Design and Fabrication of a maneuverable UGV targeting the Healthcare Industry

A Final Year Project Report

Presented to

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

Department of Mechanical Engineering

NUST

ISLAMABAD, PAKISTAN

In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

by

Muneeb Afzaal (242229)
Saim Omer (242056)
Sami Ullah (259733)
Uzair Sohail (246241)

-

May 29th, 2022

TABLE OF CONTENTS

ORIGINALITY REPORT

We hereby declare that this submission is our own work, and the intellectual content of this report is the product of our own work, except to the extent that assistance from others in the project's design and conception or in style, presentation and linguistic is acknowledged.

ABSTRACT

The following report discusses the design of an Unmanned Ground Vehicle (UGV) which will enable it to cover rough and diverse tracks, specifically focused on urban terrains (inside of a building, stairs, etc.). The aim of the project was also to provide the UGV with a commercialization application. Our application focuses on the health-care industry; however, several other relevant applications may also be drawn out of it due to its simplicity. It is an unmanned ground vehicle, aiming to have simplistic and efficient machine design, with ability to move through terrain with appropriate velocity. The UGV will be able to climb stairs with respect to the angle of inclination provided to its front flippers. We then discuss operation and control of UGV via Arduino, programming, and relevant control devices.

The UGV is to assist in situations where human intervention needs to be avoided, with healthcare industry being the prime focus. It may be used to transport drugs, food and other relevant needs to patients suffering from contagious diseases.

ACKNOWLEDGMENTS

We are thankful to the entire faculty of *School of Mechanical and Manufacturing Engineering (SMME), NUST*, who have, in these 4 years, instilled us with valuable knowledge and discipline to pursue this mechanical oriented project. We would like to thank Principal, Dr. Javaid Iqbal, who was able to guide us with his tremendous knowledge and experiences in UGVs. We have learned plenty from his supervised projects and thesis. Dr. Javaid Iqbal also cooperated with us in arranging visits to EME College, NUST, to study the UGVs there. We would also like to appreciate our highly supportive supervisor, Sir Karamdad Kallu, who always found time to listen to our progress and guide us accordingly. The idea of our project and further pursuance of it would have certainly not been possible without him.

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

UGV	Unmanned Ground Vehicle
EID	Emerging Infectious Disease
DOF	Degree of Freedom
POE	Power over Ethernet
ICR	Instantaneous center of rotation
RF	Radio Frequency

NOMENCLATURE

$v_{x,y} = UGV$'s translational velocities with respect to its local frame

$v_{Xi,Yi} = UGV$'s translational velocities with respect to its global frame

$v_{l,r} = V$elocities of left and right tracks respectively

$\omega_z = Angular\ Veloctity\ of\ UGV\ about\ its\ center$

$ICR = Instantaneous\ Center\ of\ Rotation$

$T = Total\ Torque\ Required\ by\ UGV$

$T' = Torque\ Load\ on\ one\ Motor$

$M = Mass\ of\ UGV$

$d = Distance\ between\ Tracks\ (wheels)$

$r = \ Radius\ of\ wheels$

CHAPTER 1: INTRODUCTION

Mobile robots and automatization are leading the industrial progress and innovation in the world, with robots being introduced to perform every task possible. Locomotive robots are significant players of this industrial progress due to the thousands of applications being introduced with it. Of these, Unmanned Ground Vehicles (UGVs) and their applications is a complete sector, with ever-diversifying designs and improvements. UGV Market size was valued at $ 1.5bn in 2016 and is expected to grow to $ 3.36 bn in 2023. However, more than 75% of the revenue is from the military market; it has a huge scope in various other industries. This is what provided motivation us to work on this sector and provide appropriate engineering solutions and innovations in it.

1.1 Problem statement:

Considering the facts and figures provided above, the problem statement of our project was to explore the rapidly growing UGV industry further and provide an innovative and impactful commercialization application of UGVs. After studying and considering several industries which could adapt UGV applications, we decided on the health-care Industry, due to the significant impact it will create there, it’s need for commercialization in healthcare and the rising demand. Due to the recent Covid pandemic, focus has been made on application of UGV in Health care industry to achieve human to human contact free activities. However, there is plenty of scope for innovation and entrepreneurship at this moment as not much practical progress has been noted.

1.2 Objective and application of the UGV

With respect to the motivation provided earlier and our statement to explore UGV and its applications in other industries, we concluded on the following objective and application for our project:

Design and fabrication of an Unmanned Ground Vehicle (UGV) which will enable it to cover rough and diverse tracks, specifically focused on urban terrains. It is to have simplistic and efficient machine design, with ability to move through terrain with appropriate velocity. The UGV should be able to climb stairs with respect to the fixed angle of inclination provided to it. It is to assist in situations where human intervention needs to be avoided, with healthcare industry being the prime focus. It may be used to transport drugs, food and other relevant needs to patients suffering from a contagious disease.

The UGV developed by us, considering it would be in its initial stages, would be able to be used via Remote or Mobile applications. The uplifted and continuous tracks design provided to it would allow it to climb rough terrains and stairs. It would run on simple DC batteries and motors, with plenty of control systems assigned to it to make it effective. The UGV would house a single Degree of Freedom (DOF) manipulator on top of it to assist in delivery of things; the manipulator would be able to carry a weight of minimum 7kgs. Furthermore, the UGV would also consist of a camera system for live video and audio feedback, so the controller is able to view and interact with surroundings (and patients, as mentioned in its application).

1.3 Scope of the project

The idea will fulfill the need of a robotic assistant that will aid nursing in situation of contagious diseases, thus restricting the outspread and saving lives. It will be a major help in epidemic situations, contagious wards, or other relatable situations. The use and advantages can be extended to various other aspects or needs. For example, it could be used at Nuclear/Radiation sites to transport material that would otherwise be too harmful to be handled by a human.

The need of such a UGV could be applied to the whole globe, with the COVID pandemic situation recently highlighting the need. With a cheap and simplistic design, the UGV could be afforded and used in third world countries, where outspread of diseases is much likely and needs efficient ways to be controlled.

In Africa alone, almost half of the countries experience an Emerging Infectious Disease (EID) epidemic each year. About 75% of these diseases are vector-borne or transmissible. Using a UGV for contactless transport of drugs and other necessities to patients in such situation would help control the outbreak and save the healthcare staff.

With such an effective, well needed application being delivered by the proposed UGV, the number who would benefit from it could very well range from hundreds of thousands to millions

CHAPTER 2: LITERATURE REVIEW

The literature review presented in this report can be divided into two parts:

- existing knowledge and progress in design of UGVs
- existing knowledge and progress on the application of UGV in health-care industry

2.1 Design of UGVs

Due to the robust conditions demand in military applications, there has been plenty of development in numerous UGV designs, providing them the ability to cover rough terrains and be robust. *NASA* has developed various designs for its exploration needs. *Boston dynamics* is leading the race in biomimicry to develop UGV designs. *Ecagroup* is winning multiple Million Dollar contracts for its robust UGV design along with military applications.

Several aspects may be considered when studying the UGV literature. These include

- Base structure for decent performance and stability
- Design of Mechanical System
- Type of operation: Tele-operated, Self-governing.
- Kinematic modeling approach
- Energy efficiency of Unmanned Ground Vehicles (UGVs)
- System and Control Architecture
- Level of automation: Object Detection and Assistance Program
- The software(s) used for the development of the Robot

Let us study these aspects further, with respect to recent developments, both within Pakistan and internationally. For the developments in UGV designs with in Pakistan, we studied two highly relevant thesis from the EME College, NUST library.

2.2 Research Paper Literature

Title: *PR-SOF-0594 Unmanned Ground Vehicle*

Supervised by: Dr. Javaid Iqbal

Institute: *EME College, NUST*

The *PR-SOF-0594 Unmanned Ground Vehicle* thesis talked about the design of a UGV with purpose to be robust, easy to transport, remotely operated and multipurpose. The design of the model is shown. The design used the concepts of numerous idlers and a continuous track for maneuvering; for maneuverability, it uses differential gear mechanism. The material used for chassis was Aluminum Alloy AL-6061-T6; for parts requiring greater strength, mild steel was used, e.g., in axels and shafts. The motor, driving wheel, idler and caterpillar tracks provide for the driving mechanism of the UGV. Although plenty of insight was received by studying this UGV, some flaws/ room for improvement was also noted. The total mass of the UGV was resulting to be 60kg. This also further required heavier motors. We can note that the side flippers, hosting idlers, is a huge unnecessary part which provides room for further optimization, in order to reduce weight and improve drive mechanism.

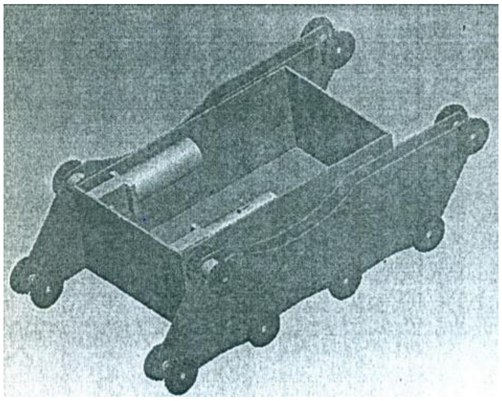


Figure 1- Chassis and body of PR-SOF-0594 UGV

Title: *PR-SOF-1343 Small Unmanned Ground Vehicle*

Supervised by: Dr. Javaid Iqbal, Dr. Nasir Rashid

Institute: *EME College, NUST*

The other thesis studied was the *PR-SOF-1343 Small Unmanned Ground Vehicle* thesis. This UGV has the most relevant and simplistic design to achieve the objective. This design is shown below. The UGV used fixed front slippers with minimum material. A continuous track was used to connect the driving wheels, main idlers, and the small idlers on the flipper. The drive mechanism used seemed to be simple and effective too. Two motors were used on both sides, in assembly that ensured balanced center of gravity in middle. Each motor drove a sprocket which, via chain, drove the sprocket at back end and then the driving wheel. This design was deemed as more efficient for negligible losses when transferring motion from motors at middle to driving wheels at rear. The use of bulky motors resulted in the total mass of 23kg which really impacted shafts and the overall design. The thesis lacked detailed insights of power calculations and parameters used to define the battery, motor selection. Furthermore, its robustness and ability to cover rough terrains was not demonstrated. There were also negligible considerations of the coefficient of frictions to study ability to cover smooth terrains and dynamic analysis using gravity to check stability. The internal placement of all the components and their effectiveness was also to be studied further by our members. Lastly, and most importantly, the UGV did not provide any specific application/ use to it. There was room to improvise and provide commercialization abilities to it.

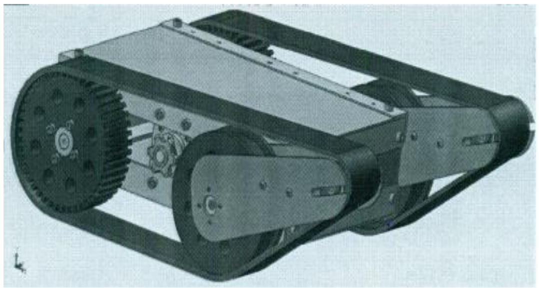


Figure 2 - PR-SOF-1343 Small Unmanned Ground Vehicle

Title: *Unmanned Drug Delivery for Covid 19 wards in Hospitals*

Authors: Uttam Desh Pandey, Virendra S Malemath, Aditya Barale

The thesis discussed a low of cost UGV that used a hexagonal structure with multiple sensors on board to help the user understand the environment around. The design incorporated plenty of self-governing/ autonomous ability, including an object detection program. When talking about the mechanical features on the UGV, it was provided traversing capability till 45 degrees inclination. This was achieved using a mechanical coupler that joined the two bodies of the vehicle (Figure 3.). The coupler provided the two bodies with adaptive motion, providing adjustment to the body's total bend in safe zone. The design also incorporated flexibility to twist and turn movements by using articulated steering system with a mechanical differential. This reserved momentum, decreased the power consumption and thus improved speed efficiency. The design of the overall UGV, although flexible, was not deemed robust. It was able to take sharp turn, cover continuous inclined slopes, but was not strong/ robust to sustain impacts. Furthermore, the design limited the UGV to climb stairs/ incremental heights. There was no analysis for the vehicle strength, stress provided, and a plastic structure was used, these features are not efficient for the commercial use. Furthermore, the UGV was really small, with low weight carrying ability; it uses could only be extended to carry a few packs of tablets.

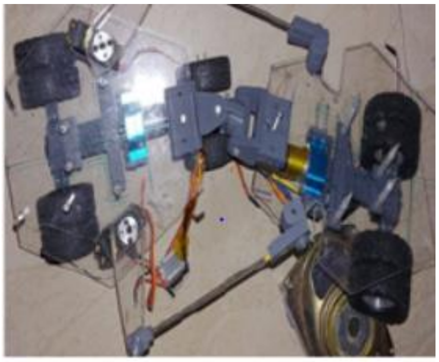


Figure 3 - Drug Delivery UGV

2.3 Commercialized UGV Models

Our team also studied some of the general UGV designs, developed worldwide.

Dragon runner (10,20)

One UGV model that we studied was the *Dragon runner* (10, 20). These were used for military applications and are designed to cover rough terrains. They can be categorized as Micro Unmanned Ground Vehicle due to their highly compact and light weights. The Dragon runner 10 weighs only 4.5kg; furthermore, it has high flexibility, providing it the ability to be thrown and survive rough handling and adverse weather. With respect to cover the diversity of terrains, it has certain restrictions due to design, with absence of flippers. Furthermore, due to its compact and light-weight design, it can only be mounted with lightweight arm, weighing 3.2kgs. The design of Dragon runner was further extended with Dragon runner 20, which incorporated flipper design, providing it to cover greater diversity of terrains, including stairs. It can lift weight up to 4.5kgs. These UGVs were teams and micro/small scale UGVs which do have plenty of scope in military applications but lack commercialization application in other industries.

Figure 4 - Dragon runner

Packbot

This is yet another highly flexible UGV designed on commercial level but with applications dedicated to military purposes only. It is based on a front flippers design. The Packbot movement refer to the use of dual rotating flippers which help it to cover obstacles and turn the UGV over after an accident. The overall design is very robust, it can survive rugged terrains and has been tested with Air Mobility System (AMS), allowing it to evolve into a man-portable hybrid UGV/UAV. The flippers of Packbot are not fixed, but have the capability to rotate 360 degrees, allowing the it to be pulled upwards and forward. This mechanic ability provides with UGV with a different sort of flexibility; it is able to cover any sort of rough/ rugged trains, be it varying slopes, incremental heights etc. However, with flippers not being fixed, it has restricted use to fast, continuous climbing of stairs as the flipper would have to be controlled and placed accordingly while climbing each of the stair. This restricts it's use for fast moving commercialization activities, such as drug deliver in hospitals.

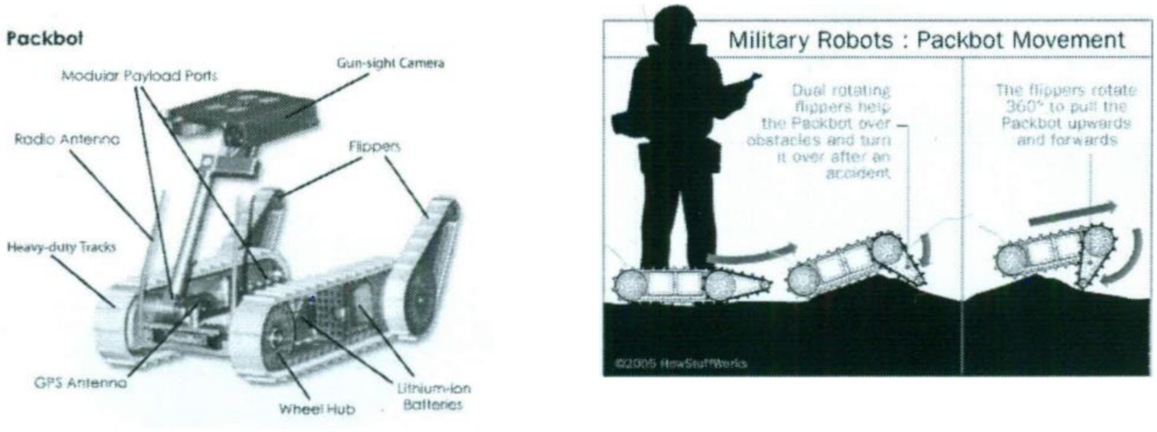


Figure 5 - Packbot

This was another commercial UGV studied by our team; its design was quite similar to the *PR-SOF-0594 Unmanned Ground Vehicle* mentioned earlier in thesis literature. Matilda is intended to have applications including target surveillance, explosive device neutralization, material pickup and transport, weapon transport and firing, and law enforcement. It can be categorized into a bit larger family of UGVs, with payload capacity of 56.7 kgs and an astonishing towing capacity of 215 kgs. This is credited to its relevantly larger size, higher torque motors, weighing over all around 24 kgs. It can travel up to 2mph, powered by 2-12 vdc Rechargeable Lead Acid battery. The slide flipper’s design result it its body having a triangular volumetric shape, which may hinder us to place a manipulator on top of it. Furthermore, better flipper mechanism may be introduced which would not require complete solid body to host the tracks.

Figure 6 - Matilda

2.4 Progress of UGVs in health-care industry

The UGV certainly has the potential to be adopted by the beneficiaries, i.e., the health care industry. The recent COVID pandemic highlighted the need for it and plenty of international grants were allotted to develop autonomous vehicles to help staff in Covid 19 situation.

A research paper covered by our team noted the positive feedback by the Healthcare industry for the use of a UGV to assist them. The idea was much appreciated by doctors and nursing staff. We further conducted a survey ourselves, taking feedback from medical staff and students. Great interest was shown on our proposal and ease of use was also accepted.

Currently, 75% of UGV market is focused on military applications and there has been negligible development for applications in healthcare industry. Hence the application provided to our UGV differentiates it from other manufacturers/ companies. One research paper was recently published, that highlighted a UGV for contactless drug transport. This is discussed in the thesis literature above (Figure 3). The design was seemed not highly effective for commercial use due to negligence in its robustness, strength, ability to climb stairs and carry greater weight. Furthermore, no commercialization progress of the design was able to be tracked, the design was not worked upon further.

Furthermore, PAL Robotics SL, in Spain, was awarded a grant for development of Autonomous vehicles to help staff in Covid 19 situation. There has been no traceable progress of their work either.

2.5 Control System of UGVs

Control system of the UGV is concerned with the controlling mechanisms of the robot. It discusses the overall level of autonomy present such as fully autonomous/ semi- autonomous/ tele-operated. For the proper functionality of UGV, a certain number of sensors are also required in the Control System. Motion control is also done by controlling several different variables such as motor speed.

To properly design the system, our team researched about the existing control systems in different UGVs:

1. **Design and Implementation of Low-Cost Remote-Operated Unmanned Ground Vehicle (Zain Murtaza, Noaman Mehmood, Mohsin Jamil, Yasar Ayaz)**
   Institution: NUST

In this paper, the authors have designed a UGV which operates on full-duplex communication. Duplex communication means that it’s a point-to-point system and the connected devices can communicate with one another in both directions. So, the human operator does not need to be part of the environment in which UGV is travelling. Relevant information from the external environment of UGV can be collected through various sensors that are placed on strategic locations. To gauge the surroundings in an accurate way, there is a camera installed on the UGV, which provides real time audio/video. The specific camera that is placed on this UGV is IP Camera. IP Camera is basically a digital security camera that transmits data via IP network, so it does not need a local recording device (like CCTV), just a local network. Some sensors that are employed in this UGV are:

- IR
- Sonar
- Magnetometer
- Motion sensor

IR sensors use infrared radiation to detect motion. Sonar uses ultrasonic sound waves to measure the distance between two objects. Magnetometers are used to measure the strength of magnetic fields. They can be used for the navigation of robot, as GPS can't immediately provide heading data without gathering several position points first. So, digital magnetometer can be configured to act as a compass. Motion sensors are used to detect motion. All the data that has been compiled through these sensors is transferred back to the base station (the point at which human operator gives commands to the robot) using XBEE. XBee modules are embedded solutions providing wireless end-point connectivity to devices. After the data has been transmitted to the base station, it is transferred to the computer screen where it is displayed using the GUI system.

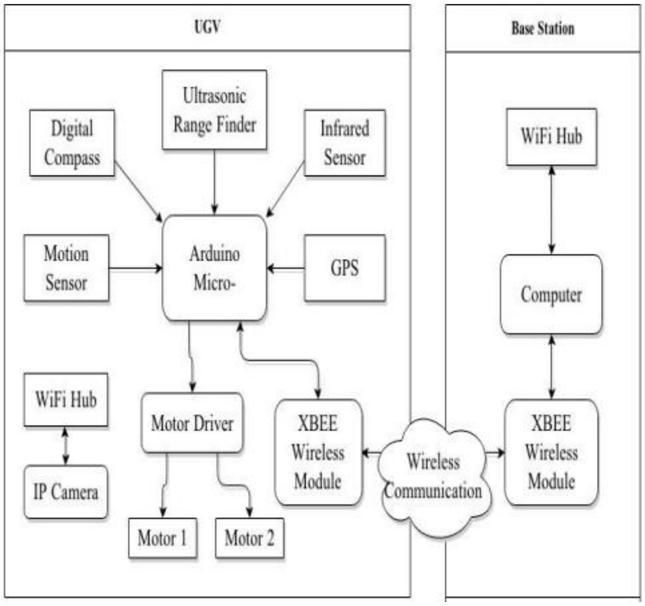


Figure 7 - Control systems chart

As far as the electrical system is concerned, each of the module in the system needs a different voltage so power regulatory circuit has been used to do that. Each module communicates with others using different protocols. The communication of microcontroller with GPS, and XBEE module is done on serial protocol. Ultrasonic and IR sensor are connected via analogue interface, to the microcontroller. Arduino-mega is used instead of Arduino-uno because in this design, two serial ports are required: one for the GPS, one for the XBEE module. Lithium-ion batteries are used as they have less weight and cost.

2. Four Different Modes to Control UGV (Azharuddin, Kumar, Sathiyanarayanan)

Institute: Rajiv Gandhi Institute of Technology, Bangalore, India

In this paper, the authors have discussed four different strategies that can be employed to design the control system of UGV. Each of the mode has its own unique strengths, and the correct choice can be made depending upon the design’s end objective and external environment factors. Following are the 4 modes:

- Command control mode: In this mode, we have considered human’s decision making and providing navigation commands based on the live video signal received from the camera mounted on the UGV
- Self-control mode: In this mode, we have considered self-decision making and self-navigation based on the GPS co-ordinates, magnetic compass, path planning and obstacle detection algorithms
- Gesture control mode: In this mode, we have considered the hand gesture signals, where the UGV will be controlled using commands sent based on the hand movements mapped by the IMU unit
- Raptor control mode: In this mode, we have considered the motion tracking system implemented through advanced image processing algorithms to locate and eliminate targets in the field vision

In this project, they have used Arduino as the microcontroller that performs the basic tasks. There are some sensors like IR (which is used for obstacle avoidance). For the transfer of signals, wifi has been employed for which there is a wireless modem that provides 3G internet signals.

3. Development of a Wireless Surveillance Robot for Controlling from Long Distance (Shahajada Mahmudul Hasan, Syed Mamun R Rasid, Avijit Mallik, Md. Rokunuzzaman)

Institute: Rajshahi University of Engineering and Technology

In this paper, authors have employed the world wide web as the controlling mechanism of UGV. The advantage of using Wifi is that the UGV can be controlled over long distances. UGV has been found to have 78% efficiency when a connection of 512 kbps is provided. The speed of internet for this efficiency is quite normal, and it is practical to provide this speed constantly. Network-based-human-robot interaction has been used which essentially means that the human operator can provide information to the robot through the web or through a mobile application. Information can be about the coordinates of the robot's next destination. The control panel is developed on a software named 'Visual Basic' Parallel port data transfer has been used, as it is inexpensive and easily programmable. Apart from that, RF (Radiofrequency) sensor has been used which is a wireless non-contact system that uses radio-frequency electromagnetic fields to transfer data from a tag attached to an object, for the purposes of automatic identification and tracking.

4. Design and Construction of a GPS Based Unmanned Ground Vehicle (Halit Hulako)

This paper has discussed the usage of GPS as the controlling mechanism of UGV. There is a filtering algorithm applied that removes the noise from the data, hence making the data less erroneous.

We also found several different options we can use as UGV controllers:

- Ni- CREO 9012
- Ni- sbRIO 9626
- Arduino Mega2560

Similarly, we can adopt these programming systems to program our UGV:

- Ni- LabView
- Microsoft VPL
- Microsoft C#, C++

CHAPTER 3: METHODOLOGY

3.1 Design Concepts

The approach for us to proceed with the conceptual design was based on our aims with the UGV, that is, to have a simplistic and efficient machine design, with ability to move through terrain with appropriate velocity. The UGV will be able to climb stairs and be used to transport drugs, food, and other relevant needs in Health-care facilities.

Numerous UGV designs were thoroughly studied by our team, as stated in the literature review. Each of the design had its pros and cons, our aim was to improvise and conclude on the most suitable one for our objectives.

Overall, we had to conceptualize the following design aspects simultaneously:

- Front inclination feature
- Chassis design
- Mating of the inclination design with the chassis
- Materials used
- Placement of components within chassis

- Center of gravity of the UGV
- Drive mechanism of the UGV
- Consideration for motor, battery
- Design for the 1 DOF manipulator
- Control units and electrical aspects

All these aspects would help us go ahead with fabrication phase of the UGV; once that is done, we will be able to go ahead with the last phase: implementing the controls.

3.2 Front inclination feature - Flippers

A common design element noted in most of the designs, aiming to climb through various terrains, was the provision of inclination at the front part of the UGV. The above literature review designs: Matilda, Packbot, Dragon runner (20), SUGV all carried this feature. The provision of the inclination at the front is an effective method to allow a vehicle to climb through terrains; this is noted in the design of tanks as well. Our aim now was to conclude on the most efficient and simplistic front inclination design and proceed with its fabrication.

A simple design to provide inclination was to use a complete material body of that shape, hosting wheels, idlers, and tracks. The Matilda UGV used this concept. The advantage of this is the greater strength and reliability provided by a complete solid body. Upon studying further designs; however, this was deemed unnecessary by our team, and it was determined that two tires directly connected to chassis, with the third inclined idler using a flipper skeleton would be a rather simpler approach and help reduce material and weight of the part. We eventually developed that design and is show in figure 9. The only material used was the flipper connecting to the small idler at the inclination. The angle of inclination provided to the UGV determines the incremental heights the UGV can climb. Usually, an angle of 30-45degrees is provided, in order to climb average stair height.

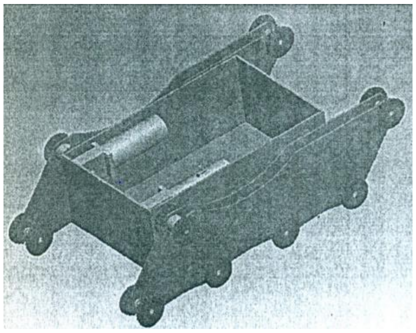


Figure 8 - Rejected flipper designs

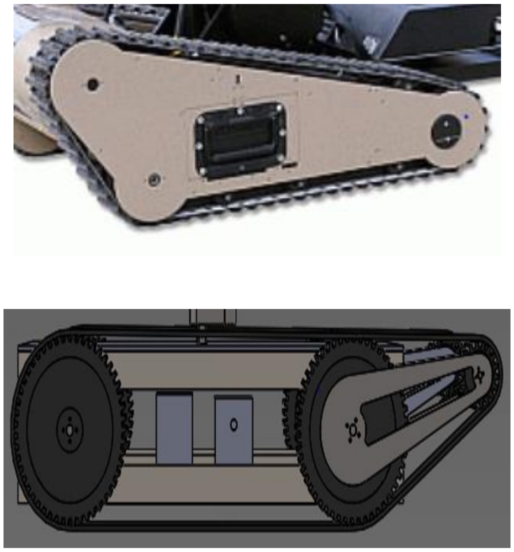


Figure 9 - Accepted Flippers design

It is to be noted that this design hosts a track/ belt on top of it which plays a major role in drive mechanism, to transfer the motion up to the inclined idler. This will be talked about in further details in the *Drive Mechanism* section.

3.3 Chassis Design

Chassis is the main body of the UGV that hosts all the components within. This includes motors, bearings, brakers, batteries, sensors and all relevant electrical and control components. This design of the chassis may very according to the application of the UGV. It may be fully packed and compact in order to host sensitive components within it, or it may have a hollow structure if too much robustness is not required. Given our UGV is not design for the robust military uses, we will be able to go ahead with a rather hollow structure of this UGV, this will in turn also help reduce material and weight of the UGV.

3.4 Mating of the tires and flipper body with Chassis

Different assembly designs may be used in order to mate the tires and flippers with the chassis, with different arrangement of components. One option was to create space for motors within the tires and flipper body, this design is used in some of the existing UGV models. However, this will lead to heavier weight of the flipper body, difficulty in adjusting the center of gravity and providing an efficient drive mechanism. The better option chosen by our team was to host the motors within chassis; the flipper body would be connected to chassis via shafts extending from the tires to the bearings placed inside chassis. Although this is the simpler design, it does also mean that the shaft and bearing assembly would carry major weight and hence the stresses of the UGV. This would have to be taken into consideration for stress analysis.

3.5 Material

The commercial UGVs studied and mentioned earlier were quite light weight (with exception to Matilda). They were able to carry substantial weight when compared to their own weight. Our

UGV, however, was estimated to exceed the normal weight limits due to heavy motors available, which could not be compromised due to the parametric requirements. Hence it was important to reduce material and weight as much as possible.

3.6 Conceptual Design 1:

Components' placement & Center of Gravity

Our initial approach was to go with the basic and efficient Motors placement, that is, placing motors at the back end of the chassis and directly connecting it with the tires. This is a simple approach as it would not require complicated drive mechanism. The motors will provide motion directly to the rear tires via shaft, resulting in back end powered vehicle. The rear tires will then be able to transfer the motion to the front two tires (idlers) via track. The shafts extending from the front idlers would be hosted into the bearings inside chassis.

Our major concern with this proposed design was the distribution of mass and hence the center of gravity of the UGV. The motors required to carry the weight of the UGV and provide required torque for the application were expected to be heavy, according to the market research, and be around 4kgs each. This would result in heavy weight distribution at the back of the UGV, disturbing the center of gravity. We analyzed the design further, with respect to its center of gravity, and concluded from the results that the UGV had high probability of toppling when it is being steered on inclined runways/ stairs. We decided to go with the safe approach of further development of the design.

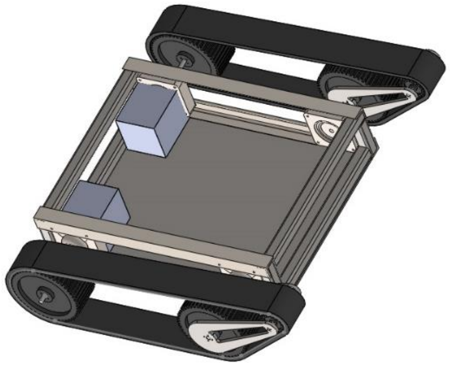


Figure 10 - Conceptual Design 1

3.7 Conceptual Design 2:

Components' placement and Center of gravity

In order to account for better mass distribution and center of gravity, we had to focus on the motors' placement inside chassis. As mentioned earlier, motors could not be placed at the rear due to toppling risks when climbing up stairs. Similarly, they could also not be placed up front in the chassis, as that would propose toppling risk when climbing down the stairs. The optimum approach was to place the motors at middle of the chassis. This would provide for the center of gravity of the UGV to be concentrated in the middle of the chassis.

Although, placing the motors in middle would be optimum approach considering center of gravity, it would also mean we could have to devise a new drive mechanism to provide movement to the tires and tracks.

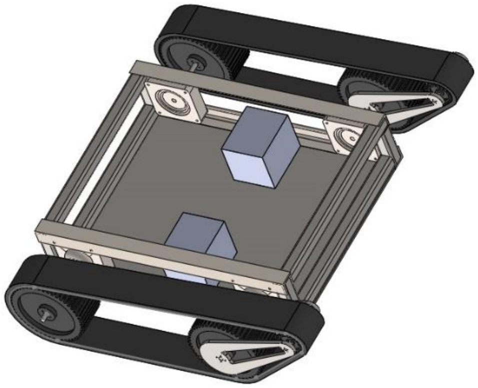


Figure 11 - Conceptual Design 2

3.8 Drive mechanism

In order to transfer movement and power from motors, placed in the center, to the rear tires was through introducing a drive mechanism for it. The first proposed drive mechanism was a simple one, the shaft extending from the motors would hold a gear, which would in turn rotate according to the motor's rpm. This gear would be connected to another gear and so on, eventually to transfer rotations till the rear shaft hosting the rear tire. This would require placement of multiple gears inside chassis, furthermore, the gear drive mechanism results in random/ irregular power losses from one gear to another. This could prove to be a major issue for us when talking about steering of the UGV. If there is a greater power loss at one side of the chassis and less on the other side, the UGV would automatically steer due to difference in rpm and torque on both sides. Hence, use of gear mechanism may result is random steering of our UGV which is not recommended.

It was then decided that a chain and sprocket system would be used to transfer motion from centrally placed motors to the rear shaft. The motors would drive a sprocket which, via chain, drive the rear sprocket. This chain is sprocket mechanism helps in efficient transfer of power and fewer losses. The rear sprocket will then drive the rear shaft and hence the rear tires. The tracks will then ensure that all the wheels (idlers) rotate and UGV moves

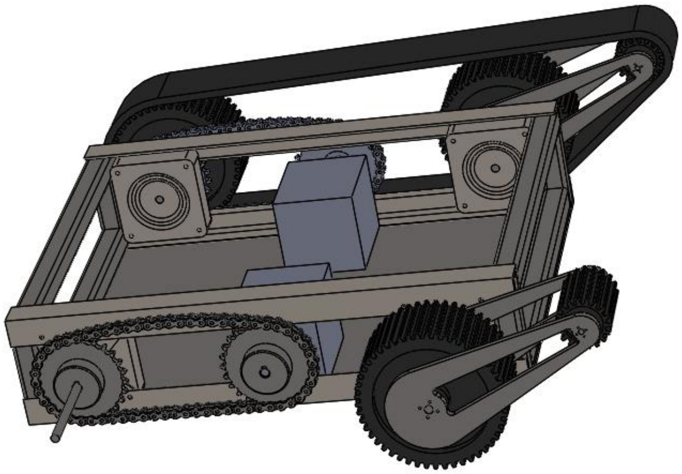


Figure 12 - Chain and sprocket drive mechanism

3.9 Manipulator for Drug delivery (and other needs)

One of the distinguishing aims for our UGV was provide it with capability to carry weight, hosted in a basket/ platter design. We could not simply attach a basket on top of the chassis as that would not be an optimum practice in terms of a commercial design, as the users (particularly patients) would have to bend down to pick the items every time. We could not also simply attach a long rod on the chassis and fit the tray on top of it, as that would mean that UGV will be carrying weight on certain height all the time. This could make the UGV topple when climbing stairs. The best practice decided by our team was to implement our goal via a linear actuator. A linear actuator is a device that provided 1 degree of freedom, via a motor. It can life a certain dedicated weight. We will place the linear actuator at the center of the UGV and attach a try on top of it. The tray will carry weight of the drugs or other required items. When it reaches its destination, it will be incremented up via the linear actuator.

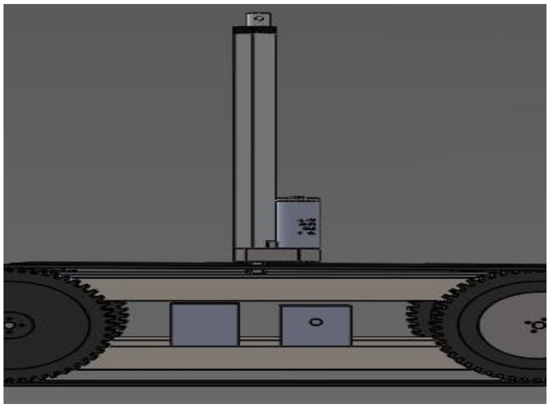
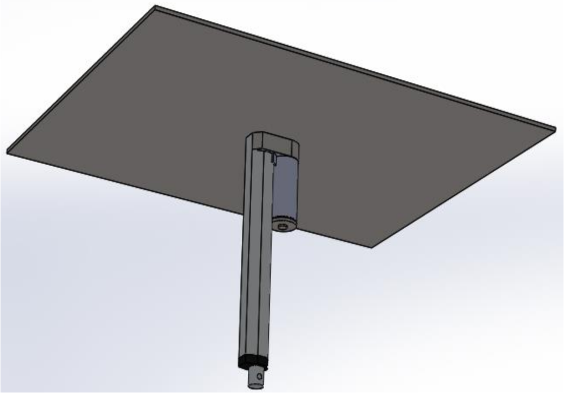


Figure 13 - Manipulator and tray design



3.10 Use of brakes

We will need to analyze the requirements of brakes as well. Although the rpm and torque of motor would be controlled accordingly, there could be times when we momentum of the UGV would need to be controlled, this would be highly important in situations of UGV climbing down the stairs. This would require use of a braking system. These would also be mounted on the shafts of the wheel, to make them unmovable when brakes are applied.

3.11 Differential Steering

The mechanism adapted to maneuver and steer the UGV would be via differential steering. It is the mechanism of steering a vehicle by applying more drive torque to one side of the vehicle than the other. This results in steering movement of the vehicle. Differential steering is the primary means of steering in tracked vehicles.

3.12 Modelling

Kinematic Modelling of UGV:

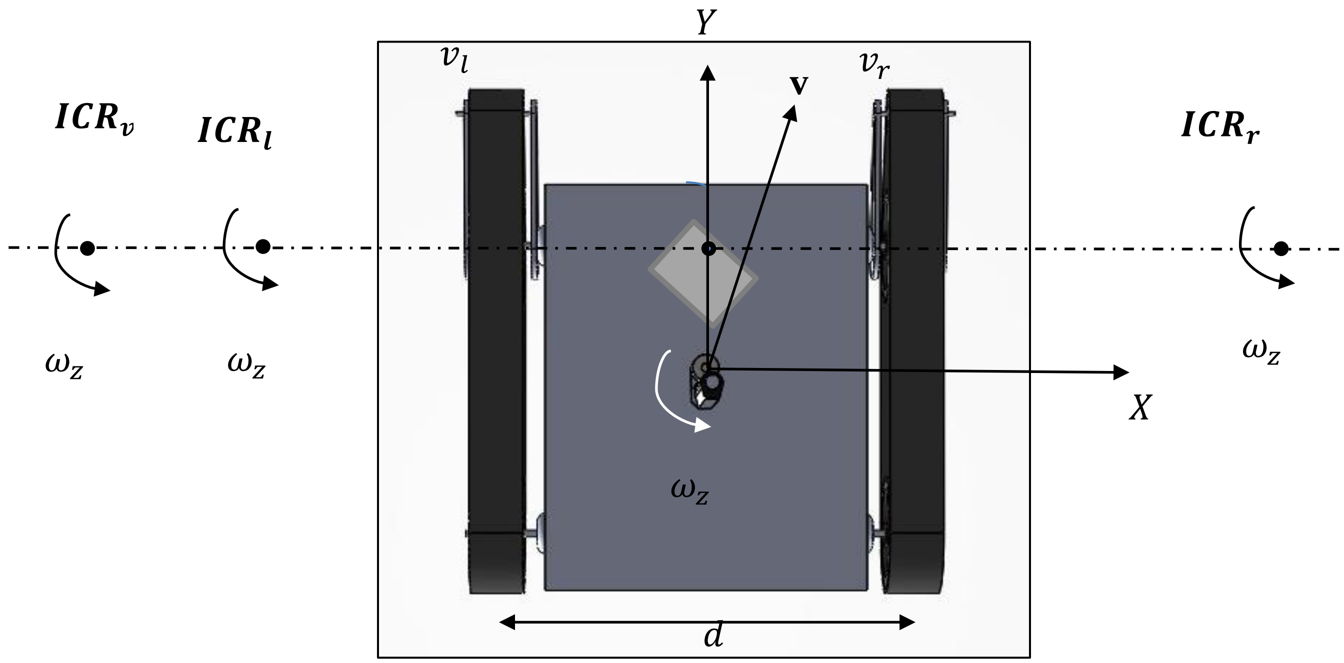


Figure 14 - Kinematic model frame reference

Tracked vehicle dynamic models have proven useful for control design and dependable simulation, but they may be too expensive for real-time robot navigation. This section, on the other hand, discusses geometric connections that can be employed instead.

So, a four-wheel differential drive robot may be used to create the kinematic model of a track drive UGV, as shown in fig 1.

The vehicle's local frame is believed to be centered on the region formed by the contact surface of both tracks on the plane, and its Y axis is aligned with the forward.

The vehicle's local frame is centered on the region formed by the contact surface of both tracks on the plane, and its Y axis is parallel with the forward motion direction. A tracked vehicle is controlled by two control inputs, like a wheeled differential drive, the linear velocity of its left and right tracks with respect to the robot frame ($\boldsymbol{v_l}$, $\boldsymbol{v_r}$). Then, on the plane, direct kinematics may be described as follows:

$$(\boldsymbol{v_x}, \boldsymbol{v_y}, \boldsymbol{\omega_z}) = \boldsymbol{f_d}(\boldsymbol{v_l}, \boldsymbol{v_r})$$

Where $\mathbf{v} = (\boldsymbol{v_x}, \boldsymbol{v_y})$ is the vehicle’s translational velocity with respect to its local frame, and $\boldsymbol{\omega_z}$ is its angular velocity. Finding control actions that result in a desired motion, on the other hand, is referred to as the inverse kinematics problem:

$$(\boldsymbol{v_l}, \boldsymbol{v_r}) = \boldsymbol{f_i}(\boldsymbol{v_x}, \boldsymbol{v_y}, \boldsymbol{\omega_z})$$

The instantaneous center of rotation ($\boldsymbol{ICR_r}$) of a rigid body with planar motion is defined as the point in the horizontal plane where the motion of the vehicle may be described by a rotation and no translation occurs. As seen in Figure 1, this point may be stated in local coordinates as:

$$ICR_v = (x_{ICRv}, y_{ICRv})$$

It would be interesting to include not just the behavior of the complete body, but also the motion of both tracks on their contact surface with the ground, while considering the planar motion of a tracked vehicle. A track may be treated as another rigid body with an additional degree of freedom, which is the speed at which it rolls. As a result, the motion of a point on the tread surface is a combination of vehicle velocity and track rolling motion. As a result, the ICR of a plane's track differs from the ICR of the overall vehicle. The ICRs for the left and right tracks may therefore be defined as $ICRl = (x_{ICRl}, y_{ICRl})$ and $ICRr = (x_{ICRr}, y_{ICRr})$ in the local frame, respectively (see Figure 2). Note that the ICR of track treads on the ground plane, not their roll axis, is referred to in this formulation.

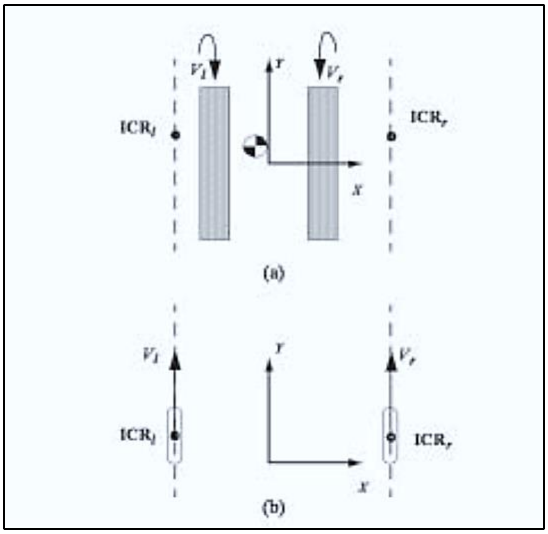


Figure 15 - Kinematic modeling

Linear Velocity:

Geometrically, the vehicle's angular and translational velocities may be used to derive local coordinates for the vehicle and track ICRs.

Without regard for track arrangement, the linear velocities of the left and right wheels are calculated using the radius of the wheels and their rotational velocities at the time, as illustrated mathematically.

The right wheel's linear velocity is:

$$v_r = r\omega_r$$

Or

$$v_r = r\omega$$

Similarly linear velocity of left wheel is:

$$v_l = (r + l)\omega$$

Average velocity of the center of mass of robot is only in y-direction since there is no motion along x-axis due to fixed wheels.

$$v_y = \frac{v_r + v_l}{2}$$

Rotational Velocity:

The angular (rotational) velocity of the UGV at the center will be given by:

$$\omega = \frac{v_r - v_l}{d}$$

Kinematic Velocity:

If the requisite linear and rotational velocity of the UGV is known, we can use the equation above to calculate the linear velocities of the left and right tracks of the UGV. Writing in a matrix:

$$\begin{pmatrix} v \\ \omega \end{pmatrix} = \begin{pmatrix} 1/2 & 1/2 \\ 1/d & -1/d \end{pmatrix} \begin{pmatrix} \mathrm{v}_r \\ \mathrm{v}_l \end{pmatrix}$$

Or:

$$\begin{pmatrix} \mathrm{v}_r \\ \mathrm{v}_l \end{pmatrix} = \begin{pmatrix} 1/2 & 1/2 \\ 1/d & -1/d \end{pmatrix}^{-1} \begin{pmatrix} v \\ \omega \end{pmatrix}$$

So, if the linear and angular velocity of the UGV is given, the velocity each track should have to give the required speed can be computed.

Rotation Matrix:

A rotation matrix describing the relationship between the two frames is required to transform the velocities determined in the robot frame of reference to the global frame of reference:

$$R_z = \begin{pmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Forwards Kinematics of UGV

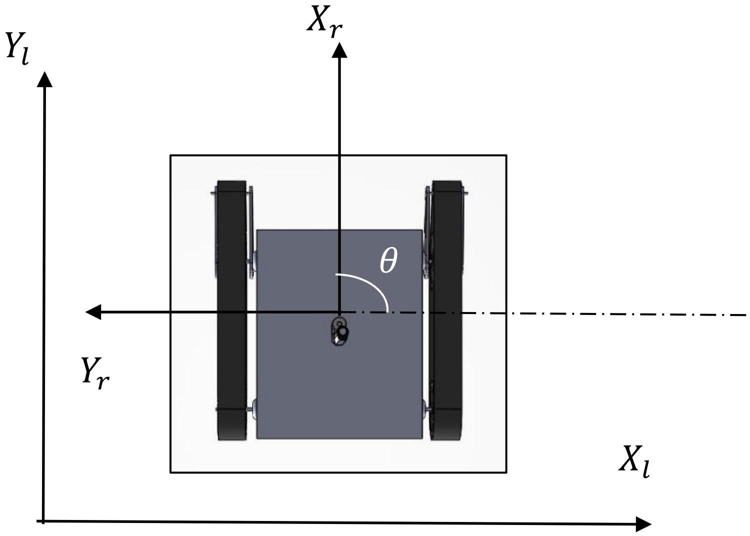


Figure 16 - Forward Kinematics modeling

A link must be built between the global and local frames to determine the robot's location in the plane. X_i and Y_i are global frame of reference coordinates, whereas X_r and Y_r are local frame of reference coordinates. θ represents the angular difference between the two frames. The rotation matrix determines the robot's orientation in the global reference frame at its present position:

$$R_z = \begin{pmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Considering the motion of the UGV in y-direction only, the linear and horizontal velocity in local frame of reference is given by:

$$v_y = \frac{v_r - v_l}{2}$$

Where $\boldsymbol{v_l}$ and $\boldsymbol{v_r}$ are velocities for left and right track respectively. Assuming **d** to be the distance between the tracks , the angular velocity is given by:

$$\omega = \frac{v_r - v_l}{d}$$

The velocity matrix is then formed as:

$$V = \begin{pmatrix} 0 \\ v_y \\ \omega \end{pmatrix} = \begin{pmatrix} 0 \\ \dfrac{v_r - v_l}{2} \\ \dfrac{v_r - v_l}{d} \end{pmatrix}$$

The velocity of the UGV in the global frame of reference can now be expressed as:

$$\begin{pmatrix} v_{Xi} \\ v_{Yi} \\ \omega \end{pmatrix}_g = \begin{pmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 0 \\ \dfrac{v_r - v_l}{2} \\ \dfrac{v_r - v_l}{d} \end{pmatrix}$$

3.13 Control Systems Methodology

As explored in the literature review, there are various approaches we can adopt to design the control systems of our UGV. We can use different sensors, different microcontrollers, and different software to achieve our objective. After careful analysis of all alternatives, we have finalized the important aspects of our design. This section would outline the design of control system of the UGV.

IP Camera:

As our UGV is tele-operated, the human operator needs to see the external environment of the robot so that it can navigate it properly. To achieve this, we need to attach a camera that would transmit live photos/videos to the graphical user interface. We have decided to go with an IP camera, that would transmit data through wi-fi. We will decide the exact model/make from companies some companies like Hikvision, Swann, Logitech, and Z3 technology. One possible option is H.265 HD IP Video Camera. It provides real-time video streaming, with an easy to control user interface. It is also POE (Power over Ethernet) which means that we don’t need to attach two separate cables for wi-fi and power, as electrical power can also be provided to this using the wi-fi cable. For video management, we can use one of these software:

- Milestone
- Onssi
- Digifort

For communication, we would be using 802.11g wi-fi protocol. It is faster and is capable of handling transmission speeds up to 54 Mbps. We can change our protocol to 802.11b if our equipment is compatible to that. This communication system has enough range for our design.

Batteries:

We have decided to use two batteries, one for driving the motors and the other for the functionality of control panel. One would be of 24V, while the other one would provide 12 V. 24V battery would be used to provide power to the motors as motors require high voltage.

Arduino:

There are several different models we can use to implement our design. After careful analysis, we have decided to go with Arduino Mega2560. It is based on AT Mega2560. It has 54 digital I/O pins, a USB connection, and a power jack. We can start it by simply connecting it to a USB port of computer. It operates on the clock speed of 16MHz and weighs just approximately 40 grams. It can be bought under Rs 3000 in Pakistan. Arduino Mega2560 is light weight, cost effective and efficient. It has more memory space and more I/O pins than Arduino Uno. It requires an input voltage of 7-12 V.

Programming:

We need to develop an easy-to-use graphical user interface through which the human operator would give commands to the UGV to move to a certain location. There is an IDE of Arduino which is called Arduino IDE, in which we will do our programming. The programming syntax resembles C/C++, so we would be able to program our UGV using this. We would introduce basic functionality such as giving commands for all 4 directions and stopping the motion through brakes. A windows application would be formed using this methodology, through which the UGV would be controlled.

Electrical circuitry:

Our basic electrical circuitry is decided between two components. First circuit is needed to control the logic circuit and the other one is required to control motors. As we would provide more voltage than what is required to the individual components, we would need a power regulator to provide a uniform voltage. The exact model of regulator would be decided based on the value of voltage. Suppose we need 5V to control the logic circuit, and we have a 12V battery in our design. We will use a LM1084 IC that would regulate the voltage. For safety purposes, we will also attach a fuse so that the circuit stops operating when the current exceeds the safe value.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Design aspects finalized

Considering the above listed methodology and the approach we've adapted for our project, let us discuss the outcomes we have concluded so far and study them further. The table below presents some of the components/ designs we were able to conclude to.

Table 1: Components Description of UGV

Components	**Description**
Chassis	It is the main body frame that hosts all the

	hardware, including motors, battery, control parts and electrical parts. It will be made of Aluminum to minimize weight. Chassis will not have a complete solid body, instead only a skeleton, in order to minimize material usage and hence weight.
Flippers	These are the two structures, on both sides of the UGV, that will hold its inclination shape. The small inclined idler wheels would be hosted on it.
Motors	We would require two motors for the UGV, one on each side, in order to control and implement differential steering. The calculation for motors is further provided in this section. Motors would be placed at the center of the UGV.
Drive Mechanism	The Drive mechanism to use two centrally placed motors would be via chain and sprocket mechanism, which transfers the torque to rear shaft and tires.

Battery	We would require a DC supply of 12V and 24V batteries. One would power the motors and other will power rest of the circuit.
Camera	An Internet Protocol (IP) camera would be used to achieve live video feedback.
Rotary Actuator	A rotary actuator would be used to host and lift the tray intended to carry weight.

4.2 Finalized conceptual design model

The figure below shows the finalized design we've been able to conclude so far and make progress on its 3D model on SolidWorks. The reasoning for various aspects of the design has been done in the Methodology section. The summary of the mechanical aspect of the design is as follow:

Aluminum frames would be used to make the chassis of the UGV. This will minimize weight; furthermore, we will also use minimum amount of material by using a frame like model of the chassis. The chassis will hold major components of the UGV including heavy motors, battery, electrical and control components. The linear actuator and the tray to mount weight would be placed via a Aluminum strip on top of the chassis. The motors would be centrally placed in the chassis and provide torque to the rear shafts via chain and sprocket mechanism. The rear shafts will then give the drive and rest of the tires will act as idlers, which will get their movement via track covering all the tires. Bearings, of standard size, would be used at the other end of the shafts. Our first approach would also be for chains, tracks and other mechanical components to be bought directly from the market, of standard sizes, in order to reduce costs and input.

The software used for the 3-dimensional modeling and analysis of force and torque is SolidWorks, as that does meet the basic analysis requirements and is easy to use. The basics of control system for the UGV has been also described earlier. We will develop an easy-to-use graphical user interface through which the human operator would give commands to the UGV to move to a certain location. The programming would be done on Arduino IDE. The programming syntax resembles C/C++, so we would be able to program our UGV using this. We would introduce basic functionality such as giving commands for all 4 directions and stopping the motion through brakes. A windows application would be formed using this methodology, through which the UGV would be controlled.

4.3 Motor Torque Calculations:

Payload	7 kg
Mass of Motors	2(3.5) kg
Mass of Batteries	2(0.8) kg
Stair Angle	$\tan^{-1}\frac{7}{11} = 32^{o}$
Mass of Control Module	2.5 kg

Radius of Wheel	0.15 m
Dimensions of UGV	75×50×21
Mass of Tracks	10 kg
Average Speed	5 mph = 2.24 m/s
Acceleration	0.5 m/s^2

Table 2 - Forward Kinematics modeling

*(Mass of Actuator is adjusted in control module)

The length of the UGV is chosen as 75 because length of hypotenuse of one stair is around 32 cm (13 inches) so to distribute mass on approximately 2.5 stairs 75 was chosen as the length.

Torque is required for the UGV to climb slopes and travel on rough terrain. The UGV weighs 27 kilograms and must travel at a pace of 2.24 meters per second.

The following calculations for torque and rpm are based on a 36-degree inclination and a 0.15-meter wheel radius:

Data Variables:

$$Total\ mass = M = 28.1 \text{ kg}$$

$$Total\ Weight = W = 275.66 \text{ N}$$

$$Velocity = V = 2.24\, m/s$$

$$Angle\ of\ inclination = \theta = 36°$$

$$Radius\ of\ wheel = r = 0.15\, m$$

Torque Calculations:

$$T = (W sin\theta)r + mar$$

$$= (275.66 \sin(36°) \times 0.15 + (28.1)(0.5)(0.15) = 26.4\ \mathrm{N.m}$$

For 1 motor:

$$\mathbf{T' = 13.2\ N.m}$$

Keeping the safety margin:

$$\mathbf{T' = 14\ N.m}$$

Also,

$$\omega = \frac{v}{r} = \frac{2.24}{0.15} = 14.9\frac{\mathrm{rad}}{\mathrm{s}} = 142\ \mathrm{rpm}$$

Thus,

$$\boldsymbol{Motor\ Torque} = \mathbf{14\ N.m}$$

$$\boldsymbol{Motor\ RPM} = \mathbf{150\ rpm}$$

$$\boldsymbol{Motor\ Power} = \mathbf{220\ Watts}$$

Note that these values calculated are threshold values just to move the UGV without considering friction. In real time situation, the power requirement of the motor might increase so the choice to buy the motors must be done to cater this.

4.4 Stress Analysis

Stress analysis is an important study in understanding the strength of any mechanical design. The most vital part of the UGV, requiring stress analysis, were the shafts. This is becase shafts are responsible for transmitting motion and power of the whole UGV to the tyres. They will hence be subjected to major force (weight) and torque. We have used 12mm diameter of shaft in our analysis, as that is the standard size available in the market and has been suggested by the vendor.

To analyse the strength of the shafts, we've evaluated them in the worst case scenarios and compared the stress results with the material's yield strength. Two such scenarios have been played: max possible force on the shaft and max possible torque on the shaft.

The maximum stress analysis was necessary because any two shafts could be loaded with the whole weight of the UGV when it is being steered on terrains. The length of the shaft chosen was from the tyre end to the sprocket end, as that part (tyre area) would carry the weight. The sprocket end of the shaft was fixed as the boundary condition. The result is as follow:

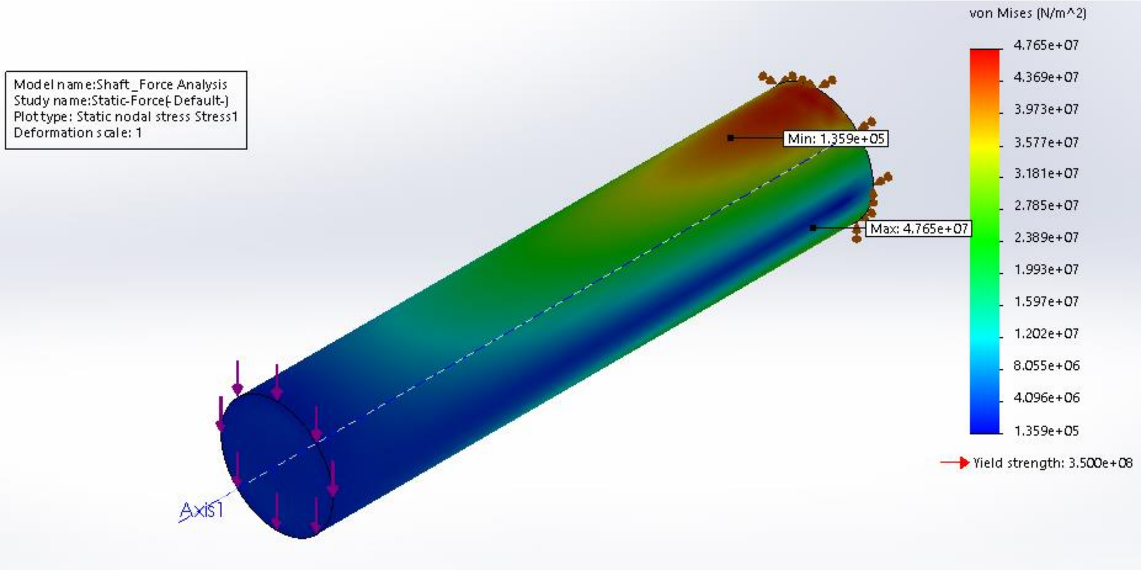


Figure 17 - Stress analysis (von mises)

It can be seen from the von Mises plot above, that the maximum stress at any point in the shaft (4.765e+07) is less than the yeild strength (3.500e+08) of the shaft. We can hence conclude that our shaft will be able to survive in the worst case scenario of carrying weight.

We have also considered the Factor of Safety (FOS) in our analysis. Since we've performed static analysis of the shaft, we aimed to keep FOS above 3 in all situation.

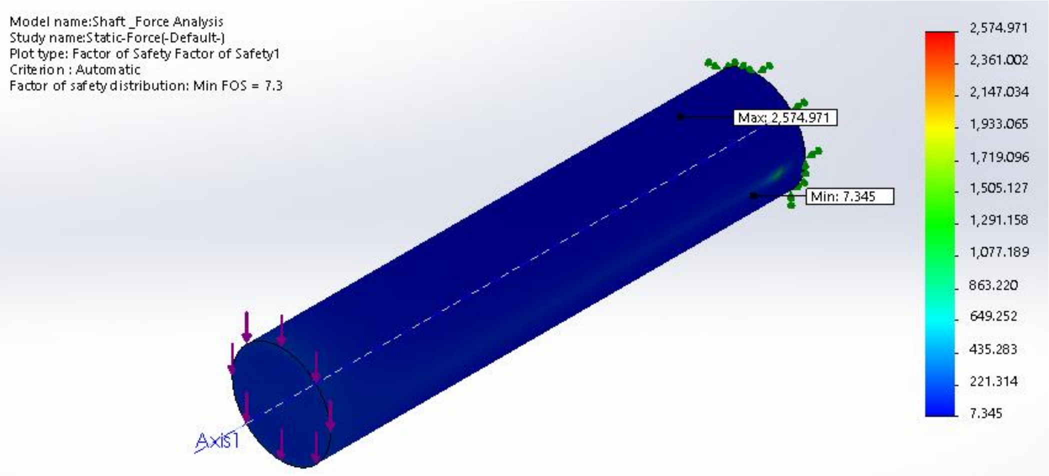


Figure 18 - Stress analysis (von mises) with FOS

We can see from the plot that the Minium factor of safety analysed for our shaft was above 7. This is well above the aim and proves high reliability of the shaft, strength wise.

The other scenarios analysed was the maximum Torque situation. This was also a worst case scenrio applied on the shaft; it can occur when we assume our tyres to be locked while the sprocket is providing the maximum power/ Torque. This will result in torsional stress on the shaft. We have analysed that by taking the length of the shaft between tyre to sprocket end. The tyre end was fixed as the boundary condition. The result is as follow:

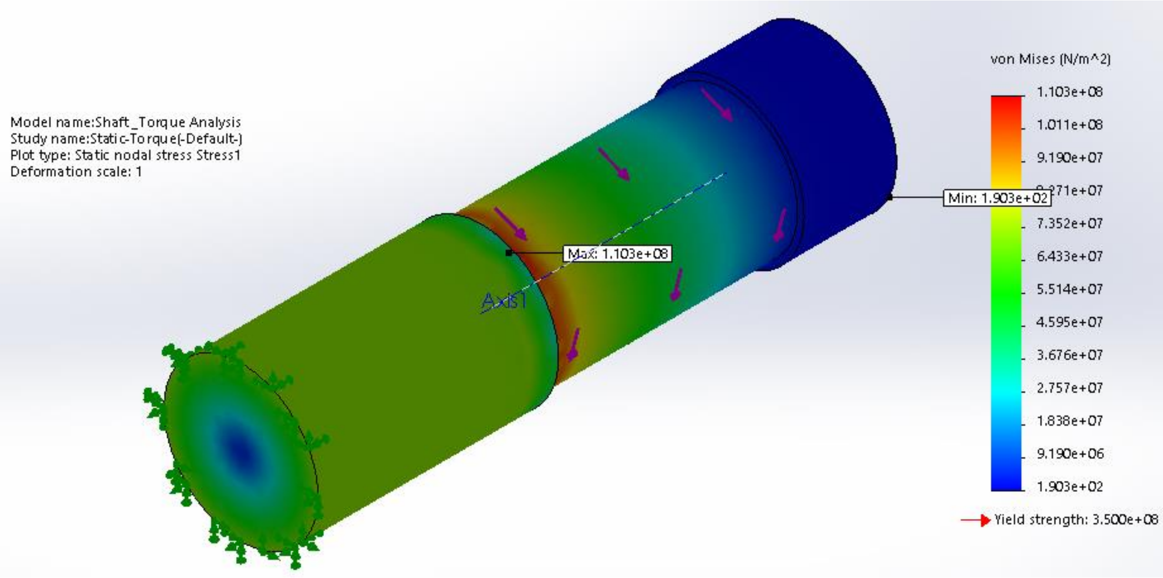
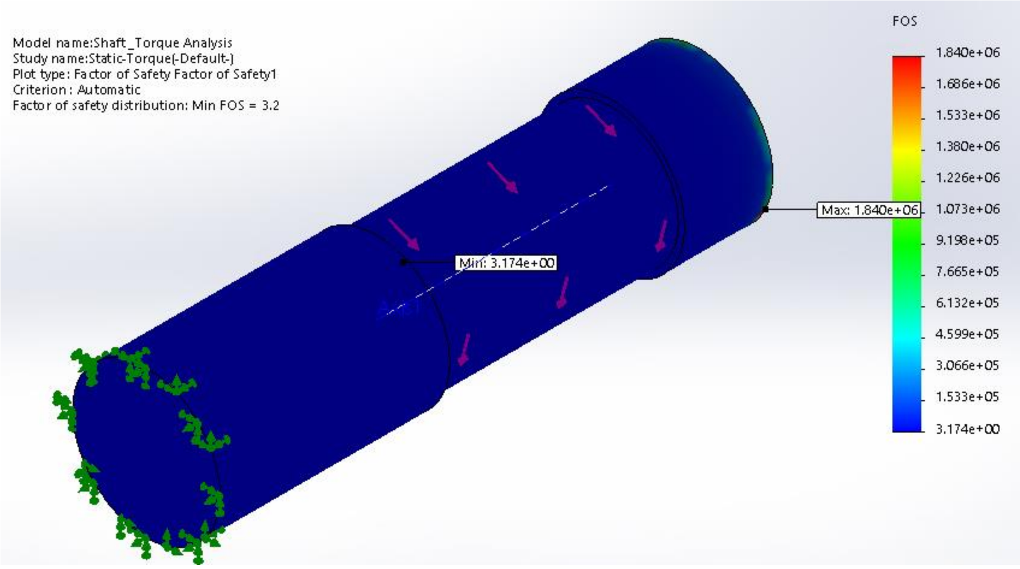


Figure 19 - Stress analysis (Torsional)

We can see from the above von mises plot that the maximum torsional stress (1.103e+08 N/m^2) on the shaft is less than the yield strength (3.500e+08 N/m^2), hence our shaft will also survive in the worst torsional scenario.

Again, we've considered the Factor of Safety (FOS) for this analysis as well. Its plot is as follow:



Model name:Shaft_Torque Analysis
Study name:Static-Torque(-Default-)
Plot type: Factor of Safety Factor of Safety1
Criterion : Automatic
Factor of safety distribution: Min FOS = 3.2

Figure 20 - Stress analysis (Torsional) with FOS

It can be seen from the above plot that the minium FOS ahieved in above 3 in this case too. It should be noted that FOS would actually be much larger. The indentation provided to the shaft geometry, to apply Torque on that area, is responbile for low Factor of safety, which will not be the case in real scenario.

4.5 Fabrication of the UGV

The fabrication of the UGV was implemented following the same design finalized in the Design phase; however, there were some alterations present in the final fabricated product, due to difference in fabrication and theoretical designing. Some aspects had to be changed as the practical implementation of the design was different than what we had theoretically predicted. It must also be highlighted that the fabrication was achieved with joint efforts of our team and Saleem Mechanic in Rawalpindi.

The first step of the fabrication was the chassis, which was made using aluminum. Aluminum frames were used and welded together via Argon welding**.** The motors were then simply bolted together to both sides of the chassis. The resulting structure was as follow:

Figure 21: Assembly of chassis and motor

The mechanical parts were also collected from the mechanic/ vendors. These included:

- 2 Motors
- 2 Chains
- 4 Sprockets
- 4 Main Tires
- 2 small idlers
- 2 Rubber tracks
- Bearings
- Shafts

The motors used were of the following specifications: 9 Nm. Torque, 140RPM. These were the standard motors available at vendors which produced more than enough power to pass the Factor of Safety calculated earlier. Please note that the earlier calculation for motors had been done assuming a weight of 28kgs for the UGV; however, with altered design that minimized use of material, and for the sake of prototyping, the UGV weight was restricted to below 12 kgs. This reduction in weight made sure our UGV was strong enough to carry heavy weights with the provided motors (and batteries).

The chains, sprockets and shafts were all made of steel. To use more accessible and cost friendly parts in the UGV, the chains and sprockets were those generally used in motorcycle/ cycle systems. Another challenge faced during the prototyping was finding the accessible Tires and tracks so that the track would rightly fit on to the tooth of the tires and match the length of the UGV. This was smartly achieved by using the gear parts of car into our UGV. The gears used in cars were altered using lathe machine and reduced to thin width tires to be used in our UGV. The tracks to be used on these tires were also those cars' gear system. Hence readily available materials, with slight alterations, were used in our UGV. The picture for one of the tires is attached below.

Figure 22: Tire machined out of Car gears, and its tracks

The 2 small idlers in the front are those at the inclined side of the UGV through which the tracks pass. These were simple plastic deigns which were machined out. There were 12 bearings used in the system, 2 along each tire or idler. Given there were 4 main tires and 2 idlers, the total number of bearings were hence (6x2) 12. The specifications of the bearings were as follow:

Bearing code	6000
Bearing type	Deep grove
Bearing dimensions	10 x 26 x 8 mm
Internal Dia	10 mm

Table 3: Bearing specifications

The diameter of the shafts used in the system was the same as the internal diameter of the bearings, that is, 10mm. Moreover, the shafts were also made of steel.

The resulting assembly of the chassis, motors, sprockets, chains, tires, idlers, and tracks was as follow:

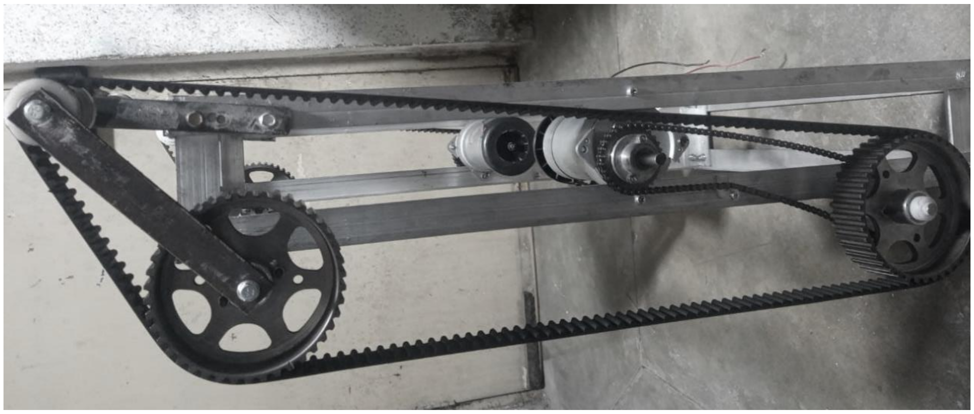


Figure 23: Final mechanical assembly

The elevation at the front was provided using steel bar structure, bolted from upper frame of the chassis and from tire and the lower side, as shown on the figure. Another feature that may be noted in the figure above is the bended chain system, leading from sprocket at the motor to the sprocket at the rear tire. This was done to reach the rear tire of the UGV which was not at the same elevation as the motor but was attached below the lower frame of the chassis, to provide elevation. The elevation was provided to the chassis frame to avoid it touching the ground when moving.

Another mechanical feature that came in later in the fabrication stages was attachment of the actuator and its tray, for the purpose of lifting weight. The tray to be attached to the UGV was simply made via bending of metal sheet, which was then welded to the actuator. The actuator used was not a linear actuator, but a rotary actuator system that rotated and resulting in transmission of movement to that lifted the tray. It is controlled by Arduino through a Bluetooth module and a GUI interface (app). It has a motor of 12 V. It is placed such that it’s rotation is in vertical direction and the holding box moved in above direction.

Figure 24: Actuator

CHAPTER 5: HARDWARE METHODOLGY

5.1 Electronic Hardware Components List

The electronic hardware of our Unmanned Grounded Vehicle consists of:

- Motors
- Batteries
- IP Camera V380
- Bluetooth Module for controlling motors
- Wi-Fi Module for controlling
- Arduino UNO
- Regulators
- H-Bridge

5.2 Operations Overview

The basic operations of our UGV include:

- The device got connected to RC Controller via Bluetooth.

- The instructions will be generated in the application which will be sent to Arduino.
- The Arduino controller will generate the corresponding voltage that will be sent to the H-Bridge to regulate the motor speed and direction.
- The IP Camera is wireless and controlled via a Wi-Fi module.
- It will be directly connected to a mobile phone via the V380 mobile app to provide video feedback.

5.3 Drive Motors

We have used two motors, one on each side, to drive our UGV. The torque, RPM, and power of each motor are calculated based on the total loading conditions. We have considered our total payload of 7kg. With the help of this data, we have already calculated the torque of one motor to be 14 N.m. The total RPM of each motor is calculated as 150.

Since the weight of the motor is quite large, its placement was an important factor in considering the stability of UGV while moving, especially during upstairs or downstairs movement. To consider this issue, we have placed both motors exactly at the center of our UGV to maintain its stability.

Following are some of the specifications of the motors we used.

Motor RPM	150
Motor Power	150 W
Motor Torque	14 N.m
Motor Weight	3.5 kg each

5.4 Batteries

We have used two 12V Volta batteries. These are Lead Acid batteries manufactured by Pakistan Accumulators Pvt. Ltd. These batteries are used to power motors to move UGV. They are most used in UPS and to power small vehicles. It is a rechargeable dry battery with long life and the best part of it is that it is maintenance-free.

Figure 25: Battery

The technical specs of the Volta battery we used are given below:

Battery Type	Lead-Acid Battery
Voltage	12 V
Electric Charge	7.2 AH
Weight	3 kg

5.5 Internet Protocol Camera

To have a live feedback option, we have used V380 WIFI wireless camera. The camera is attached to the backside of the UGV to cover the whole front view. It is controlled with the help of the V380 mobile app available in the Google Play Store. It has exceptional features like:

- 1080P HD
- WIFI Connect
- AP Hotspot
- App Control
- Infrared Night Vision
- SD card slot
- Wide Angle coverage of about 150°
- Motion Detection
- Loop Recording
- Magnetic Back

Figure 26: Camera

5.6 Arduino Module

The control module is attached in UGV with the help of an Arduino controller. There are several different models we can use to implement our design. After careful analysis, we have decided to go with Arduino UNO. It is a single board microprocessor since we only require a small control circuit. All the programming is done in C/C++ syntax with Arduino as IDE, which will be later explained in the control section.

Figure 27: Arduino UNO

Some of its technical specifications are given below in the table.

Model	UNO Rev 3
Digital I/O pins	14
Operating Voltage	5 V
Input Voltage Limit	6-12 V
Length	68.6 mm
Width	53.4 mm
Weight	25 g

5.7 Bluetooth RC Controller

We have used Bluetooth RC Controller to control our Arduino and Bluetooth-fitted UGV on our smartphones. It is available as an application in the Google Play Store. It has a quite simple and easy user interface as shown below.

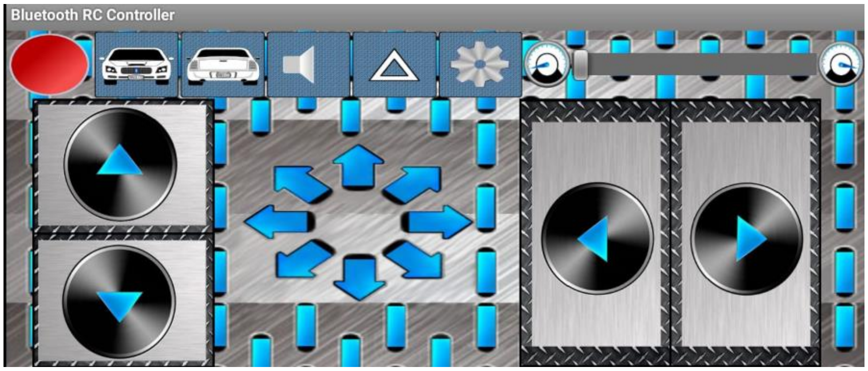


Figure 28: Controller Interface

We must connect our UGV to this app via Bluetooth. We have only six controls in this application. They are:

- Right Motion
- Left Motion
- Front Motion
- Reverse motion
- Actuator’s Upward Motion
- Actuator’s Downward Motion

5.8 Regulators

Any electrical or electronic device that keeps the voltage of a power source within acceptable limits is known as a voltage regulator. The voltage regulator is required to keep voltages within the appropriate limits for electrical equipment that uses that voltage. This type of gadget is commonly employed in all types of motor vehicles to adjust the generator's output voltage to the electrical load and the battery's charging requirements. Voltage regulators are also employed in electronic devices where excessive voltage changes might be hazardous.

Figure 29: Regulator

5.8 Bluetooth Module

The Bluetooth module is used for communication between two devices. It wirelessly transmits and receives the data from a Host Controller Interface.

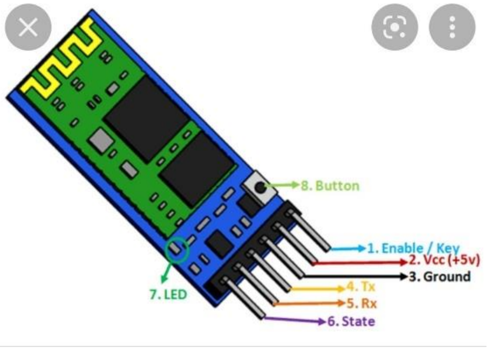


Figure 30: Bluetooth Module

5.9 H-Bridge

The polarity of a voltage delivered to a load is switched using an H-bridge. These circuits are frequently used in robotics and other applications to enable DC motors to move forward or backward. The name comes from the usual schematic diagram representation, which shows four switching elements as the branches of a "H" and the load as the crossbar.

The H-bridge we are using is named L298 with 10 A rating. The bridge will be controlled by Arduino. The bridge uses pnp transistors for forward motion and npn for reverse motion. The signal is sent in pulses.

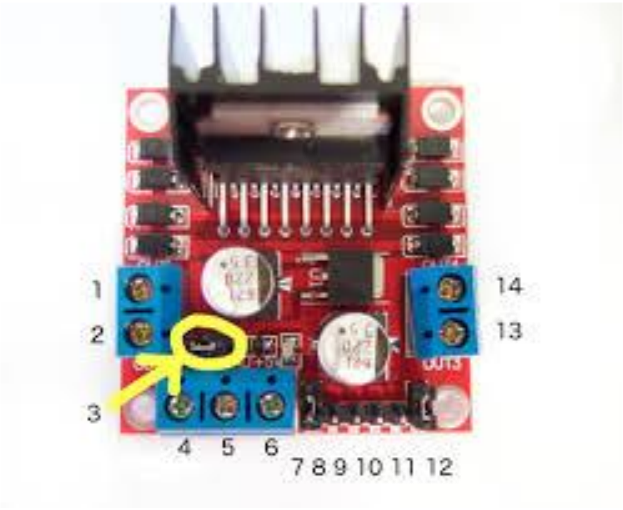


Figure 31: H-Bridge/Motor Driver

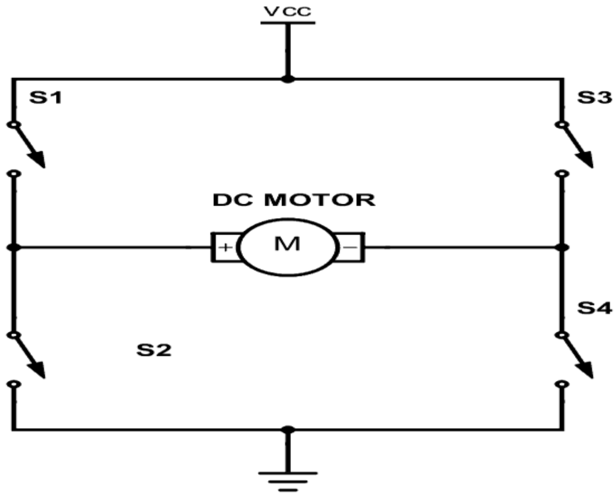


Figure 32: H-Bridge Schematic

CHAPTER 6: SOFTWARE METHODOLGY

6.1 Coding

```
char t;
```

```
 void setup() {

pinMode(13,OUTPUT);   //left motors forward

pinMode(12,OUTPUT);   //left motors reverse

pinMode(11,OUTPUT);   //right motors forward

pinMode(10,OUTPUT);   //right motors reverse

pinMode(9,OUTPUT);   //Led

Serial.begin(9600);

 }

 void loop() {

if(Serial.available()){

  t = Serial.read();

  Serial.println(t);

}

 if(t == 'F'){            //move forward(all motors rotate in forward direction)

  digitalWrite(13,HIGH);

  digitalWrite(11,HIGH);

}

else if(t == 'B'){      //move reverse (all motors rotate in reverse direction)
```

```
  digitalWrite(12,HIGH);
  digitalWrite(10,HIGH);
}
 else if(t == 'L'){      //turn right (left side motors rotate in forward direction, right side motors doesn't rotate)
  digitalWrite(11,HIGH);
}
 else if(t == 'R'){      //turn left (right side motors rotate in forward direction, left side motors doesn't rotate)
  digitalWrite(13,HIGH);
}
else if(t == 'W'){    //turn led on or off)
  digitalWrite(9,HIGH);
}
else if(t == 'w'){
  digitalWrite(9,LOW);
}

else if(t == 'S'){      //STOP (all motors stop)
```

```
  digitalWrite(13,LOW);

  digitalWrite(12,LOW);

  digitalWrite(11,LOW);

  digitalWrite(10,LOW);

}

delay(100);

}
```

The first part of code is the setup of Arduino, it would only run when the whole system powers on for the first time. The loop is going to execute whenever the Arduino is powered on. This part of code explains which motor is connected to which pin of Arduino. It can be observed that there are two pins for each motor. One is for forward direction and the other is for reverse direction, which is varied by changing the current's direction. Left motor is connected to the pins 12,13 whereas the right motor is connected to the pins 10,11. Next part of code is used to establish a communication network which works on serial communication, it is used to connect to the Bluetooth module. 9600 is the baud rate which represents the number of packets moving in one second (9600 bits per second).

The last part of code deals with the movement of UGV. When we give command to move forward, both the motors move in the forward direction, and vice versa for backward direction. When we want the UGV to move right, left motor rotate in the forward direction whereas the right motor does not rotate. The second last part of loop deals with the working of actuator, when the LED is pushed HIGH signal is given on Pin 09 which moves the actuator in the upward direction. The last part of code is used to stop all the motors, which can be seen from the LOW signals given on all digital pins.

6.2 Circuit Diagrams

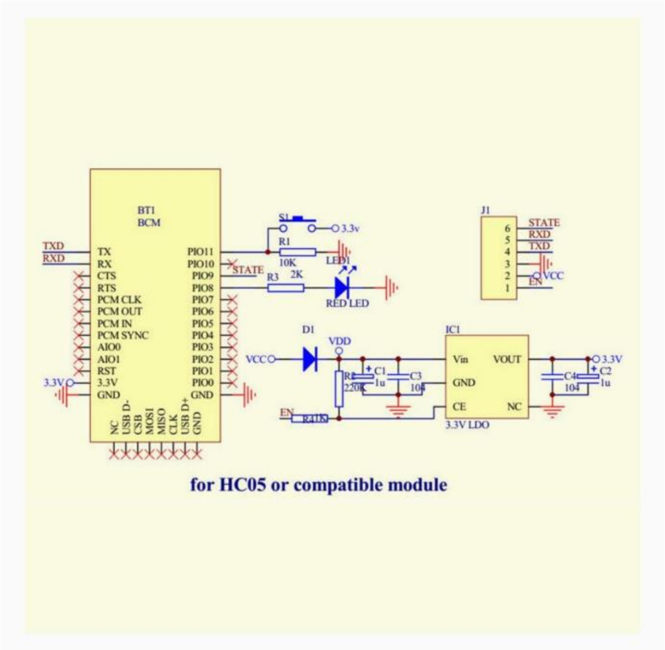


Figure 33: Main Circuit Diagram

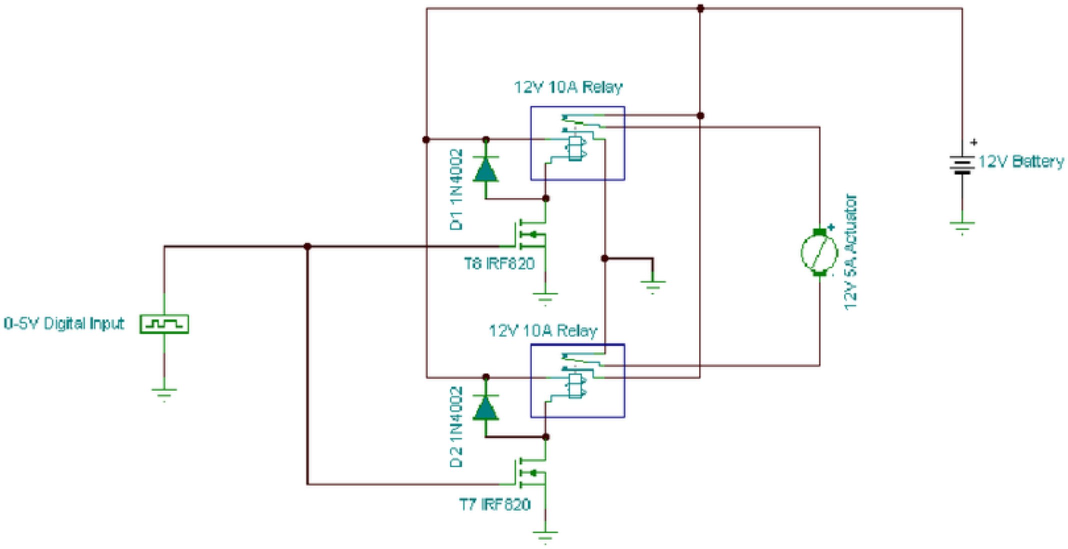


Figure 34: Actuator Circuit Diagram

CHAPTER 7: CONCLUSION AND RECOMMENDATION

As mentioned in the earlier chapter of the report, the aim of the project was to design an Unmanned Ground Vehicle (UGV) which will enable it to cover rough and diverse terrains, specifically focusing on urban terrains (inside of a building, stairs, etc.). Furthermore, the aim of the project was also to provide the UGV with a commercialization application. Both goals were planned and designed successfully. After thorough study of existing literature available for the UGVs, including both thesis and commercialized models, we were able to present a comprehensive mechanical design of the UGV. The design will allow the UGV to smoothly cover various inclinations while balancing its center of gravity and not toppling. An efficient drive mechanism was also introduced to achieve this.

The goal of providing commercialization application to the UGV was also similarly pursued. The UGV industry was thoroughly studied, and it was noted that it is dominated by the military sector. Furthermore, the rising need of robotic assistance in the health-care industry was also studied, this was particularly highlighted in the recent covid pandemic. An innovative and efficient solution for such situations was proposed by our team: Unmanned transport of drugs and other necessities via use of UGVs, to avoid human to human contact. This may save thousands of lives in the healthcare industry, especially when used in situation of contagious diseases.

The prototype was tested, and the following results were obtained:

- The basic maneuvers were executed, and the steering was smooth.

- The actuator was able to lift a weight of 4 Kg. After numerous trials and testing, ample speed of the actuator was achieved since initial tests gave a very slow response.
- The batteries and other electrical devices were charged and running smoothly.
- The camera gave clear visual feedback, there was no lag and smooth maneuvers were achieved with the help of that feed quality.
- Differential Steering was with out any jitters and followed the programming (coding) perfectly
- For the sake of prototype demonstration, the UGV was tested on low height stairs with a very small angle and the flipper arms (inclination design) worked as per the requirement.

Scope of the project & future recommendations:

The UGV certainly has the potential to be adopted by the beneficiaries, i.e., the health care industry. The recent COVID pandemic highlighted the need for it and plenty of international grants were allotted to develop autonomous vehicles to help staff in Covid 19 situation. With a simplistic and cheap design, there will be high ease of fabrication; furthermore, the UGV would be easy to control via a simple remote or mobile App.

The need of such a UGV could be applied to the whole globe, with the COVID pandemic situation recently highlighting the need. With a cheap and simplistic design, the UGV could be afforded and used in third world countries, where outspread of diseases is much likely and needs efficient ways to be controlled.

In Africa alone, almost half of the countries experience an Emerging Infectious Disease (EID) epidemic each year. About 75% of these diseases are vector-borne or transmissible. Using the

UGV for contactless transport of drugs and other necessities to patients in such situation would help control the outbreak and save the healthcare staff.

With such an effective, well needed application being delivered, the number who would benefit from it could very well range from hundreds of thousands to millions.

One of the major advantages of this design is that it is not simply restricted to use of drug delivery in hospitals. The two innovative and efficient features provided to it: ability to cover any terrain and ability to transport weight, allow the UGV to be used in any sort of industry that demands for it. One of its major potentials also lies in transporting nuclear waste at nuclear facilities, this will avoid human contact to nuclear contaminations.

REFERENCES:

[1] J.Iqbal, N.Rashid. Small Unmanned Ground Vehicle

[2] J.Iqbal. Unmanned Ground Vehicle

[3] U. Pandey, V.Malemath, A. Barale. Drug Delivery for Covid 19 wards in hospitals.

[4] Z.Murtaza, N. Mehmood, M. Jamil, Y. Ayaz. Design and Implementation of a Low-cost remote-operated unmanned ground vehicle

[5] S.M. Hasan, M. Rasid, A. Mallik. Development of a wireless surveillance robot for controlling from long distance

[6] H.Hulako. Design and Construction of a GPS based unmanned ground vehicle

[7] Martínez, Jorge & Mandow, Anthony & Morales, J. & Pedraza, Salvador & Garcia, Alfonso. (2005). Approximating Kinematics for Tracked Mobile Robots. The International Journal of Robotics Research. 24. 867-878. 10.1177/0278364905058239