO pins of the raspberry pi

5. Wireless video streaming control

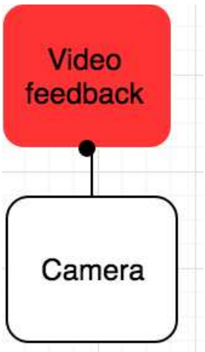

Figure 3.19

Figure 3.19 shows the parent sub-system of the camera

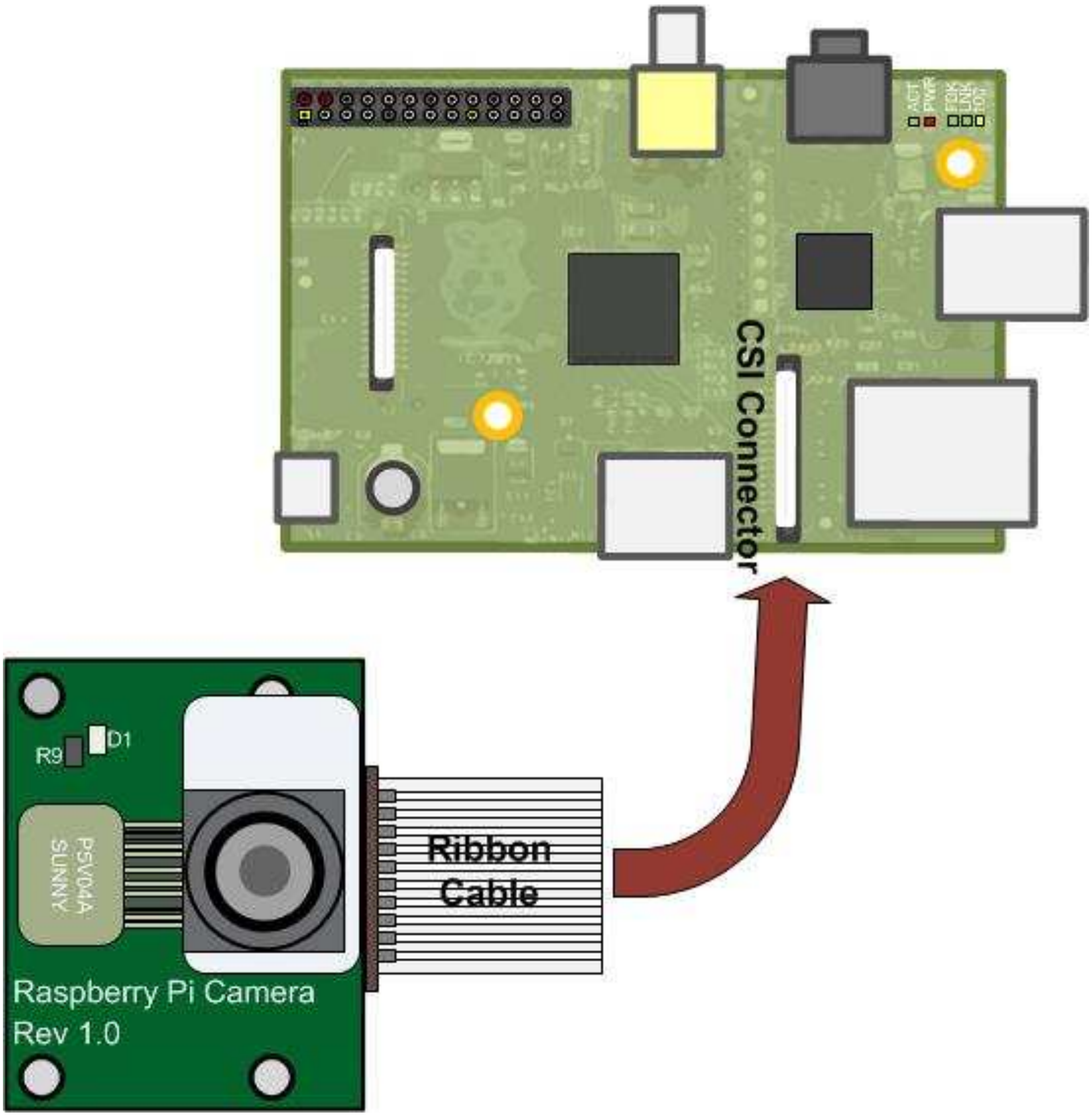

Figure 3.20 Raspberry pi camera connection

The raspberry pi is connected to the camera using a ribbon cable. The connection can be seen in figure 3.20

Design revisions

There were 3 revisions before the final product was finalized these are detailed below

<u>Design 1</u>

The first design was an initial 3D simulation that was proposed for implementation. This design has many weaknesses such as:

1. Unstable design
2. Very large rear wheels
3. Redundant front wheels

This design can be seen in figure 3.16

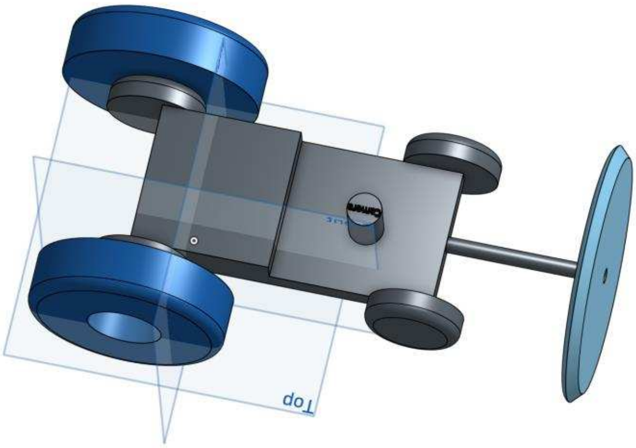

Figure 3.21 AutoCAD design

<u>Design 2</u>

The second design was also finalized till the implementation stage however because it was unstable the team had to scrap the design and make a better design. This design can be seen blow in figure 3.22

Figure 3.22 Previous design rejected due to instability

Final Design

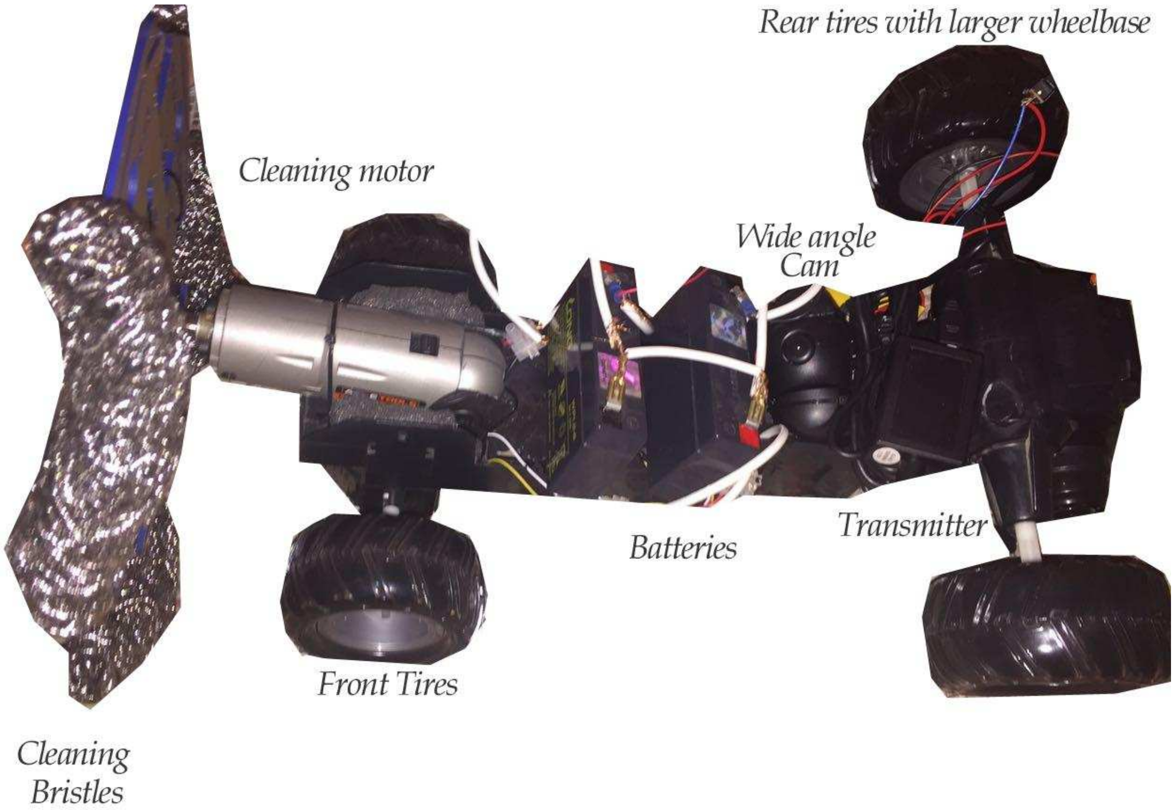

Figure 3.23 Final design

After much reconsideration and revisions a stable design was achieved as seen in figure 3.23

4. System Testing and Analysis

4.1 Motor RPM and torque

4.1.1 Objectives

1. Find the max motor torque & RPM of the front mobility motor
2. Find the max motor torque & RPM of the back mobility motor
3. Find the max motor torque & RPM of the cleaning motor

4.1.2 Setup

1. To test the motor in the pipe using a multi meter
2. To find the torque the current and voltage is needed. For this actual voltage and current during test are used

   $$HP = \frac{V \times I \times Eff}{746}$$

   Eq. 4.1

   We assume constant torque inside the pipe for simpler calculations and the average efficiency of DC motors is about 65%
3. To find the torque we fist find the max RPM

   $$T = \frac{5252 \times HP}{Rpm}$$

   Eq. 4.2

4. Use Matlab to simulate and find out results

4.1.3 Results

Table 4.1: Horsepower and torque for front mobility motor

At Max RPM 4127	For front mobility motor		
T = 5252 x HP/rpm (lb-ft)	HP = V x I x Eff / 746	V	I
4.43532E-05	3.48525E-05	4	0.01
8.87064E-05	6.97051E-05	4	0.02
0.00013306	0.000104558	4	0.03
0.000177413	0.00013941	4	0.04
0.000221766	0.000174263	4	0.05
0.000266119	0.000209115	4	0.06
0.000310472	0.000243968	4	0.07
0.000354825	0.00027882	4	0.08
0.000399179	0.000313673	4	0.09
0.000443532	0.000348525	4	0.1
0.000487885	0.000383378	4	0.11
0.000532238	0.000418231	4	0.12
0.000576591	0.000453083	4	0.13
0.000620945	0.000487936	4	0.14
0.000665298	0.000522788	4	0.15
0.000709651	0.000557641	4	0.16
0.000754004	0.000592493	4	0.17

Table 4.2: Horsepower and torque for back mobility motor

At Max RPM 4400	For back mobility motor		
T = 5252 x HP/rpm (lb-ft)	HP = V x I x Eff / 746	V	I
4.43532E-05	3.48525E-05	4	0.01
0.00013306	0.000104558	4	0.03
0.000266119	0.000209115	4	0.06
0.00036961	0.000290438	4	0.083333333
0.000480493	0.000377569	4	0.108333333
0.000591376	0.000464701	4	0.133333333
0.000702259	0.000551832	4	0.158333333
0.000813142	0.000638963	4	0.183333333
0.000924025	0.000726095	4	0.208333333
0.001034908	0.000813226	4	0.233333333
0.00114579	0.000900357	4	0.258333333
0.001256673	0.000987489	4	0.283333333
0.001367556	0.00107462	4	0.308333333

0.001478439	0.001161752	4	0.333333333
0.001589322	0.001248883	4	0.358333333
0.001700205	0.001336014	4	0.383333333
0.001811088	0.001423146	4	0.408333333

Table 4.3: Horsepower and torque for cleaning motor

At Max RPM 6600	For cleaning motor		
T = 5252 x HP/rpm	**HP = V x I x Eff / 746**	**V**	**I**
5.15856E-05	6.48257E-05	6	0.0124
0.00026292	0.000330402	6	0.0632
0.000425581	0.000534812	6	0.1023
0.000845754	0.001062828	6	0.2033
0.001032751	0.001297822	6	0.24825
0.001287268	0.001617664	6	0.30943
0.001541785	0.001937505	6	0.37061
0.001796301	0.002257347	6	0.43179
0.002050818	0.002577189	6	0.49297
0.002305334	0.002897031	6	0.55415
0.002559851	0.003216873	6	0.61533
0.002814367	0.003536714	6	0.67651
0.003068884	0.003856556	6	0.73769
0.0033234	0.004176398	6	0.79887
0.003577917	0.00449624	6	0.86005
0.003832434	0.004816082	6	0.92123
0.00408695	0.005135924	6	0.98241

Note: the maximum RPM for the front mobility motor is 4127, back mobility motor is 4400 and the cleaning motor is 6600.

4.2 Camera video feedback test

4.2.1 Objectives

1. Test communication range
2. Test battery
3. Test clarity
4. Test angle of view
5. Test lighting

4.2.2 Setup

The camera was tested outside the pipe for varying conditions to be created

4.2.3 Results

After the testing the following results were achieved:

1. Battery life (Only of camera without motors running): 1h
2. 110 degrees viewing angle
3. Good clarity
4. Range: 50 m

Figure 4.1 Camera image retrieved during testing

4.3 Movement and cleaning

For each subsystem mention the test:

4.3.1 Objectives

1. To check if cleaning is affective
2. To find if the torque is sufficient
3. If the robot is stable
4. Test angle of view
5. Test lighting

4.3.2 Setup

The robot is placed inside the pipe and a cleaning is simulated

Pipe calculations and specifications:

- Radius of the pipe opening (Inside): 5 Inches
- Diameter = 2* Radius = 10 inches
- Kind of corrosion inside the pipe: General attack corrosion
- Level of corrosion inside the pipe: Mild to moderate

- Thickness of corrosion inside the pipe:

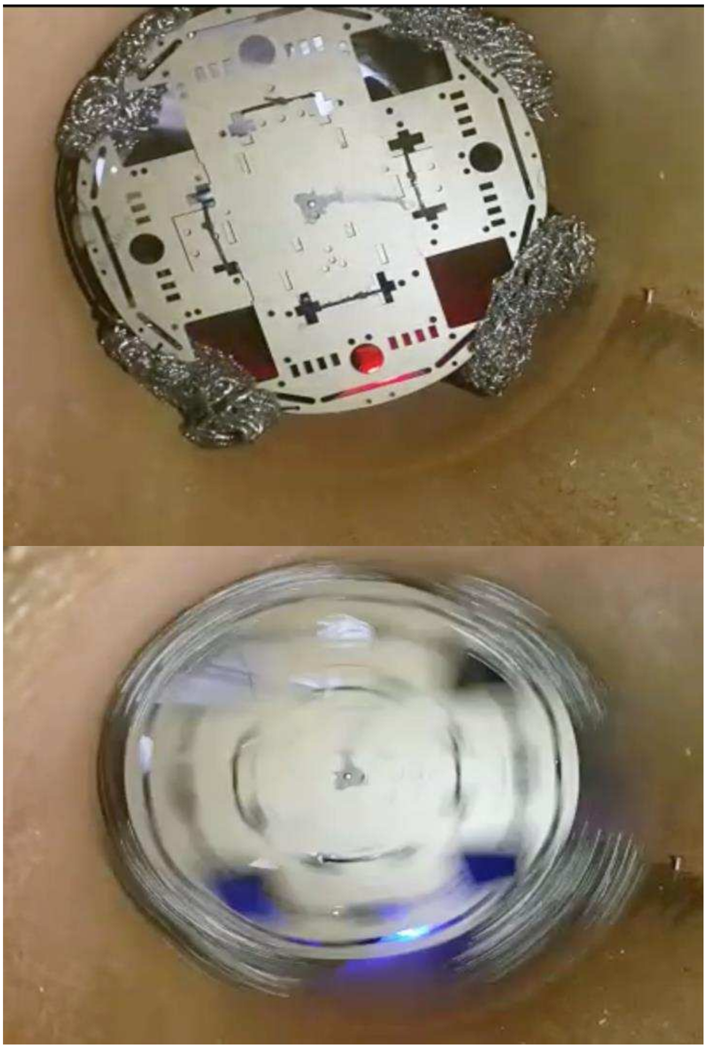

Figure 4.2 a and b: Cleaning mechanism being tested

4.3.3 Results

After the testing the following results were achieved:

1. The robot did not move with the lower power motors (Higher torque motors were added)
2. The robot did not clean the bottom of the pipe (The cleaning brush pipe was readjusted)
3. There was significant difference in color and appearance on the interior of the pipe after cleaning.
4. Due to cleaning the rust was dropped and dissipated in the form of a dusty cloud
5. The amount of rust removed in the pipe was approximately 4 grams this could be calculated by weighing the dust after the process of cleaning

4.4 Overall Results, Analysis and Discussion

The over all results of the testing are detailed in the following steps:

4.4.1 Setup:

The setup for the test was as follows:

1. Video transmission ON
2. All motors turned ON (Mobility and cleaning)
3. Battery initially fully charged

4.4.2 Analysis:

For the analysis the following parameters were observed:

1. Battery life

   below is the battery consumption figure of the lead acid battery

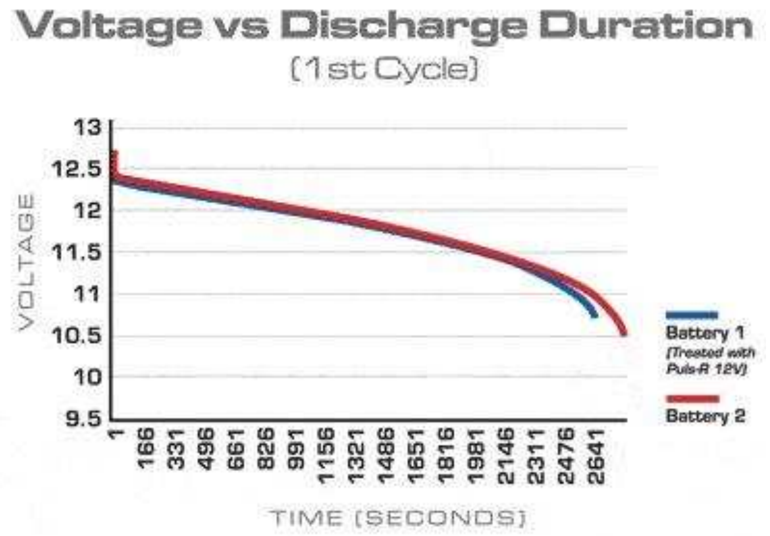

Figure 4.3-battery consumption diagram of the 12V battery

The figure 4.3 above shows the battery consumption curve versus time

2. Cleaning area of 0.398 m2 was used for testing (Half meter pipe with 10 inch diameter)

   For this test the PIAC was put inside the pipe and made to clean the interior. Adjustments had to be made to clean the bottom and the top evenly

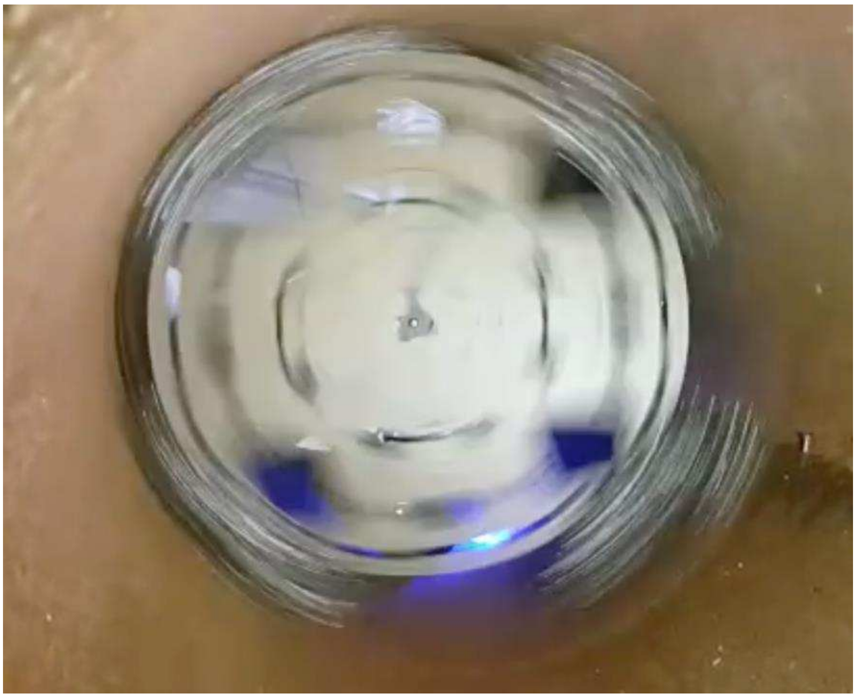

Figure 4.4 Cleaning brush test

3. Motor current consumption

   The DC motor current consumption diagram can also be seen below as seen as the load increases the current consumed also increases

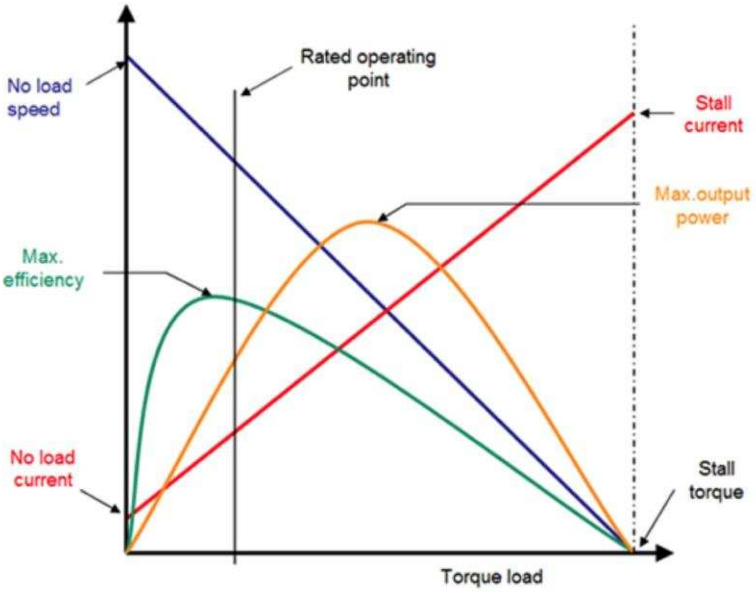

Figure 4.5 DC motor characteristics under various conditions

The figure 4.5 shows the motor characteristics of the DC motor

Results changes and observations:

1. At excessive required torque there is exponential consumption of power

2. Motors consumes a peak in power during startup
3. The brush angle was not correct and the cleaning was not even
4. The maximum RPM of the mobility motors was 4400 and 4130 RPM whereas the max torque of the cleaning motor was 6600 RPM
5. The values of torque at different values of current is represented in section 4.1

1.1.Rated voltage:	5 V DC
1.2.Motor Position:	To be measured with motor horizontally held.
1.3.Enviromental temperature:	+5℃～+35℃
1.4.Enviromental humidity:	40%～85%RH.

ELECTRICAL CHARACTERISTICS (At initial stage after 30 seconds run-in):

2.1.At No load	
2.1.1.Speed:	14000 ±10%rpm
2.1.2.Current:	≤55mA
2.2.At On load	
2.2.1.Torque:	3.1g.cm
2.2.2.Speed:	9800±10%rpm
2.2.3.Current:	≤200mA
2.3.At Stall	
2.3.1.Torque:	≥8.0g.cm
2.3.2.Current:	≤500mA
2.4.Direction of Rotation:	CW (Clockwise when viewing from the output shaft end with positive voltage applied to positive terminal.

5. Project Management

5.1 Project Plan

Our project has been divided into the following tasks and in the figure 5.1 we have slit it into the execution timeline:

1. Finalize team: this step involves the selection of the team members and forming a team officially. This has to be made official with the course instructor
2. Brainstorm ideas: The selection of ideas is the most interesting as our team decides the ideas that will most appropriately display our understanding of our degree, fit in our budget and interests all the group members. After the project is finalized an approval must be sough from the instructor to confirm commencing work on the project
3. Literature review of ideas
   After the finalizing of the project ideas it was very important to acquaint ourselves with similar projects that were done with a similar title and functionality. This is a continuous process and will require reading and summarizing academic journals
4. Finalize ideas
   Ideas need to be finalized and the product features and objectives may need to be determined these decisions can be based on the knowledge gained from the literature review
5. Prepare first report and presentation
   After finalizing the project and its features an official presentation needs o be done in front of the department. This involves some progress in terms of the prototype, calculations and simulations. Critical feedback will be give during this session that can be used to mold the project in the right direction
6. Work on the structure of the robot
   Before finalizing or starting work on the electronics of the project it was very important to work on the structure of the project. We need to make sure that the structure is stable and can easily house the static and translational components of the project
7. Final design of structure

After several trials we are expected to finalize the design of the project. After this step the actual building of the prototype structure is required

8. Build structure

   The structure is actually built with the confirmed design and using the decided materials of use

9. Design cleaning blade

   In this project the cleaning blade will depend on the design of the prototype structure. This step requires laser cutting of plastic sheets of exact size to create the mold of the cleaning brush. Cleaning bristles are attached to the blade accordingly

10. Video streaming

    As mechanical engineers this is the most difficult step for the group we need to make a wireless camera that sends video to the controller

11. Test sub-systems separately

    Each sub system needs to be tested separately before we combine them all

12. Movement addition

    The 3 translational components of the system need to be made separately (3 motors)

13. System integration

    All systems need to be combined

14. System testing

    The complete project is tested for effectiveness

15. Final Report

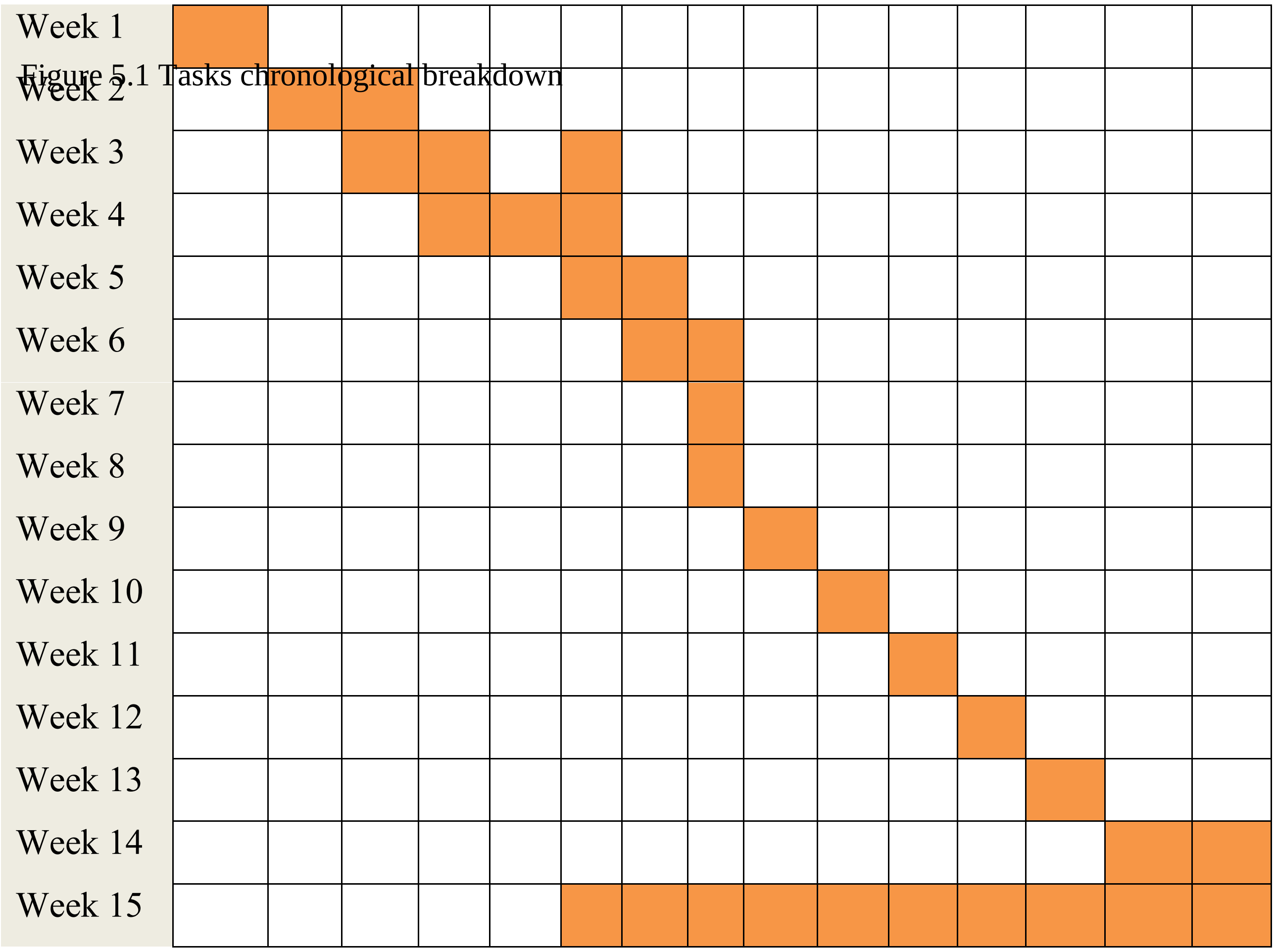

Figure 5.1 Tasks chronological breakdown

1.2 Contribution of Team Members

As can be seen above our tasks are well divided. Each team member is responsible fro a part of the project

Abdullah Al Deghreer 25%
Programming
Team management
Materials procurement

Mohammed Alyami 25%
System integration
Finance handling

Naif Al Mahasheer 25%
Structural building

Ahmed AlShalawi 25%
Electrical work & testin

5.3 Project Execution Monitoring

For the successful execution of the project it was critical to organize and have regular meetings with the advisors. Here were the following steps taken to monitor project execution

- Meeting advisors every 2 weeks to discuss project details
- 3 team meetings every week in the initial part of the project
- Team meetings increase as work load increases
- Testing was done using an actual sized pipe
- Synergy is something we believe in hence all of the team members had involvement in the others work

5.4 Challenges and Decision Making

There were several challenges that we faced during the project. This project had to be made from scratch and there was no platform or readymade solution for it hence each system is separate and it had to be integrated into the final product. The following were the main challenges and also how we have overcome them

Structure of the PIAC: The structure of the PIAC was changed 3 times because the first 2 designs were not stable. Hence finally we choose a design that has different wheelbase for the rear wheel giving better stability

Camera streaming: the camera system used to stream the live video from the PIAC is banned in Saudi Arabia (Wireless camera systems banned in KSA). This led us to search for the camera in Bahrain and also Dubai but it was not available anywhere. To come around this problem we decided to make a custom wireless camera

Familiarity with electrical systems: As mechanical engineering students it is important to understand basic electronics however our project demanded much more and we had to learn tremendously to overcome this challenge

5.5 Project Bill of Materials and Budget

The project budget was limited to ten thousand riyals. However as engineers we are always looking to cut on the costs of the product design without undermining the objectives. Overall we have remained in budget and are proud of the team for this achievement.

The main expense of this project was expected to be the electronic components but however with careful planning this was kept under check

Sno	Description	Qty	Total
1	Arduino	1	160
2	Radio transmitter	1	220
3	Camera	1	250
4	Camera Transmitter	1	210
5	Camera receiver	1	210
6	Circuit components	Na	60
7	Structure	Na	400
8	Batteries	2	60
9	Ferro connectors	NA	10
10	Wires (single core)	1 bundle	25
11	Connecting wires	1 roll	60
12	Relay	1	20
13	Relay holder	1	15
14	Radio receiving board 24 MHz	1	45
15	Radio transmitting board 24 MHz	1	45
16	Motors	4	400
17	Raspberry Pi	1	250
18	Packaging	NA	1000
19	Lazer cutting	1	200
20	Bristle for cleaning	1 pack	20
21	Wire roll	1	60
22	Box for transmitter	1	50
		Total	**4360**

2. Project Analysis

6.1 Life-long Learning

There is a plethora of knowledge, skills, and experiences that we have acquired by our own (by way of self-learning, independent learning) while working on this project. These are the following technologies used:

- New hardware devices (Arduino, temperature & humidity sensor , Wi-Fi, humidity sensors, actuators)

- 3D modeling tools
- New software tools (Arduino IDE)
- Project management skills,
- Time management skills,
- Team management
- Deadline management
- System integration
- System testing
- Debugging skills
- Overcoming technical challenges
- Working under pressure
- Laser cutting
- Corrosion types
- Pigging technology and its applications
- Team work
- Task delegation
- Report writing
- Presentation skills
- Product engineering
- Making literature review
- Working with Lead acid batteries
- DC motors
- LED arrays
- Wireless technologies

6.2 Impact of Engineering Solutions

The costs of removal or treatment of waste from plants has become a major expense to many liquid processing companies. Additionally, changes in legislation and restrictions from environmental policies can require extra resources and incur further costs.

An effective way of reducing these costs while promoting carbon footprint reduction is to pig the product transfer pipelines. This significantly reduces waste and associated costs, and the environmental benefits of pigging are significant.

In today's environment, raw material, manufacturing, and waste disposal costs are rising. At the same time, customers are placing smaller more frequent orders and demanding higher product quality. Pigging systems provide significant cost savings by recovering previously lost product that was trapped in pipelines and eliminating flush waste and disposal expense. Pigging systems help manufacturing plants become more competitive, attain continuous improvement goals, and become better stewards of the environment.

Often products that remain trapped in process piping are flushed after transfer with a cleaning media or the next product in the campaign. Disposal methods for the resulting flushed product can range from dumping down the sewer drain to collection for burning as hazardous waste disposal. Pigging systems help by preventing this unnecessary waste stream from directly entering the environment or pollution from waste processing facilities.
Every pound or gallon of waste product represents a consumption increase in a natural resource. Pigging systems conserve natural resources by preventing the generation of product waste.

Liquid manufacturing companies across the world now see Carbon Footprint Reduction as a marketing tool as well as an ethical approach to business. Pigging can significantly reduce your organizations direct and indirect Carbon Footprint, which is a key benefit to many organizations.
For example, the power resources saved by reducing cleaning times and associated waste are often considerable. Indirectly, the reduction in numbers of tankers or trucks required for removal of waste or delivery of waste treatment chemicals also reduces things like road degradation, exhaust emissions and traffic congestion. [9]

6.3 Contemporary Issues Addressed

Put simply the PIAC systems help you recover more useable product from your processes, you have more product to sell. But that’s not the only way they help you increase your profits, productivity and efficiency. Product recovery and pigging systems streamline processes, reducing effort required and making various operations a lot quicker. They can even eliminate some process stages altogether.

Because they massively reduce waste and increase yields along with productivity and efficiency, PIAC systems deliver a high return on investment. The payback time is also low. Typically, if you choose a PIAC solution, your savings will pay back the initial cost of the system in less than one year. So after the first year, it's nearly all profit. That makes a great business case for including pigging as part of your liquid processing operation.
By increasing product yields through pigging, there's less product to send to waste. What's more, the cleaning and changeover processes also use less cleaning fluids and water. In this way hygienic product recovery and pigging systems directly reduce waste processing costs. [9]

Evermore stringent environmental restrictions continue to drive up flush waste disposal costs. As plant production expands increasing demands are placed on both on-site and public waste treatment facilities.

Pigging systems reduce the generation of flush product waste thereby increasing the service life of treatment facilities and lowering the cost of municipal waste disposal. PIAC systems may qualify for credits other incentives based on their environmental impact. Pigging Solutions continuously monitors current legislation and trends for potential tax credits and incentives eligible to clients.

7. Conclusions and Future Recommendations

7.1 Conclusions

- The PIAC project has achieved its initially set objectives and we have finally been able to make a robot that cleans the inferiors of the pipes wirelessly and also monitor it. During our testing we were able to see that there could be many improvements made in the system such as the pipe was cleaned a little better on the top side than the bottom side. This problem is resolved repositioning the rotor of the cleaning brush in the middle
  From our literature review we are able to see several implementations of the idea. Some of them were highly sophisticated well-funded research projects.

However we got great insight through them and were able to take cues from their design

The PIAC robot was built with a plastic structure and the cleaning brushes were made up of laser cut glass and metal bushes. With this project were able to clean the interior of metal pipes and simultaneously stream live video from the interior to monitor the process of cleaning. The robot has a total of 3 motors as seen in the report. 2 of the motors are used for mobility and the other single motor is used for cleaning the interior of the pipe. We have also tested the cleaning capability of the motor as explained in previous parts of the report and found out that the robot is effectively able to clean the interior of the pipe. This was verified by the visual difference seen after the completion of the cleaning process

Our project only works on a pipe of fixed diameter 10 inches in this case. We would definitely like to overcome this challenge in the future. There are many things that we learnt during the course of this project, which includes problem solving, undertaking pressure, electrical systems, 3D modeling and system integration. The project is especially challenging to the mechanical engineering students because of the electronics that are involved in it.

7.2 Future Recommendations

This is the first implementation of the project and hence there is huge scope of improvement in the future. Some of the areas where improvement should be sought include the following:

1. Versatility: currently the PIAC only works with pipes of fixed diameter. This has to be corrected in the future enabling the robot to work with different sizes of pipes and even at horizontal and vertical angles.
2. Battery life: currently a 1.2 AH 12V lead acid battery is used to power the system. Due to the low capacity of the battery the system runs out of charge relatively quickly. This should be corrected in the future with the use of larger size batteries and also by improving the over efficiency

3. Engineering standards: since this build is the first prototype just to prove the concept no engineering standards are approved. In the later build basic electrical NEC, IEEE and mechanical ASME standards should be included certifications

8. References

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[3]Shyam Lal Sharma, Abdul Qavi & Kamlesh Kumari (2014) Oil Pipelines/Water Pipeline Crawling Robot For Leakage Detection/Cleaning Of Pipes Al Falah School Of Engineering And Technology, India

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[5] H. Choi And S. Roh, "In-Pipe Robot With Active Steering Capability For Moving Inside Of Pipelines," In Bioin-

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[6] V. G. H. Schempf, E. Mutschler And W. Crowley, "Grislee: Gasmain Repair And Inspection System For Live Entry Environments," The International Journal Of Robotics Research, Vol. 22, No. 7-8, Pp. 603–616, 2003.

[7] J. Z. Z. X. Li, "Development Of The Self-Adaptive Pipeline Cleaning Robot," In Advanced Materials Research,

2010, Pp. 97–101.

[8] Kentarou.Nishijima, Yixiang.Sun, Rupesh Kumar.Srivastava,Harutoshi.Ogai1and Bishakh.Bhattacharya (2010) Advanced Pipe Inspection Robot Using Rotating Probe Department Of Automation, Shanghai Jiao Tong University, China 3Department Of Mechanical Engineering, Indian Institute Of Technology Kanpur, India

[9] Hygenic Pigging Systems (U.D.) Retrieved From Http://Www.Hps-Pigging.Com/About-Hps/Benefits-Of-Pigging/ England Wales. Company No. 2974969 VAT No. GB 653 6975 93

Appendix A: Progress Reports

	SDP – WEEKLY MEETING REPORT
	Department of Mechanical Engineering Prince Mohammad bin Fahd University

SEMESTER: ACADEMIC YEAR:	**FALL 2016-2017**	**Date:**	
PROJECT TITLE	pipe inspecting and cleaning robot		
SUPERVISORS			

Member Name	Present/Absent	Arriving on time
1. Abdullah Al Deghreer	201002190	
2. Mohammed Alyami	201002191	
3. Naif Al Mahasheer	200800447	
4. Ahmed AlShalawi	200700542	

Task progress report for the last week effort:

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Finalize project idea		100	Report
2	Review literature		100	Report
3	Compose Literature review		100	Report
4	Compare proposed project		100	Report

Task allocation for the next week:

#	Task description	Team member

		assigned
1	**Study materials required**	1,2,3,4
2	**Order materials**	1,2,3,4
3	**Finalize physical structure**	1,2,3,4

Outcome f:

An understanding of professional and ethical responsibility.

Criteria	None (1)	Low (2)	Moderate (3)	High (4)
f.1 Demonstrate professionally responsibility at all times.	Fails to demonstrate responsibility for his actions and does not deal with others professionally	Shows some sense of responsibility for his actions but needs improvement in dealing with others professionally	Takes full responsibility for his actions and deals with others professionally	Demonstrates high moral and professional ethics, takes complete responsibility for his actions and is excellent in interacting and dealing with others

Outcome d:

An ability to function on multidisciplinary teams.

Criteria	None (1)	Low (2)	Moderate (3)	High (4)
d.1 Develop a work plan and distribute tasks	Fails to develop a work plan and tasks are assigned ad hoc	Develops a work plan without much thought and tasks distribution is not balanced	Develops a good work plan and distributes tasks in a balanced way	Develops a realistic and well thought out work plan and distributes tasks in a balanced way and according to the skills and expertise of the team members
d.2 Take responsibility in team efforts to complete the assigned tasks.	Does not perform assigned tasks; often misses meetings and, when present, does not have anything constructive to say; relies on others to do the work;	Performs assigned tasks but needs many reminders; attends meetings regularly but generally does not say anything constructive; sometimes expects others to do his/her work;	Performs all assigned tasks; attends meetings regularly and usually participates effectively; generally reliable;	Performs all tasks very effectively; attends all meetings and participates enthusiastically; very reliable.

d.3 Show respect to other team members.	Often argues with team mates; doesn't let anyone else talk; occasional personal attacks and "put-downs"; wants to have things done his way and does not listen to alternate approaches;	Usually does much of the talking; does not pay much attention when others talk, and often assumes their ideas will not work; no personal attacks and put-downs but sometimes patronizing; when others get through to him, works reasonably well with them;	Generally listens to others' points of view; always uses appropriate and respectful language; tries to make a definite effort to understand others' ideas;	Always listens to others and their ideas; helps them develop their ideas while giving them full credit; always helps the team reach a fair decision.

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (d1)	Criteria (d2)	Criteria (d3)	Criteria (f1)
1	**Abdullah Ali Al Deghreer**	3	3	4	4
2	**Mohammed Alyami**	3	3	4	3
3	**Naif Al Mahasheer**	3	3	4	3
4	**Ahmed AlShalawi**	3	3	4	3

Comments on individual members

Name	Comments
Abdullah Ali Al Deghreer	All members worked equally
Mohammed Alyami	All members worked equally
Naif Al Mahasheer	All members worked equally
Ahmed AlShalawi	All members worked equally

SDP – WEEKLY MEETING REPORT

Department of Mechanical Engineering

Prince Mohammad bin Fahd University

SEMESTER: ACADEMIC YEAR:	**FALL 2016-2017**	**Date:**	

PROJECT TITLE	pipe inspecting and cleaning robot
SUPERVISORS	

Member Name	Present/Absent	Arriving on time
1. Abdullah Al Deghreer	201002190	
2. Mohammed Alyami	201002191	
3. Naif Al Mahasheer	200800447	
4. Ahmed AlShalawi	200700542	

Task progress report for the last week effort:

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Report corrections (From last week)	All	95	Report
2	Review literature (Continued from last week)	All	50	Report
3	Literature review (Add more references)	All	95	Report
5	Market survey for sample pipe	All	0	
6	Solid works design	All	20	Drawing

Task allocation for the next week:

#	Task description	Team member assigned
1	Basic remote movement	1,2,3,4
2	Scavenge off shelf components (delayed), solid works design (in progress)	1,2,3,4
3	Appearance and choice of material	1,2,3,4

Outcome f: An understanding of professional and ethical responsibility.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
f.1 Demonstrate professionally responsibility at all times.	Fails to demonstrate responsibility for his actions and does not deal with others professionally	Shows some sense of responsibility for his actions but needs improvement in dealing with others professionally	Takes full responsibility for his actions and deals with others professinally	Demonstrates high moral and professional ethics, takes complete responsibility for his actions and is excellent in interacting and dealing with others

Outcome d: An ability to function on multidisciplinary teams.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
d.1 Develop a work plan and distribute tasks	Fails to develop a work plan and tasks are assigned ad hoc	Develops a work plan without much thought and tasks distribution is not balanced	Develops a good work plan and distributes tasks in a balanced way	Develops a realistic and well thought out work plan and distributes tasks in a balanced way and according to the skills and expertise of the team members
d.2 Take responsibility in team efforts to complete the assigned tasks.	Does not perform assigned tasks; often misses meetings and, when present, does not have anything constructive to say; relies on others to do the work;	Performs assigned tasks but needs many reminders; attends meetings regularly but generally does not say anything constructive; sometimes expects others to do his/her work;	Performs all assigned tasks; attends meetings regularly and usually participates effectively; generally reliable;	Performs all tasks very effectively; attends all meetings and participates enthusiastically; very reliable.
d.3 Show respect to other team members.	Often argues with team mates; doesn't let anyone else talk; occasional personal attacks and "put-downs"; wants to have things done his way and does not listen to alternate approaches;	Usually does much of the talking; does not pay much attention when others talk, and often assumes their ideas will not work; no personal attacks and put-downs but sometimes patronizing; when others get through to him, works reasonably well with them;	Generally listens to others' points of view; always uses appropriate and respectful language; tries to make a definite effort to understand others' ideas;	Always listens to others and their ideas; helps them develop their ideas while giving them full credit; always helps the team reach a fair decision.

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (d1)	Criteria (d2)	Criteria (d3)	Criteria (f1)

1	**Abdullah Ali Al Deghreer**	3	3	4	4
2	**Mohammed Alyami**	3	3	4	3
3	**Naif Al Mahasheer**	3	3	4	3
4	**Ahmed AlShalawi**	3	3	4	3

Comments on individual members

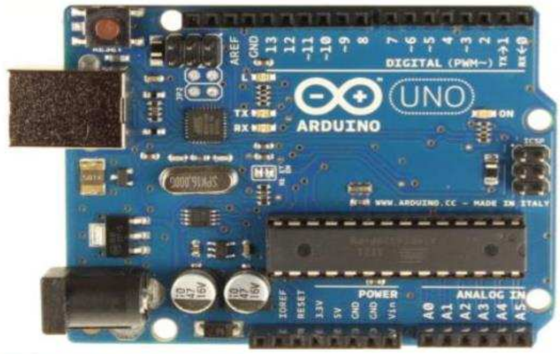
Name	Comments
Abdullah Ali Al Deghreer	We are satisfied by group member performance
Mohammed Alyami	We are satisfied by group member performance
Naif Al Mahasheer	We are satisfied by group member performance
Ahmed AlShalawi	We are satisfied by group member performance

Appendix B: Bill of Materials

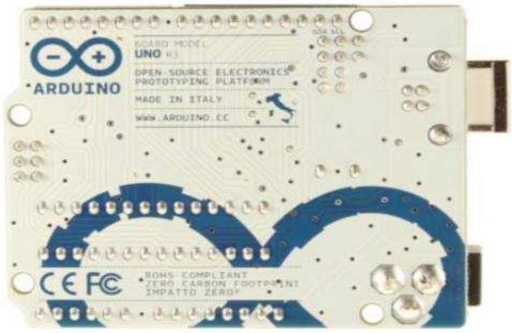
Sno	Description	Qty	Total
1	Arduino	1	160
2	Radio transmitter	1	220
3	Camera	1	250
4	Camera Transmitter	1	210
5	Camera receiver	1	210
6	Circuit components	Na	60
7	Structure	Na	400
8	Batteries	2	60
9	Ferro connectors	NA	10
10	Wires (single core)	1 bundle	25
11	Connecting wires	1 roll	60
12	Relay	1	20
13	Relay holder	1	15
14	Radio receiving board 24 MHz	1	45
15	Radio transmitting board 24 MHz	1	45
16	Motors	4	400
17	Raspberry Pi	1	250
18	Packaging	NA	1000
19	Lazer cutting	1	200
20	Bristle for cleaning	1 pack	20
21	Wire roll	1	60
22	Box for transmitter	1	50
		Total	**4360 Sr**

Appendix C: Datasheets

Arduino Uno



Arduino Uno R3 Front

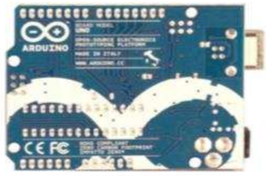


Arduino Uno R3 Back

Arduino Uno R2 Front

Arduino Uno SMD

Arduino Uno Front



Arduino Uno Back

Overview

The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.
The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter.
Revision 2 of the Uno board has a resistor pulling the 8U2 HWB line to ground, making it easier to put into DFU mode.
Revision 3 of the board has the following new features:

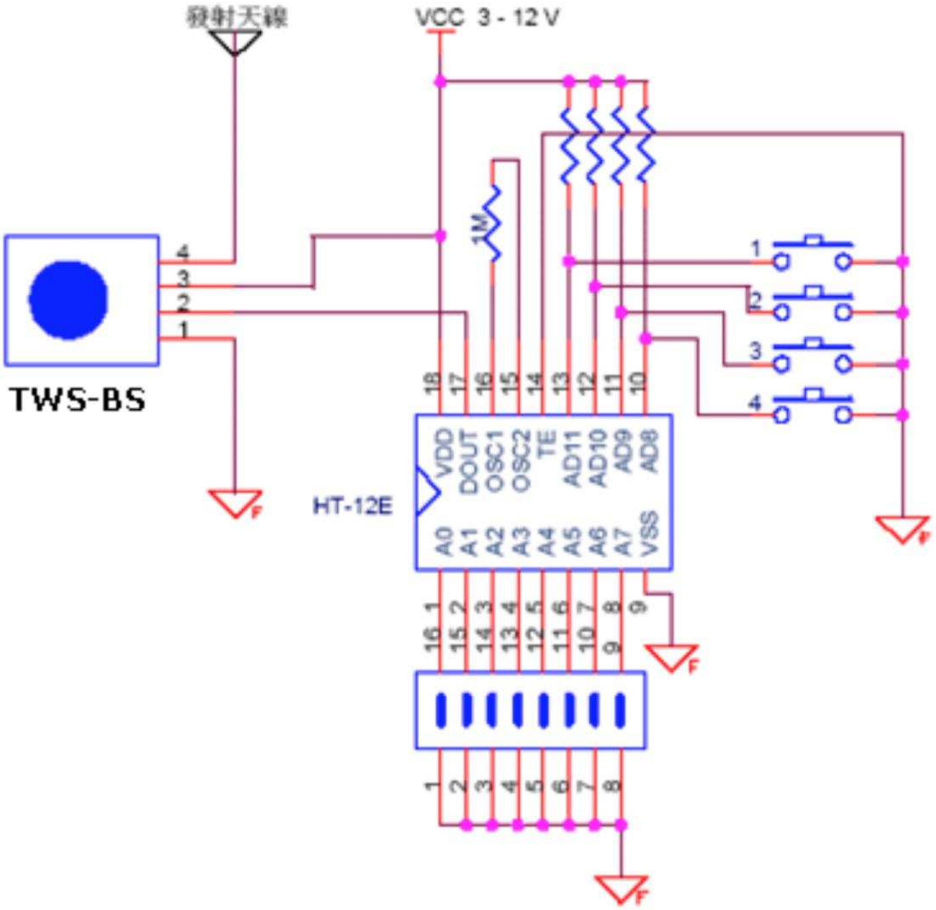
- 1.0 pinout: added SDA and SCL pins that are near to the AREF pin and two other new pins placed near to the RESET pin, the IOREF that allow the shields to adapt to the voltage provided from the board. In future, shields will be compatible both with the board that use the AVR, which operate with 5V and with the Arduino Due that operate with 3.3V. The second one is a not connected pin, that is reserved for future purposes.
- Stronger RESET circuit.
- Atmega 16U2 replace the 8U2.

"Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno and version 1.0 will be the reference versions of Arduino, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform; for a comparison with previous versions, see the index of Arduino boards.

Summary

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V

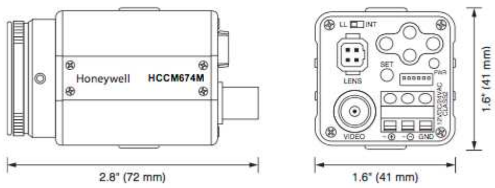
Demo Circuit



SPECIFICATIONS

Operational	
Video Standard	NTSC
Scanning System	2:1 interlace
Image Sensor	1/3" Sony Interline Transfer CCD
Number of Pixels (H × V)	976 × 494
Minimum Illumination	0.1 lux at F1.2, 50 IRE
Horizontal Resolution	650 TVL
Video Output	1.0 Vp-p at 75 ohms
Sync System	Internal or line lock
S/N Ratio	50 dB (AGC off)
Auto Gain Control	Off/On
Automatic Electronic Shutter	1/60–1/100,000 s
White Balance	ATW/ Push/User 1/User 2/Anti CR/ Manual/Push Lock
BLC	Off/BLC/HLC
Picture Adjust	Mirror/Brightness/Contrast/Sharpness/ Hue/Gain
ATR	Off/On
Motion Detection	Off/On (with on-screen notification)
Privacy Masking	Off/On
Day/Night	Auto/Color/BW
Noise Reduction	Y/C reduction
Camera ID	Off/On (24 alphanumeric characters)
Languages	English, Japanese, German, French, Russian, Spanish, Portuguese
Electrical	
Input Voltage	12 VDC/24 VAC
Input Range	10–14 VDC, 20–28 VAC
Surge Suppression	1.5 kW transient
Power Consumption	3.5 W (max)

Mechanical	
Dimensions (L × W × H)	2.8" × 1.6" × 1.6" (72 × 41 × 41 mm)
Weight	0.35 lb (0.16 kg) camera only
Construction	Housing: Aluminum Finish: Charcoal powder coat
Camera Mount	1/4" - 20 UNC (top and bottom)
Lens Mount	C/CS adjustable mounting ring
Connector	Video Output: BNC connector Lens: 4-pin connector Power Input: 3-pin screw terminal
Environmental	
Temperature	Operating: 14°F to 122°F (–10°C to 50°C) Storage: –4°F to 140°F (–20°C to 60°C)
Relative Humidity	0% to 85%, non-condensing
Regulatory	
Emissions	FCC: Part 15, Class A CE: EN 55022
Immunity	CE: EN 50130-4
Accessories	
Recommended Lens Options	
HLD28V8F95L	2.8–8 mm, F0.95, VFAI lens
HLD5V50F13L	5–50 mm, F1.3, VFAI lens
Transformers	
HTP2420	24 VAC, 20 VA, Class 2 plug-in with thermal cut-out
HTP12DC500	12 VDC, 500 mA, plug-in regulated 2.1 mm coax plug, UL Listed/CSA Certified
Power Supply	
HPTV2404UL	24 VAC, 4 A, 4 output, fused, UL Listed



Ordering	
HCCM674M	1/3" CCD, High Resolution Day/Night Miniature Camera with DSP, 650 TVL, 12 VDC/24 VAC, NTSC

NOTE: Honeywell reserves the right, without notification, to make changes in product design or specifications.

C23 Series Specifications

SPECIFICATION AND NUMBERING SYSTEM

Part Numbering System

C ☐☐ -L ☐☐ W ☐☐ M ☐☐ ☐☐☐ - ☐☐☐

FRAME COMMERCIAL DC MOTOR
23 – Size 23
34 – Size 34
42 – Size 42

LENGTH
33 – 40 – 45 – 50 – 55 – 60 – 70 – 80 – 90 – Refer to motor data table for standard offerings.

WINDING
10 – 20 – 30 – 40 – 50 – Refer to motor data table for standard offerings. Call factory for custom windings.

MECHANICAL OPTIONS
00 – Standard Shaft
Refer to Index for standard motor options offered. Many other custom mechanical options are available.

FEEDBACK OPTIONS

FEEDBACK OPTIONS
T – Tachometer
R – Resolver
E – Encoder

FACTORY OPTIONS
For custom unit types.

C23 SERIES SPECIFICATIONS – *Continuous Stall Torque 16.5 - 27 oz-in (0.117 - 0.191 Nm) Peak Torque 125 - 250 oz-in (0.883 - 1.765 Nm)*

Part Number*		C23-L33					C23-L40				
Winding Code**		10	20	30	40	50	10	20	30	40	50
L = Length	inches	3.33					4				
	millimeters	84.6					101.6				
Peak Torque	oz-in	125.0	125.0	125.0	125.0	125.0	250.0	250.0	250.0	250.0	250.0
	Nm	0.883	0.883	0.883	0.883	0.883	1.765	1.765	1.765	1.765	1.765
Continuous Stall Torque	oz-in	16.5	16.5	16.5	16.5	16.5	27.0	27.0	27.0	27.0	27.0
	Nm	0.117	0.117	0.117	0.117	0.117	0.191	0.191	0.191	0.191	0.191
Rated Terminal Voltage	volts DC	12 -24	12 - 24	12 -36	12 - 60	12 - 60	12 - 24	12 - 48	12 - 60	12 - 60	12 - 60
Terminal Voltage	volts DC	12	12	24	36	48	12	24	36	48	60
Rated Speed	RPM	4700	2150	4200	3750	3000	2300	3600	3500	2850	2250
	rad/sec	492	225	440	393	314	241	377	367	298	236
Rated Torque	oz-in	7.5	12.6	12.7	14.4	15.8	17.3	25.5	25.3	25.6	24.2
	Nm	0.05	0.09	0.09	0.10	0.11	0.12	0.18	0.18	0.18	0.17
Rated Current	Amps	4.75	4.3	3	2	1.4	4.9	4.3	2.75	1.8	1.1
Rated Power	Watts	26.1	20.0	39.5	40.0	35.1	29.4	67.9	65.5	54.0	40.3
	Horsepower	0.03	0.03	0.05	0.05	0.05	0.04	0.09	0.09	0.07	0.05
Torque Senstivity	oz-in/amp	2.65	4.25	6.2	10.25	15.75	4.84	7.74	12	18.5	28.75
	Nm/amp	0.0187	0.0300	0.0438	0.0724	0.1112	0.0342	0.0547	0.0847	0.1306	0.2030
Back EMF	volts/KRPM	2	3.15	4.6	7.6	11.5	3.58	5.72	8.82	13.82	21.22
	volts/rad/sec	0.0191	0.0301	0.0439	0.0726	0.1098	0.0342	0.0546	0.0842	0.1320	0.2026
Terminal Resistance	ohms	0.60	1.00	1.70	4.00	9.00	0.70	0.96	2.30	5.50	12.00
Terminal Inductance	mH	0.35	0.94	2.00	5.50	13.00	0.50	1.30	3.10	7.36	18.00
Motor Constant	oz-in/watt^1/2	3.4	4.3	4.8	5.1	5.3	5.8	7.9	7.9	7.9	8.3
	Nm/watt	0.024	0.030	0.034	0.036	0.037	0.041	0.056	0.056	0.056	0.059
Rotor Inertia	oz-in-sec^2	0.0022	0.0022	0.0022	0.0022	0.0022	0.004	0.004	0.004	0.004	0.004
	g-cm^2	155.4	155.4	155.4	155.4	155.4	282.5	282.5	282.5	282.5	282.5
Friction Torque	oz-in	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	Nm	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Thermal Resistance	°C/watt	6.2	6.2	6.2	6.2	6.2	5.4	5.4	5.4	5.4	5.4
Damping Factor	oz-in/KRPM	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Nm/KRPM	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Weight	oz	27	27	27	27	27	38	38	38	38	38
	g	765	765	765	765	765	1077	1077	1077	1077	1077
Electrical Time Constant	millisecond	0.5833	0.9400	1.1765	1.3750	1.4444	0.7143	1.3584	1.3478	1.3382	1.5000
Mech. Time Constant	millisecond	26.07623	17.2056	13.72994	11.82747	11.44547	16.91906	9.052773	9.100907	9.00927	8.237676
Speed/Torque Gradient	rpm/oz-in	-113.2075	-74.69655	-59.60729	-51.34788	-49.68944	-40.39891	-21.61598	-21.73091	-21.51211	-19.66971

Notes:

(continued on next page)

1. For MS (military style) connector, please specify connector housing and terminal.
2. Data for informational purposes only. Should not be considered a binding performance agreement. For specific applications, please contact the factory.

*Many other custom mechanical options are available – consult factory.
**Many other winding options are available – consult factory.

Model : TWS-BS-3

- Frequency Range: 433.92MHz
- Modulate Mode: ASK
- Circuit Shape: SAW
- Date Rate: 8Kbps
- Supply Voltage: 1.5~12V
- Output Power : 14dBm
- Working temperature: -20~+85℃
- Solder temperature: 230℃(10 seconds).
- High sensitivity is designed.

Application

● Wireless Data Transmission	● Wireless Game Pad
● Remote Control	● Wireless Toys
● Car Key	● Home Automation
● AMR- Automatic Meter Reading	● Remote Keyless Entry

NSHING Confidential Distribution

Absolute Maximum Rating

Rating	Value	Unit
Power Supply and All Input/ Output Pins	-0.3~+12.0	V
Non-Operating Case Temperature	-20~+85	℃
Soldering Temperature(10 seconds)	230	℃

Appendix D: Program Codes

Arduino codes:

```
#include <IRremote.h>
#include <Servo.h>

Servo gripper;  // create servo object to control a servo
                // a maximum of eight servo objects can be created
 Servo middle;  // create servo object to control a servo
Servo bottom;  // create servo object to control a servo

int RECV_PIN = 5;

IRrecv irrecv(RECV_PIN);

decode_results results;

void setup()
{
    gripper.attach(9);  // attaches the servo on pin 9 to the servo object
  middle.attach(10);  // attaches the servo on pin 9 to the servo object
  bottom.attach(11);  // attaches the servo on pin 9 to the servo object

  Serial.begin(9600);

  irrecv.enableIRIn(); // Start the receiver
}

void loop() {
  if (irrecv.decode(&results)) {
```

```
   int a =results.value;
   Serial.println(a);

   if(a == 2704)
   {}
     if(a == 2705)
   {}
      if(a == 2706)
   {}
      if(a == 2707)
   {}
      if(a == 2708)
   {}
      if(a == 2709)
   {}

    irrecv.resume(); // Receive the next value



}
  delay(100);
```

Appendix E: Operation Manual

Below is a general guideline on using the PIAC

1. Running the project prototype

   To run the project the following steps need to be taken

   a. There are 3 switches that need to be turned on
   b. Switch one is to turn on the cleaner blade
   c. Switch two is to turn on the mobility motors
   d. Switch three is to turn on the camera transmitter
   e. After all the 3 switches are turned on the remote needs to be turned on
   f. After turning on all the systems test the mobility motor, the camera and the cleaning motor and make sure the battery is charged full
   g. Attach the cleaning brush to the project. Many different types of cleaning brushes can be used and developed at later stages
   h. After attaching the brush insert the PIAC into the pipe; move it using the controls and clean accordingly
   i.
2. Troubleshooting
   a. Camera not working:
      i. Check if the camera switch is turned on
      ii. Check if the receiver is powered on
      iii. Check if the batteries are charged
   b. Motors not working
      i. Check if motor switches are off
      ii. Check if the connection with battery is secure
      iii. Check the battery charge
   c. PIAC stuck in pipe
      i. Check if transmitter is powered on
      ii. Direct the antenna directly at the opening of the pipe

Assessment- Final Year Project

The pipe inspecting and cleaning robot (PIAC)

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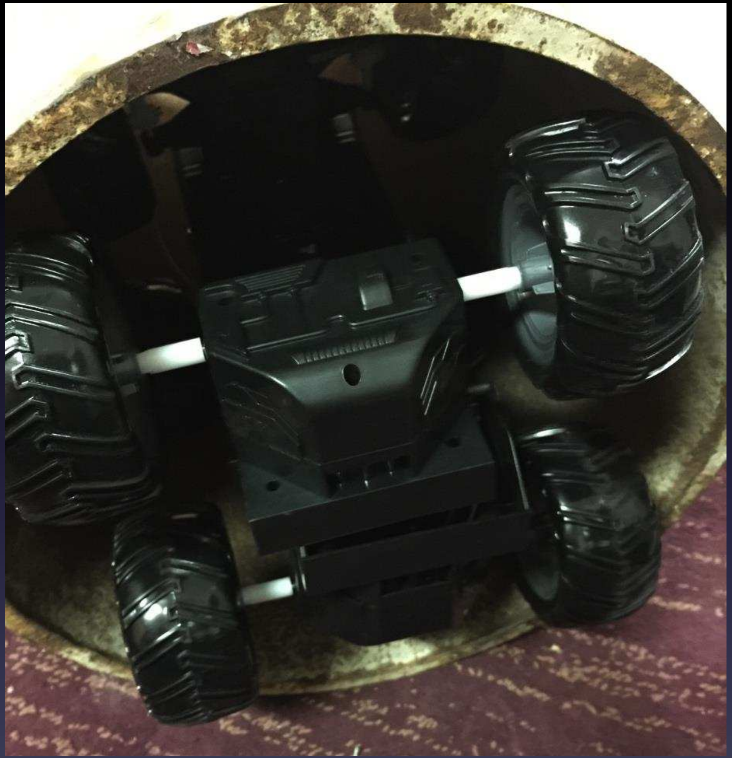
Outline

- Recap (Main points of last presentation)
- Objectives
- Grant Chart
- Project Description and functions
- Project Sub systems
- Tasks Accomplished -**DEMO**
- Main Challenges faced
- Demo
- Conclusion

Recap: Main points of last presentation

- Project Idea: a robot that will be used to clean the interior of the pipes and also monitoring the interiors
- First 3D Model was prepared
- Preliminary structure built
- Electronics were not installed

Recap: Important Points



Our old design from last presentation

Objectives

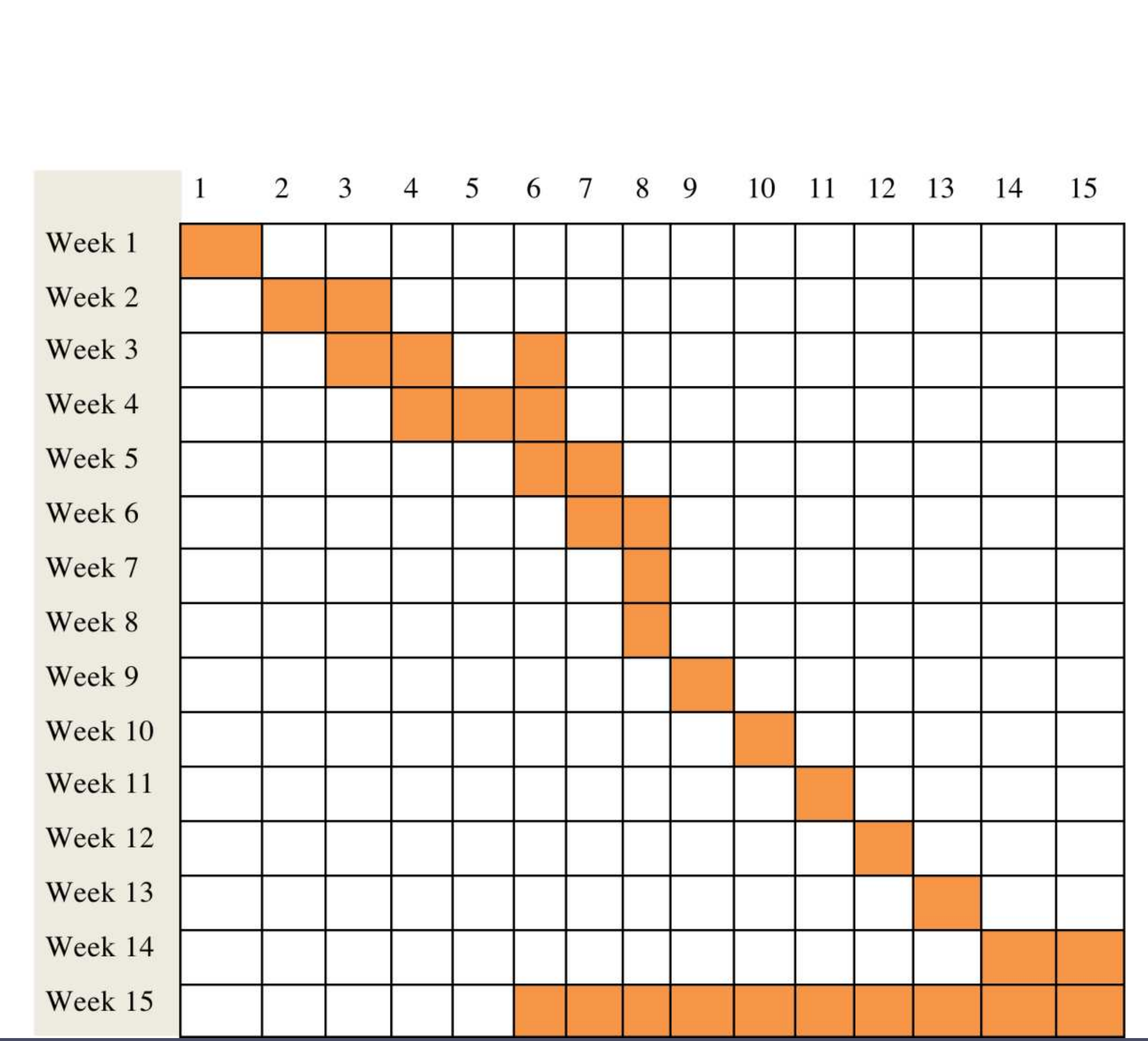
- Build prototype robot with the following features:
- Cleaning for 10 inch metal pipe
- Wireless video feedback
- Sturdy (Strong) design
- Battery operated wireless robot

Benefits

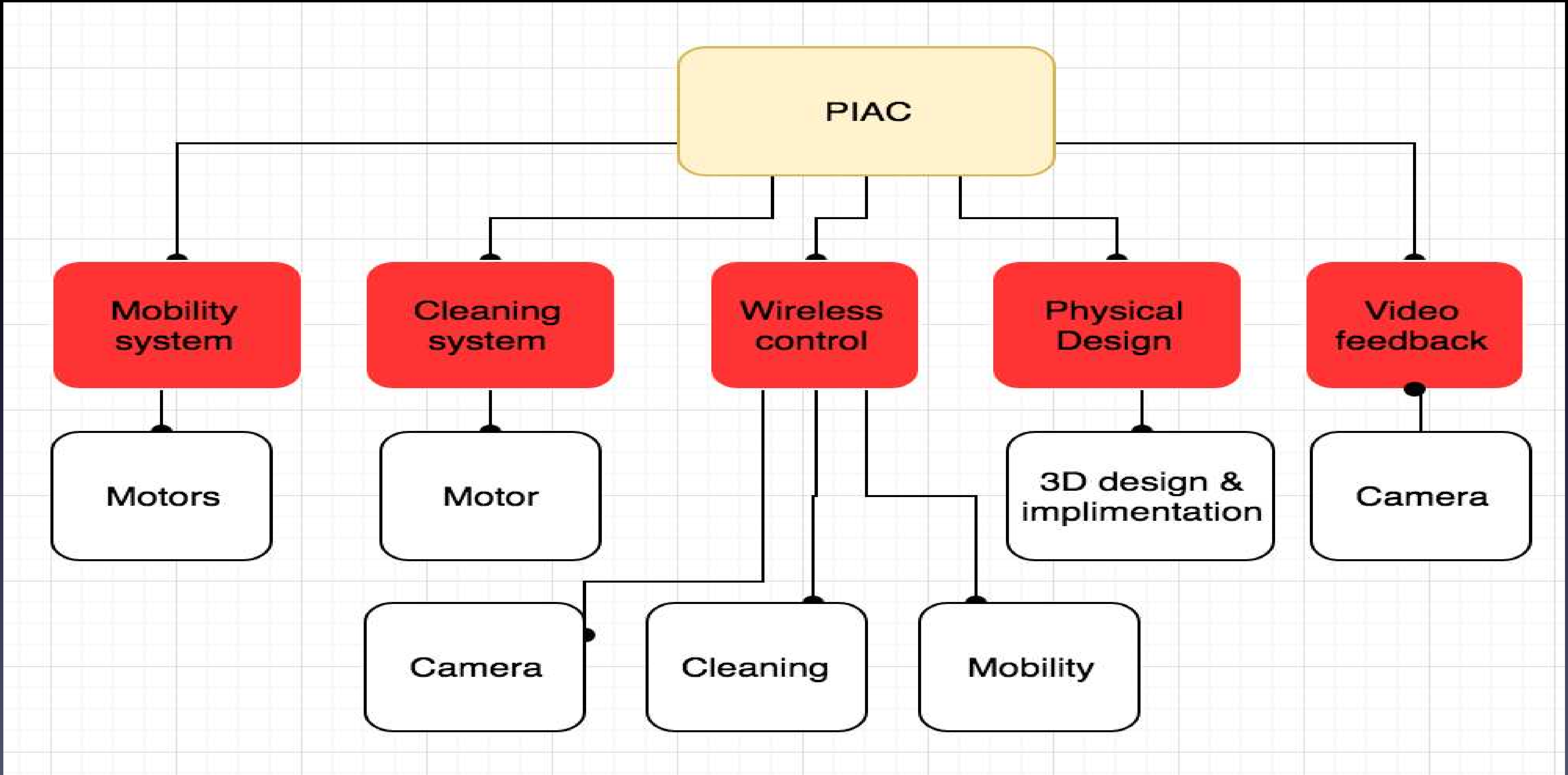
- Increased pipeline carrying capacity
- Improved product quality
- Power savings by reducing pump pressure
- Confirmation of pipe and flow integrity
- Live video streaming
- Remote robot control

Grant Chart

1. Finalize team
2. Brainstorm ideas
3. Literature review of ideas
4. Finalize ideas
5. Prepare first report and presentation
6. Work on the structure of the robot
7. Final design of structure
8. Build structure
9. Design cleaning blade
10. Video streaming
11. Test sub-systems separately
12. Movement addition
13. System integration
14. System testing
15. Final report



PIAC: Functional Diagram



PIAC: Description

- 5 Sub Systems:
  - Mobility
  - Wireless
  - Cleaning
  - Physical Design
  - Video feedback

Task Distribution

Mohammed

System integration:
Checking that the system is working after we have the system for three days to make sure that it is working without mistakes.

Finance handling:
The finance handling, purchase and collect.

Abdullah

Programming:
Make the schedule for the meetings and made the plan to finish the project and divide the work between the members of our team.

Team management:
The leader of the group and was following with the other members.

Materials selection:
Made the decision and select the plastic and discuss that with the other members and we agree, after that look for the materials and select the best for our project.

Naif

Structural building:
Contribute in the structural building of the project.

Pipe providing:
Provide the pipe after we choose the size of it.

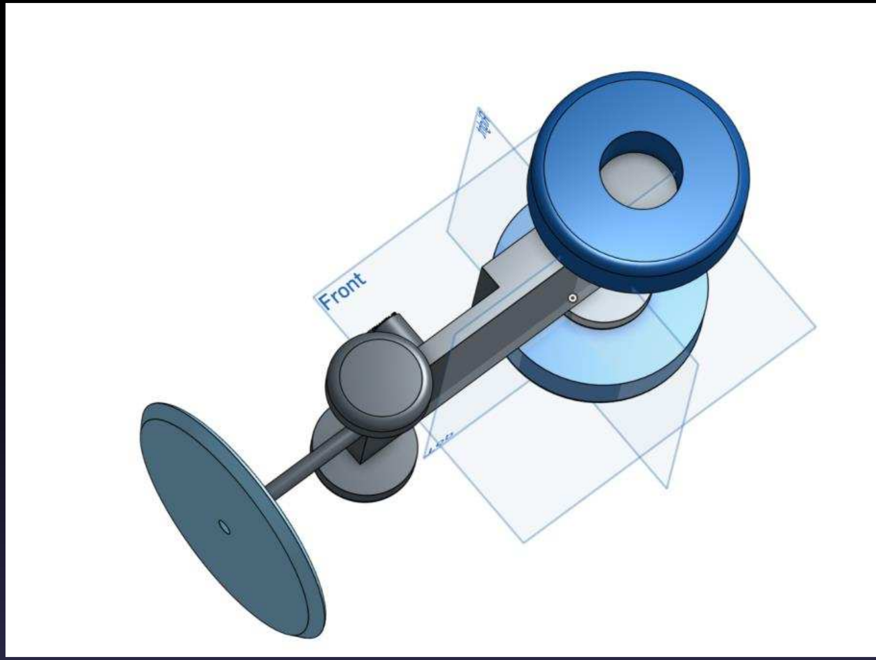
Materials purchasing:
Purchase the materials after we select them.

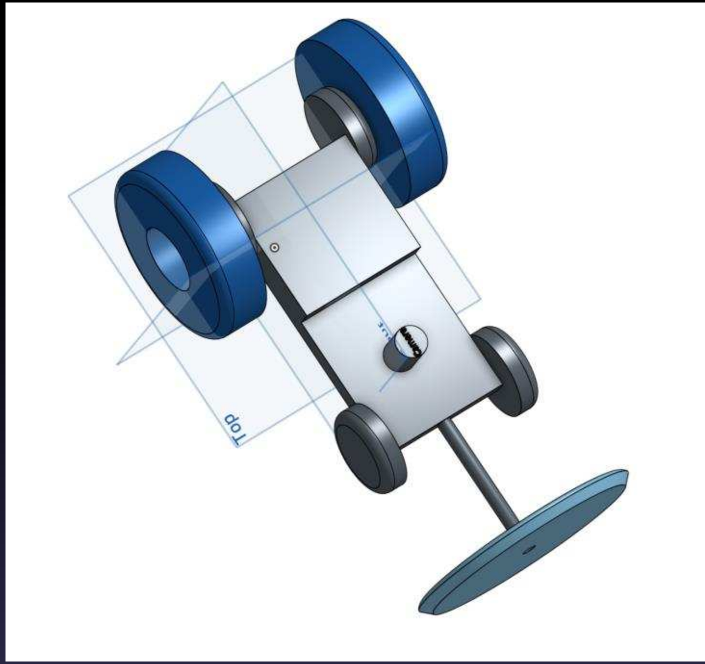
Ahmed

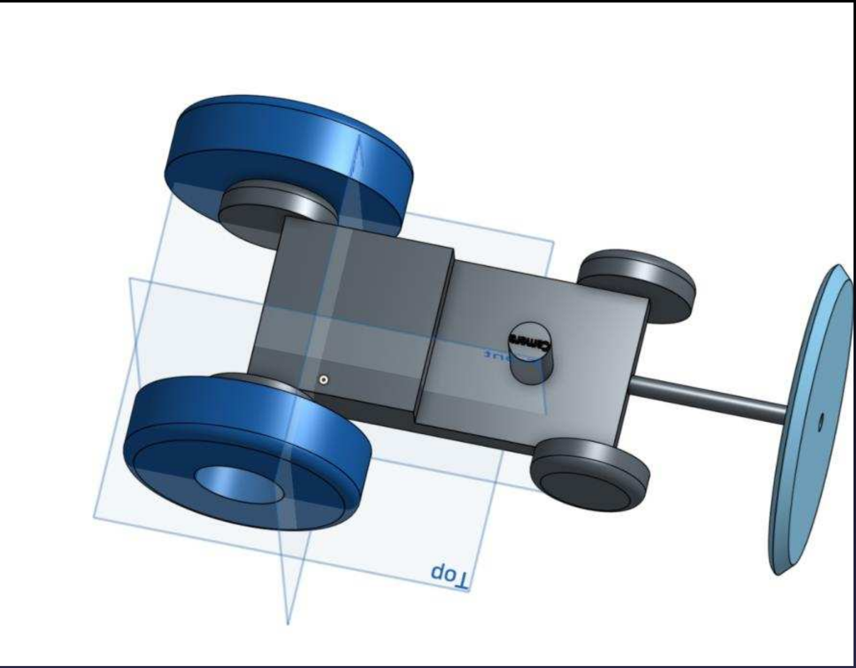
Electrical work:
looked for specialist in electrical and programing and electronics.

Testing:
Made the test for the project to make sure it is working.

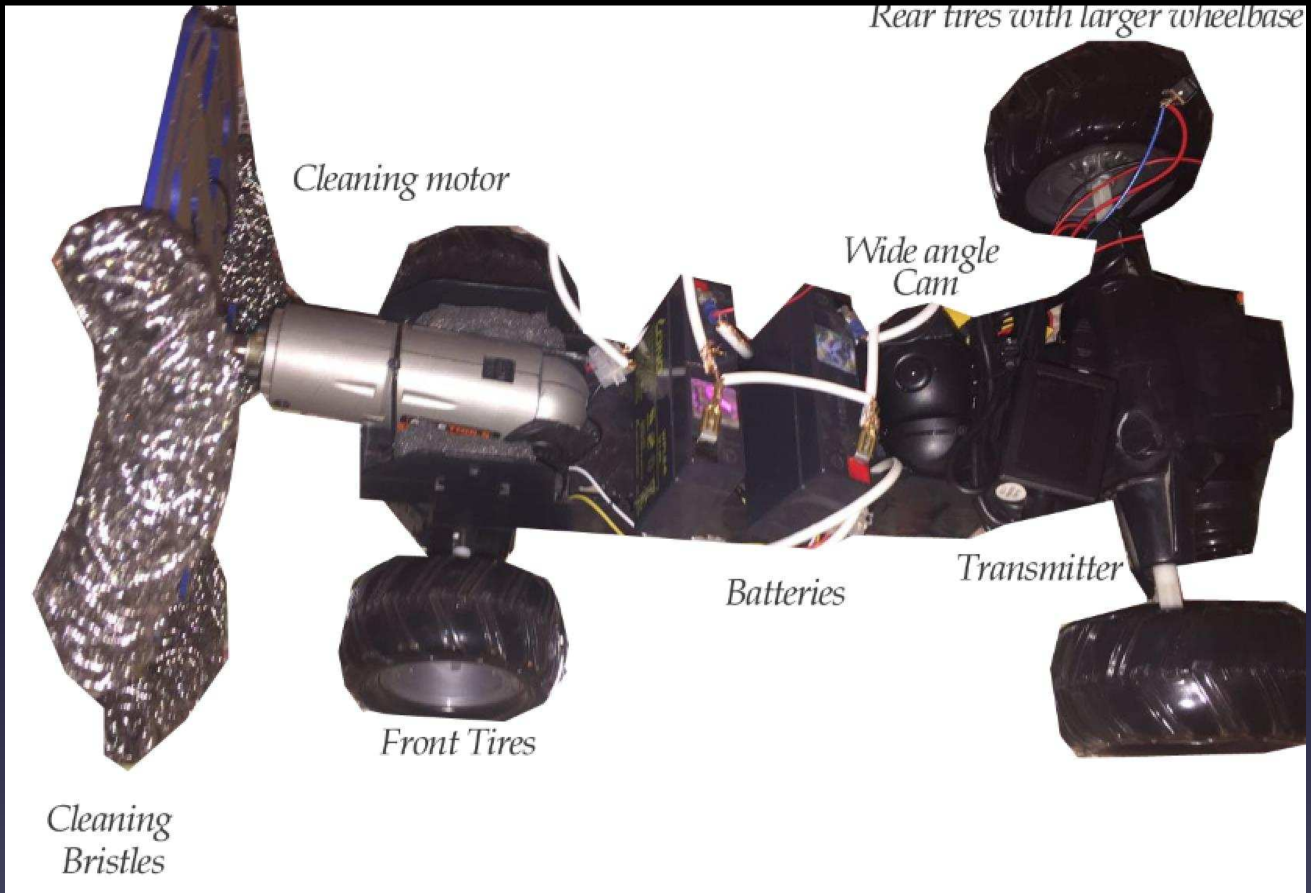
3D modeling

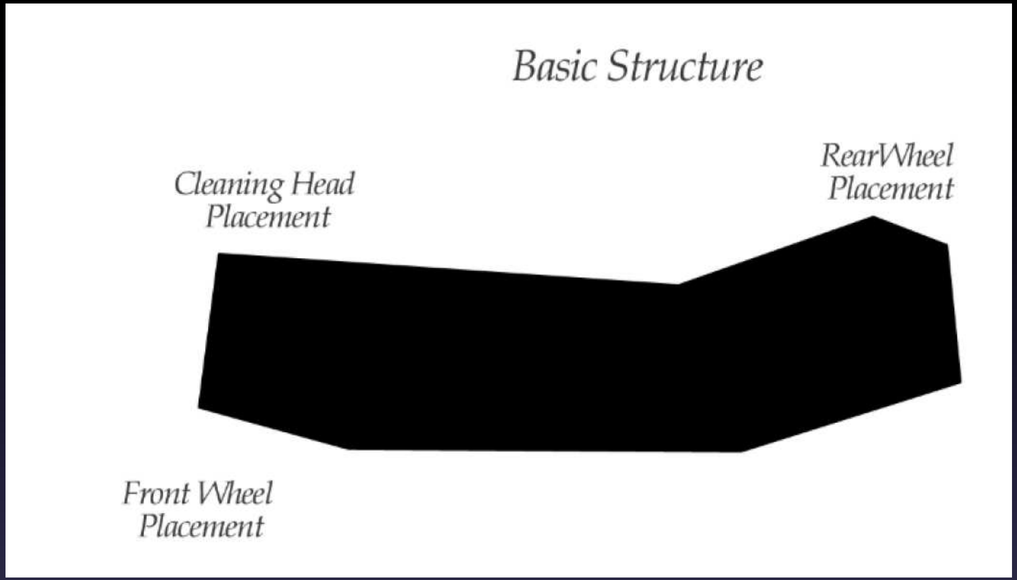




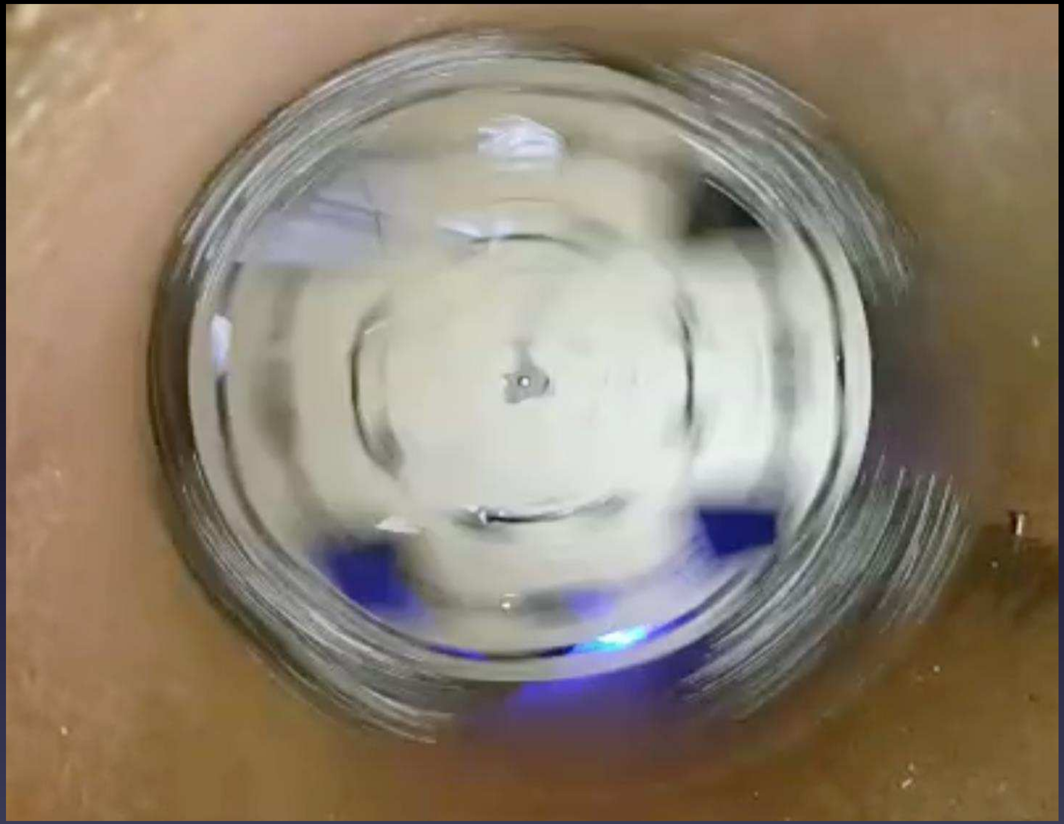


PIAC Physical Breakdown

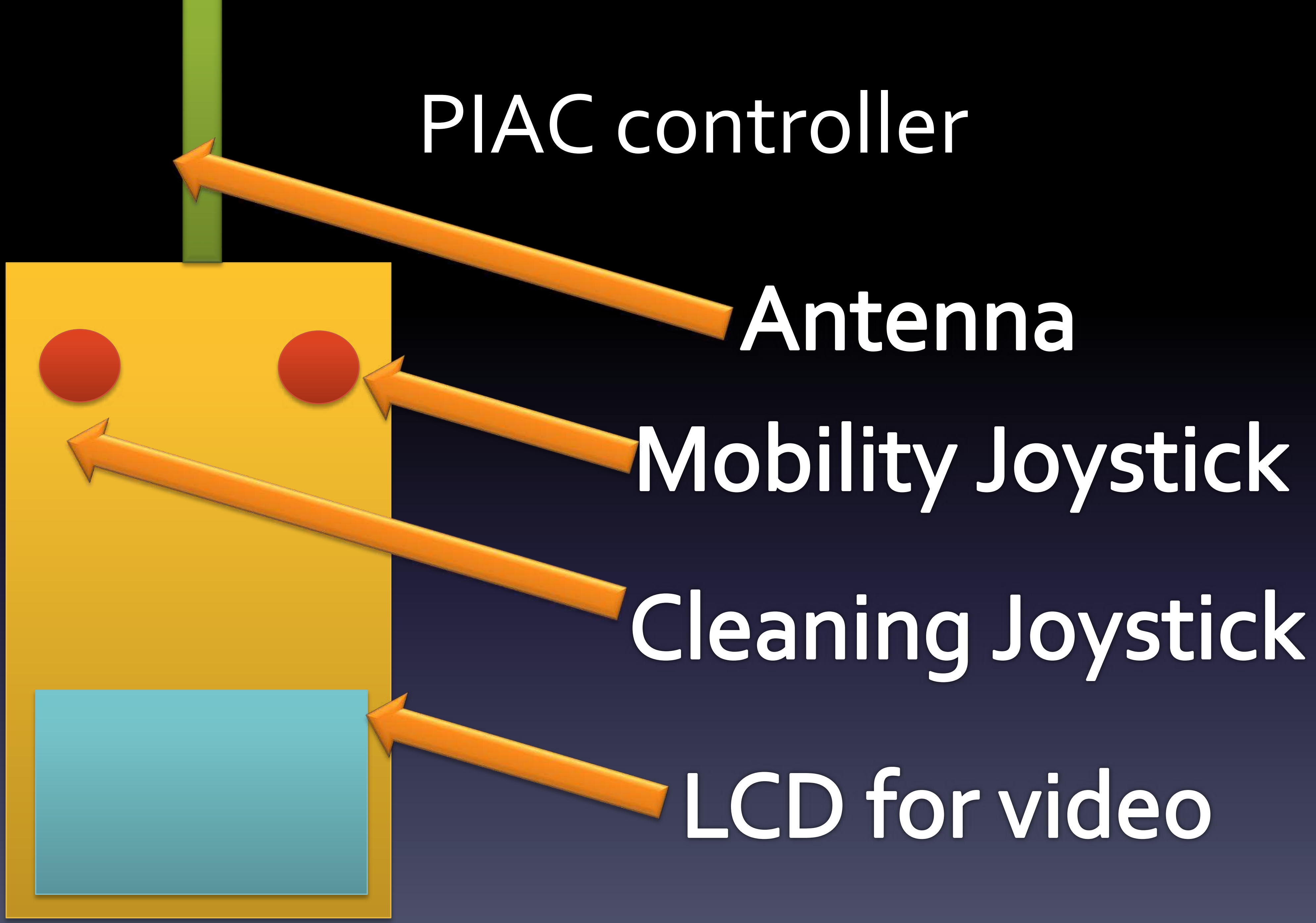




PIAC in action



PIAC controller



Challenges faced

- Camera Banned in Saudi Arabia
- Electrical systems
- Finalizing physical design (3 Times we had to redo physical design)

Rejected design due to instability

Conclusions

- Project Objective achieved
- PIAC is able to clean 10 inch pipes
- Wireless video
- All systems tested and integrated
- More improvements can be done in:
  - Adding engineering standards
  - Improving battery life

Video Demo

- Please Enjoy our video demo