# Project Proposal - Team W08

Katarina Chiam - 1004908996

Catherine Guo - 1005042687

Armaan Lalani - 1005023225

# TABLE OF CONTENTS

# Section 1: Problem Framing

## 1.1 High-Level Objective

The ultimate goal of the project is to design, test and build a mechatronic device capable of delivering and inserting a SAE J1772 charging plug to a port on a setup located within a 1m x 0.5m box proximity. The port will be located at a height not lower than 36.9 cm or higher than 59.7 cm from the ground. The coordinate system shown to the right will be used throughout the document.

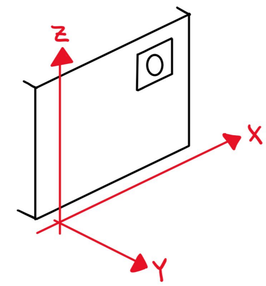



*Figure 1: Coordinate System*

## 1.2 Design Objectives

Through careful consideration of the project requirements, and taking into account the interests, strengths and experiences of each team member, it was decided that the following design objectives would be of particular consideration. A brief justification for each DfX is provided.

| Design Objective | Justification | Metric/Measurement |
|---|---|---|
| *Reliability* | Given the repetitive nature of the task (as electric cars must be charged on a regular basis), and the limitation of 2 trials, we felt it was important to ensure that the device could consistently achieve success. | Consistency - to what degree of accuracy can the given design perform with many repeated trials? |
| *Adaptability* | With the project timeline split into multiple milestones, and various degrees of freedom to be addressed, it is important that the device can be continuously improvable while remaining functional. | Degrees of freedom a particular design allows us to pursue - does it make achieving certain degrees of freedom more difficult? |
| *Assembly* | Given the lack of professional mechanical expertise and financial limitations, the design must be able to be assembled by ourselves. | Number of parts to assemble, and difficulty/skill-level of assembly techniques. |
| *Testing* | Ease of testing will allow us to be more time-efficient and effective in identifying and addressing issues with the design and/or build. | What are the time and financial commitments required to create and test both low and high fidelity prototypes? |
| *Repairability* | Since the device must perform at multiple events/milestones, it is important that failure or damage to a particular component is fixable and will not drastically hinder future attempts. | Are broken components easily removable/replaceable, and does failure of one component hinder the rest of the design? |
| *Cost* | With a limited amount of money that can be spent on the project, purchases should be financially responsible and reasonable. | Dollars spent on each component of the design. |
| *Safety* | Apart from avoiding physical harm to any team members, taking appropriate safety precautions will | Number of risk factors involved, magnitude of each. |

| | | |
|---|---|---|
| | also prevent construction/assembly failures and address design risks. | |

### 1.3 Constraints

In addition to the above metrics, the following constraints were imposed in order to help meet the design objectives:

***Cost***: The total value of parts used in the final product may not exceed $300.
***Autonomy***: With the charger located in the 1m x 0.5m box provided, and the device in the 2m x 1.5m setup zone, the device must be able to complete the following tasks without human interference: locate the port, move towards the port, insert the charger.
***Time***: The above steps must be completed within 2 minutes.
***Indication of Success***: The device must provide a visual/audio cue when it has succeeded.
***Setup Space***: Alterations to the setup space must be easily removable without residue.

**Note on changes in framing:* After receiving comments on system integration and clarifying project guidelines, we have decided to revisit our project goals and plan. Initially, we decided to tackle yaw, x, y directions and the alignment tab. However, after coming up with a design that would satisfy the baseline goal and taking a closer look into the integration of all of the parts of the system, we decided to shift our goals to tackle x, y, z-directions, and alignment tab as we felt it worked better with our basic system strategy.

## Section 2: Alternative Designs/Components

The following design components are alternatives that were proposed in the diverging process, and were considered most heavily in the convergence process.

### 2.1 Port Identification Alternatives

**2.1.1 Computer Vision:** Computer vision was considered because of its potential to provide a more widespread view of the setup; a single device would be able to provide all of the information needed to locate the car body and charging port. The idea was to outline the charger port with coloured tape and use a basic shape/object tracking algorithm to find its location relative to the rover. If successful, this would provide great reliability and simplify implementation.

**2.1.2 Sensors**: Ultrasonic sensors were considered as they provide a very cheap way of determining proximities, and are easy to implement. IR sensors can provide visual readings which are useful when trying to locate a spot on a flat surface. Since the use of tape on the setup is permitted, proper planning and implementation would allow these to be a viable way of locating the charger port.

### 2.2 Mobility Alternatives

**2.2.1 Movement of Rover:** Higher-level alternatives such as wheels, tracks, and even a hovering system. However, in terms of accessibility, comfort-level with the material, and efficiency, we decided to eliminate tracks and the hovering system and focus on different types of wheels. The types of wheels that were most investigated are standard fixed wheels, omni wheels, and mecanum wheels.

**2.2.2 Linear Motion devices:** Linear motion mechanisms are needed to insert the charger into the plug, and for varying the coordinate positions of the charger. The investigated alternatives were a leadscrew system and a belt drive system. Both systems convert the rotational energy of stepper motors into linear motion. The conveyor belt would be built atop a linear guide rail to ensure straight motion, while the leadscrew consists of a threaded rod, a metal nut block, and support rails with freely-moving ball-bearing blocks.

**2.2.3 Structural Alternatives:** Two primary materials were considered for the structure of the device: wood and acrylic. The use of aluminum extrusions to build a chassis was also considered.All three options provided a viable option for constructing our mechanism and each were evaluated according to associated metrics.

### 2.3 Charger Insertion Alternatives

**2.3.1 Charger Gripping/Holding Alternatives:** Options for securing the charger to the device included a claw that would wrap around the charger base and rings that would grip around the charger base. The claw would be a simple 2-pronged structure that would loosen or tighten with a screw. This would be achieved using a spring system that would attach itself to the base of the claw, as seen below. Aside from that degree of freedom, the rest of the claw is fixed in place and attached to the linear rail system. Another proposition was a sleeve made of an elastic but stiff material, such as neoprene, that would stretch slightly to accommodate and keep a tight hold on the charger. This sleeve would be hooked onto the linear rail system. The final alternative was to build a frame that would have 2 adjustable metal rings attached, capable of securing the charger tightly with a buckle.

## Section 3: Convergence Process

The high-level task was split into 3 independent subtasks: identification of the port, delivery of charger to the port, and structural design. After proposing alternative ideas for accomplishing each of these tasks, research was undertaken to flesh out and understand each alternative fully, and each alternative was judged in its ability to satisfy the above design objectives and the intended task.

### 3.1 Identification of the Port

The following metrics were outlined to guide us in determining the best system for detecting the port's location and ensuring the final product could gain enough information to act autonomously. The alternatives being considered were computer vision, ultrasonic sensors, and infrared sensors.

| Port identification | |
|---|---|
| Metric | Reasoning |
| Consistency of Measurements: Variability of the same Measured Quantity (Reliability) | Use of equipment and sensors should display consistency --> results of the same measured quantity should remain fairly constant (greater mechanism performance due to consistent data influx) |
| Components Required for | Greater number of required components can cause an organized mechanism |

| | |
|---|---|
| Implementation (Assembly) | (greater number of wires) as well as more headache regarding implementation |
| Ease of Implementation (Assembly) | Integration of components into a working system --> more parts required for implementation creates more cost and the potential for technical issues |
| Time Investmentment (Cost and Testing) | Autonomy of the robot requires the most time investment --> too difficult of a recognition method can leave little time to work on other important aspects of the design |

To begin, research was performed about each of the proposed alternatives. Given the lack of experience with computer vision on your team, we searched for cameras with high functionality that would facilitate implementation. Two cameras were investigated - the Pixy2 camera (~$80) and the ESP32-CAM (~$9). The Pixy2 provided excellent technical specifications, with a high frame rate and CV-oriented software available, but was eliminated due to its high cost; $80 formed too high a portion of our budget, and there was no way of testing the alternative without committing to the price. The ESP32-CAM scored excellently on consistency, components required for assembly, and financial cost, but its ease of assembly and implementation, as well as time investment required to learn about computer vision and debug algorithms and code, were questionable, so we decided to move on to consideration of the sensors, and compare all the options.

Since sensors were readily available and cheap, a testing protocol was used to determine their reliability and accuracy (exact set up and guidelines for the protocol are provided in the appendix). The ultrasonic sensors were subjected to two tests.

Test 1 tested the accuracy and consistency of the distance readings they provided. Test 2 tested their ability (when working in pairs of 2) to identify angled surfaces. This was done by setting off an LED when the angle of the surface it was facing deviating by a certain number of degrees.

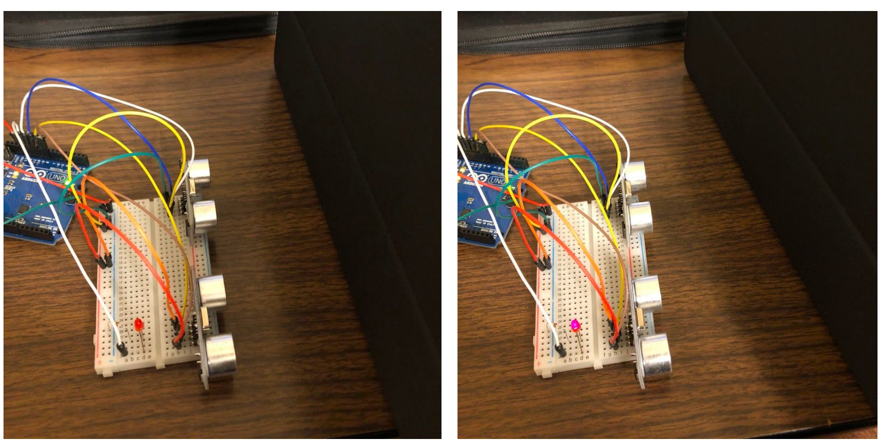


*Figure 2: Display of setup used for testing ultrasonic sensors*

## 3.2 Mobility

The final product must be able to move in the X, Y and Z directions. The device must also have a structure capable of dealing with these motions without hindering movement or falling apart.

### 3.2.1 Mobility in the XY plane

Since this plane is the floor, alternatives for this motion consisted mostly of wheels and motors. Since it was not feasible to purchase and test all different types of wheels, the alternatives were researched and compared using the following metrics system.

| Wheels | |
|---|---|
| Metric | Reasoning |
| Coefficient of Friction (Reliability) | Higher coefficient of friction allows for greater traction between the wheel and the ground --> greater precision for stopping and turning |
| Degrees of Freedom (Adaptability) | More degrees of freedom allow the robot to traverse in several directions --> change in direction and motion is more seamless [1] |
| Height of Mechanism above ground divided by the wheel diameter (Reliability) | The higher the wheels hold the mechanism above the ground relative to their diameter leads to a higher centre of balance --> higher degree of instability, greater risk of tipping with sudden jerking motions [2] |
| Width of Tire Touching Ground (Reliability) | Wheels that are too wide or too thin can both lead to significant downside with handling --> too thin: issues with cornering and direction change, too wide: issues with straight line acceleration [3] |

| Motors | |
|---|---|
| Metric | Reasoning |
| Voltage Requirement (Assembly and Cost) | Relatively low voltage needed for motors --> faster speeds is not favourable in this situation, greater precision and accuracy is far more important |
| Maximum Torque vs Speed (Personal) | High torque is favourable in this situation --> most motors have to support a significant load and must be able to begin moving from a standstill position [4] |
| Precision and Repeatability (Reliability) | Motors should perform consistently in similar situations, should not be significant variability between trials |

### 3.2.2 Mobility in the Z-axis

Two linear motion systems were considered: a leadscrew, and a belt drive. First, the main features of each mechanism were investigated and compared. The results are provided in the table below.

| Metric | Lead screw | Belt drive |
|---|---|---|
| Positioning Accuracy | Better - high rotational speeds are required to generate small linear motion, so it is easy to fine-tune motion. | Worse - Elasticity in the belt can cause uncertainties. |
| Speed | Lower - vertical motion depends on the slow vertical gradient of the rod's threads | Higher - rotational motion is more directly translate into linear motion |
| Load capacity | Higher - threaded rods are extremely strong, and support rods are also present | Lower - belts are susceptible to slippage and tensile stretching |
| Cost | Higher | Lower |

The, the requirements of the Z-axis motion system were identified:

- *Accuracy*: the Z-axis motion system is responsible for bringing the charger to the correct height to be inserted into the port, and therefore excellent control of the position is required.
- *Load Capacity*: Being in the vertical direction, the Z-axis motion is directly subject to the gravitational forces exerted by all the objects it supports. In this case, it must support the charger, as well as the plate supporting the charger, and the entirety of the charger insertion mechanism.

### 3.2.3 Structure and Materials

Since the shape and strength of the general rover structure also affects its mobility, the following criteria were considered as well.

| Structure and Materials | |
|---|---|
| Metric | Reasoning |
| Tensile Strength (Repairability) | Material used to design frame of mechanism will have to endure a constant load --> material should not crack and fail through a tensile crack [5] |
| Fracture Toughness (Repairability) | If there happens to be an unwarranted crack, the failure should not propagate --> rest of the mechanism should be kept in tact and allowed to complete the task [5] |
| Ease of Attachment (Testing and Adaptability) | Drilling holes in the material should not cause cracks --> additional attachments should be a seamless process |
| Density (Assembly and Cost) | The lower the density the better --> less strength on the wheels and allows for greater magnitudes of acceleration with a lesser load |

## 3.3 Charger Insertion

### 3.3.1 Insertion Motion

The same two alternatives for linear motion - the lead screw and the belt drive - were considered. Thus, the table used in section 3.2.2 was reconsidered. However, the needs of the application changed as follows:

- *Accuracy*: since the Y-axis motion is only used to push the charger into the port, and not to locate the port, accuracy is not of great importance.
- *Load Capacity*: Since gravitational forces are not directly acting in this direction, and the only weight this system must hold is the weight of the charger (~378g), load capacity is not of great importance either.
- *Speed*: Since no locating is happening when moving in this direction, it may be preferable to move a little faster given the required timeframe of the entire task.

*Figure 3:Medium fidelity prototype of belt drive system*

The belt drive seemed to be a better option, but since slippage of the belt was still a slight concern, a test was performed to determine the force it takes to slip the belt from the pinion when going around a 90 degree bend. The testing protocol is provided in the appendix. A medium-fidelity prototype was also constructed as a proof-of-concept.

### 3.3.2 Charger Holding Mechanism

Two of the three holding mechanisms proposed were prototyped and subject to a testing protocol (provided in the appendix). Upon attempting to prototype the sleeve alternative it became apparent that no readily available material would have the rigidity required to hold the charger in place well enough to prevent the charger moving around and slipping, and causing uncertainties in its position relative to the port. The prototypes for the claw and metal-ring alternatives are shown below.

*Figure 4: Display of low-fidelity prototypes for the charger holding mechanism*

The two remaining prototypes were tested on their ability to hold the charger in place when dealing with light to vigorous motion in the X, Y, and Z directions.

## 3.4 Additional Convergence Tools Used

In order to further evaluate how different alternatives met the criteria described in the previous sections, several visual convergence tools were used. The first, shown in figure 5, is a ratings matrix examining how various detailed alternatives met the metrics for mobility and autonomy (ie. locating the port).

| ***Objective:*** | **AUTONOMY** | | | | **MOBILITY** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ***Metric:*** | **Consistency** | **Components Required** | **Implementation** | **Investment** | **Coefficient of Friction** | **Degrees of Freedom** | **Speed** | **Precision** | **Limitations + Disqualifications** |
| Omni wheels with DC using sensors, raspberry pi and clamp | high | 3 | medium | medium | 0.5-0.6 | 3 | high | medium | Omni wheels may not have as much traction to push off with enough force for high speeds. |
| Rubber wheels with DC using sensors, Raspberry Pi and clamp | high | 3 | medium | medium | 0.6-0.85 | 3 | high | medium | DC motors are less precise, however faster, more power and more torque. Raspberry pi's are expensive. |
| Mecanum wheels with DC using sensors, Arduino MEGA and sleeve | low | 2 | medium | low | 0.5-0.6 | 2 | high | low | Sleeve is less precise and mecanum wheels may not have as much traction to push with enough force for high speeds |
| Mecanum wheels with stepper using sensors, Arduino MEGA and clamp | high | 3 | medium | medium | 0.5-0.6 | 3 | low | high | Stepper motors are slower and require more power in order to reach the same speed as DC motors |
| Rubber wheels with stepper using sensors, Raspberry Pi and claw | medium | 5 | high | high | 0.6-0.85 | 3 | low | high | Claw mechanism requires high investment in joints and rely on precision of joints in order for it to work. |
| Mecanum wheels with stepper using sensors, Raspberry Pi and claw | medium | 5 | high | high | 0.5-0.6 | 3 | low | high | Claw mechanism requires high investment in joints and rely on precision of joints in order for it to work. |
| Mecanum wheels with DC using CV, Raspberry Pi and clamp | | | | | | | | | Computer Vision is too difficult to implement given no one on the team has experience with it. Although it theoretically has a high consistency for deteremining the charger port location, the investment is much higher in terms of cost and time. |
| Mecanum wheels with DC using CV, Raspberry P iand clamp | | | | | | | | | |
| Mecanum wheels with DC using CV and clamp | | | | | | | | | |

*Figure 5: Ratings Matrix for Mobility and Autonomy*

The second is a morph chart used to outline alternatives for each of the major components we are using to build our system. The chosen components are highlighted in yellow. They were chosen based on a series of tests outlined in 3.2 and based on research, requirements, cost-comparison and feasibility.

| | | DESIGN 1 | DESIGN 2 | DESIGN 3 |
|---|---|---|---|---|
| **MOBILITY** | | | | |
| | **Wheel Type** | mecanum | omni | rubber wheels + castor |
| | **# of Wheels** | 2 | 3 | 4 |
| | **Wheel Motor** | dc | stepper | servo |
| | **Power Source** | nimh battery | rechargeable battery | |
| **AUTONOMY** | | | | |
| | **Detection** | computer vision | ultrasonic | IR |
| | **Processor** | raspberry pi | arduino | arduino mega |
| **INSERTION** | | | | |
| | **Holder** | sleeve | hose clamp | claw |
| | **Pusher** | linear rail | lead screw | gear |
| | **Arm Motor** | dc | stepper | servo |
| | **Z-axis** | linear rail | lead screw | gear |

*Figure 6: Morph Chart Summarizing success of different components*

## Section 4: Proposed Design Solution

*Design Concept Overview:* The proposed design solution is a 4-wheel rover with a wooden body. A smaller plate atop the body will have the freedom to move up and down on the z-axis. On this plate will be mounted a linear guide rail, sliding back and forth along the Y-axis, which will serve as the base on which the charge sits.

### 4.1 Mobility

#### 4.1.1 Wheels

In terms of mobility, our rover makes use of mecanum wheels, as they allow for motion in both the x and y directions. As a result of no motors being manufactured entirely identical to one another, the wheels may not travel in a perfectly straight line and any slight non-linear motion may result in an accurate placement of the charger. Thus, being able to travel in both the x and y direction without needing to back up, rotate, and adjust would prove useful in terms of timing, especially given the time constraint. Mecanum wheels achieve this by having four different wheels oriented such that they all point in different angled directions so that both lateral motion and longitudinal motion can be achieved when the horizontal and vertical components interact with each other.

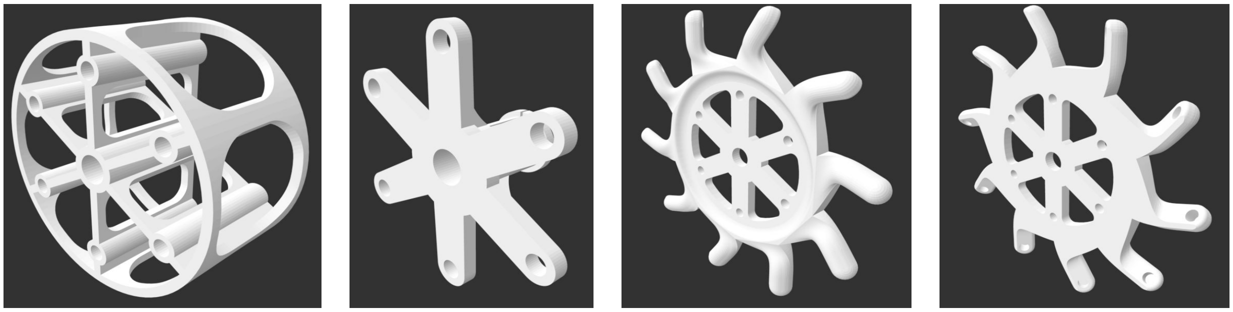


*Figure 7: STL files of mecanum wheels being 3D printed*

### 4.1.2 Motors

The wheels would be controlled by 4 individual 6V DC motors. Because the wheels each have their own unique direction, individual motors would be required to control the motion of each in order to achieve motion in the lateral, longitudinal, or angled directions. DC motors were chosen because of their suitable power, speed and weight compared to stepper and servo motors [6]. This ensures fast enough delivery, which is important when considering the constraint on time. Since the rover only needs to get into a general range that is suitable for the linear rail system to be accurate enough to plug in the charger, high precision is not needed, and the factor of precise stopping motion can be adjusted for based on running tests at speed and calculating the delay in stopping.

### 4.1.3 Insertion Mechanism

In order to plug the charge plug into the charge port, a belt drive will be used. The system will be built on a linear rail to ensure straight motion. The plate mounted atop the linear rail will be fixed to the length of flexible rubber belt, which will rotate around the rail with the help of two freely moving pinions on the other side.

The belt and pinion system was chosen for this application because the task at hand is neither very high-precision nor very high torque. Inserting the charger requires a very straight motion in the y-direction, but its exact y-coordinates do not require immense accuracy so long as the direction of movement (in or out of the port) is correct. The task is also relatively low torque because it is a horizontal motion system, meaning it is not particularly susceptible to gravitational forces, and because the maximum weight of the charger is only 378 grams. Given these freedoms, this was the most cost-effective and time-efficient option.

### 4.1.4 Z-axis adjustability

Motion in the Z-axis will be accomplished using a leadscrew linear motion system. This mechanism, while slower and more expensive than the belt-pinion system, was chosen due to its ability to provide extreme accuracy in position, as well as adequate torque to deal with the gravitational forces acting in the vertical direction.

The copper nut on the leadscrew will be attached via screws to a rectangular plate that will be laser-cut from plywood. On each end of the plate, there will be a ball-bearing fixture that glides up and down a support rod. Thus, the plate's orientation in the XY plane is fixed, forcing it to change its Z-axis position as the leadscrew rotates. The plate will be laser cut plywood, and it will hold the guide-rail system supporting the charger.

#### 4.1.5 Gripper Mechanism

To deliver the charger plug, 2 rings will clamp onto the charger plug to secure it in place and limit the movement the charger will have as it travels from its initial position to the charger port. The rings will then be attached to the linear rail system by printing a custom board that will fit the adjustable portion of the hose clamp (as seen in the figure below) and fit onto the linear rail system.

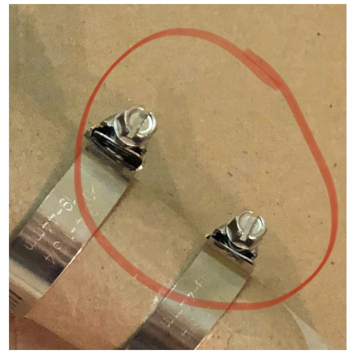


*Figure 8: hose clamps to be used  for charger gripper*

#### 4.1.6 Power Source

A NiMh (nickel-metal hydride) battery pack will be used due to the low cost, and ability to be recharged. Since the Arduino Mega operates at 5V, and the DC motors at 6V each, a voltage of 7.2V will be used to provide a margin of error [7].

### 4.2 Autonomy

To achieve autonomy, the ultrasonic sensors and infrared sensors will work in conjunction with each other in order for the robot to gain as accurate of a representation of its current location relative to the charging port as possible.

The setup below has been determined with the intention of achieving four degrees of freedom: X, Y, and Z in association with the alignment tab charger. The robot will be able to autonomously locate and plug in the charger through the following process:

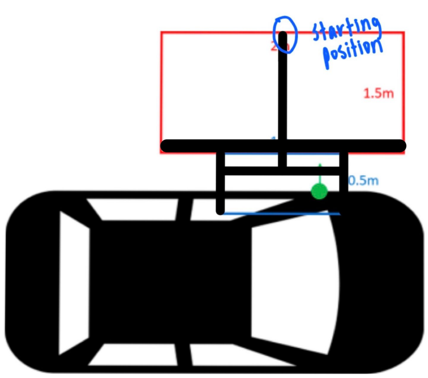



*Figure 9: [left]  proposed setup of the testing area (black lines represent tape placed on the ground, fluorescent tape will also be placed around the charging port) [right] proposed tape that will be placed around the charging port*

1. Robot drives from the starting position along the straight black line using two IR sensors until either:
    a. Both IR sensors see the second horizontal black line (Y has not been altered)
    b. Either of the two ultrasonic sensors on the front recognize the car door is in front
    c. Both IR sensors see the first horizontal black line (X and Y have both been altered): robot will turn 90 degrees and traverse the black line

2. Robot turns 90 degrees clockwise until the two ultrasonic sensors on the left side provide a reading that are within an acceptable range of each other (according to testing protocol 3.2.1)
    a. If the robot stopped due to the horizontal black line: robot traverses the black line until the IR sensors are stopped by the black tape enclosing the testing area or the door tape
    b. If the robot stopped due to the ultrasonic sensors: robot will travel parallel to the car door utilizing the two ultrasonic sensors on the left side of the robot to ensure that the robot is travelling straight until the IR sensors are stopped by the black tape or door tape

3. Lead screw will start moving the platform upwards until the IR sensor recognizes the green fluorescent tape indicating the platform is at the correct height for charger insertion into the port

4. Servo motor controlling the linear rail will begin moving the charger towards the charging port

### 4.3 Integration between Locating System and Driving System

The data received from the rover's sensors will be processed using an Arduino Mega microcontroller board. Software will be written in the Arduino IDE using C++. There are 3 primary types of data that will be received: distance readings from the ultrasonic sensors, visual readings from the IR sensors, and rotary encoder readings from the motors. There are also 3 mechanical motions systems the software will control: the DC wheels, the Z-axis leadscrew system, and the Y-axis insertion system.

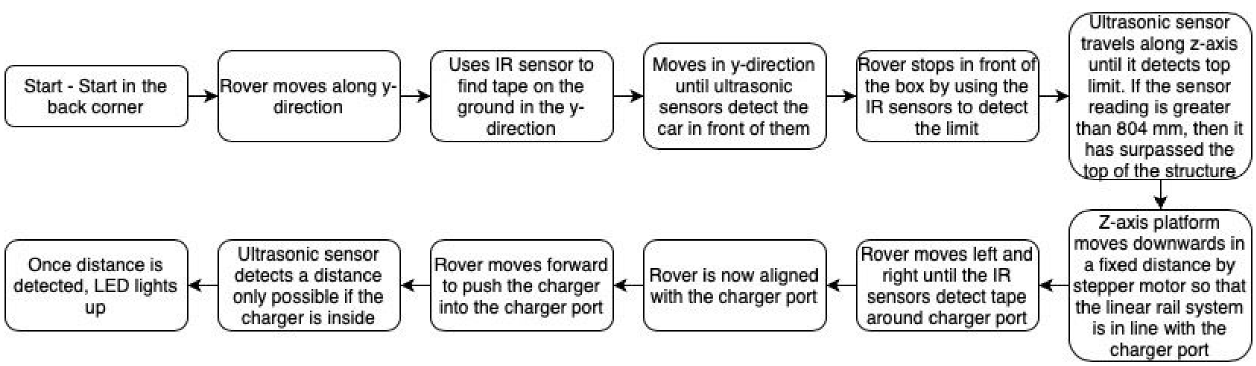
In order to ensure the rover is travelling straight in the intended direction, a PID control loop will be implemented to regulate the PWM output being fed to the rover's wheels. For the sake of increasing simplicity in the software, the rover will travel only in directions either parallel or perpendicular to the car, ie. along the X and Y directions. This also allows the system to use the coloured tape on the ground as a means of locating the charger. The 90 degree rotations needed to turn will be achieved simply by spinning one DC motor backwards while the other goes forwards, which will cause the rover to spin in place.

## 4.4 Design Structure - CAD Models

*Figure 10: CAD model of initial robot design concept*
*I. Mecanum Wheels; II. Lead Screw; III. Linear Rail; IV. Ultrasonic Sensors; V. Gripper Mechanism; VI. IR Sensors*

## 4.5 System Strategy

The steps our design will take in order to reach the final goal are illustrated by the flowchart below.




## 4.6 Budget Breakdown

| Bill of Materials | | | | |
|---|---|---|---|---|
| **Item** | **Price per Unit** | **Quantity** | **Total** | **Source** |
| Arduino MEGA | $ 14.08 | 1 | $ 14.08 | LFF |
| Ultrasonic Sensor | $ 1.13 | 4 | $ 4.52 | LFF |
| IR Line Follower (pack of 5) | $ 12.29 | 1 | $ 12.29 | https://amzn.to/37Pdt4J |
| IR Sensor | $ 6.57 | 1 | $ 6.57 | LFF |
| 3D Printed Mecanum Wheels | $ 2.50 | 4 | $ 10.00 | LFF |
| Motor Driver | $ 2.62 | 2 | $ 5.24 | LFF |
| DC Motor | $ 15.99 | 4 | $ 63.96 | https://bit.ly/2SOK1HO |
| Servo Motor | $ 4.80 | 1 | $ 4.80 | LFF |
| Stepper Motor | $ 13.93 | 1 | $ 13.93 | LFF |

| | | | | |
|---|---|---|---|---|
| Pulley System | $ 19.95 | 1 | $ 19.95 | https://amzn.to/2HP8wyh |
| Linear Rail Guide | $ 20.19 | 1 | $ 20.19 | https://amzn.to/2HNaRtw |
| Lead Screw | $ 17.89 | 1 | $ 17.89 | https://amzn.to/2T59GLm |
| Linear Shaft Rail (z-axis) Kit | $ 53.35 | 1 | $ 53.35 | https://amzn.to/39UWCik |
| 3D Printed Plate | $ 0.50 | 1 | $ 0.50 | LFF |
| Wood (18 by 24 sheet) | $ 2.61 | 2 | $ 5.22 | LFF |
| Hose Clamps | $ 1.65 | 2 | $ 3.30 | https://bit.ly/37P02lo |
| System screws (3 per bag) | $0.56 | 8 | $ 4.48 | https://thd.co/37VaLum |
| Battery Pack | $21.45 | 1 | $21.45 | https://amzn.to/2HNRYqv |
| Total | | | $ 281.427 | |

## 4.7 Risk Assessment

| RISK | PROBABILITY | EFFECT | SOLUTION |
|---|---|---|---|
| MECHANICAL | | | |
| 3D printed wheels do not have enough traction to push the robot off | Considering how both PLA and the floor are quite smooth, there is a medium risk | If the wheels do not have enough traction, they will be nearly unusable | Investigate sprays for tires that improve traction, or switch to rubber wheels |
| 3D printed wheels do not come out uniformly (e.g: small deformities or warping) | The wheel components are small, has no overhang and are not flat, which reduces the chance of warping | If the wheels are not uniform, then the path it travels will not be straight | Sand the wheels down to see if there are any deformities, 3D print the deformed part (if time permits), or switch to rubber wheels |
| Stepper motor will not be able to stop at a precision required for the z-axis | Stepper motors are known to have a high degree of accuracy when it comes to stopping motion | The charger will not be plugged into the correct location | Find a correlation between the amount of stopping time required based on extra distance travelled, and speed and implement the relationship into software |
| DC motor does not stop in time | DC motors are known to have less accuracy than stepper and servo motors | If the DC motor has prolonged stopping motion, then the robot will stray too far from its target | Find a correlation between the amount of stopping time required, and speed and implement the relationship into software |
| AUTONOMY | | | |
| IR sensors are unable to detect coloured lines | IR sensors may react to a different material depending on the lighting and given inaccurate readings | Path to the charger port will not be found | The use of two ultrasonic sensors will mitigate this issue by ensuring both sensors provide a similar reading before acting upon any data fed to the arduino |
| | | Charger port location will not be found | If the IR sensor recognizes a colour resembling the contour of the charging port, stop the robot and send out three more signals that confirm the consistency of the readings |
| Ultrasonic sensors are unable to detect | Ultrasonic sensors may detect object in front of | Car door will not be found | Using two ultrasonic sensors on opposite sides of the robot will help |

| | | | |
|---|---|---|---|
| distances to a degree of precision required for this project | it but isn't the target we want | | cover a wide range of space (additional testing will need to be done to verify the spread of the testing area) |
| | | The robot is not aligned with the car door correctly | The use of traversing horizontal lines as well as the two ultrasonic sensors on the side will ensure that the robot is as straight as possible when performing its<br>necessary tasks |
| | | Z-axis coordinate will not be found | Similar process to not being able to locate the charge port location |
| | Ultrasonic sensor range is too short so that the sensor does not register a small distance | LED doesn't go off | Create a dynamic variability parameter that changes based on distance away from an object to ensure the sensors can accurately determine if the robot is straight or not |
| CIRCUITRY | | | |
| Electric shock through contact with live conductor | Low risk - given the power source is only 7.2 V, it is unlikely serious harm will be done to any persons. | Discomfort and/or injury. | Make sure all power sources are turned off when doing any circuitry work, and do not leave any electrical components exposed for extended periods of time. |
| Burning out components | This is a valid concern, since many components operate at different voltages/currents, and will be drawing from the same power source. | Irreparable harm done to components. | Take note of all components' operating currents and/or voltages prior to using, and implement resistors, voltage regulators, etc as required. |
| Circuitry is not debuggable | It is certain that during testing the rover will not perform certain tasks as initially anticipated, so being able to identify the issue is a must. | Extreme time loss and inability to identify and fix errors | Use clean circuit practices, such as colour coding wires and keeping all circuitry for the same component together. |

## Section 5: Project Management

### 5.1 Division of Work and Timeline

Since all team members are interested in developing skills in software, hardware, and mechanical design/building, and because certain phases involve more of one activity than the other, tasks have not been split up and assigned as such. Instead, each team member is in charge of identifying, organizing and delegating tasks for a particular subsystem. Armaan organizes software, Cathy organizes hardware, and Katarina organizes mechanical design.

Below is our project timeline with division of labour and weekly milestones starting from Week 7. The full timeline and project management tool samples can be found in the appendix. Since our workshops are on Wednesday, we count the weeks starting on Wednesdays, rather than Mondays. Colour coded as follows: Armaan, Cathy, Katarina, Group Work, Incoming Deadlines.

## Source Extracts:

[1] "Robot Platform: Knowledge: Types of Robot Wheels," RSS. [Online]. Available: http://www.robotplatform.com/knowledge/Classification_of_Robots/Types_of_robot_wheels.html. [Accessed: 23-Feb-2020].

[2] "How to Build a Robot Tutorials," Society of Robots. [Online]. Available: https://www.societyofrobots.com/mechanics_chassisconstruction.shtml. [Accessed: 23-Feb-2020].

[3] "Wheel Tech, Part II: Width Matters," Tuner University, 15-Aug-2018. [Online]. Available: http://www.tuneruniversity.com/blog/2011/04/wheel-tech-part-ii-size-matters/. [Accessed: 23-Feb-2020].

[4] "Considerations in Choosing Motors for Robotics," Mouser Electronics Canada - Electronic Components Distributor. [Online]. Available: https://www.mouser.ca/applications/considerations-choosing-advance-robotics/. [Accessed: 23-Feb-2020].

[5] "Why Material Selection is Crucial for Engineering Design Process?," TrueCADD. [Online]. Available: https://www.truecadd.com/news/why-material-selection-is-crucial-for-engineering-design-process. [Accessed: 23-Feb-2020].

[6] Thomasnet.com. (n.d.). *Stepper Motors vs. DC Motors - What's the Difference?*. [online] Available at: https://www.thomasnet.com/articles/machinery-tools-supplies/stepper-motors-vs-dc-motors/ [Accessed 23 Feb. 2020].

[7] C. Benson, "Basics: How Do I Choose a Battery?," RobotShop, 17-Sep-2018. [Online]. Available: https://www.robotshop.com/community/tutorials/show/basics-how-do-i-choose-a-battery. [Accessed: 23-Feb-2020].

[8] C. Layosa, "Carlicia Layosa," MISUMI Blog, 20-Mar-2015. [Online]. Available: https://blog.misumiusa.com/blog-post-987/. [Accessed: 23-Feb-2020].

## Appendix

1) Ultrasonic Sensor Testing Protocol

Two ultrasonic sensors were installed on opposite ends of a breadboard along with a singular LED used for indication purposes.
Test 1: (reliability of readings)

- System was placed parallel in front of a flat surface
- Readings from each ultrasonic sensor were relayed to the serial monitor

- Consistency of the readings were determined
    - Readings that were within 5% variability of each other was deemed successful
    - Otherwise, the readings were considered unsuccessful
- This test was completed with several different ultrasonic sensors, and based on the results, it can be concluded that readings were primarily successful
    - Ultrasonic sensors will be reliable when determining the distance from an object

Test 2: (displayed above - determining the systems accuracy in remaining parallel to the surface)

- This test was completed to determine if using an ultrasonic sensors on either end of our final prototype would be accurate in keeping it straight and parallel to the surface
- A threshold variability was set (10%)
- If the two readings of the ultrasonic sensor were within 10% of each other, the LED would be turned off, indicating that the prototype is straight in relation to the surface
- Otherwise, the LED is left on indicating that the prototype is at an angle in relation to the surface

## 2) Charger Holding Mechanism Testing Protocol

To test the gripper, a prototype charger will be made of similar size, weight and shape of the charger being used (both 3D printed version and the off the shelf version)

Test 1: Fit Test

The purpose of this test is to determine how well the gripper mechanism could fit the charger under various movements.

- Gripper mechanism is placed onto the prototype charger
- Mark where the mechanism is placed on and in contact with the prototype charger
- Move the charger around in various x, y and z direction motion for 2 minutes
- Record if there is any variation in position of the gripper mechanism after shaking
- Repeat 5 times
- If the position varies by more than an average of 10% after shaking, the mechanism fails the test.

Test 2: Support Test

The purpose of this test is to determine how well the gripper mechanism supports the prototype charger under various movements.

- Gripper mechanism is placed onto the prototype charger
- Mark where the mechanism is placed on and in contact with the prototype charger
- Attach a rod through the mechanism and hold it upright such that the rod is parallel to the ground
- Record the vertical distance (z-direction) between the bottom of the charger and the ground
- Time for 2 minutes
- Record the vertical distance (z-direction) between the bottom of the charger and the ground
- Repeat 5 times
- If the vertical distance varies by more than an average of 5 mm after no movement, the mechanism fails the test.
- If not, repeat the protocol with various x and y direction motions, noting any variations in z direction.
- If the vertical distance varies by more than an average of 5 mm, the mechanism fails the test.

## 3) Belt drive testing protocol

To test whether the belt drive could provide enough load capacity to move the charger back and forth on the Y-axis, the rubber belt and pinion purchased were subjected to varying load to see whether slippage was likely

Test 1:

- Place a rod through the pinion, and attach it somewhere where it will not move.
- Lay the rubber belt over the pinion, so that it hangs down on either side.
- Attach light weight to each side to ensure tension in the belt, and that the teeth are aligned with the pinion's.
- Increasingly add weight to one side of the belt.
- Record the weight at which the teeth on the gear slip, and the heavy weight begins to fall.

4) Project Management (Trello Screenshots):

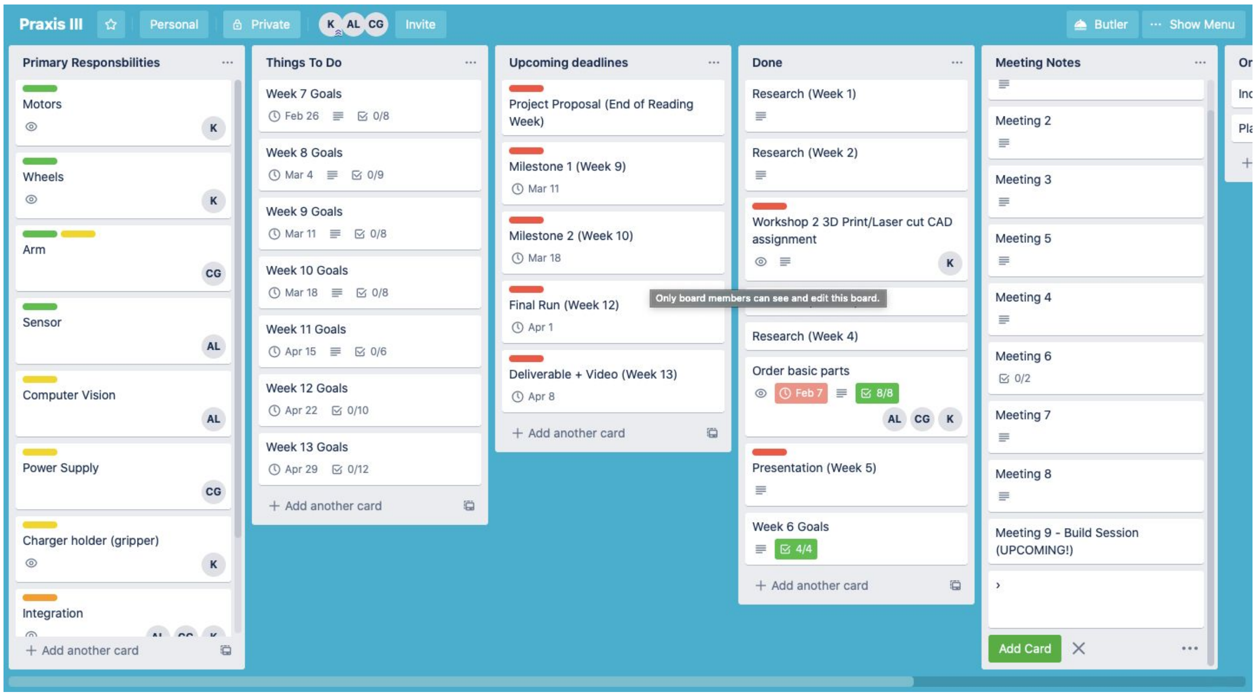



Figure 11: An overview of the project management tool featuring individual responsibilities, a to-do list, upcoming deadlines, a completion list, and meeting notes

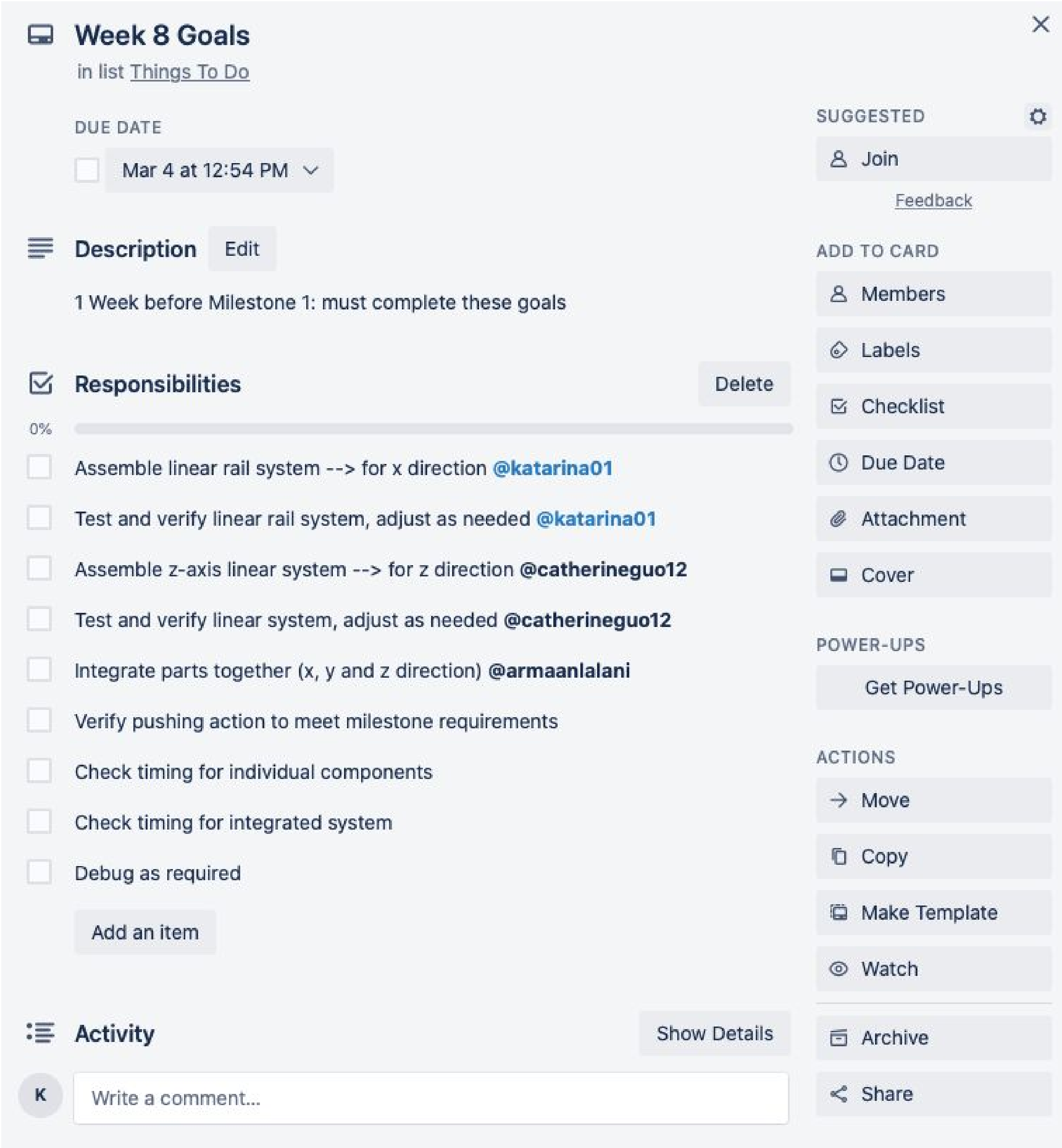



Figure 12: A sample of a weekly goal checklist, complete with a due date and responsibilities for each team member and for the group