Project MARINA

Machined to Aid and Rappel In Nullifying Areas

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Abstract

Recent Development in the single board computers market have encouraged robotics and fanatics of the subject matter to undertake many interesting projects. One such field of robotics is the exploration robots. As humans have started to explore new regions of earth, many accessibility related challenges have come up. Such areas present the researcher/investigator a narrow and risky access. These are robots with the capability to move through various terrains and carry out tasks programmed by the user. SBCs (Single Board Computer) have made it easier for enthusiast and developers to put together sensors and motors to build such robots. SBC's Accommodate sensors with GPIO pins and a user-friendly interface for programming. The project MARINA aims to aid these difficulties by creating a robotic vehicle that can be rappelled into these environments to gather data efficiently and monitor situation safely. MARINA stands for Machined to Aid and Rappel In Nullifying Areas. Essentially designed to aid research and rescue teams. In recent memory, a group of young boys and their sports teacher accidentally fell into a cave in Thailand (Bbc.co.uk, 2018). Such Disaster struck areas are very tough to monitor safely since the structures are collapsed and it leaves very narrow entry point for a rescue team to monitor the situation. The cave had a risky narrow gateway for the rescue team to learn about the positioning of the trapped boys. MARINA is intended to rappel into an area like this and provide the team with valuable insight of the occurrence. Any investigation team/rescue teams will be benefitted from this device. The justification being that the data from sensors will be transmitted to the attending teams and they would use it to create maps and made aware about the situation. Environmentalists, research teams, rescue teams are the target user group. This project is a combination of many engineering fields such as mechanical, electrical and computer engineering. Additionally, the project aims to use SBC's and open source code base to design the robot. The report will gather some ideas from previous attempts and look at it from a technical scope. The literature review aims to try to depict the design choices made for it and discuss how it can modify the rappelling robot. Using open source projects, this project will accommodate a modular design aspect to replicate SBC's design methodologies. It will also attempt to understand the current progression of robotics in the field of autonomy.

Acknowledgement

This project would not have been completed without the mental support provided by the person who is credited for the name of the robot, Marina Hossain. Thank you.

I would also like to thank my module lecturer Chris J. Bass for truly inspiring me to create a habit of grasping a concept in depth, for replying to my mails about topics that are beyond the scope of the project so quickly and providing all the support I needed. You have been a saviour on many occasions.

Thanks to Andrew J. Tickle for his suggestions and guidance throughout the development period of the project.

Forever grateful

Md Sakibul Alam

Declaration of Originality

All work done in this project is my own, except when credit is given and no section or portion of it has been submitted to support an application for any degree, qualification or certification to any other organization or learning environment.

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Chapter 1 Introduction

Project MARINA is intended to be a self-repelling robot for rescue and investigation operations. Often, after a natural disaster or the collapsing of an old structure, investigation and rescue teams find themselves in a very tight space to reach the target area. To tackle this issue, a primary step is to have rescuers rappel into the area by the means of a rope. This introduces new problems for the rescuers. As they are unaware of the situation in the collapsed structures, they put themselves in danger. MARINA is intended to be sent instead of a team member. The robot will be repelled into the disintegrated architecture equipped with sensors and cameras to provide a feedback of the ruins, if required be used to send aids for trapped victims. Being a vehicle means it will have control mechanism with a drive train to move around the target area giving flexibility to user to move and further investigate. The user will have an easy to use interface to control the robot. Environmentalists and archaeologists also find themselves in nullifying areas known to have unstable network. As the robot is intended to be used wirelessly to reduce chances of a connection flaw, an unstable network may allow the robot to be harmed losing valuable insight and data collected from the area. As a precaution, this robot will also have 'somewhat' autonomy to understand when the connection is lost and keep track of the vertical positioning of itself and rappel back to the user. This report will document the design aspects of the robot.

1.1 Aim

This project is combination of mechanical, electrical and software engineering. The project MARINA has 3 primary objectives;

- Develop a robot as close as possible to the proposed design.
- The robot must have a rappelling system.
- The robot must be able to navigate itself out of a target area.

Along with these, there are some low level aims this project will attempt to satisfy. They are as follows;

- Develop a manageable code base for easy addition, troubleshooting and modification.
- Make the vehicle as robust and lightweight as possible.
- Have an auto navigation system that can control its direction.
- Develop a 'user input detection' system for it to automatically rappel up or down depending on the presence of the user.

Through this project, the designer also expects to learn some skills such as;

- Learn and attempt to implement NodeJS to be the primary coding platform.
- Gain better knowledge in 3D modelling.
- Go through the complete process of developing a product from scratch.

There will be some difficulties this project is expected to face. Designing a robust chassis for the vehicle is essential. The intended use cases will present the vehicle with tough, difficult to manoeuvre terrain. This is a crucial reason to have a robust drive train. In the initial stage, the best approach is seemly having a 'wheels on belt' drive train. This design may receive some modifications in the testing stages. Other than that, all the other design decisions of this project are well thought out and are not expected to face any negative changes. Negative because, in the testing stage, if a change appears to benefit the overall design, it will be implemented. The end report is also expected to document every aspect of the project as a priority.

1.2 Motivation

Wikipedia published a list of all the recent disasters that have occurred since 2018 (en.wikipedia.org, 2019). Multiple earthquakes and tornados have contributed in the destruction of many establishment. These incidents have worked as a minor motivation for this project. But the crucial influencing event happened a few years earlier. In 2013, a garments factory in Savar, Bangladesh collapsed and resulted in killing around 1134 leaving workers severely injured (Safi, 2018). Weak and faulty design of the building may be an attribute for sure, but the post-accident rescue mission did not go accordingly as well. Firefighters had no information on the positioning of the victims resulting in the death of more people. The rescue team sent people down on a rope to get insights of the building and a few of the ravens suffered from deep injuries and even death. If a robot went down instead of a human to receive the data, it would have been safer and more efficient. A disaster affected areas present rescue teams with tough to reach environments through scattered configurations and collapsed structures. A scenario like this was experienced recently while trying to rescue the boys and their teacher trapped in a hard to reach cave in Thailand (BBC,2018). 87 fire fighters have been recorded dead on duty in the US in 2017 (USFA, 2018). The paper from USFA confirms that deaths on duty often occurs because of not having enough intel of the accident spot. The aim of the project, the motivation of the project is to assist these situations as this self-rappelling robot will allow the user to remotely inspect the nullifying places while staying away from damage. Thus, satisfying the probing needs of the user in a safer way.

1.3 Project Background

Bernard et. al. (2011) discussed the possibilities of using drones in search and rescue missions by confirming that drones can be used for more than just monitoring. According to their research and the prototype, a drone can be used to send supplies to the victims as well as do monitoring and inspecting from a safe distance. “Disaster Robotics (Intelligent Robotics and Autonomous Agents series)” is a mentionable book on this field by author Murphy (2014). Here, the writer discusses in depth about the advantages of using pre-existing robotics technology in combination with some autonomy to aid the post-disaster response. The buzzword AI (artificial intelligence) technology is being utilized heavily due to its self-control abilities and rescue mission and investigation projects often present the system with difficult terrains to move around and by doing so, it learns a variety of situation while it gradually improves the algorithm. With global warming on the run and older structures slowly breaking down, the logical implementation of rescue robots is on demand more than ever. Therefore, recent designs like the “big dog” (Wikipedia, 2019) from Boston dynamics are increasing and the public curiosity is at all the high. This project shares some of the common logistics with the previous designs from other projects. But the addition of a rappel system along with the mobile structure which is set to set apart from the flock. The field of inspection translates to dealing with remote and difficult terrain. Researchers have dealt with the idea of developing robots in support of the problem. The evidences show that there is a need for such a robot and project MARINA intends to join the development process.

Chapter 2 Literature Review

Robotics in general allow the designer to implement and test multiple features on a single project. All robots are built to aid day to day objectives of human. Until recently these were only utilized in factories for automation process and it has drastically reduced cost and increased production quality and capabilities. With the introduction of SBCs such as raspberry pi in 2012, developers and companies have started to automate not only production process but also their own daily tasks. This has allowed a scope of opportunities for robotics to flourish and young students find it easier to learn engineering when they undertake simple robotic design tasks. This project will attempt to design an aid robot named MARINA (Machined to aid and rappel in nullifying areas) that can be rappelled into tough to reach places for gathering information. This robot will have some autonomy to it as it can recognise if the user has lost signal and act accordingly. Act meaning take decisions such as rappelling back to the top or descending the rope and move around the target area, avoid obstacles. This document will look at some similar projects and try to co relate them with the rappelling robot.

As mentioned, robotics is now being utilized in multiple sectors. There is a pattern in the recent methods of robot designing which will be seen further in the document.

Schempf (n.d) discussed in his design of a rappelling robot that for a disaster-response robotic should have some common attributes like small, lightweight footprint, capable of carrying sensors and be designed to be used in disaster-oriented space. These attributes are similar to the project this document represents. In the article, Schempf (n.d) conducted a research to find robots aimed at being used in collapsed buildings. With the aging infrastructure, it has become extremely important to consider the disastrous situation of old structures collapsing and robotics can surely aid this situation. The proposed design has a strong tethering system which sends power through the tether rope/wire. This is a design choice being considered for the MARINA project. The main shortcoming here is that this robot has no autonomy. Meaning without human input, this robot cannot carry out any tasks. Having a certain level of autonomy is important for MARINA. Glotzbach (2004) discussed in his paper on adaptive autonomy that having autonomy in modern robotics was a crucial factor in the usability of that robot.

In a collapsed structure human may not always be able to see and recognise an object to avoid collision. Shin et. al. (2013) tackled this issue by proposing a software framework to create a 3D map of the surroundings of the robotic vehicle. In the article they argued that knowing the size and positioning of an obstacle in a rescue mission is key since these operations are operated in a very congested space. This robot is not autonomous by any means, but it has the elements of autonomy which MARINA will use to some extent. MARINA will aim to gain autonomy by analysing data from sensors, deciding an action using the analysed data. MARINA will provide user with video data to project an image of the obstacle in front but to gain autonomy it will use some onboard sensors.

Surveillance is an emerging field using robotics technology to ease their tasks. A paper by Abdalla et. al. (2017) elaborates on the difficulties faced by the military authorities guarding the borders. In I, a surveillance robot is proposed to monitor and aid the authority. They have used the raspberry pi to interface with sensors such as PIR, camera and IR to gather data and provide the user with options to take actions based on these data. This robot design is very similar to the MARINA robot, but this has no automation. The robot has no rappelling system, but this is demonstration of how SBCs help a designer prototype a robot. The versatility of SBCs allow designer to use multiple technologies at once such as this project where they have implemented communication through internet. Though this, the user can control this robot without any physical connection if this has an internet connection. MARINA aims to provide user with inputs but also takeover controls when the user has lost connection to the system.

Siegwart et. al. (2004) in the book “Introduction to Autonomous Mobile Robots” mentioned that just robotic arms comprised of a 2-billion-dollar industry and that was back in 2004. Now this is even larger. The manufacturing purpose built have always been at the forefront of robotic technologies. But now that field has started to change.

By now the pattern in recent robotics development is visible. All these projects attempt to build a prototype robot with an aim to aid a certain problem of the society, for example self-driving cars aim to reduce accidents caused by cars. Nearly 37,133 people have died due to car accidents alone in the USA in the year of 2017 (Wikipedia, 2019). SBCs have made it possible to build these prototypes.

Varying terrains is a challenge for an exploration robot. Over the years many solutions have come up to tackle this problem. Chain and belt wheels, suspension mechanism and many other solutions to name a few. Project MARINA aims to have a ‘tracked wheel’ mechanism to work with. Sanngeon (2009) proposed a solution to this problem by designing a triangle shaped robot that contracts and extrudes to suit the need of a terrain. Although it is not autonomous, the author showed an intension to add autonomy to the robot in the coming stages of the project. Here, the author expressed the desire to use a better SBC, the PC104 to reduce required space. The pattern of making robots autonomous by using low cost, low end SBC is present here as well.

Till now, this review has looked at a variety of robots that does not necessarily have all the features that the MARINA project is expected to have, but individually these designs and implementations tackle one problem at a time. There’s been a pattern recognized in the design of all the robots. They all have or try to have some level of autonomy in their movements. Krishna et. al. (1997) designed a robot that was intended for construction inspection which has a rappelling/tethering mechanism like that of project MARINA. Here, the designer suggested other use cases for the tether other than support which are supplying power, transmitting data, carrying fluids for repair needs etc. This robot has similar properties to that of MARINA. Project MARINA will not require such powerful tethering design since the intended use case is for monitoring purpose only, but this provides an overview of the winch mechanism needed for the project.

Exploration robots can always be utilized in a disaster related response. SeungSub et. al. (2017) talked about various types of disaster response robots. One such type is the Integrated Operation System. In this sub category, the robot supports situational understanding and can operate independently. Project MARINA fits into this section of disaster response robots.

2.1 Succession of the project

How will this project be considered successful? The goal of this project is to develop a robot that can;

- Rappel on a support structure
- Have a self-aware object detection system using an SBC
- Have a well-off drive system

All the discussed project above has most of these criteria. Project MARINA aims to combine these individual designs and create a better robot that checks all the high-level criteria.

2.2 Autonomy and robotics

All robots now in general will have some level of autonomy. Self-driving car is the best example of autonomy in robotics. These self-driving car industries is one of the most thriving new technologies. Litman (2018) said that by 2030 self-driving cars will be reliable by 2030. SBCs have allowed developers to fiddle with the idea of self-driving cars. Jain (2018) designed a basic model of an autonomous car using raspberry Pi. Here, the vehicle again gathers data from a camera and uses machine learning to recognize objects and make decisions. The autonomy level of this project is not like project MARINA, the idea of automation is frankly similar. Here, the credibility of SBCs in robotics is again clearly indicated. Low cost SBCs have given enthusiast the opportunity to create robots and autonomy gives those robots a self-awareness to make low level decisions.

2.3 Single Board Computers in Robotics

Robots are, at the end of the day, a machine that follows instructions from a computer. This document has been emphasising the growth and development in single board computers over the recent years. And this trend will keep expanding with the new and even cheaper SBCs gain popularity. Vandevelde et. al. (2013) in a conference paper mentioned that the demand for engineers in Europe has tripled since 2006, which indicates that now the demand is even higher. This is since young enthusiasts are finding it easier to develop little robots and learn on a PBL (problem-based learning) scheme. And this is being aided by the growth of application of robotics in the industrial sectors. Statista (2017) published a report demonstrating the increase of the use of robotics in the industry and it visibly showed an increase of 71% by 2020. Low cost, low end Single board computers will only increase the availability and opportunity of robotics enthusiast. Easy to use GUI (graphical user interface) based programming kit like Scratch lets these upcoming engineers get used to various programming concepts from an early age. Single board computers have had a contribution in the field of cloud robotics as well. Krishna et. al. (2016) developed a robot using an SBC that can interact with sensors as such through the internet with an intension to be used the manufacturing industry. This implies that IOT (internet of things) has been heavily benefitted from the surge of single board computers. The adaptability and use case will only go up as manufacturers of these SBCs have been equipping their boards with higher, more powerful specifications to carry out heavier workloads.

This study has investigated various projects co relating to the project MARINA. The core ideas of each of these projects are similar yet very different. The aim of this literature review was to skim through the technical aspect in the field of robotics and knit the similarities between the projects while picking up the trends that have been occurring in the field of robotics as well as providing a look into the future of the sector. Autonomy in robotics using low end single board computers is a pattern that has been reoccurring in all the projects. The MARINA project aims to take inspiration from these findings and target to meet the criteria as closely as possible. The future of robotics is very bright as single board computers can only get better.

Chapter 3 Methodologies

Tyres (2019) in a lecture of his on the matter of agile methodologies stated that agile supports changes. The project MARINA will encounter multiple positive changes in its development cycle, needing a design and methodologies to embrace changes when need be. The agile approach aims at releasing developments in small short cycles with the intention of making sure that each release has a working feature. Figure 1 briefly visualizes the iron triangle of agile method.

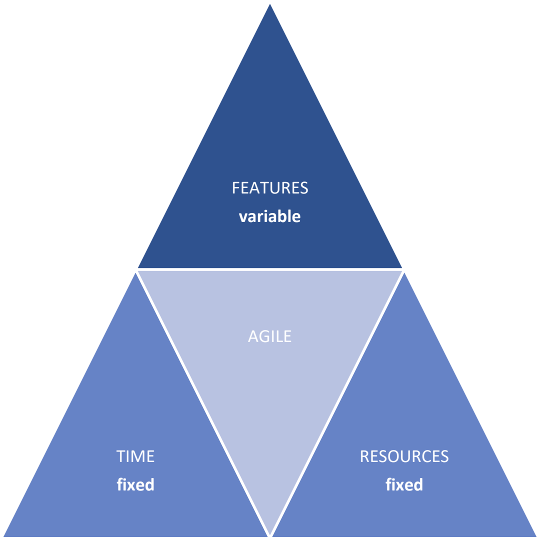

Figure 1: Iron Triangle of Agile

The project requires an extensive planning to detail what requirements must be met and what the project aims to be. The project has a fixed timeframe for its completion as well as a financial and workforce limit. Proper planning makes sense due its scale and diversity of skills required. The objectives lay a foundation of desired features for the project and the goal is to produce an MVP (minimal viable product) at the end of each sprint. Although, there are a few features that are advanced and must have and the planning stage will prioritize them over all the others. The subsections below detail and overview of stages this project should take to achieve a working product at the end of its development period.

3.1 Problem Description

In the initial stage of the development period, the task was to identify what this project is expected to be. Basic description of the project is that this is a 'self-rappelling' robot. The title does not define its form factor. Meaning it may have a 'human like' design or it may have a vehicle-based architecture. The purpose of this stage is to conduct a study to decide which design will suit the use case. To do that, completing a literature review in the field of this topic from a broad spectrum along with a detailed depiction of previous attempts by the industry related personals to gain sufficient understating of the topic.

The project brief serves as the base to outline the outcome of the project expected by the designer and the project owner/ supervisor. Literature review and brief allows the designer to filter out the expectations and possibilities of the project. This stage answers questions such as, what the project wants to uphold in a broader sense and what has been working as the initiator of such concepts and the answers are, in a nutshell, the project attempts to demonstrate the developments in the field of robotics through Single Board computers and open source projects that initiated the abstract.

3.2 System Design

As stated before, this project requires knowledge from various perspective due to its large scale and depth. Design stage is the most important stage of the project to ensure its success.

The first design choice made is about the form factor since the robot will have winch mechanism of some sort to help it rappel on ropes, it needed to be lightweight, preferably maneuverable and have the capacity to contain the components. Therefore, a vehicle like form factor was chosen as it satisfies the requirements.

Another design decision was of power supply problems. This robot is intended to travel vast distance without having any repair support in close proximity. This meant that the system must manage its power usage well along with having back up power ready in case in the event of a supply power interruption. The core concept is that it would receive power through the winch rope by having twisted pair cables. In the event of a power supply hiccup, the system will also have battery power on standby on board. This introduces new complications as the system will require a custom designed power supply and management system. More on this in the design chapter.

A testbench was required to test the design concepts before sourcing the hardware and ordering components. Proteus is the preferable simulator tool. The complexity of this design meant, there will be more than one platform required for different design simulations.

The system should provide user an easy to use interface with modularity in mind. This meant the choice of networking/communication with the user and the robot was crucial. Bluetooth is a good choice for such system, but this results in the user having to have a specific application/ controller to use for the robot. Adding to that, Bluetooth does not have superior range. This also complicates the decision of microcontroller to pick. The most available application on any modern device is a browser. So, if the system can host a web application, user or users can access it from any device from any range given the vehicle has a strong enough WIFI connection. WIFI then becomes preferred communication method. This also indicates that a regular Arduino/pic microcontroller will not be good enough to carry out such web hosting task, add video/data streaming to that.

3.3 Sourcing Hardware

Multiple hardware can achieve same result. Thus, this stage will require intensive time planning and testing as well as gathering information from pervious users of the intended components. The idea was to use a simple physical test bench before ordering parts and build a prototype using the designs made earlier. Once that's complete, next job was to decide what to use and ordering a chassis that would fit all the components and still be light weight.

Even after deciding and ordering parts in stage 1, there were more that were bought throughout the development cycle. Turning this section of the process into an asynchronous stage. Complete list of parts is available at the appendix section of the report.

3.4 Code Development

The project planning implanted some code at the initial design stage using python as its core language. The bulk of the code was based around the movement of the vehicle and its networking methodologies. The code was written by replicating the events that happens when power is supplied to the H-bridge motor driver. More on this later.

Code development was the most asynchronous process in the entire development period. It was dependent on the feedback received from the hardware and accumulated any changes that was required. The code base has seen one massive shift from python to JavaScript as the intent was to make the robot web based and have a website to control it, which was much easier to do in JavaScript and NodeJS in particular and it offered more support. This development process keeps the projects key concept in heart as it only utilizes opensource libraries and applications to develop its code base.

3.5 Implementation and Calibration

This stage consists of setting up the hardware and uploading code to the chips and use simulation environment to test the hardware. Throughout the test period, the hardware setup hasn't seen many changes, but the code base has experienced multiple calibration and many additions. This section has removed many possible features due to time shortage, expense cuts and other issues.

The main problem this section dealt with was the power train. The system had multiple devices needing separate voltage support. The design of the power supply system required different circuits to accommodate the specific requirements of these components thus making the use of current and voltage probes. The idea was to send power through winch rope. And the power supply was built following that scheme. But the problem arose while trying to pair twist the cables with the rope as the space was not enough for three wires.

The section also dealt with researching for open source streaming libraries to stream the video from the robot to the website. And it required an intensive installation and calibration. The website itself was built at this stage to include keys and windows for information. The motor direction was calibrated on multiple occasion. The self-rappelling section of the project was built at this stage which also took multiple tries as many of the techniques previously assumed were proven to be unsuited for the project.

Chapter 4 Problem Analysis

The problem this project aims to solve is the necessity of a monitoring solution to provide information for a potential team in nullifying areas. The project aims to solve this by developing a robotic vehicle is by combining a winch mechanism, video streaming system and a failsafe rappel system mounted on a vehicle chassis. Doing this takes a lot of co relation between multiple domains of technologies. Succession of the project depends on implementing the connection. To do so, one must understand the underlying concepts of these problem domain.

This chapter will discuss each problems zone individually, in depth and find out how it is related to the project possibly generate a solution. This section will briefly talk about why specific decisions were taken to solve each of the problems.

4.1 Vehicle Drive Train

The MARINA bot will be sent to remote places that have difficult terrains. Surfaces like sand, grass and wet terrain makes it really difficult for a vehicle to navigate through them. MARINA is in no way a project about efficient drive-trains, but this project will try to solve the possible problem from a distant attempt by conducting research on which drive terrains have benefitted the most in such use case.

Regular four-wheel based designs are efficient enough for predictable terrains with smooth and frictional grits. This robot is intended to be sent into unpredictable areas. Thus, this design will not benefit the needs. Spiked wheels were considered for this project as a substitute, but they were rejected as they would not provide enough grip on a smooth surface. The next design to be considered was tracked wheel.

Tracked wheel is essentially used to build tanks. By placing gear-like wheels on top of a chain, this design proves to be efficient for an ATV (All Terrain Vehicle). Hata et. al. (2014) developed a concept on the topic of ATV where they discovered that tracked wheel was the best choice when designing such vehicle because it offers modularity and as it is on tracks, the friction is generated from the weight of the vehicle on the track as well as providing a push and pull effect on the wheels offering more torque. Coetzee et. al. (2012) used tracked wheel for their mining robot design as it allowed for climbing over unexpected obstacles. The use cases for tracked wheel is similar to what MARINA expects to do. Hence, tracked wheel was chosen as the drive train of choice for this project. Two motors can be used as the driving wheel pushing the tracks to spin the other two wheels removing the need of 4 motors.

4.2 Navigation

Initially, this robot is designed to be driven by the user through a website. The user would press or click on the directional button to control the wheels and sensors of the robot. Figure 2 shows the desired input methods. This project does not require an autonomous system as it is assumed that exploration and rescue missions will always have human supervision available.

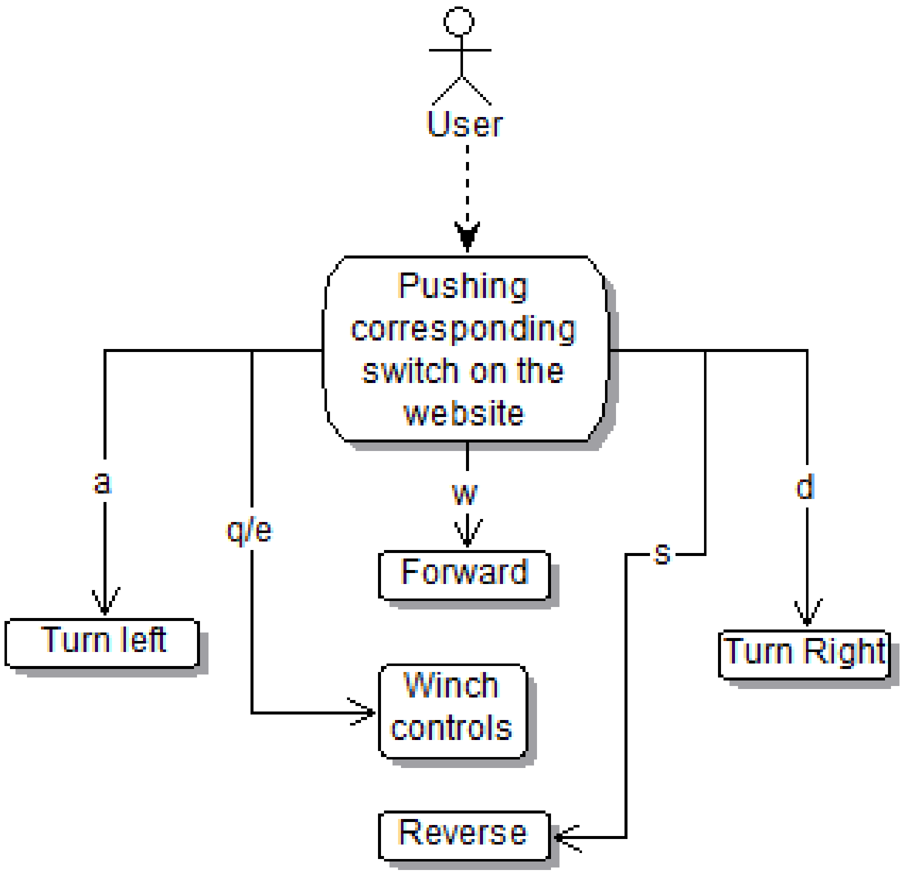

Figure 2: User control diagram

The possibility of using an autonomous navigation system appeared promising at the beginning of the project but to decide where and when a user may require such feature is difficult to determine.

4.2.1 Autonomy

Elon Musk on an interview at TedTalks stated that no matter how many sensors we use, cars will never drive like humans drive until we figure out computer vision (2017). Computer vision is a complex domain beyond the scope of this project. Another common way autonomy is tackled in the field of autonomous driving is through using distance sensors, LIDAR and GPS.

A common distance sensor is the HC-SR04. This sensor uses ultrasonic sound waves to measure the time between sending an ultrasonic wave and receiving it. The constant speed of sound is also used to derivate the distance. Equation 1 represents the calculation.

$$d\ (distance) = \ s\ (speed\ of\ sound\ 343\ m\ per\ s) * \frac{t\ (time)}{2}$$

Equation 1: Distance calculation

The system can send a signal and wait to receive back the wave and calculate the distance and decide to move towards the direction with the largest distance. The system can implement a constant signal sending and make an interrupt routine to be executed as soon as a signal appears on the input pin of the chip.

LIDAR on the other hand uses illumination technology to illuminate the objects ahead and read the reflection data thus measuring distance using equation 1 except this time the speed of light will replace the speed of sound. This technique is much faster because light travels much faster than sound and can be used to generate 3D images of obstacles from the light data bouncing and reflecting off them.

GPS is a great system if the robot was given a specific location to drive itself to as GPS is a location-based detection system. Project MARINA is a different breed of robot thus it has no use of GPS in this case.

4.2.2 Machine Learning

With open source Libraries like Google TensorFlow, Keras, Scikit Learn and OPENai, machine learning is becoming popular in the autonomous field. The basic idea is to have user navigate different areas (training data) and design an algorithm that will take sensor data as input and training data as reference to decide on some new locations (testing data) and train itself to find the relationship between sensor states and preferred navigation decision. For MARINA, user will generally supervise the situation and sensor data may often become corrupted as these places are undiscovered and designers are unaware of the types of obstacles the robot may face. Although the use of an ultrasonic sensor seems logical to use as collision avoidance mechanism.

4.3 Communication

The project will stream video to the user on a website. This means the system must host a website and require a wide bandwidth to transfer data between the user and the robot. Given that the system uses a website to communicate, the most preferred way of networking is via WIFI. WIFI uses a legal frequency bandwidth of 2.4Ghz and 5Ghz and it is long range enough for this use case plus it allows the range to be expanded by using large antennas. Although any communication device can have an extended range by antennas, the justification of using a powerful chip and WIFI is to satisfy the streaming needs of the system.

LoRa is another fast-growing communication standard that was considered for this project. The idea was that this chip would be used to send control signals and a continuous connection signal to detect present connection. If a connection is not sensed, the system would activate self-rappelling mode better explained in figure 3.

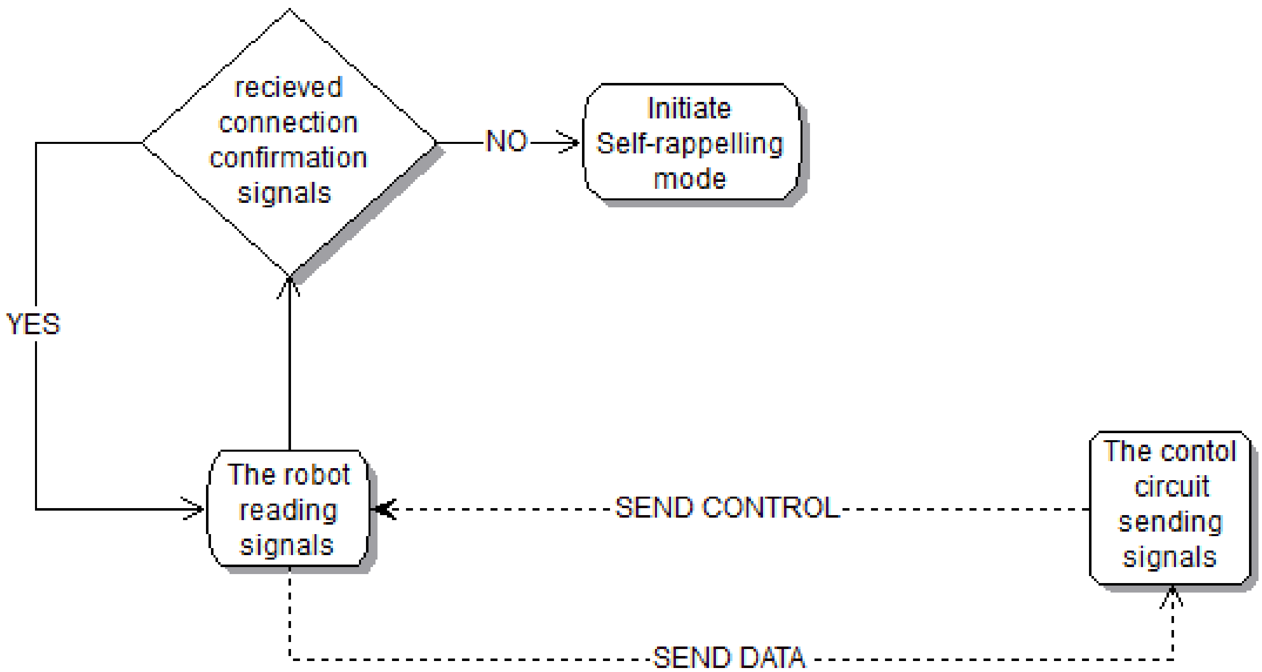

Figure 3: Communication diagram

The method is very effective for a physical control device, but it still cannot push video data at a satisfactory rate. So WIFI is still the best contender for this project.

4.4 Video Data

All the decisions taken till now is to make sure the video data is easily sent to the user domain. The camera of choice for this project is the raspberry pi camera, an OEM (Original Equipment Manufacturer) developed module. This module will not take up any GPIO (General Purpose Input Output) pins as it uses a ribbon connector specifically built for this purpose. This module has the perfect form factor to fit in the tight space of the chassis. Is fast enough to broadcast hi-res video data to the server side of the project.

Chapter 5 Design

The analysis done in the previous chapter assists the understanding of the link between all the components of this projects and the underlying concept for the connections. This chapter will discuss the details of the designs implemented and present visualization of how they were set up. The purpose of the discussion is to provide real world solution to the problems discussed before.

5.1 Power System

Each components of the project required different power source as the voltage required is limited to the specification of these components. The solution to this problem is to build a power system for the project. Figure 4 shows the power supply design chosen for project MARINA.

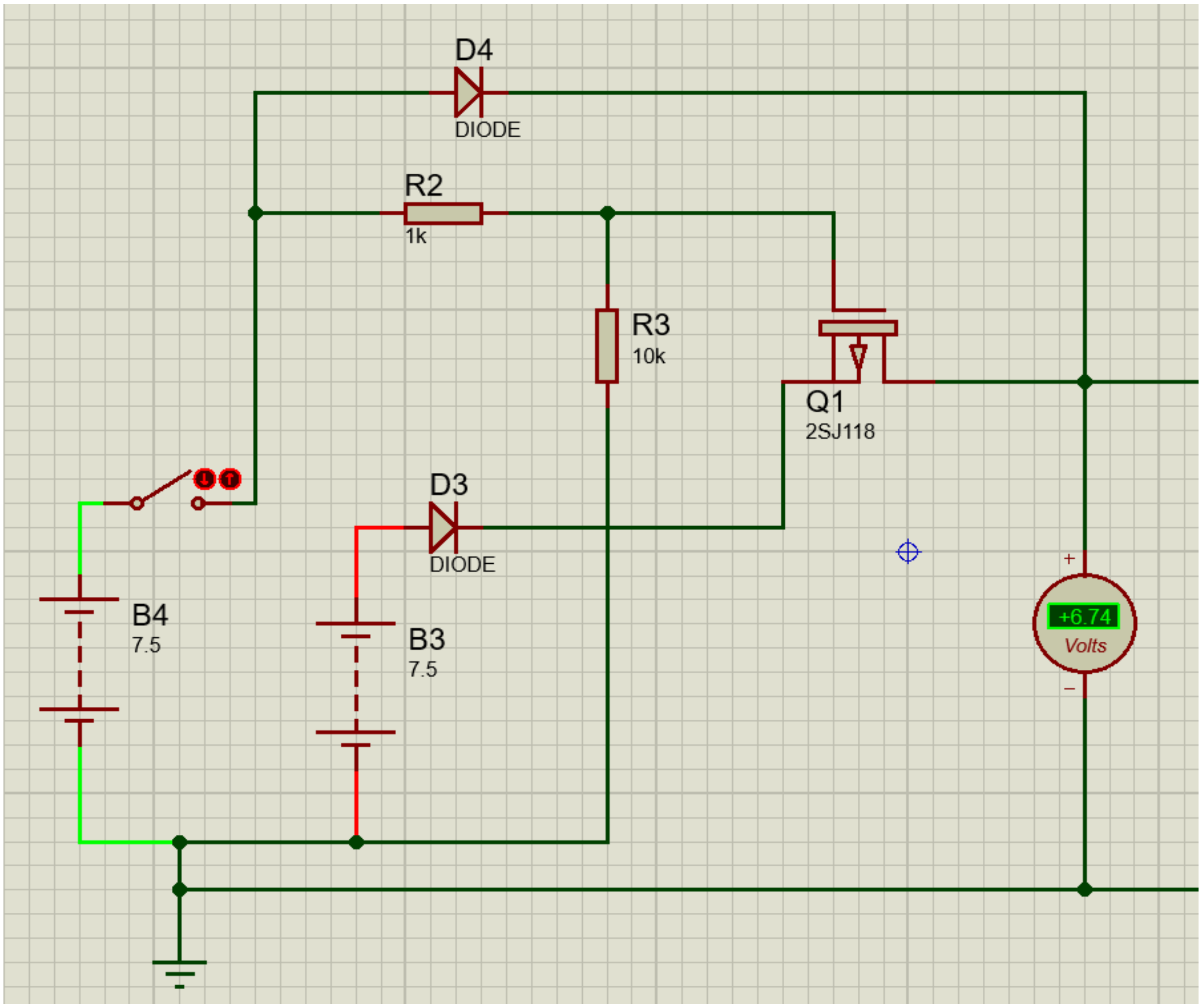

Figure 4: Power supply

The first problem figure 4 tackle is the possibility of a power supply failure of the robot. The idea is that the circuit will mainly be powered through a power supply unit. The power will be sent through the wires pair twisted with the rope of the winch. Raspberry pi, ultrasonic sensor and SN754410 half bridge chipset require a 5V supply while the motor, the winch mechanism need 6V. The half bridge chip drops around 1.5 volts before supplying the motors with power. To account the drops and keep up with the standard battery found, this design will use 7.5V as its input power. In figure 4, the green wired battery represents the power sent from the user's power supply unit. The switch simulates a power supply failure. Possible cost may be due to wires breaking, the user not being near a power source. The red wired battery is the onboard battery to be used in case of such events. The recognition of the absence of power supply is done by using a P-channel mosfet transistor (Q1/2SJ118). The gate of the mosfet is connected to the power ssupply (B4) the idea being if that source does not supply power, it will become 0V. If so, the on-board battery (B3) will be allowed to pass through the gate of the mosfet thus continuing to supply power to the circuit. D3 and D4 diodes are used to protect the circuit from reversed current flows expected to be generated when motors spin. This is because diodes allow current to flow only in one direction. Resistors R3 and R4 are used to make sure that the gate of the mosfet open in the air as it may have random noise leftover. In summary, the circuit will prevent the flow of reverse current at any node, prevent noise from dictating the gate and only enable battery to power the circuit if the other source fail.

Next problem this design deals with is the conversion of voltage from 7.5V to 5V. Initially the LM2596 adjustable voltage regulator was chosen to convert the voltage. Figure 5 shows the circuit connection for the respective board.

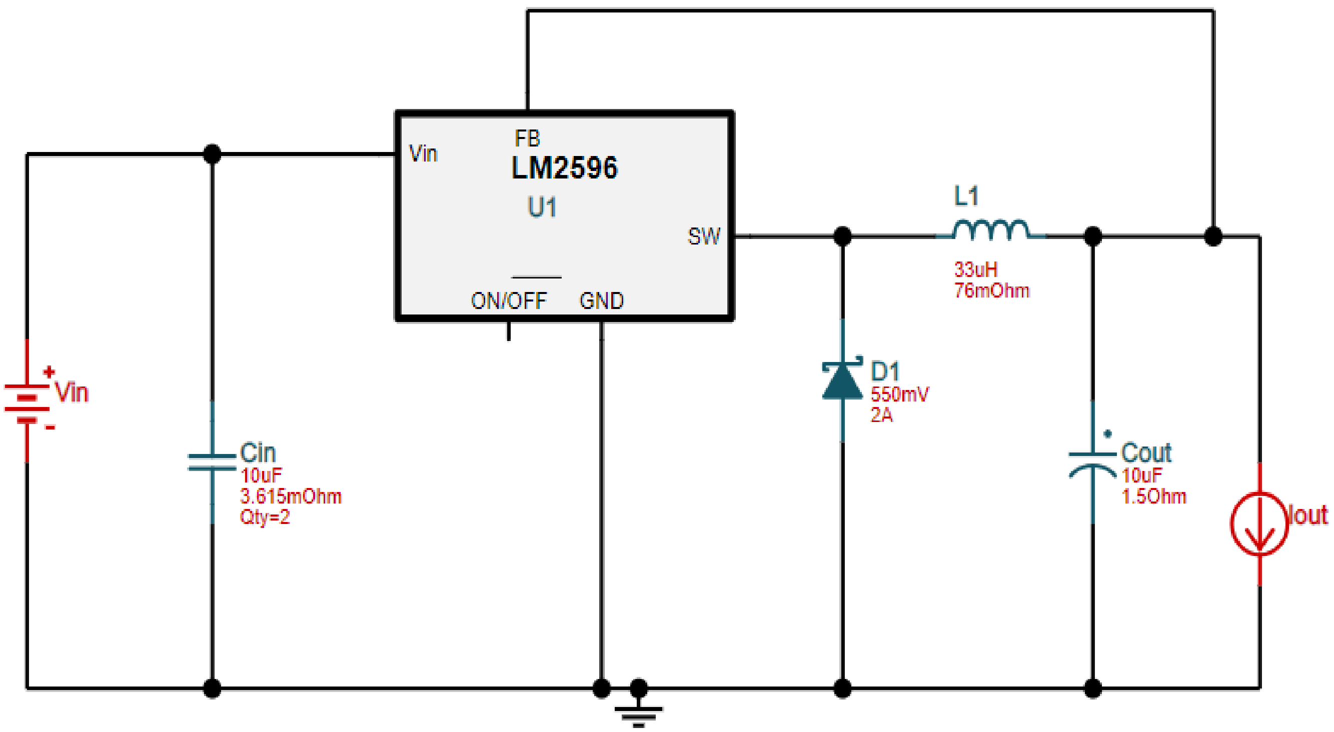

Figure 5: LM2596 voltage converter

The chipset bought for this project was not very modular and was too large to fit into the chassis of the vehicle. Thus, it was replaced by LM7508 voltage regulator. This chip has a small form factor although the efficiency is questionable. It drops the voltage by dissipating it as heat. A heatsink is must for this chip. Figure 6 shows the schematic used for the voltage regulator.

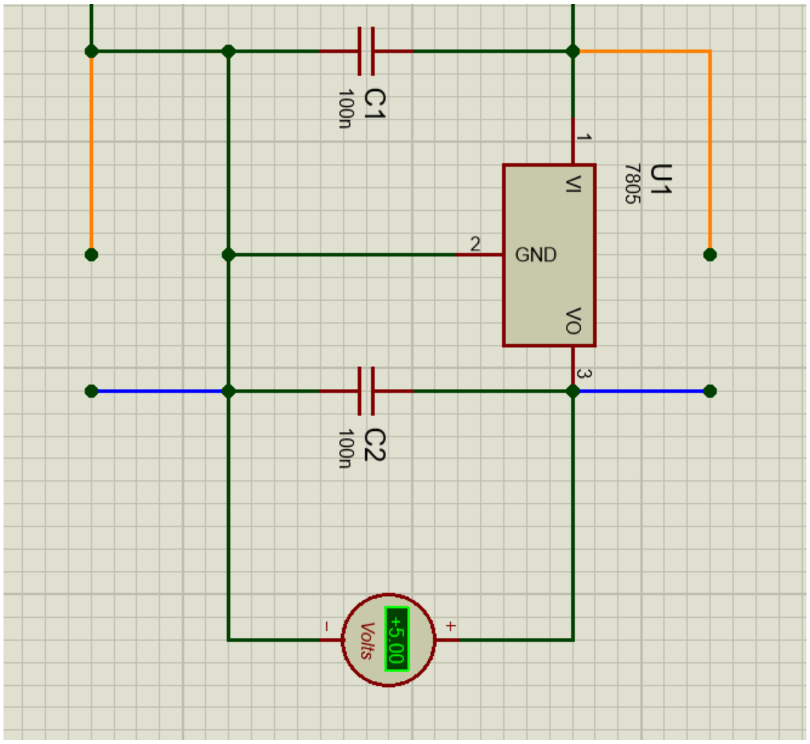

Figure 6: LM 7805

Capacitors C1 and C2 prevent the components from getting any unexpected voltage surges. The orange wires will be used for components needing a 7V input and blue for 5V inputs.

5.2 Chassis

The problem analysis provided a solution to the terrain problem of the robot with tracked wheel drive train. Henceforth, initially, a 3D model of the different parts of the robot were made, displayed in figure 6, intending to 3D print them. The problem is that designing such complicated parts require experience and time which was proven to be unnecessary as a

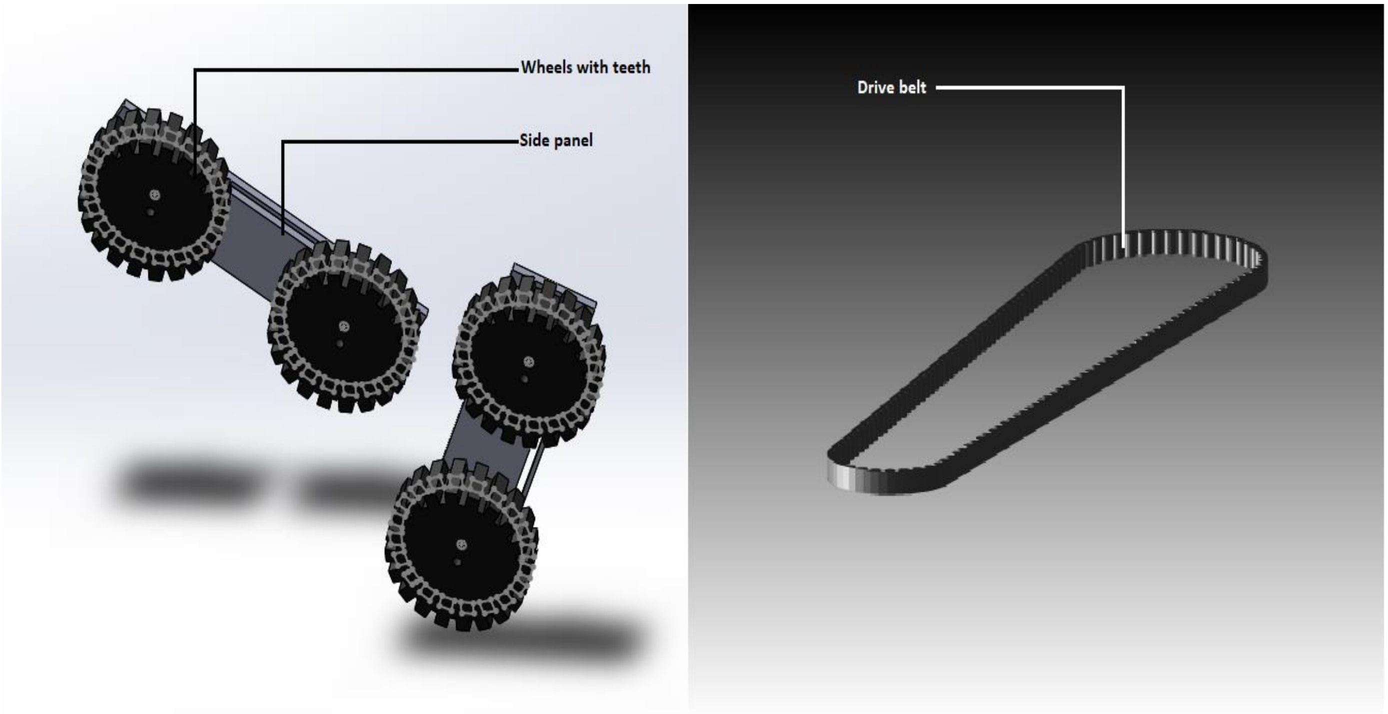

Figure 7: SolidWorks model

similar chassis was found relatively cheaper than 3D printing it. The chassis was small and compact. It was made from plastic making it lightweight. Chassis in figure 8 was chosen for this project.

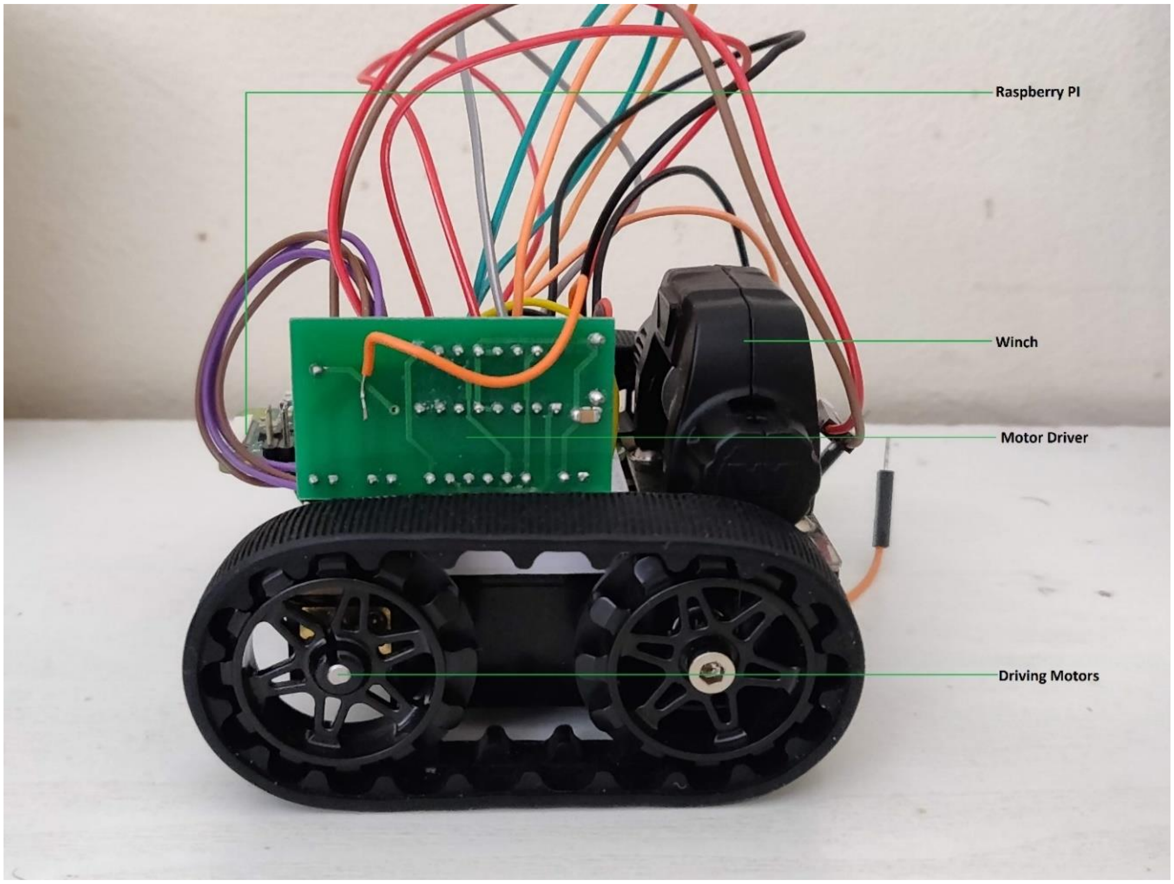

Figure 8: The chassis

5.3 Winch

Like the chassis design, a 2:1 winch mechanism design was built using SolidWorks shown in figure 9. But, after a certain amount of testing, it was discovered that this gear ratio is not strong enough for MARINA's use case. There were two ways of solving this. One was to buy a motor with high torque or designing a winch with a higher gear ratio to provide more torque. This can be attributed to the gear ratio equation.

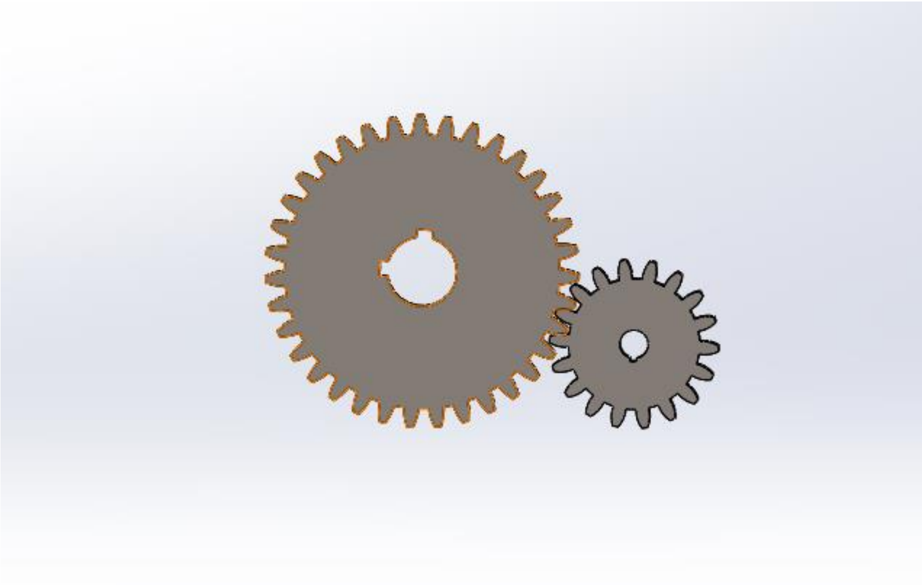

Figure 9: 2:1 gear

2:1 gear ratio briefly means that the large wheel has more teeth than the smaller driving wheel. This is effective enough for small torque requirements but for this project torque will play a crucial role as the winch must carry its own weight along with the weight of the components combined. 2:1 means for every rotation of the driven gear, the driver gear must rotate twice and there will be a gain in turning effect of 2. In layman's terms term Higher gear ratio means more gain in turning effect meaning more strength.

$$gain\ in\ turning\ effect = \frac{Torque\ of\ the\ driven\ gear}{Torque\ of\ the\ driving\ gear} = \frac{Number\ of\ teeth\ in\ driven\ gear}{Number\ of\ teeth\ in\ driving\ gear} = gear\ ratio$$

Equation 2: Relation of gear ratio and torque

After some searching, a prebuilt small winch was found online with a gear ratio of 298:1 able to carry weight of around 3 kilograms. This was ample for the robot and did not need much work to set up and was relatively cheaper to buy than to build. It also had the small form factor project MARINA required.

5.4 Drive Train

The robot will use a sn754410 half bridge driver to control the motors. Sn754410 is quad motor controller. This is important because MARINA has 3 motors to control. The chipset has two motor connection pins. Two driving motors of the chassis were connected individually to these pins as shown in figure 10, while the winch motor shared these pins.

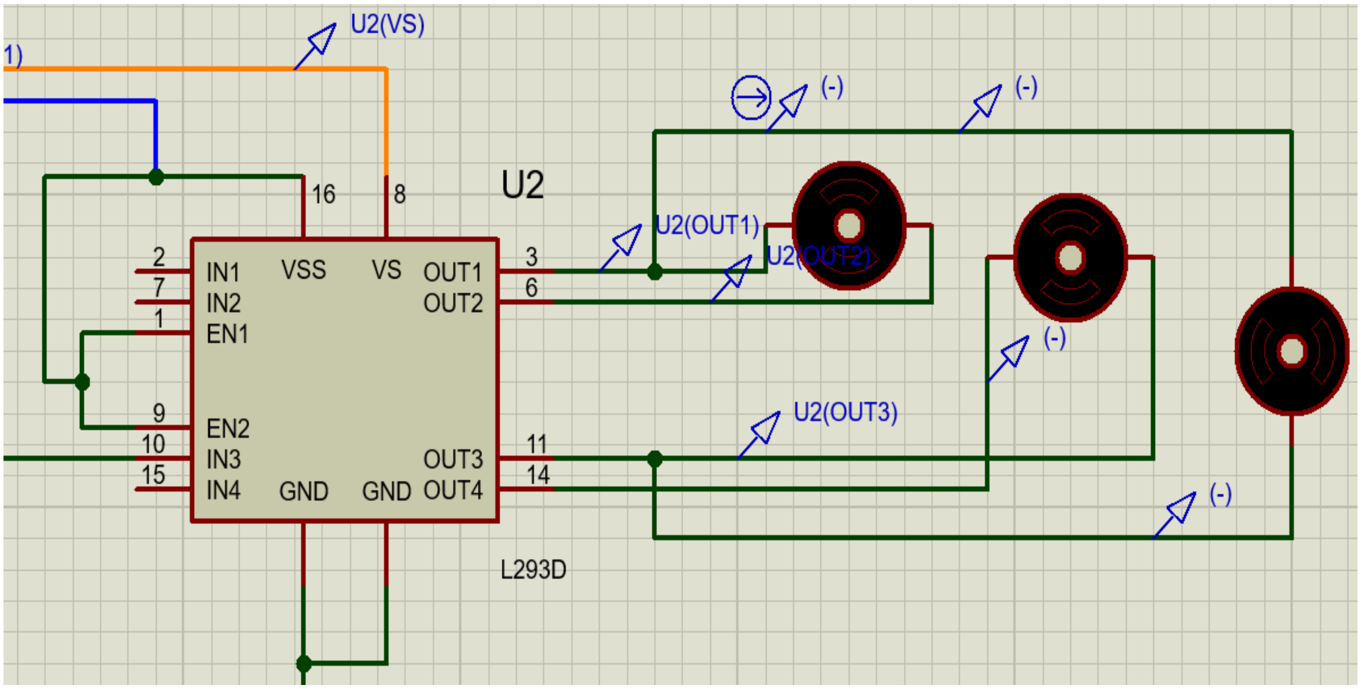

Figure 10: Motor configuration

Note that in proteus, the simulation tool used for this project did not have the sn754410 chip instead l293D is being used as the pin configuration is like that of the preferred chip. Pin 2, 7, 10 and 15 will be controlled by the raspberry pi's GPIO pins. When all pins have a high or a low signal, the circuit will stop spinning the motors. By altering the pin values, MARINA can control each motors direction individually.

This brings an end to all the electronic design elements of the project. In the physical implementation phase, some of these designs will be used and others will be modified to fit better.

Chapter 6 Software

Raspberry pi is based on a version of the Debian Operating system, Raspbian OS. This meant, there are no specific programming language that needs to be used. At first python, an interpreted language and very easy to use. This was used to test all the components. The code design bit was designed with modularity in mind. Hence, each component and its task were scoped in a single function.

```
def init():
   gpio.setmode(gpio.BOARD)
   gpio.setup(7,gpio.OUT)
   gpio.setup(11,gpio.OUT)
   gpio.setup(13,gpio.OUT)
   gpio.setup(15,gpio.OUT)
```

The Initiation function is called before any command is executed to make sure that no pins were busy carrying out other tasks, reducing the possibilities of noise. For example the forward function will call init() before setting up pin values.

```
def forward(tf):
   init()
   print("forward")
   gpio.output (7,gpio.LOW)
   gpio.output(15,gpio.LOW)
   gpio.output(11,gpio.HIGH)
   gpio.output(13,gpio.HIGH)
   time.sleep(tf)
   gpio.cleanup()
```

The tf (time frame) was being used for testing purpose only. This is meant to mimic a user pressing and holding a keyboard button for a period of time.

After all the testing, it was time to decide which platform to use for the website. NodeJS has been a growing platform for web apps due to its open source nature, a must for this project and a supportive community to get help if need be. NodeJS has a library named express that makes setting up a server simple. This project utilizes that as well. One deeper concept this project must integrate is WebSocket. Regular websites are mostly static. Information between the client and server is not continuous. Once data is loaded, there is no communication between server and client in the traditional http protocol. But the WebSocket modules offer a full duplex communication method. This is necessary because, the user will want to see real time video stream output and control the robot following it. WebSocket is designed to do exactly that. Even after a page is loaded, the communication pipeline between the two are kept alive for further data transfer. In this case the server will transfer video data to the client and the client will transfer control inputs to the server. The client is designed to transfer the key a user presses and string to let the server know to stop the vehicle when the user has stopped holding the key. All of this is possible in relatively real time using only WebSocket.

```
var express = require('express'),
   app = module.exports = express.createServer(),
   sio = require('socket.io'),
   io = sio.listen(app);
```

The system is setting up an express server by importing the module itself and using a built in createServer() function to start the server. Then import a Websocket module to start listening for incoming requests.

Like the test software this iteration will also create a function for each task. Each movement will require a function for example,

```
tank.moveForward = function(){
 async.parallel([
  gpio.write(p7,0),
  gpio.write(p15,0),
  gpio.write(p11,1),
  gpio.write(p13,1)
 ]);
};
```

This function will pin values for the circuit to move forward. In the brief, a top view goal of the project was to create a self-rappel mode given the system may lose data connection to the user. This creates two problems to solve.

- How to recognize if a connection is lost?
- How to remember where to go back?

The recognition of a present connection can be done easily through NodeJS and Websocket's integrated connection manager functions.

```
 socket.on("disconnect", function(){
  console.log("Connection lost");
```

When a connection is lost, a possible action to take would be to go back to the user's initial start position.

Remembering the start position has many answers. Project MARINA deals with this by counting the time. When the user sends signals to the server to start the winch motor, a variable starts counting the amount of time the motor has been working. Start position is the zero position. If user presses the button to make the robot go down, the system will keep adding the time the motor has been working to the variable. If the user rappels up, the system counts the time the motor was working, and subtract it from the variable.

```
socket.on('keydown', function(dir) {
  switch(dir){
    case 'goup':
     time = new Date().getTime();
     console.log(time);
     tank.goup();
     break;
    case 'godown':
     time = new Date().getTime();
     console.log(time);
     tank.godown();
     break;
```

When the user presses a key, the system counts time. When the user releases the key, the system will do its calculation.

```
 socket.on('keyup', function(dir){
  switch(dir){
    case 'goup':
    time2 = new Date().getTime();
    var diff = time2 - time;
    console.log("diff "+ diff);
    totaltime -= diff;
    console.log("total " +totaltime);
    tank.stopAllMotors();
    break;
```

```
    case 'godown':
    time2 = new Date().getTime();
    var diff = time2 - time;
    console.log("diff  "+ diff);
    totaltime += diff;
    console.log("total " +totaltime);
    tank.stopAllMotors();
    break;
    default:
    tank.stopAllMotors();
```

Through this method, the system is continuously counting the time the winch motor is being used. Once, the connection is lost, the system will use this time count to deploy the robots self-rappel mode like below.

```
 socket.on("disconnect", function(){
   console.log("Connection lost");
   tank.goup();
   setTimeout(tank.stopAllMotors,totaltime);
   console.log("done");
});
```

On connection lost, the system starts the winch motor to go up the rope, and used the time gained from previous calculation to set an interval function. Interval function is a NodeJS built in feature that lets the programmer call a function after a certain period, the period here is the total time the winch motor needs to work for to get back to the start point.

6.1 Video Streaming

MJPG-STREAMER is an opensource project developed by Tom Stöveken and other open source contributors on GitHub. The aim of the project is to stream the raspberry pi camera to a browser. It does this by taking continuous photos and storing the images in a folder and then hosting the images on a port of the raspberry pi. Project MARINA intends to stream that image directly on its own webpage by using the html’s iframe property.

6.2 Flowchart of the Software

Flowchart allows a viewer to see the projects workflow from a top view and help understand how the specific components link up together to form the bigger picture. Figure 10 illustrates how the software functions in a flowchart format.

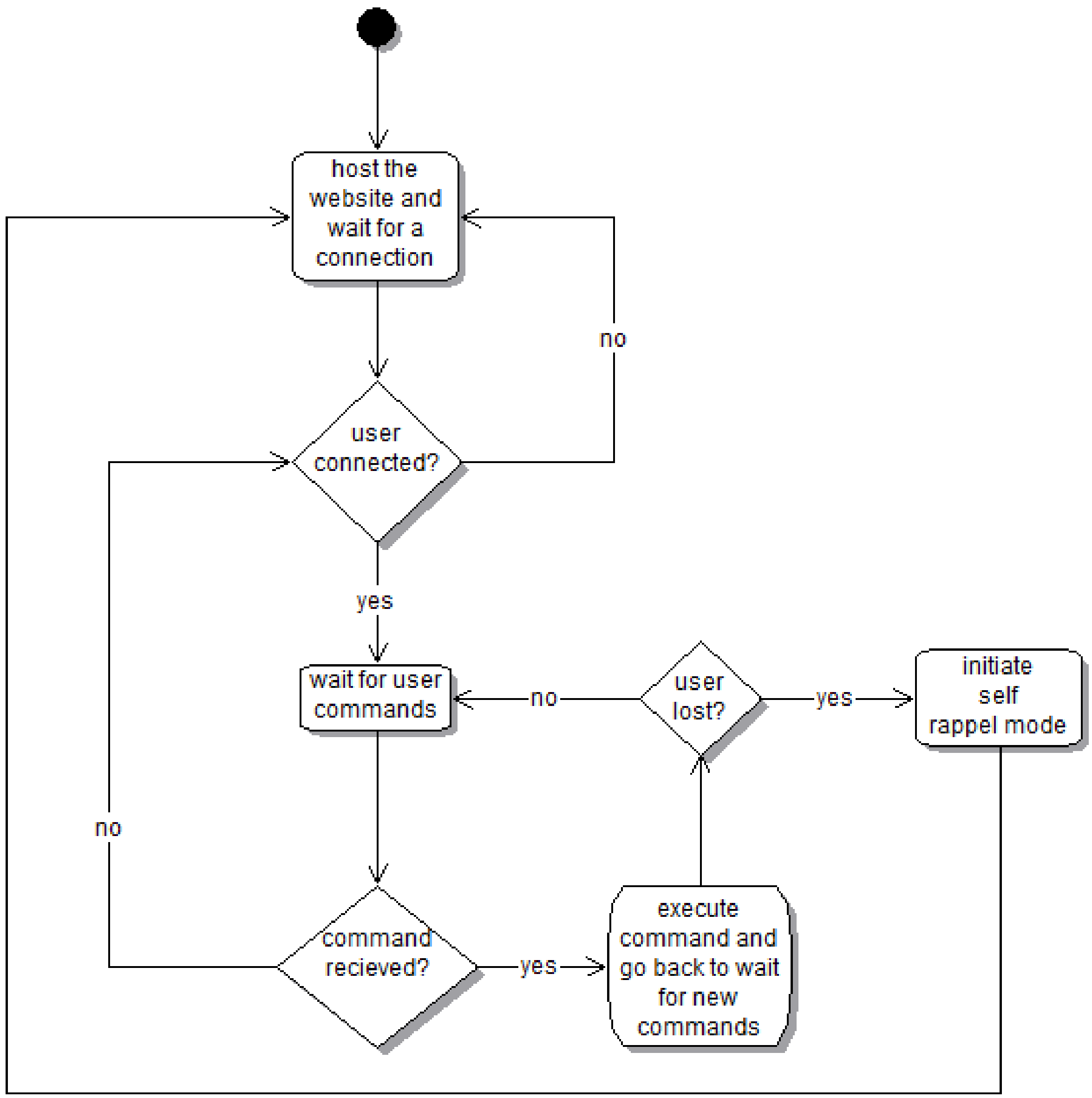

Figure 11: UML flowchart

6.3 User Experience

NodeJS allows the designer to choose render engines from a large list of choices like jade, pug, es6 etc. Project MARINA will use and older rending engine to design because it offers modularity and the support community available for it is larger due to its age. The website has a simple design with a window for video streaming and a grid of 6 buttons for direction and winch controls as shown in figure 12.

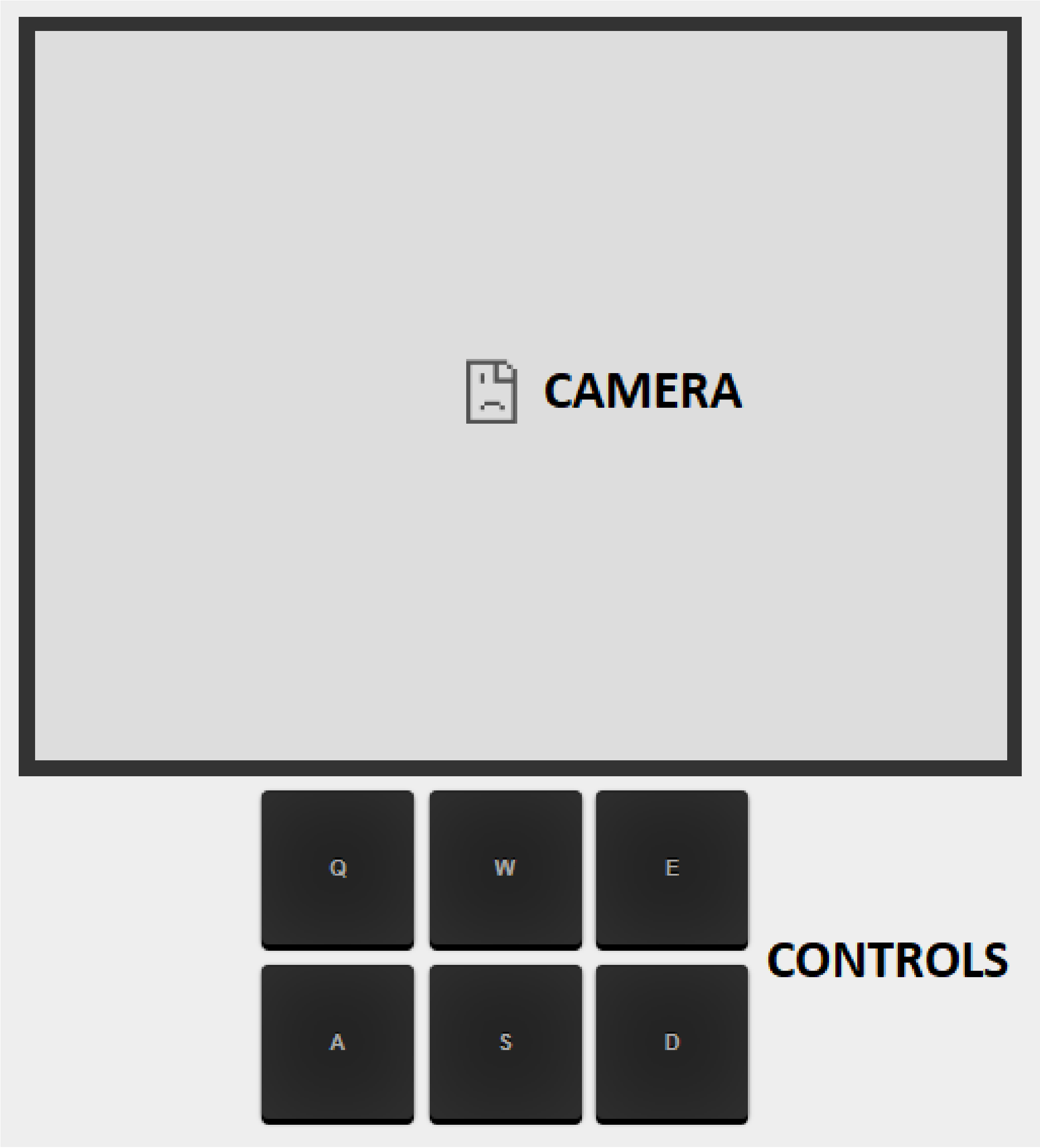

Figure 12: User window

The modular design allows the user to add as many buttons necessary without writing much code although the positioning of the button must be referenced separately like below:

```
a.up() w
a.left() a
a.down() s
a.right() d
a.goup() q
a.godown() e
```

With this the software for this project is complete. To run the server first the NodeJS script must start first and then some commands related to the MJPG-STREAMER must run as well as follows:

```
$ node app.js
$ export LD_LIBRARY_PATH=.
$ ./mjpg_streamer -o "output_http.so -w ./www" -i "input_raspicam.so"
```

A simple script was written to make the initiation process quicker.

Chapter 7 Implementation and Testing

The design stage of this project is detailed and prudent leaving the implementation stage no unexpected surprises. This stage follows the design patterns made in the design stage progressively giving more definition to the concept of the project.

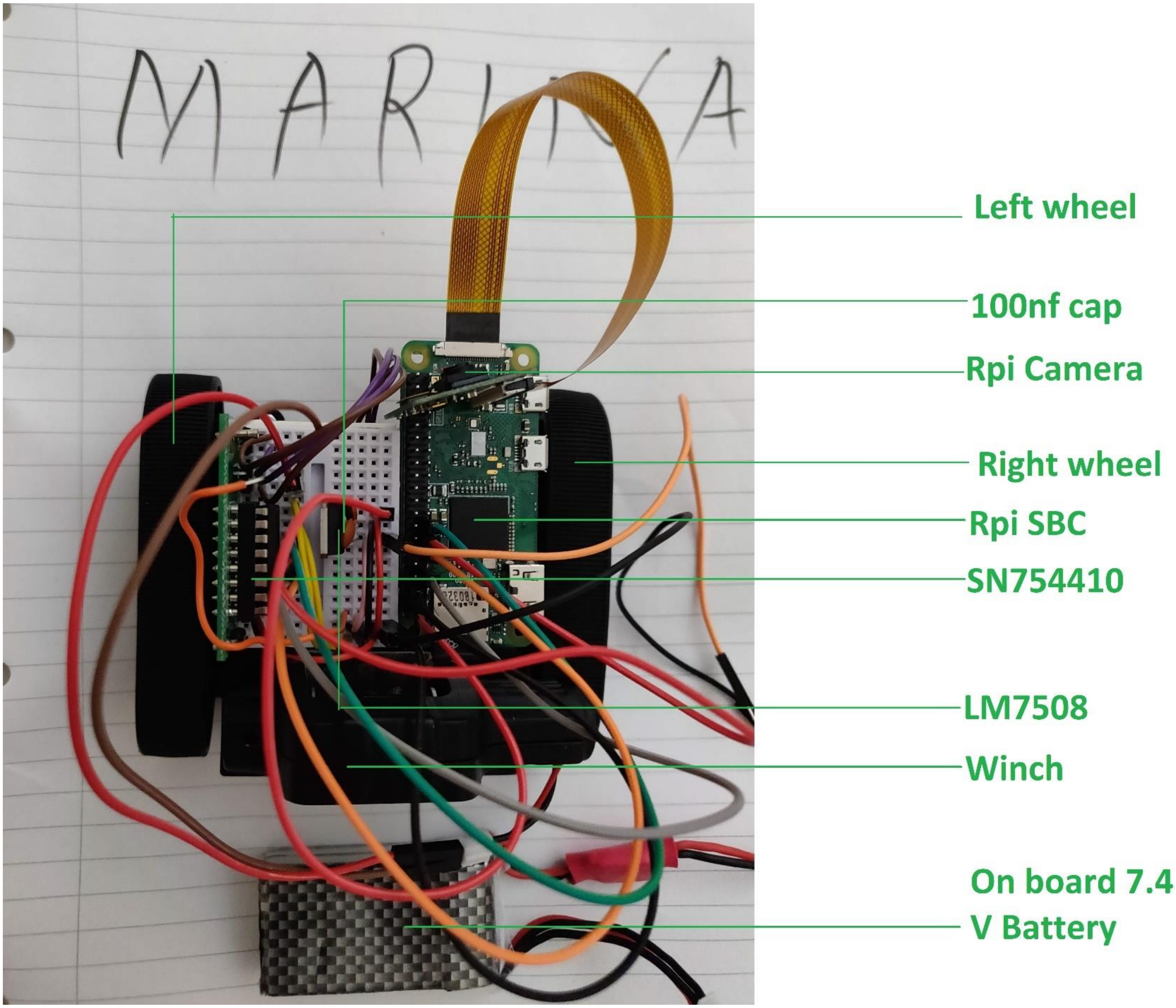

Figure 13: Final design of the vehicle

The only section in the physical implantation that needed some changes was the calibration of half bridge input pin configuration. the 4 input pins required specific high and low value combination for directional output. The half bridge was the first device to be implemented. It was discovered that if the ground pin of the driver were not that of the raspberry pi, the chipset would not function. Another factor that was discovered is that the 7.4V on board battery supplied enough power for the system to function even though the motors functioned poorly and slowly. The problem being that the battery did not supply enough current to power everything efficiently. The circuit needed around 800mah to function. This battery supplied around 500mah current. This problem has provided the designer with many future directions. Another problem that was supposedly solved in the design stage was the noise produced by the 5V voltage regulators. The two 100nf capacitors in parallel took care of that problem. The power supply that was designed for this system was never physically implemented due to the lack of time and resources as well as budget allocation. The time counting system used to record current location of the winch was good in many cases but in the testing section it was discovered that pulling the robot up the winch took a little longer than rappelling it down. In this stage the use of an ultrasonic sensor was removed since there was no real use noticed in a robot like this given its use case. Figure 14 represents a possible situation MARINA may face in the field.

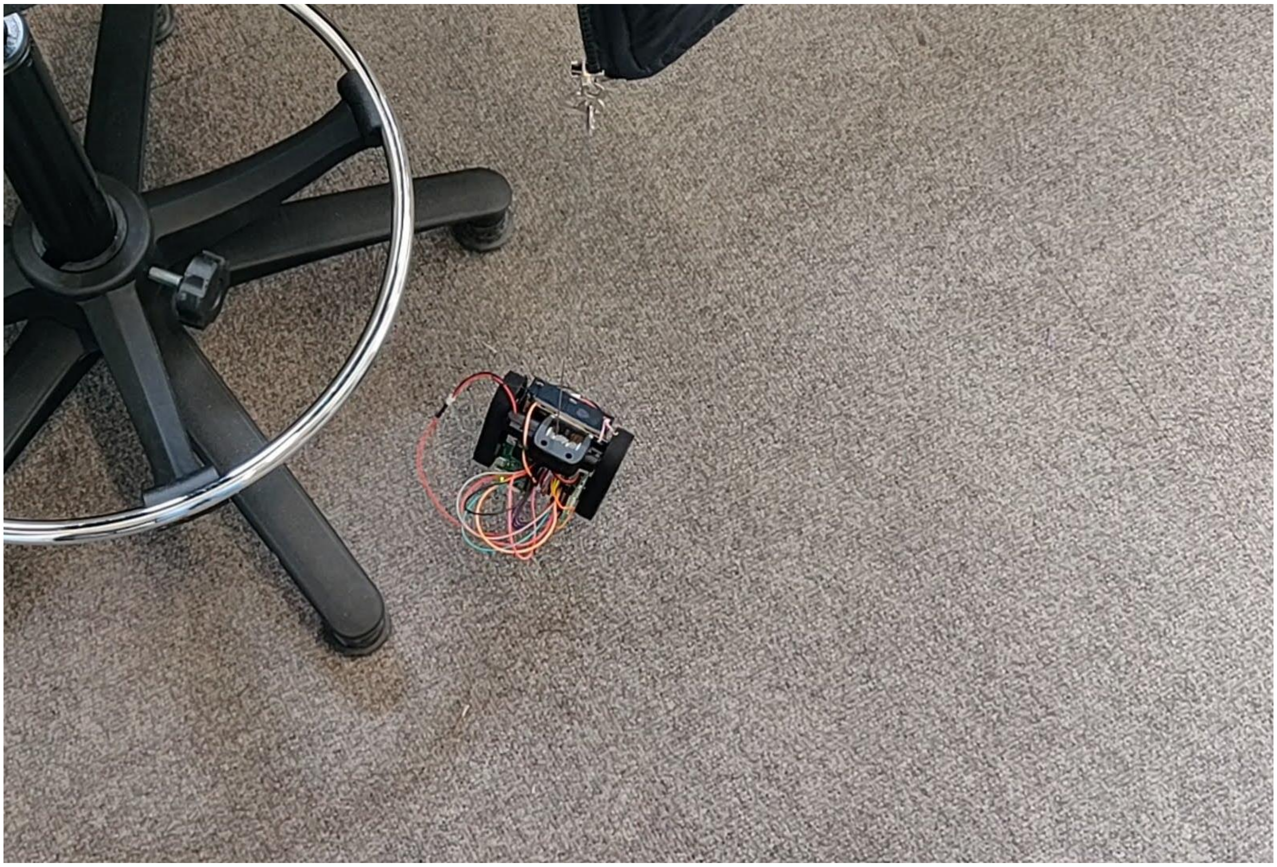

Figure 14: MARINA in action

The tracked wheel also proved to be perfect for the environment. Tracked wheel provide enough grip for the vehicle to go over obstacle keeping true to its AT (All Terrain) nature.

Among all the stages of the project, the physical implementation phase was the easiest and the smoothest process attributing to the project management and the agile methodologies used leaving space for modularity.

Chapter 8 Conclusion

8.1 Critical Appraisal

This project, in a broad sense started with an aim to combine multiple requirement possibilities in an ever-growing exploration and rescue field. The design choices made for this project were influenced by attempts made previously by industry professionals. The projects goal is to create a motorized platform for rescue and investigation teams to safety carry out investigation tasks and the claims made in this report suggests that these teams require a machine that can move in a 3D space. Here, the wheels give it the x and y movement capabilities which most of the previous attempts had but the winch gives it a z axis movement capacity. The other problem this project tackles is the possibility of network loss by using a network presence recognition system and an auto rappelling system. Although in predictable testing environment, this technique appears to be working but in real environment a revolution counting system may appear to be more accurate. This may be obtained by using a magnetic tick sensing mechanism. The device may be required to go underground probing a need of waterproofing. And if there is no possible harness to attach the hook, this vehicle may not be of any use. A detachable drone may be used and a location sensing mechanism for the vehicle to find the drone appear to be a better direction of the project. The use of a raspberry camera is a bad choice as the support for the camera and the opensource software have not yet been officially recognized thus may present with many unknown problems. The camera software may benefit from an image recognition system in combination with a neural network algorithm to keep learning about the discoveries made while on duty. This will benefit rescue teams to identify objects when the robot is investigating an unseen area.

The planning and designing stage of the project leave nothing to be desired. Implementation of agile methodologies have proven to be useful since the implementation stage faced no diversion. The modularity design aspect is praiseworthy leaving space to add more feature with relative ease.

8.2 Summary and Recommendation

The project followed all the steps mentioned in the project brief. The design did not severely pivot from its original concept. Overall, the project was able to check off all the features required. The project went from sketches on paper to a functional robot. The report was able to document the development process. Claims made in the document were made with proper justification. The critical appraisal was able to present statements that can be used to pin point the projects shortcomings and can be used to dictate the room for improvements. For instance, the way this robot measures time to keep track of its z axis positioning is very clever but it is not well suited for this project. A revs counter may have been well suited with the use of hall effect sensor and magnets. Each time the wheel rotates, it will go over the sensor creating a spike due to the presence of a magnetic field thus enabling a better z axis position calculation. Other parts such, the addition of an autonomous navigation may not appear to be important now but gradually the system may have the need to carry out investigation tasks on its own by learning from previous investigation tasks controlled by the user. The possibility of attaching the vehicle to a drone may present new use cases like using it as a ration supplier in a disaster struck area. The possibilities of combining SBC with opensource software projects are endless especially applicable for this project as this combines three core engineering fields which are electrical, computer and mechanical aiming to solve a field that is gradually growing due to increase in expeditions to find archeological treasures, old structures slowly aging and collapsing and with the increase of global warming resulting in increased natural disasters. In short, this project attempted to solve a probing problem by using open source community supported software and hardware projects in well planned robot design.

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Appendix A

Parts	Quantity
Raspberry PI Zero W	1
Pololu - Zumo Robot	1
298:1 Motor	2
Lipo 7.5V	1
Raspberry PI Camera	1
298:1 100:1 scale winch	1
LM7805 Voltage Regulator	1

Appendix B

Task	Hours
Project Background research, preparing brief	10
Reviewing previous work in the field, writing the literature review	20
Developing a 3D model	40
Getting initial required parts	5
Building the test bench to start off with	10
Developing the core software	20
Testing the base design	30
Troubleshooting existing issues and finalizing the design	40
Printing the parts/buying the parts	20
Building the final project	10
Producing the final report	30
Oral assessment preparation	5
Total	***240***

Appendix C

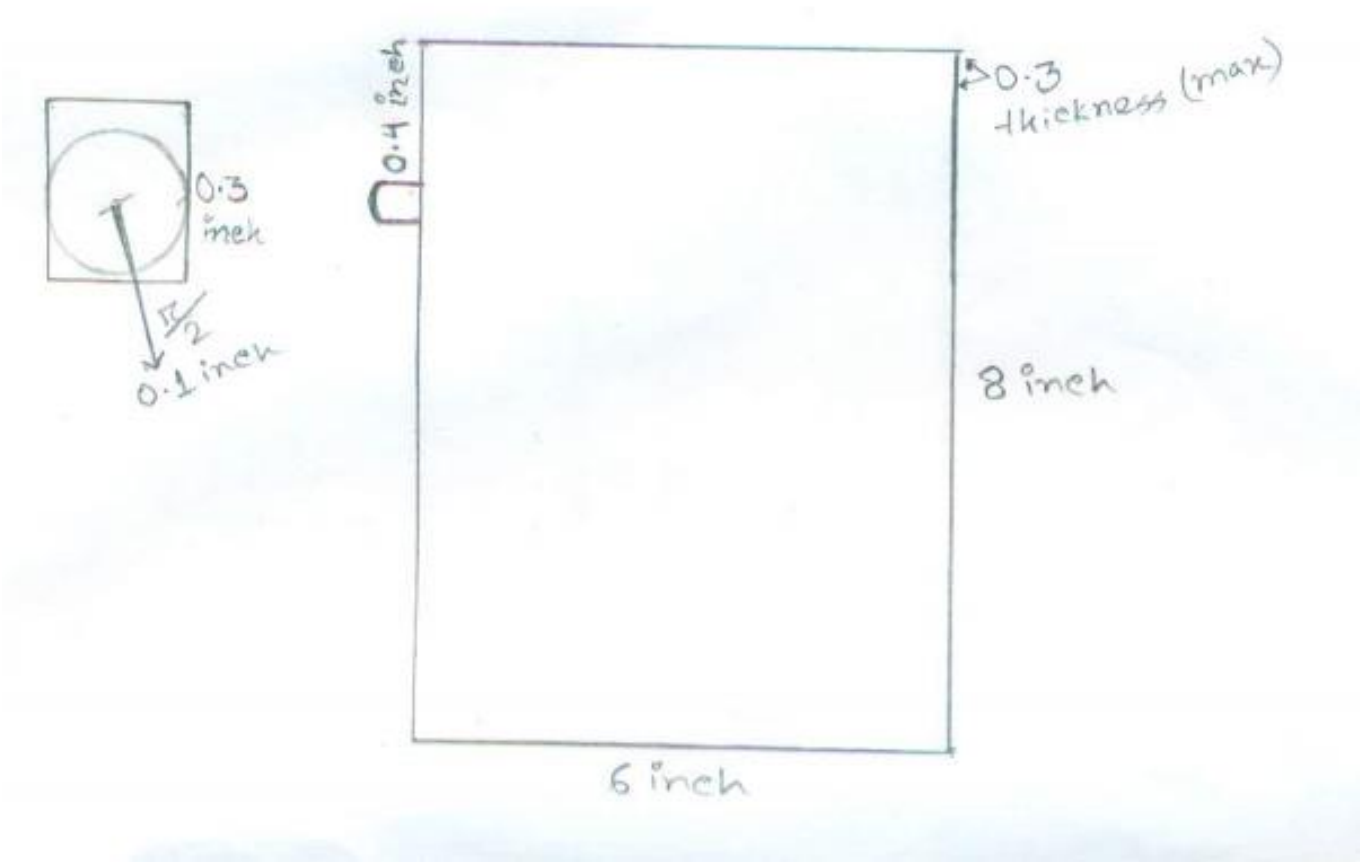

Figure 15: Sketches of the body

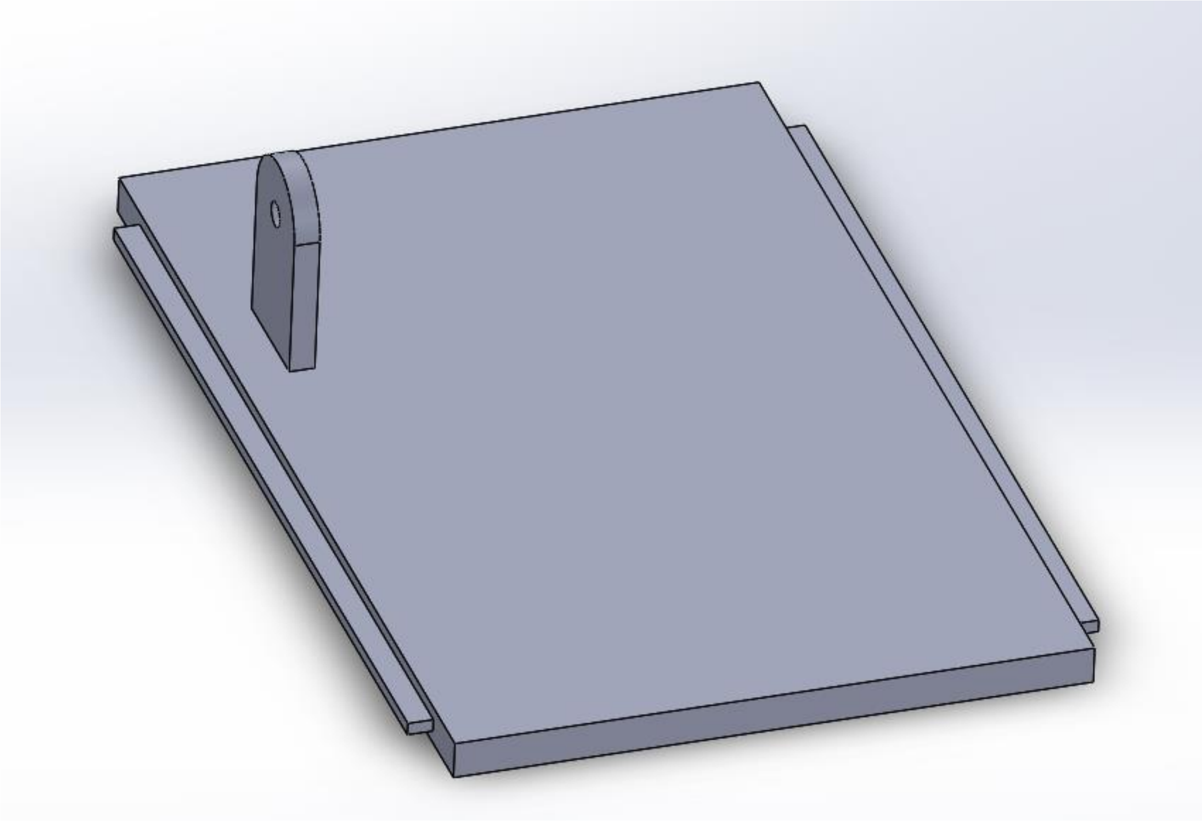

Figure 16: 3D design of the body

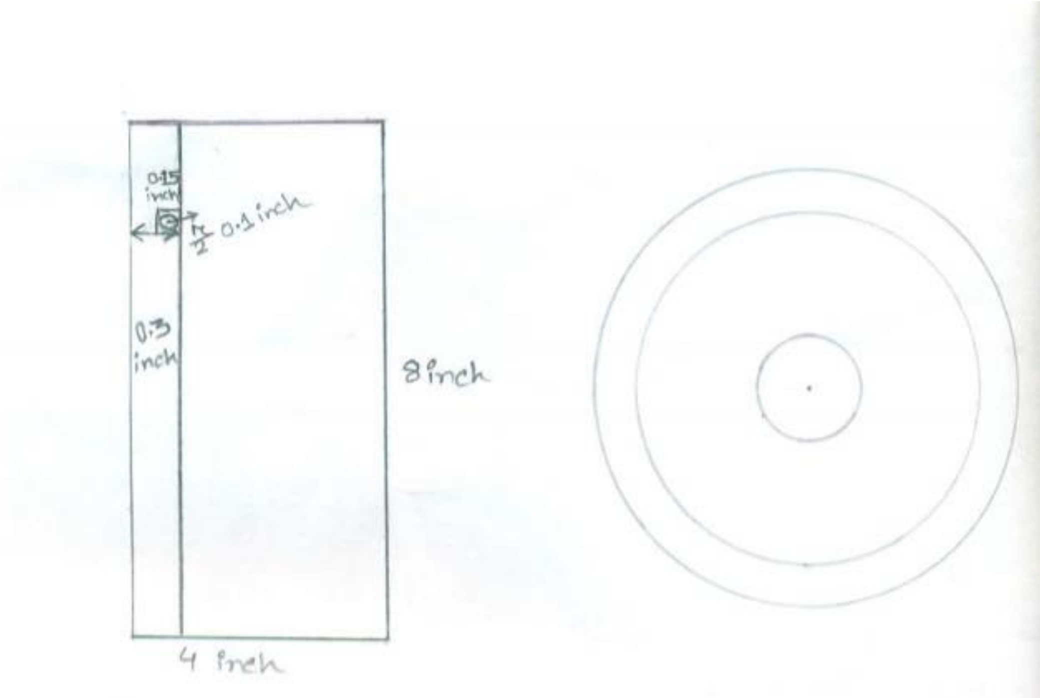

Figure 17: Sketches of the side panels and wheels