UNIVERSITY OF WATERLOO

Faculty of Engineering

Detailed Design of an Automated Refuelling System

MTE 481

Prepared by

Group 15

Ahmed Syed	20484061
Ben Mendis	20456783
Jasdeep Dhillon	20468850
Atakan Efe Kanman	20479368

4A Mechatronics Engineering

December 5, 2016

December 5, 2016
Prof. Sanjeev Bedi
Department of Mechanical and Mechatronics Engineering
University of Waterloo
Waterloo, Ontario
N2L 3G1

Dear Prof. Bedi,

This report, entitled "Detailed Design of an Automated Refuelling System" was prepared as Group 15's detailed design report for the MTE 481 fourth year design project. The purpose of this report is to describe and analyze our automated refuelling system that we are designing for our fourth year design project.

We would like to acknowledge your assistance in defining and clarifying the objectives of the project, and clearing up confusion regarding the reporting structure and content.

We are the sole authors of this report and, unless otherwise stated and properly referenced in the report, the entire content of this report is original work done by us. We have all read the report and are aware of the content. The content of this report has not received credit in this or any other course that we have taken in the past or are currently taking at this time.

Sincerely Yours,
Group 15

Ahmed Syed Jasdeep Dhillon Ben Mendis Atakan Efe Kanman

Table of Contents

List of Tables

List of Figures

Executive Summary

The main purpose of this report is to describe and analyze our automated refuelling system and identify the best possible design. The report mainly focuses on the detailed design of the the system, determining the components and doing analysis. The report assumes the reader has basic knowledge of mechanical design and analysis concepts, electrical design and software design. This report is intended for Mechanical and Mechatronics Engineering Department at University of Waterloo.

The major points of this report are the comparison of the possible designs, design selection based on the decision matrix result, analysis of the selected design in terms of stress, strain, displacement and factor of safety, selection of electrical components and the software design and architecture.

The major conclusion is that the design of the system has met the objectives and criteria specified in this report. The performance of the designed solution is expected to meet the design standards of locating the fuel door using image processing, opening it and the fuel cap, inserting the nozzle in within a process time of three and a half minutes.

The major recommendations are to find backups and different methods, in case failure occurs. This will also improve the design and the efficiency of the system. The next steps to assembly the complete mechanical system and integrate it with electronics to test the basic functionality before detailed testing can be done. Also, image processing has to be polished.

1.0 Background and Introduction

The automotive industry is a fast moving industry, where a lot of innovations is occurring from electric cars to autonomous cars to using hydrogen fuel. Based on personal experience and past coop terms, there was inspiration to create a project to solve a problem in the automotive industry. The issue chosen to tackle was innovating the refuelling experience and bring it into the 21st century. All of the group members know fuelling can be a tedious job and needs a more convenient method that is completely automated. To get a better picture on the refuelling process, a survey was conducted. This helped to paint a picture of what issues exist with refuelling. From the survey, it was found that 58 percent of people would use the automated refuelling system in any condition and only 4.5% would not use it, these values are summarized in Figure 1. This provides a validation that there is a need for an automated refuelling system.

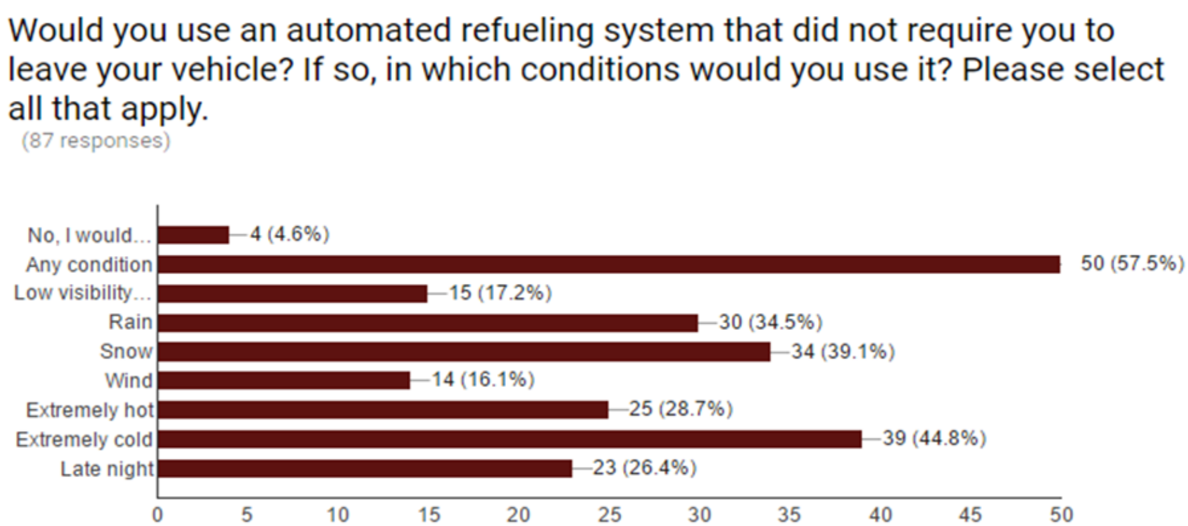

Figure 1: Survey Results of Which Conditions People Would Use an Automated Refuelling System

The survey also gave information on what features people want in an automated fuelling system. The results from the survey are summarized in the pie chart in Figure 2. Not all of the features could be tackled, so it was decided to go with the top three. The three main requests that were made were a mobile app to interact with the system, fully automated (no need to exit vehicle) and safety.

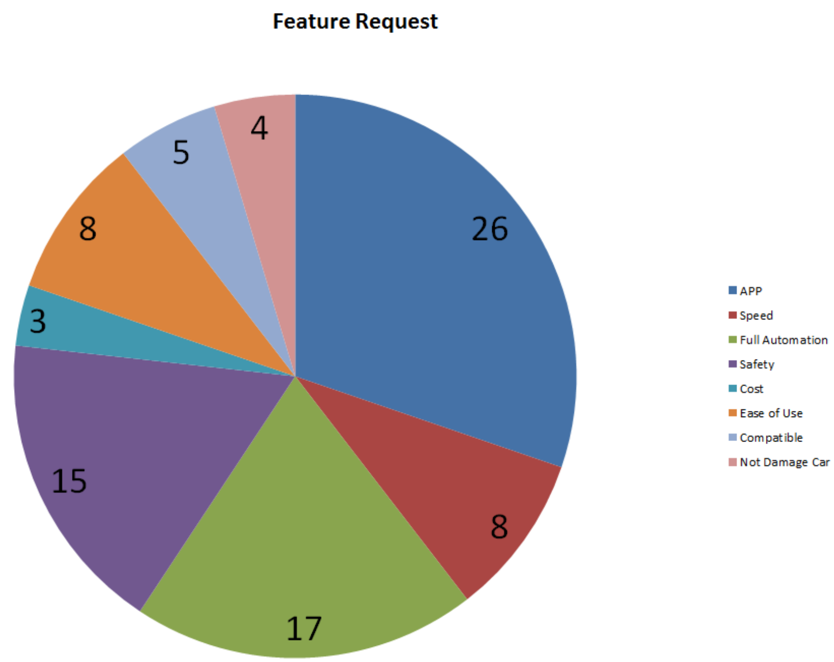

Figure 2: Survey Results of Feature Requests

1.1 Needs assessment

The need for the fourth year design project is to develop a fully automated refuelling system that is safe and reliable in any condition that eliminates the need for the user to exit their vehicle.

1.2 Problem formulation

The problem that is being solved requires a solution that can locate a fuel door, open/close a fuel door, remove/replace fuel cap and insert/remove the fuel nozzle. Also, the scope of the problem is limited to passenger vehicles that have hinged, metallic, circular or rectangular fuel doors and untethered, screw on fuel cap.

1.3 Constraints

A few constraints were decided for the project and are quantified below:

- Complete process in 3.5 minutes
- Mass under 30 kilograms
- Total development cost under $2000

The first constraint was determined by gathering data on the average time people spend on fuelling their vehicles by observing various gas stations. The average process time of 3.5 minutes includes grade selection, inserting the nozzle and payment at the pump and in store, but doesn't include the actual pumping time. This sets the maximum processing time for the project.

The mass constraint is based on making the system easier to relocate when testing and developing. Also, since the group doesn't have access to a vehicle to transport the system, this limited the amount of mass that can be transported. The last constraint is based on the project not having sponsors and requires the funding to come from the group. This means that there is a limited budget to use and the maximum that can be spent is $2000.

1.4 Criteria

The design criteria were determined to help evaluate several viable alternative designs and be able to make a selection. The criteria are:

- Ease of implementation
- % of vehicles accommodated
- Accuracy and Reliability of positioning system
- Minimum processing time
- Select Design that maximizes cost efficiency
- Minimize Mass
- Workable operation space

One of the most important criteria is the ease implementation because of the limited time to complete the project. In order to make the implementation easier, it would be best that too much time isn't spent on learning new skills and can apply what the group know already knows. The second one is the number of vehicles that can be accommodated by the design. For the purpose of the project, the scope of vehicles that can be serviced has been limited to passenger vehicles that have a hinged fuel door that can be unlocked by the user within the car, the fuel cap is screw based and untethered and the fuel door cover has to be rectangular or circular and be metallic. Also, only passenger vehicles are allowed. Accuracy and reliability of positioning system evaluates how the fuel door and cap are located. These three constraints that were mentioned are the most important for the system and are weighted heavily.

The other criteria that are listed are for minimizing the mass of the system, choosing a system that maximizes cost efficiency, has minimum processing time and workable operation space. These criteria aren't important as the first three mentioned and aren't weighted as much. The weightings for these criterions can be seen in Section.

1.5 Patents

Research was done on patents to find existing automated refuelling systems and, in order to get some background information and ideas for automated refuelling. Also, from this research any patent infringement by the group can be determined. In total 6 patents were found and each one is discussed below.

1.5.1 Patent 1: Rotec Engineering Pitstop (Patent #: EP2053015 A1)

This automated refuelling system was patented by Rotec Engineering and is called Pitstop. The system involves using an industrial robotic arm, housed in a small box that has a rotating end effector attached to the end. The end effector has 3 arms that allow the arm to open the fuel door, remove the fuel cap, put the nozzle into the car, put the fuel cap back on and close the door. The system also uses an RFID tag that is provided to the driver, in order to lookup details on the car from an online database in order to find where the fuel cover is. An image of this system can be seen in Figure 3 [1] below.

Figure 3: Rotec Engineering Pitstop in Action

1.5.2 Patent 2: Shell Oil Automated Fuelling System (Patent # US5609190 A)

Shell Oil designed an automated fuelling system that differs from the previous design by using a Cartesian robot instead of an industrial robotic arm. The end effector is a sealed cylinder, seen in Figure 4 [2], that houses 3 arms to open the fuel door, remove the cap and the fuel nozzle and pushes the arm that required forward to do one these 3 actions. This end effector is moved on a giant gantry, which can be ineffective since it involves making property changes and compared to Pitstop is bigger. In order to find the fuel door cover, a magnet is placed near the fuel cover and by using a magnet sensor can be located.

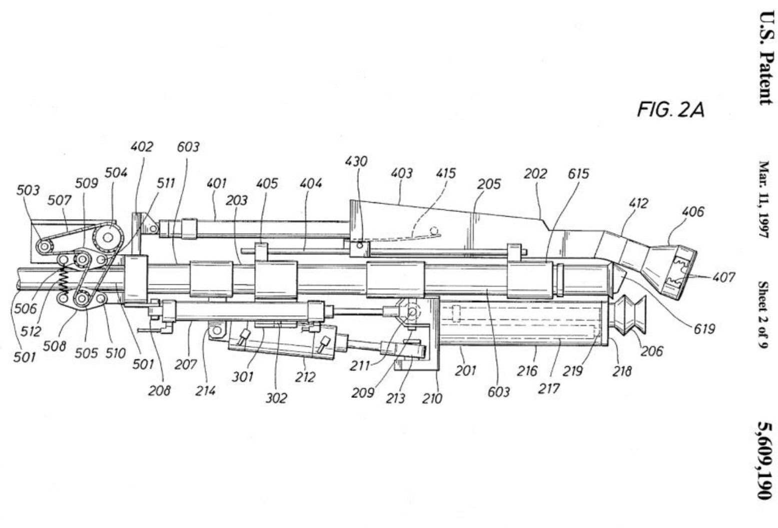

Figure 4: Shell Automated Refuelling System End Effector

1.5.3 Patent 3: Automated Refuelling System (Patent# US8393362 B1)

This is the last patent that shows an automated fuelling system and is the only one that wasn't patented by a company. The automated refuelling system, seen in Figure 5 [3], is similar to Pitstop, in that it also uses an industrial robotic arm and. The differences in this design from the other designs is that the vehicles requires a fuel cover modification, meaning in order to use the refuelling system the vehicles need to be capless. This feature limits the type of cars it can service and isn't a desired feature for the project. Besides that downfall, the system has an interesting feature where one of the vehicle's wheels is locked in a predetermined location, which helps in aligning the vehicle. This makes working with the vehicle easier.

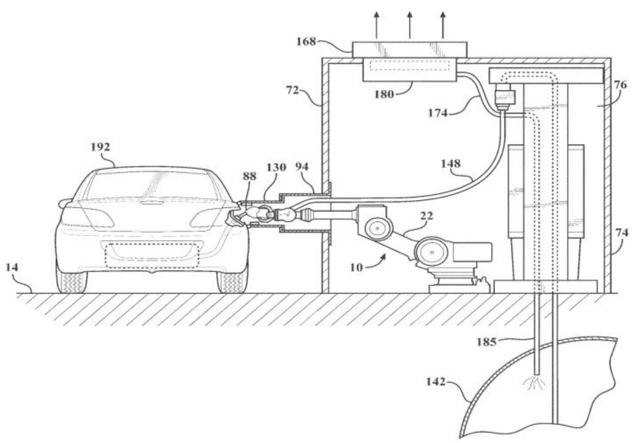

Figure 5: Automated Refuelling System Patent 3

1.5.4 Patent 4: Motion Converting Device (Patent#: US3169407)

The patent is a motion converting device that is made of a rotating threaded rod and traveling nut, which can be seen in Figure 6 [4]. This device converts the rotational motion from the motor into a linear motion. The use of this principle can be seen in the rail system, which moves in linear movements from the stepper motors.

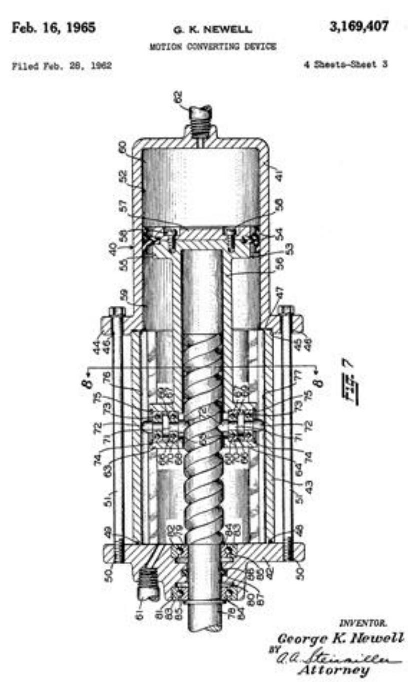

Figure 6: Motion Converting Device

1.5.5 Patent 5: Robotiq Inc. Gripper (Patent#: US20140265401 A1)

This is a two finger gripper that was patented by Robotiq, as shown in Figure 7 [5]. The gripper is able to adapt, allowing stable pinch grasping. This means that the gripper can grip any type of object that was a width that is less than the extension of the two grippers. For the design, a gripper similar to this was created a gripper because it allows the system to grip fuel caps that differed by small variances in diameter or grip onto the slit on the fuel cap.

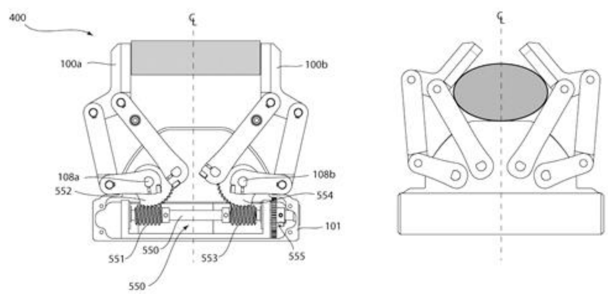

Figure 7: Robotiq Gripper

1.5.6 Patent 6: Automatic Refuelling Station (Patent#: US6237647 B1)

The important part of this patent is the flow process that is used by the automated refuelling system and can be seen in Figure 8 [6]. The steps that the system goes through are detecting the vehicle, polling for vehicle identification and access an online database to obtain vehicle information. In the later sections, it can be seen that a similar process to this is used for the automated refuelling that is being designed, expect that a mobile app is used to provide the vehicle information.

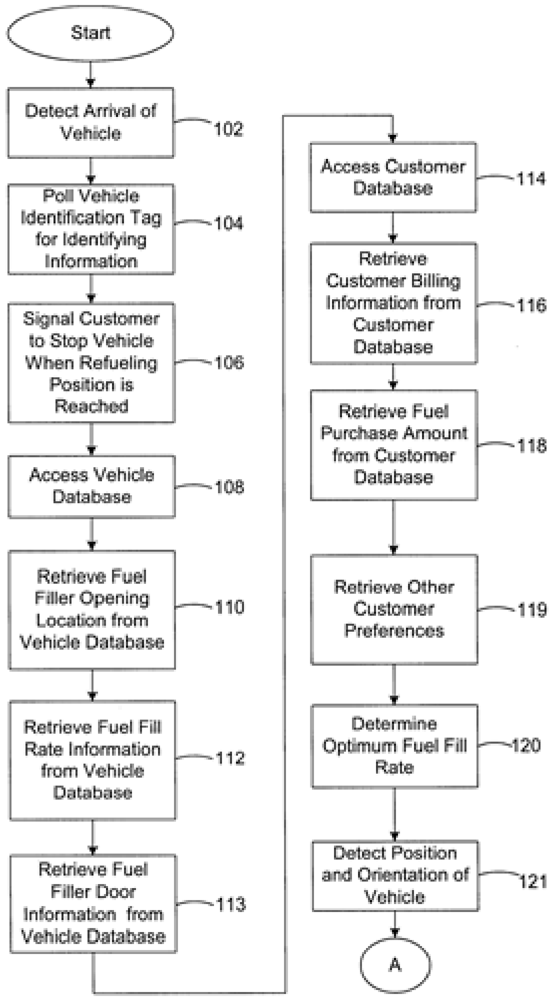

FIG. 1A

Figure 8: Automated Refuelling System Process Flow

From these existing patents a few ideas were borrowed and used in the project, like using a Cartesian robot and the design for the gripper was inspired by the Robotiq patent. Due to the fact that the project borrows ideas from these existing designs and no major improvement has been made on them, the system isn't patentable.

2.0 Proposed Solution

In order to come up with alternative design solutions and the proposed solution, a morph chart was utilized. First the functions that the system has to accomplish were brainstormed and came up with 5 main components. The first one is the end effector, which is responsible for opening the fuel door, removing the fuel cap and inserting the nozzle. Then there is the movement function, a system for moving the end effector to the desired position. A method is also required for locating the fuel door on the vehicle as well as ensuring that the vehicle is in the workable space of the system. After determining these 5 functions, different parts were brainstormed and are summarized in the morph chart in Table 1.

Function	1	2	3
End Effector	3-arm	2 prong Electromagnet with Swivel	2 prong Electromagnet Underneath
Movement	Rail System	Robotic Arm	Pneumatic Pump
Position	RFID + Vision	RFID + Magnetic Flux	Computer Vision
Vehicle Alignment	Camera with birdview	Grooves & Bump	Pressure Sensor
UI	Web APP	Mobile APP	Screen Interface

Table 1: Morph Chart for Alternate Designs

2.1 Alternate Design Solutions

The morph chart from the previous section yielded 3 promising designs. The first design can be seen in Figure 9. This design uses a motorized linear rail system to move the end effector, which consists of a rotating 2 finger gripper, to the appropriate position. The gripper in the figure has tips that are electromagnetic to open the fuel door and the fuel nozzle is connected to a separate arm that lowers into position when required. In order to determine the approximate location of the fuel door, an RFID tag is used. Also, a magnetic sensor to locate the fuel cap. The positioning of the vehicle is controlled by physical cues by grooves or speed bumps.

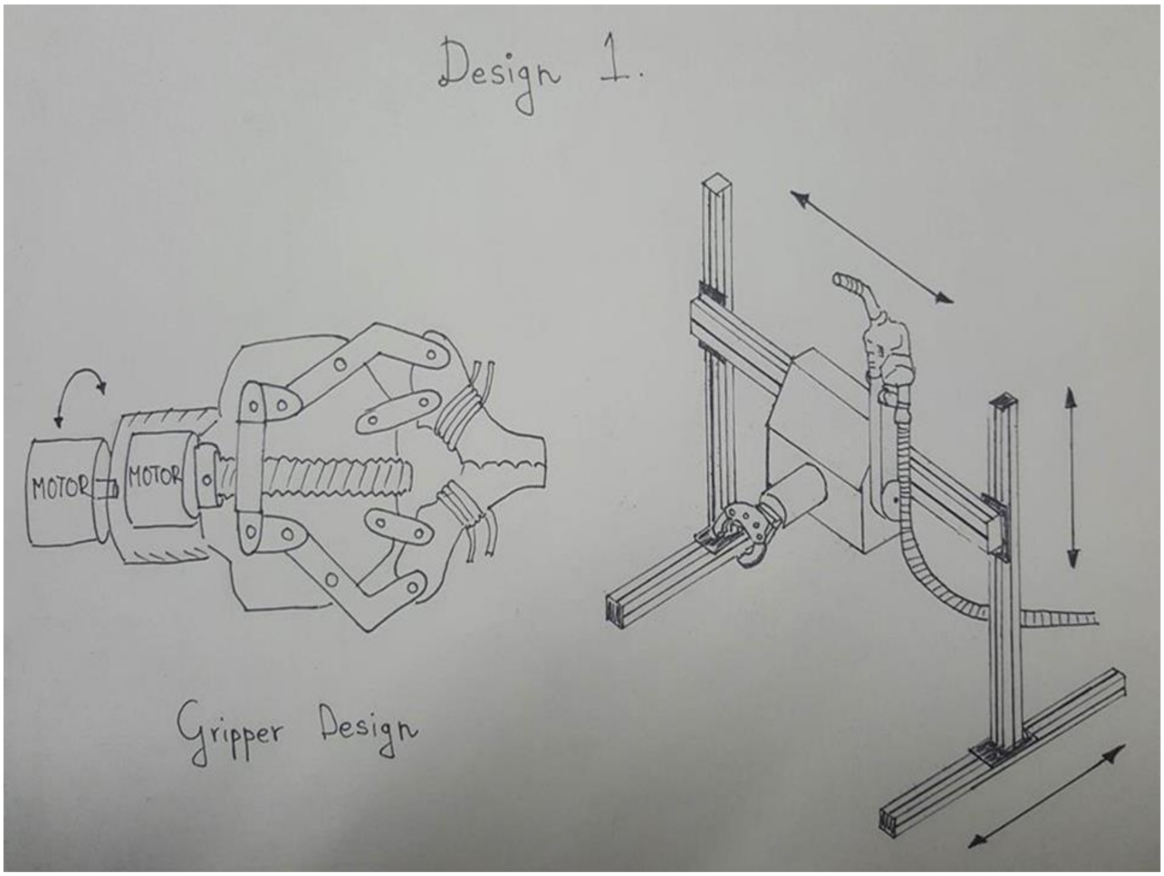

Figure 9: Alternate Design 1

Design 2 and 3 are similar to each other in that they both use a robot arm. Design 2 differs in that its end effector is different from design 3. Seen in Figure 10, Design 2 has an extendable electromagnetic gripper with the fuel nozzle attached underneath. Also, in order to locate the fuel door Design 2 uses RFID and computer vision. The feature difference in Design 3 are that it uses an end effector that has 3 separate extendable arms that can form the function of opening the fuel door, removing the cap and inserting the fuel nozzle ,and uses only computer vision to find the fuel door.

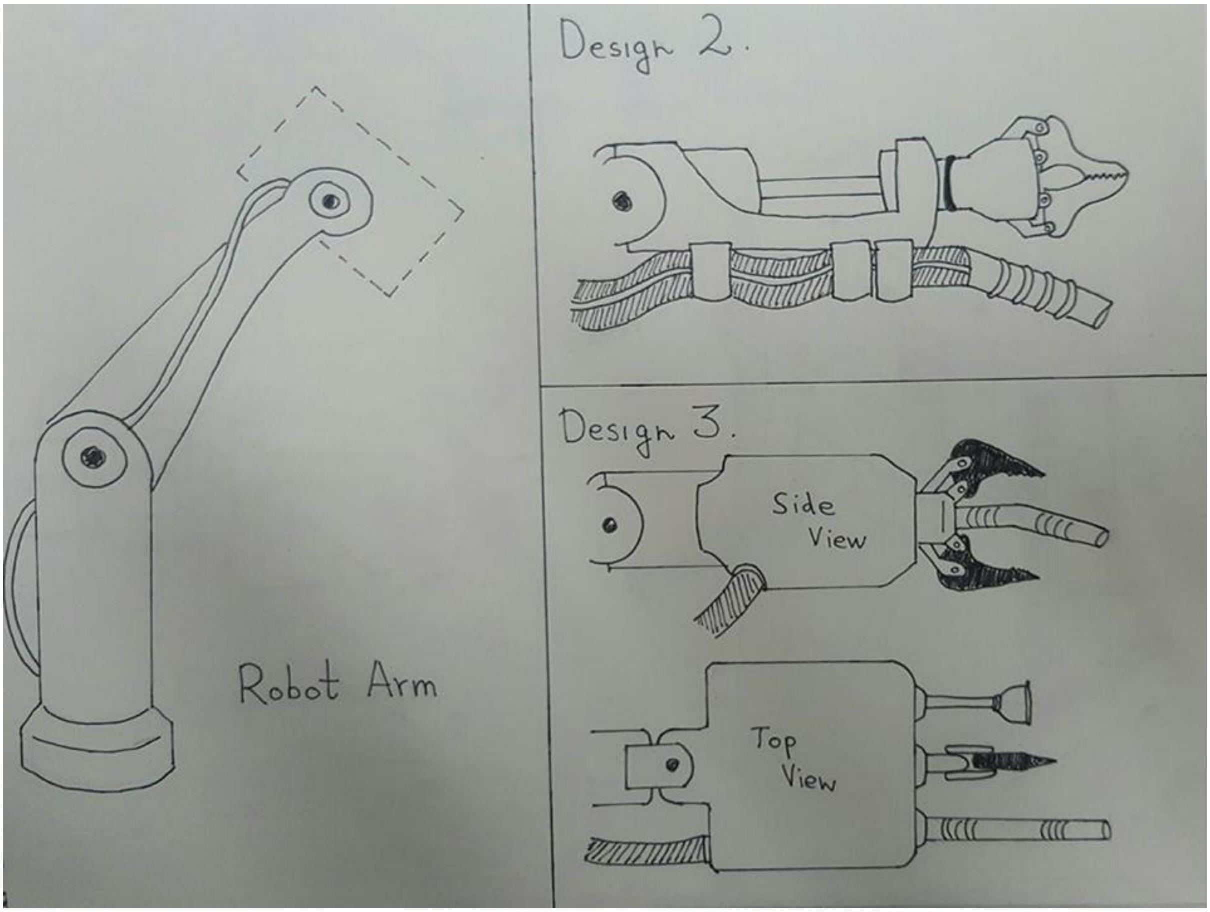

Figure 10: Alternate Designs 2 and 3

The three designs do share a common design feature that they use a combination of a mobile app and touch screen interface for the UI.

2.2 Selection of Proposed Solution

In this section the criteria are weighted and that the three different designs are compared using a decision matrix to determine the best and efficient design for the problem.

2.2.1 Criteria Weights

Before selecting a proposed solution, the criteria listed in Section 1.5, need to have weights assigned to them. The weights assigned were based on the relative importance of the criteria to the project. As mentioned in Section 1.5, the three important criteria for the project are ease of implementation, vehicle accommodation, and accuracy and reliability. So these three were assigned the highest weight values and the other criteria were given low weight values. The weight values are summarized in Table 2.

Criteria	Weight(%)
Ease of Implementation	30
Vehicle Accommodation	20
Accuracy & Reliability	20
Minimize Process Time	10
Maximize Cost Efficiency	10
Minimize Mass	6
Workable Operation Space	4

Table 2: Criteria Weights

2.2.2 Decision Matrix

After establishing the weights for the criteria, a decision matrix, Table 3, was created to select a design. For the first criteria, Design 1 got the highest score because it uses linear rails which are easier to construct than a robot arm for the other two designs. Vehicle accommodation criteria was won by design 3 because the end effector has a suction cup, which allows it to open a fuel door regardless of it being metallic, whereas the other two designs rely on grippers with magnets and require the fuel doors to be metallic. Computer vision is a more accurate and reliable method to locate the fuel door and is only used by Design 2 and Design 3, so they scored the highest for values for this section. Design 1 scored less because it relies on magnets to find the location, which gives an approximate location of the fuel door and not an exact one like the computer vision. All 3 designs scored the same for the process time because the difference in software process time would be insignificant and the robot arm, used in Design 2 and 3, will be very close to the linear rail system because they all rely on electromechanical movement. Design 1 is the most cost efficient solution because it’s easier to build a rail system from cheaper and accessible parts, whereas constructing a robot arm is more expensive because it relies on custom machine parts. So Design 1 was given the highest score. For the last two categories, Design 1 had the best score since rails are lighter than a bulky robot arm.

Criteria	Design 1		Design 2		Design 3	
	Raw / 10	Weighted	Raw / 10	Weighted	Raw / 10	Weighted
Ease of Implementation	8	24	7	21	7	21
Vehicle Accommodation	7	14	7	14	8	16
Accuracy & Reliability	8	16	10	20	10	20
Minimize Process Time	8	8	8	8	8	8
Maximize Cost Efficiency	8	8	6	6	6	6
Minimize Mass	8	4.8	6	3.6	6	3.6
Workable Operation Space	9	3.6	5	2	5	2
Total		*78.4*		*74.6*		*76.6*

Table 3 Decision Matrix for Selecting Proposed Design

From this decision matrix, it can be seen that Design 1 has the highest score. Therefore it is the design that will be used for the project.

2.3 Proposed Design of Selected Solution

The proposed solution for the project is a 3 axis rail robot with an end effector that has an extendable electromagnet, two pronged gripper and swivel fuel nozzle arm. In the previous section, in Figure 9, a sketch depicting a skeleton of what the proposed solution was seen. The next sections document the detailed design and analysis for the Mechanical, Electrical and Software sections of the system.

3.0 Mechanical Design

This section focuses on the complete mechanical design for the solution chosen in the previous section. The mechanical design includes the 3-axis linear rail system and the end effector or payload. Component selection and parts that were designed are described as well. A force analysis using Solidworks Simulation is also carried out on critical components to analyze their design viability and correct any designs appropriately if failure occurs.

3.1 The System

The mechanical system consists of two main components, the 3-axis linear rail system and the end effector with its respective tools. This section describes and analyses in detail what these components comprise of, their functions.

3.1.1 3-axis Linear rail system

The primary function of this system is to appropriately move and position the payload as required, in order for it to carry out its different functions on the vehicle. Since different cars have their respective fuel door in differing positions, the payload is required to move in all three dimensions. This can be achieved by using a linear actuator for each axis, to allow for 3D motion.

The final system design was inspired by and based on Do It Yourself (DIY) CNC machines made using parts sold by Openbuilds store. There are multiple ways of building a linear actuator. The linear actuators that can be created using these parts are cheaper compared to ball screw versions. The end product is also highly modular allowing for change in dimensions and orientations of the actuators, very easily.

3.1.1.1 The Linear Actuator

The linear actuator is an assembly of several different components. It uses a gantry plate which is connected to an 8mm threaded rod via a threaded nut block. This threaded rod is connected to a NEMA type motor using a motor shaft coupling. The motor rotates the threaded rod, which in turn moves the gantry back and forth. The gantry plate rides on an extruded 6063 Aluminum beam. And all the components are fastened to this beam. The gantry plate has special wheels called Solid V-wheels that are designed to ride a v shaped slot that runs along the length of the beam. The use of these wheels decreases the coefficient of friction between the loaded gantry plate and the beam, allowing for smooth motion, as well as, reducing the load torque on the motor.

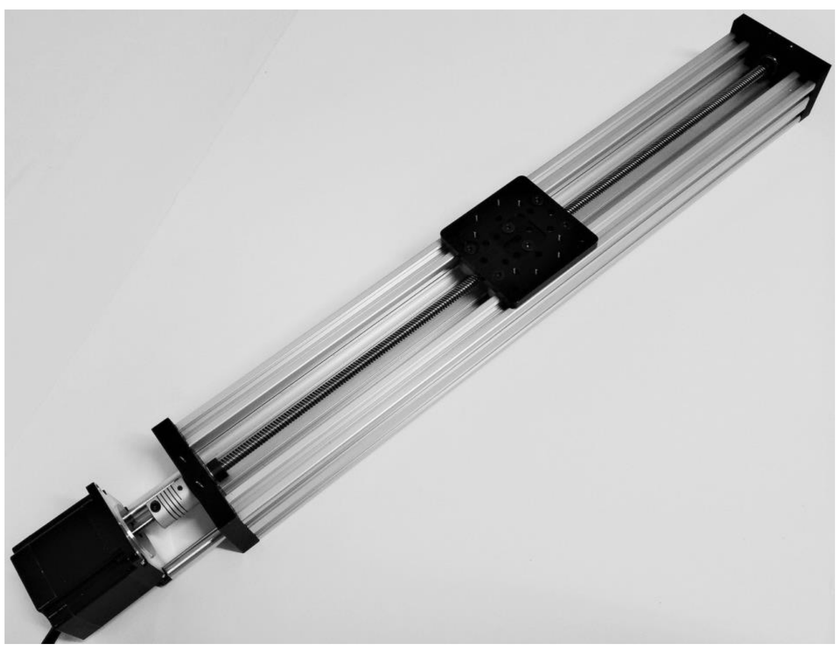

Figure 11: Linear Actuator Assembly

Figure 11 [7], above, shows a photo of the linear actuator assembly. The final design contains one linear actuator for the x and z-axis, each, and 2 actuators for the y-axis. All the linear actuators are fastened together, to create a rigid system.

3.1.2 The Payload

The payload is what houses all the components creating the end effector. All these components are mounted to the custom designed bottom plate which attaches the to Z-Axis gantry plate. The end effector has three primary functions; Open/Close the fuel door, Remove/Replace the fuel cap and Insert the fuel nozzle into the fuel inlet. All three functions are carried out by three separate devices. These are as follows:

1. The extendable electromagnet

The function of this device is to open and close the vehicle's fuel door. It was determined that most cars have a metallic fuel door, through multiple field tests. Therefore using an electromagnet would be an ideal method to attach to and pull the fuel door open. This electromagnet is attached to the end of a mini linear actuator called L16 Mini Linear Actuator manufactured by Actuonix. This is done to increase the reach of the electromagnet beyond the housing of the payload and the other devices. The connection between the electromagnet and the linear actuator also contains a hinge that allows the electromagnet to swivel about the z-axis. This design ensures that the electromagnet is always perpendicular to the fuel door while it is being opened. Figure 12 below, shows the complete assembly of the extendable electromagnet.

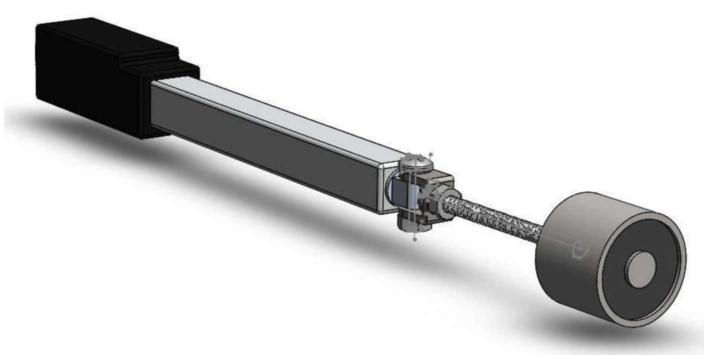

Figure 12: Assembly of Electromagnet

2. The rotating gripper

The function of the gripper is to unscrew the fuel cap, allowing it to be removed and thereby revealing the fuel inlet of the vehicle. It also has to replace the fuel cap ones the refuelling process is completed. In order to complete this function, a two pronged motorized gripper was chosen. After the gripper is positioned accurately over the fuel cap, it can grip the extruded gripping slot in the center of the fuel cap. The action of the gripper is controlled by a small motor that is connected to a threaded rod. There is a threaded block that moves along the rod and is connected to the prongs by linkages. Depending on the movement of this block, the gripper either opens or closes. The gripper chosen is a Robot Gripper manufactured by Makeblock. Figure 13 [8], below shows a photo of the gripper.

Figure 13: Robot Gripper

The maximum opened width of this gripper is approximately 67mm, which is larger than the gripping slot of most fuel caps. Since the fuel cap will have to be unscrewed, the whole gripper will have to be rotated. This requires it to be mounted onto stepper motor to allow for controlled rotation. The gripper will also be mounted at a set angle of 45 degrees below the horizontal. This is a constraint set as it was determined through research that this angle is an SAE standard, used in a variety of cars.

3. The fuel nozzle arm

The function of this component is to support the fuel nozzle and lower it down when required. The arm holds the nozzle in a vertical position when it is not in use. This position does not obstruct the working of the other devices in the payload. The arm is attached to a motor, housed within the payload, which allows it to be turned downwards into a horizontal position, in order to be inserted into the fuel inlet. Ball bearing would have to be used in order to support the weight of the structure and ease the load of the motor shaft.

Figure 14 below shows the preliminary 3D CAD model of the payload. This design for the payload will probably have to be iterated upon, in order to make it more efficient in the future.

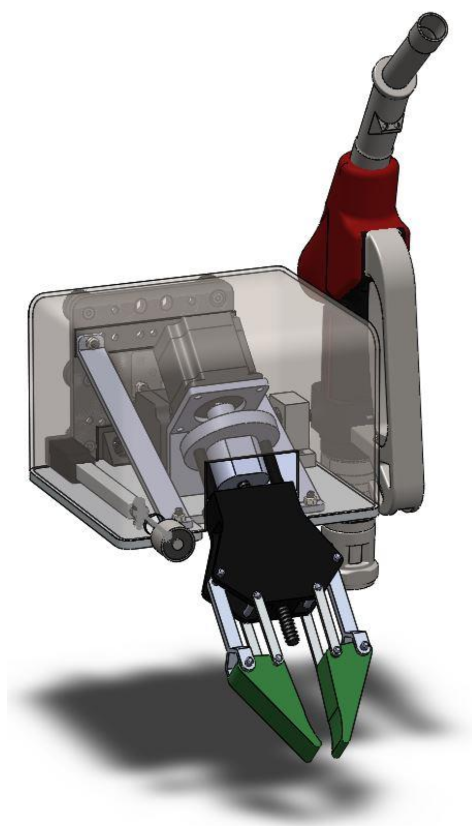

Figure 14: 3D Model of Payload

3.2 The Final Assembly

The payload is connected to the gantry plate on the Z-axis, allowing it to move in all three dimensions. The Z-axis is connected to the X-axis beam via the X-axis gantry plate. The X-axis is supported by two custom designed plates called the Y support plates. These plates support the weight of the X-axis beam and the payload, as it moves along the two Y-beams. The Y-beams are connected by two additional 20mmx20mm V-Slot beams, providing additional support to the system and ensuring that they are square. Figure 15 below displays a render of what the final system could look like. The detailed drawing for the final assembly, with different views as well as the complete Bill of Materials can be found in Figure 42 and Table 10, respectively, in the Appendix.

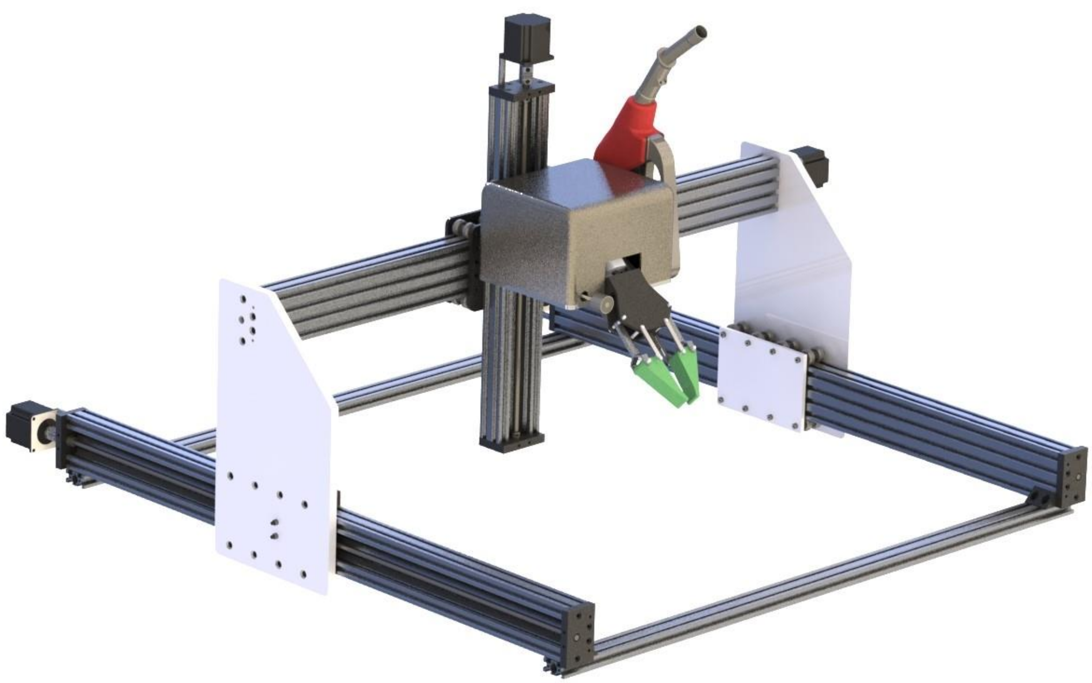

Figure 15: Full render of the system

3.3 Major Mechanical Components and Custom Parts

This section describes the different significant parts that were either purchased or designed for the mechanical system.

3.3.1 C-Beam™

The C-Beam is based on V-Slot® Linear Rail design. The V-Slots an extruded aluminum linear rail profile that has a cross sectional area of 20mm x 20mm. It has extremely smooth v-grooves on all 4 of its faces, which allow for linear motion. It is highly precise, easy to use and has a modular nature, which allows the creation of a variety of different designs. The C-Beam incorporates a C shape cross sectional profile, which provides extra strength and functionality. It is considered to have a 40mm x 80mm profile. The OpenBuilds C-Beam is made with 6063 T-5 Aluminum and has a clear anodised finish to provide a smoother ride for the gantry. It is sold in three different lengths; 0.25m, 0.5m and 1m. These beams can easily be cut in order to change its length. It is also relatively light, with a 1m long beam weighing approximately 2 kgs. This makes it an ideal part to be used to create the linear actuator. This is a proprietary part sold by OpenBuilds. The Figure 16 [9] below, shows a photo of the C-Beam.

Figure 16: C-Beams for linear actuator

3.3.2 Gantry Plate

This part is the main plate that moves in the linear actuator. It is pre-machined part made from a 6mm thick 6061-T5 aluminum plate. It has a number of pre drilled holes, some of which are pre-tapped to allow for mounting purposes. It also has counter bores to allow for the screws to be flush with its surface. The center square recess is used to mount the threaded nut block that attaches the plate to the threaded rod. It supports up to 6 Solid V wheels to be mounted on it and its wide distance between the two rows of wheels creates a sturdy axis. All these advantages make it an attractive and necessary part to purchase. This is a proprietary part sold by OpenBuilds. The Figure 17 [10] below shows a photo of the gantry plate. The length and breadth of the plate are 125 mm.

Figure 17: C Beam Gantry Plate

3.3.3 Threaded Rod

This part is a threaded rod used as the lead screw to allow for linear motion. It connects the motor with the gantry plate via a thread nut block mounted on the latter. It has a diameter of 8mm and trapezoidal threads with a pitch of 2mm. Therefore, with every revolution of the motor shaft the gantry plate will move 2mm. It is machined from stainless steels and is sold in a variety of lengths that correspond to the length of the C-Beams. This is an important component of the linear actuator and can handle high torque and speed applications. The Figure 18 [11] below, shows a photo of some of these threaded rods.

Figure 18: ACME Threaded Rods

3.3.4 Flexible Motor Coupling

This part is used to connect the stepper motor shaft to the acme lead screw. It is machined from aluminum and is flexible in nature to correct any misalignment in concentricity between the shaft and the rod. This particular coupling attaches a motor shaft of ¼" diameter to a threaded rod with a diameter of 8mm. It has an overall length of 25mm and an outer diameter of 20mm. Each linear actuator will require one coupling, making a total of four couplings that will be required. The Figure 19 [12] below, shows a photo of the flexible motor coupling.

Figure 19: Flexible Motor Coupling

3.3.5 Anti-Backlash Nut Block

This part connects the threaded rod to the gantry plate and is mounted on the latter. Mounting is achieved by using two 15mm M5 low profile screws. The rod is screwed into the threaded hole in its center, and the block moves as the rod is rotated by the motor. The movement of the block in turn moves the gantry plate. It is machined from Delrin. This nut block is a special variant as it eliminates the mechanical backlash created by moving mechanical parts and allows for smoother and precise control of motion. The setscrew on the lower lip of the part is tightened as required to remove the backlash. This is a very useful part and is required in every linear actuator; therefore four of these are required for the system. This is a proprietary part sold by OpenBuilds. The Figure 20 [13] below shows a photo of the Anti-backlash nut block. The length of the block is 32 mm, breadth is 31 mm and the height is 12 mm.

Figure 20: Anti-backlash nut block

3.3.6 Xtreme Solid V Wheel Kit

These Solid V wheels are designed specifically to ride the V-grooves cut into along the length of the C-Beam. They are made to support high loads of up to approximately 11 kg per wheel. They are created using a high strength polycarbonate material with a Rockwell Hardness of M75 and a compressive strength of 86MPa.

Each wheel has two ball bearings (625-2RS) within it. Its external dimensions include an outer diameter of 24.39mm, inner diameter of approximately 15.974mm and a thickness of 10.23mm.A maximum of six wheels can be attached to the gantry plate to allow for an even distribution of the load across them. The number of wheels used in the system is expected to be approximately 50, but this number can be reduced in the future as the design is optimized. This is a proprietary part sold by OpenBuilds. The Figure 21 [14] below, shows a photo of the Xtreme Solid V wheel assembly.

Figure 21: Xtreme Solid V Wheel Assembly

3.3.7 Electromagnet

This part is used in the extendable electromagnet device located in the payload. Its function is to attach to and allow for the fuel door to be opened. It has a maximum lifting force of 50N and draws a current of 0.33A at a voltage of 12V. The external dimensions of this part is 25mm x 20mm (diameter x length). Only one of this part is required and is sold by Amazon.ca and can be seen in Figure 22 [15].

Figure 22: Uxcell Electromagnet

3.3.8 Black Angle Corner Connector

This part is used to mount any two surfaces together at a 90 degree angle. It is milled from solid aluminum, giving it high strength and durability. Its external dimensions are 20x20x20 mm. It is used for two different purposes in the final system. Eight of them are used to connect the two V-slot support beams to the two Y-axis C-Beams and two of them are used to mount the Payload bottom plate to the Z-axis gantry plate. Mounting is done in conjunction with two 8mm M5 screws and two M5 T-nuts. This is a pre-machined part and is sold by Makerparts.ca. The Figure 23 [16] below shows a photo of the corner connector.

Figure 23: Black Angle Corner Connector

3.3.9 C-Beam End Mount

This part is used as the end mount for the C-Beam. Only two of these parts are required for the Z-axis. It is machined from a 12mm thick 6061 - T5 aluminum plate. It has seven holes drilled into it. The center hole is where the lead screw and its respective bearing sit. Four holes with counter bores in them are used to mount it to the end of the C-beam. The final two holes are pre-tapped and are used to mount the NEMA-23 stepper motor to the linear actuator. All mounting holes use M5 screws. It has external dimensions of 50x80 mm. This is a pre-machined part sold by OpenBuilds. The Figure 24 [17] below, shows a photo of the C-Beam end mount.

Figure 24: C Beam End Mount

3.3.10 Aluminum Spacers

These parts are used for spacing and standoff purposes. There are machined from aluminum with an outer diameter of 10mm and an inner diameter of 5mm, in order to house M5 screws. They come in different lengths. For the purposes of this system, lengths of 3mm, 6mm and 40mm will be used. The 3mm and 6mm spacers will be used for spacing the wheels appropriately on the C-Beam and the 40mm spacers will be used as standoffs for the NEMA-23 motors at the end of each linear actuator. The Figure 25 [18] below, shows a photo of aluminum spacers of different lengths.

Figure 25: Aluminum Spacers

3.3.11 Lock Collar

This part is used to lock the threaded rod ball bearing in place, on either side of each linear actuator. The locking shaft collar slips onto and fastens to the threaded rod using a set screw. Two of them are required for each linear actuator. It is made from steel with a black oxide finish and has an inner diameter of 8mm, outer diameter of 14mm and width of 7mm. The Figure 26 [19] below, shows a photo of the lock collar.

Figure 26: Lock Collar

3.3.12 Eccentric Spacers

This is a very significant part used to adjust the friction between the gantry plate and the C-Beam, as well as the ride. They are added to one side of a wheel set and allows for an adjustment range of approximately 0.79mm. Using this part allows the user to control how far into or out of the V-slot the wheel is. It is machined from stainless steel and has and length of 6mm. It has a bore through it of 5mm, to house an M5 screw. This bore, however is offset from the center of the part, and allows for this adjustment. It also has a rim on one side which sits inside a recess either on the gantry plate or a custom built plate. A 10mm flange is also present to provide a sturdy base for a stable wheel mount. The Figure 27 [20] below, shows a photo of the eccentric spacer.

Figure 27: Eccentric Spacer

3.3.13 Ball Bearing 688Z

This is a single row deep groove ball bearing with external dimensions of 8mm x 16mm x 5mm. It is used to support the threaded rod on either end of the C-Beam ends. It has a dynamic load rating of 1,600N and a static load rating of 710N, making it the ideal choice to be used in this application. Two of each is required per linear actuator; therefore 8 bearings in total are required for the system. The Figure 28 [21] below shows a photo of the ball bearing 688Z.

Figure 28: Ball Bearing 688z

3.3.14 Y-Support Plate Assembly (Custom Part)

A critical component of the mechanical design is the Y-Support plate. Two of these plates support the X-beam as it rides on the two Y-beams. The plate is designed to be machined from a quarter inch plate of 6061 aluminum with external dimensions of 0.4m x 0.23m, as shown in Figure 29. The detailed drawing for this part with all its dimensions can be found in Figure 43 in the Appendix.

The smaller rectangular plate is added to increase the stability of the motion of the Y-Support plate as it moves along the Y-beam. This design allows the part to hug the beam as it moves. The external dimensions of this plate are 166x6.35 x 116 mm. The detailed drawing for this part with all its dimensions can be found in Figure 44 in the Appendix.

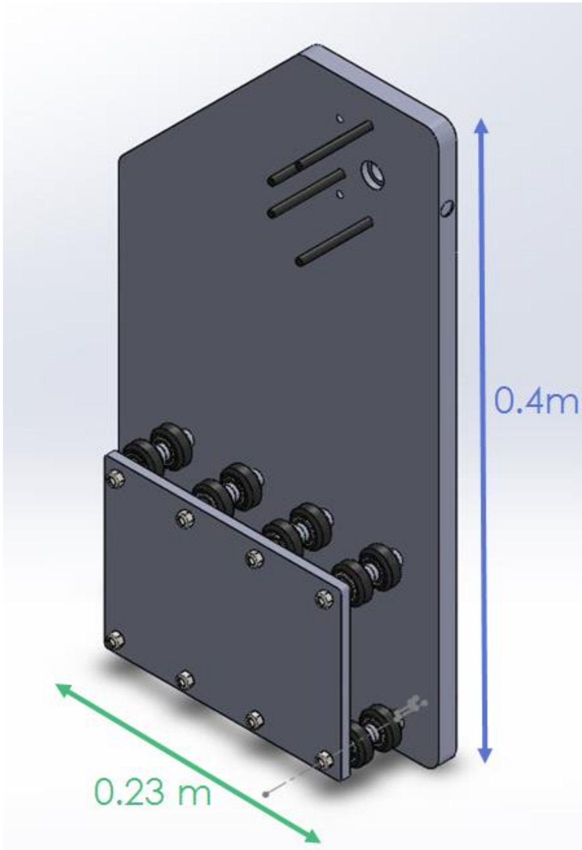

Figure 29: Y-Support Plate Assembly (Custom Part)

The weight of the payload acts on the system as shown in Figure 30. It creates a moment on the plate and a force downwards.

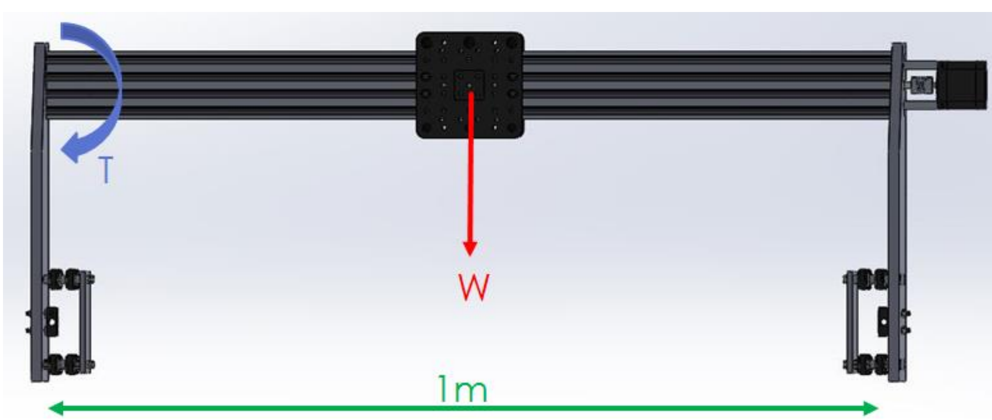

Figure 30: Free Body Diagram of X beam

The mass of 3-axis rail system is estimated to be approximately 10kg, which allows the payload to have a maximum mass of 20kg. This load is shared between the two plates equally. Therefore the max force and torque acting on the plate are -98N and 98Nm respectively. Refer to the equations below:

$$F_z = \frac{mg}{2} = \frac{20 \times 9.8}{2} = -98\ N \qquad T = F_z d = 98 \times 1 = 98\ Nm$$

3.4 Force Analysis on Y-Support Plate

This section focuses on running the Solidworks Force simulation on the Y-Support plate. This part is a critical component, since it carries the weight of the payload and the X-beam as it moves along the Y-beams. The results obtained will determine whether the component will fail under the applied loads requiring them to be redesigned. The force and moment used are the same as calculated in Section 3.3.15.

The test will include stress (N/m^2), strain, displacement (mm) and a factor of safety analysis. All the material properties used in this analysis are the ones stored in the Solidworks library. This part is machined using 6061-T6 Aluminum which has been tempered. It has a Yield strength of $275 \times 10^6\ N/m^2$ and an Elastic modulus of $6.9 \times 10^{10}\ N/m^2$. It also has a tensile strength of $310 \times 10^6\ N/m^2$. A solid curvature based mesh with the maximum mesh quality allowed by Solidworks was used for the analysis.

3.4.1 Von-mises Stress Analysis

Figure 31 below shows the results of the Von Mises stress analysis on the part.

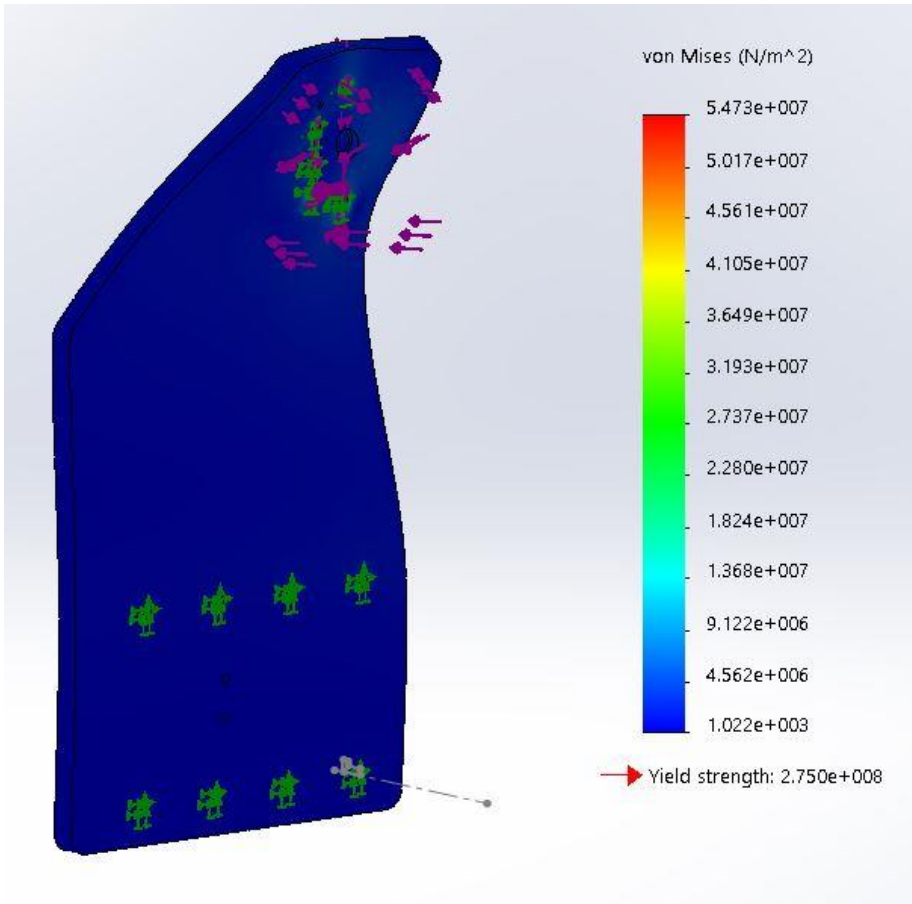

Figure 31: Von Mises stress analysis on Y-Support Plate

The maximum stress exerted on the part is around 5.473 x 10^7 N/m^2, which is well below the yield strength of the material. The larger forces are concentrated around the four X-beam mounting holes located at the top of the part.

3.4.2 Strain Analysis

Figure 32 below shows the results of the strain analysis on the part.

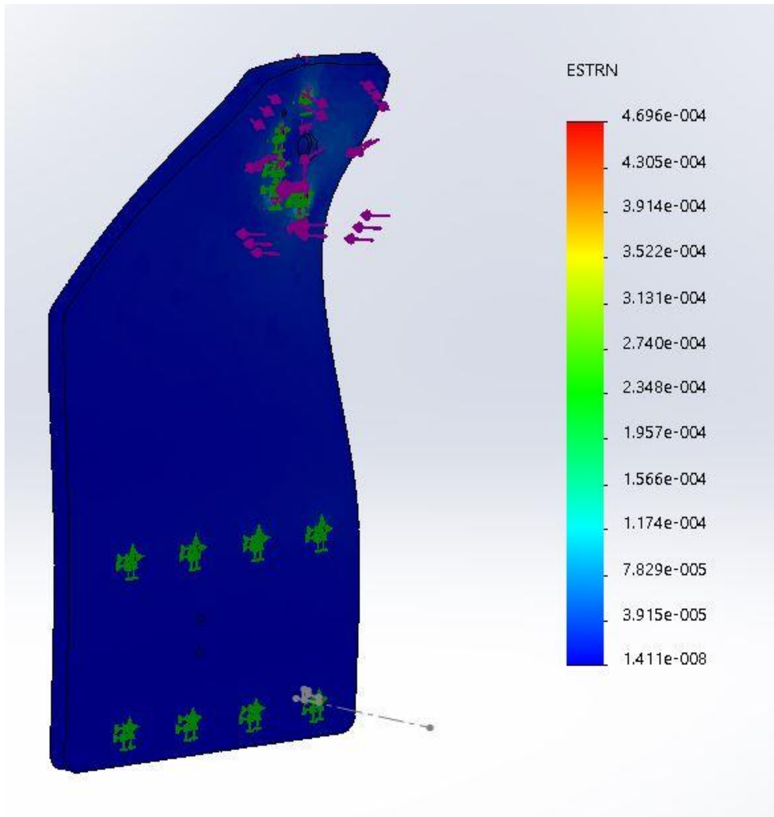

Figure 32: Strain analysis on Y-Support Plate

The maximum strain experienced by the part is approximately 4.696 x 10^{-4}, and is again mainly around the mounting holes. This is a very small number and will not cause failure.

3.4.3 Displacement Analysis

Figure 33 below shows the results of the displacement analysis on the part.

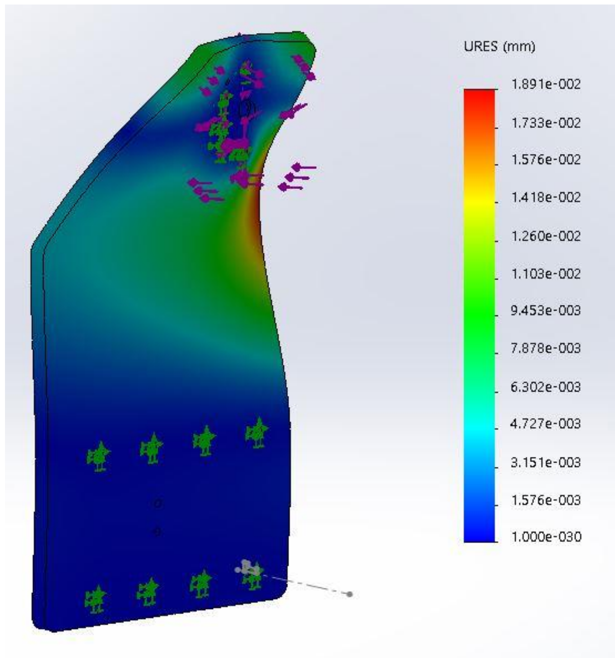

Figure 33: Displacement analysis on Y-Support Plate

The maximum displacement of the part relative to the center is 1.891×10^{-2} mm. It occurs at top rear section of the part and is as expected since the force downwards and the moment acts at the 4 mounting holes. This is again a very small number and is negligible

3.4.4 Factor of Safety Analysis

Figure 34 below shows the results of the displacement analysis on the part.

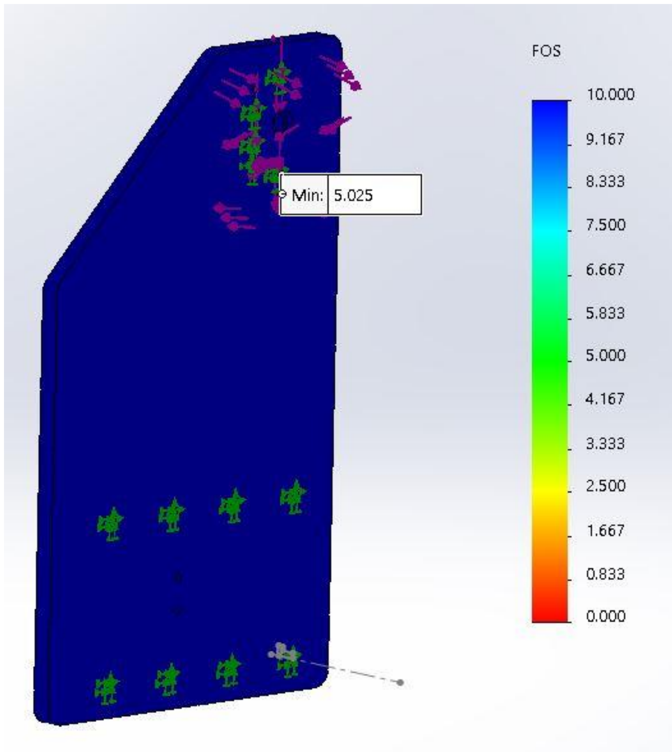

Figure 34: Factor of Safety analysis on Y-Support Plate

Based on the results of the FOS analysis, the minimum factor of safety is calculated to be 5.025. The critical point is again the four mounting holes at the top. This is a good value and further ensures that the part will not fail. This calculation is acquired by the following formula:

$$SF = \frac{\sigma_{max}}{\sigma_y} = 5$$

According to the results obtained from the force simulation, it can be concluded that the Y-Support plate is appropriately designed for its function and will not fail during the operation of the machine.

4.0 Electrical Design

In Figure 35, is a chart that outlines the components that need to be selected for the project and how they communicate with one another. The first main component is the PC which does handles majority of the communications to help control the linear rails. Image processing, and end effector. First, the PC communicates with the webcam to capture images so that the PC can perform image processing to find the fuel door cover and the LEDs help ensure that there is a constant illumination on the fuel door to make image processing easier. The second communication is sending signals to the motor controller. Based on the communication, the motor controller controls the motor axes to move the system on the linear rails. Lastly, the PC indirectly controls the end effector by communicating with microcontroller and this microcontroller actually handles how the end effector operates. Based on what function the system needs to operate, it can control the extendable electromagnet to open/close fuel doors and signal to the motor control to either use the gripper to remove the fuel cap or the fuel nozzle to insert the nozzle. The last component is the ultrasonic which is used to let the system know how far the car is and this communicated to the microcontroller.

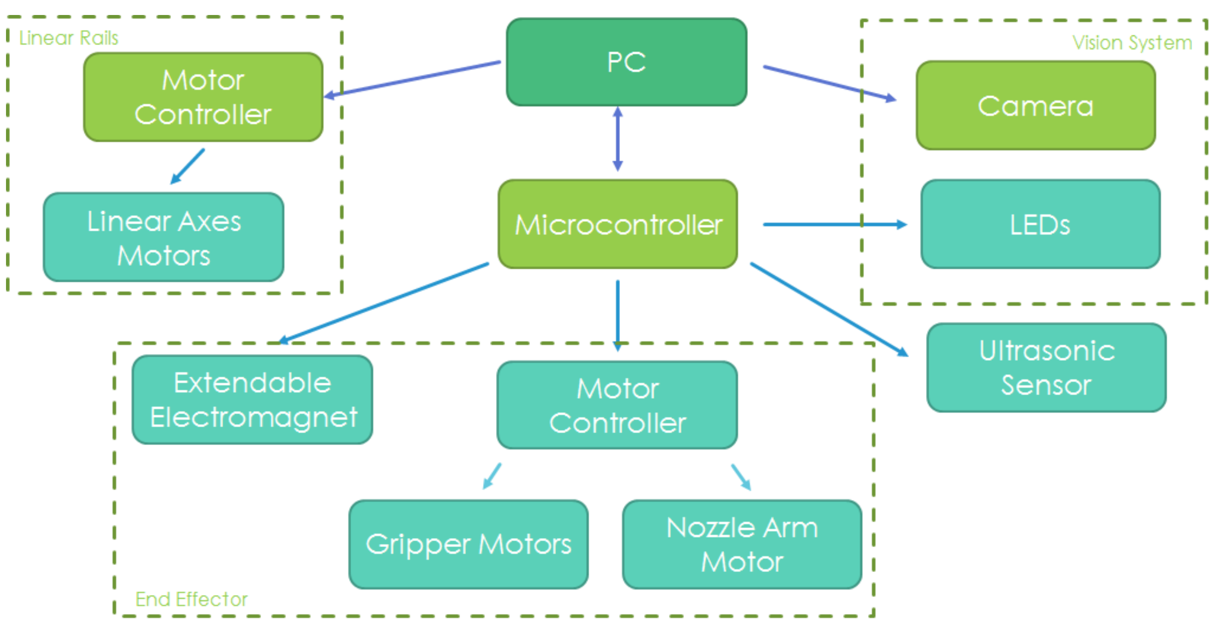

Figure 35: Components Required

4.1 Torque Calculations

Before selecting any of the components, the torque requirements need to be calculated for the linear rail motors to ensure that the system can move on the rails. The torque requirements need to be calculated for the X, Z and Y beam due to the fact that all the beams don't have the same values for the calculations. This can be seen in Table 4 below, which also summarizes the values that are used for the torque calculations.

	X Beam	Z Beam	Y Beam
Mass of Payload (kg)	20		
Dwell Time (s)	0.5		
Time (s)	5		
Length (m)	1	0.5	0.5
Peak Velocity (m/s)	0.2	0.1	0.1
Pitch of Lead screw (mm)	8		
Total Reflected Inertia	2.55×10^{-3} kgm^2		
Screw Efficiency	85%		
Angular Acceleration	141.3	70.65	70.65

Table 4: Torque Calculation Values

The torque required to accelerate the payload across the beams can be found the formula:

$$T_a = J_t \times \alpha + \frac{cos\emptyset mg\mu \times p}{2\pi \times \eta} + \frac{sin\emptyset mg \times p}{2\pi \times \eta}$$

The deceleration torque is the negative of the acceleration torque. The torque to overcome gravity is represented by the third term in the formula above and the torque to overcome friction is the second term. These four values of torque were found for all three beams and are summarized in Table 5 below.

Torque (Nm)	X beam	Z beam	Y beam
Torque to overcome friction	0		
Torque to overcome gravity	0.4411		
Acceleration Torque	0.4479	0.4445	0.4445
Deceleration Torque	-0.4479	-0.4445	-0.4445

Table 5: 4 values of Torque on each beam

Next a velocity profile is chosen for the motor. Motors have two velocity profiles, triangular and trapezoidal. The payload will move at low speeds, so a trapezoidal profile is chosen and can be seen in Figure 35 [22].

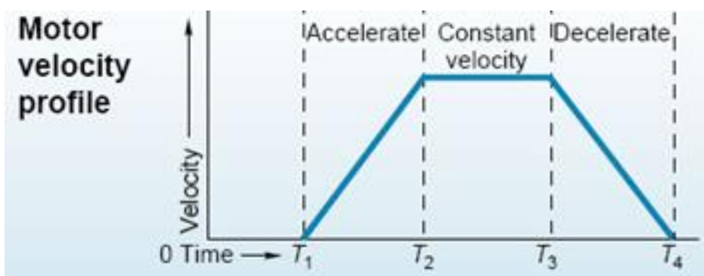

Figure 36: Trapezoidal Velocity Profile of Motor

In this profile it can be seen that the payload goes through different velocities of acceleration, constant and deceleration. This allows means that different torque values occur during this motion, so a constant torque value has to be found. The constant torque can be found by the RMS torque formula below.

$$T_{rms} = \sqrt{\frac{t_1 T_a^2 + t_2 T_d^2 + t_3 T_g^2}{5.5}}$$

The RMS torque values are summarized in Table 6 below. So the motors that are selected for the linear rails need to exceed 0.3 NM in order to move the payload.

	X Beam	Z Beam	Y Beam
RMS Torque (Nm)	0.2833	0.2818	0.2818

Table 6: RMS Torque for each beam

4.2 Component Selection

In the previous section, the motor torque requirement were found to be greater than 0.28 Nm. Based on this torque, 4 NEMA 23 Stepper Motors were selected. A NEMA 23 Stepper Motor has a torque of 1.26 Nm, which is greater than the torque requirement and will be able to move the payload. The selected motor led to choosing CNC xPro V2 Stepper Motor Driver for the linear axis motor controller because it has a 12 V operating voltage, which can run the motors that require 12 Volts. The controller has 4 channels for the motors, where one of them can be a slave, which means that one of the motor can be following another motor, so only 3 motors need to be programmed. This is helpful since the Y beam uses two motors to move the payload, so one can be used as the slave to follow the other. Another feature is that it provides 12 and 5 volts for powering peripherals if required.

For the microcontroller, an Arduino Mega is being used. The advantages of using this microcontroller are that there is large community support, so there are a lot of resources available. Also, there are a high number of IO ports. Next is the motor controller for the end effector, which is selected to be the VHN2SP30-E based motor drive for its high current capabilities. These are the controllers for the system.

On the end effector, a motor is required for the nozzle, gripper princer and gripper rotation. A NEMA 23 is selected for the nozzle motor because it has high torque to handle the arm weight and a NEMA 17 for the rotation of the gripper because it provides high enough torque to unscrew the fuel cap. Finally the gripper princer uses a geared DC motor.

The end effector also has an arm that is used to open the fuel door. This accomplished by the system by using an Uxcell electromagnet to open the fuel door because of 12 V operating voltage and it has 50 N lifting force, which can lift the fuel door and was confirmed by using the magnet on an actuator to open a fuel door. The electromagnet is attached to a L16 P linear actuator, so that the magnet can be extended forward to open the fuel door and the actuator has 10 cm of extension.

The image processing will be done by using a Logitech C310 webcam because it can easily interface with the PC and has 5 MP resolution to get good quality pictures for the image processing. In order to provide a constant illumination to the cars for the image processing, 5 mm white LEDs are selected. Also, a HC-SR04 ultrasonic is selected to detect how far cars are because it is easy to work with and it has a 2 cm - 500 cm range that works in the work space. The components selected are summarized in Table 7 below.

Purpose	**Component**
Linear Axis Motor	NEMA 23 Stepper Motor
Linear Axis Motor Controller	CNC xPro V2 Stepper Motor Driver
Microcontroller	Arduino Mega
End Effector Motor Controller	VNH2SP30-E based motor driver
Nozzle Motor	Nema 23
Gripper Rotation Motor	Nema 17
Gripper Princer Motor	Geared DC motor
Ultrasonic Sensor	HC-SRO4
Webcam	Logitech c310
Lights	5 mm white LEDS
Electromagnet	Uxcell
Linear Actuator	L16-P linear actuator

Table 7: Electrical Components Selection

4.3 Power and Current Calculations

The only competent not chosen in the previous section was the power supply unit that is required to power the system. Since all the other components have been selected in the previous section, the power and current drawn has to be calculated to help decide what power supply unit to use. Summarized in Table 8 below are the power consumption and current drawn for each component.

Component	**Power**	**Current**
Nema 23 Stepper Motors	(12 V x 2.8 A) = **33.6 W [23]**	**2.8 A [23]**
Nema 17 Stepper Motors	(12 V x 1.68 A) = **20.2 W [24]**	**1.68 A [24]**
Geared DC Motor	(12 V x 150 mA) = **1.8 W [25]**	**150 mA [25]**
HC-SR04 Ultrasonic Sensor	(5 V x 15 mA) = **0.075 W [26]**	**15 mA [26]**
Uxcell Electromagnet	(12 V x 0.33 A) = **3.96 W [15]**	**0.33 A [15]**
L16-P Linear Actuator	(12 V x 650 mA) = **7.8 W [27]**	**650 mA [27]**
LEDs	(3.3 V x 30 mA) = **0.099 W [28]**	**30 mA [28]**

Table 8: Power and Currents of Electrical Components

From Table 8, it can be seen that the biggest power consuming components are the Nema 23 and Nema 17 motors. The peak power that system will endure will occur when 5 Nema 23 motors are operating at maximum load and the Nema 17. The total power consumption is 202.83 W and the current drawn is 17.125 A. The power consumption and current drawn takes into account that the system uses 5 Nema 23 motors and 10 LEDs. So the power supply unit needs to exceed 202.83 watts to power the system. Based on the power consumption, an ATX PSU called CoolMax 14800 was chosen. CoolMax 14800 provides 12 V at 400 W, which exceeds the power consumption that was calculated. Also, it can provide 3.3 and 5 volts, which can be used to power the electronics. The connection of the power supply to the motors and motor board is shown in the Figure 37 [29] below.

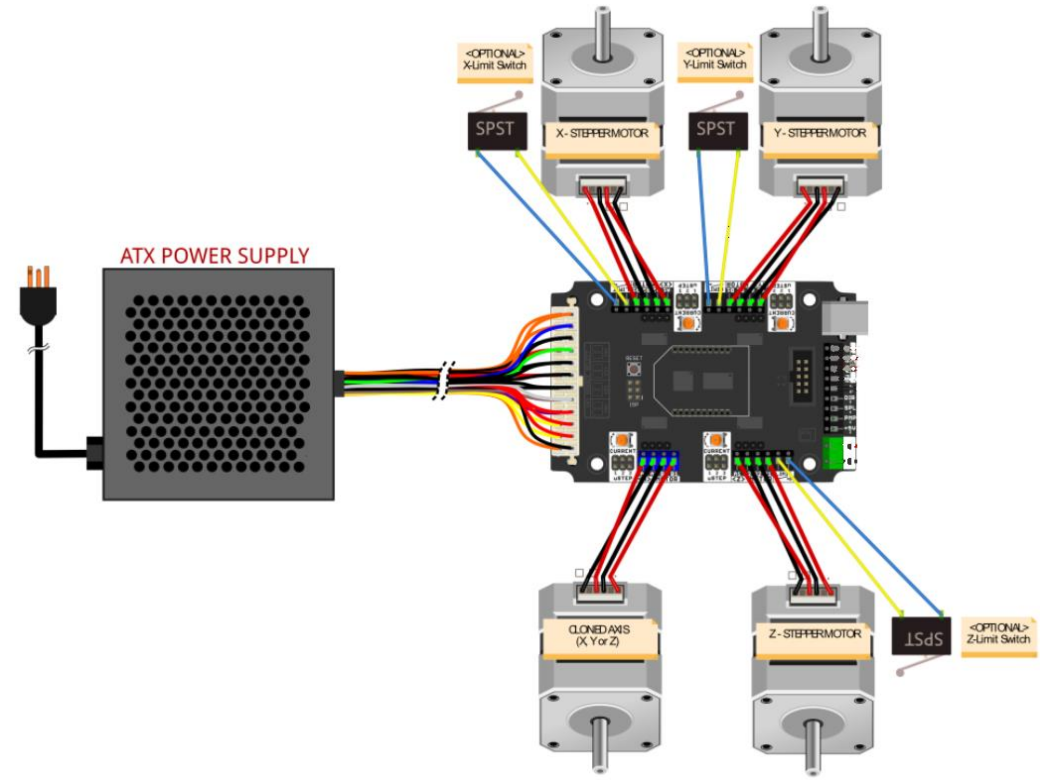

Figure 37: Wiring of PSU and Motors to Motor Controller

5.0 Software Design

The section focuses on the image processing, showing the general structure and fuel door detection. Prototype screens of the user interface are also displayed.

5.1 General Structure

The overall structure of the system is broken down into two tiers, as seen in Figure 35. The highest level is responsible for the main flow of the system. This includes the image processing for location the fuel door, communication with the user through the mobile app, as well as the motion of the end effector on the rails. The second tier, which is the microcontroller, is responsible for interfacing the various sensors and actuators with the main system. This involves the components on the end effector, as well as the ultrasonic sensors and lighting.

The general structure of the software is designed around this hierarchy and relies heavily on the communication between the main computer and the microcontroller. An overview of the program flowchart can be seen in Figure 38.

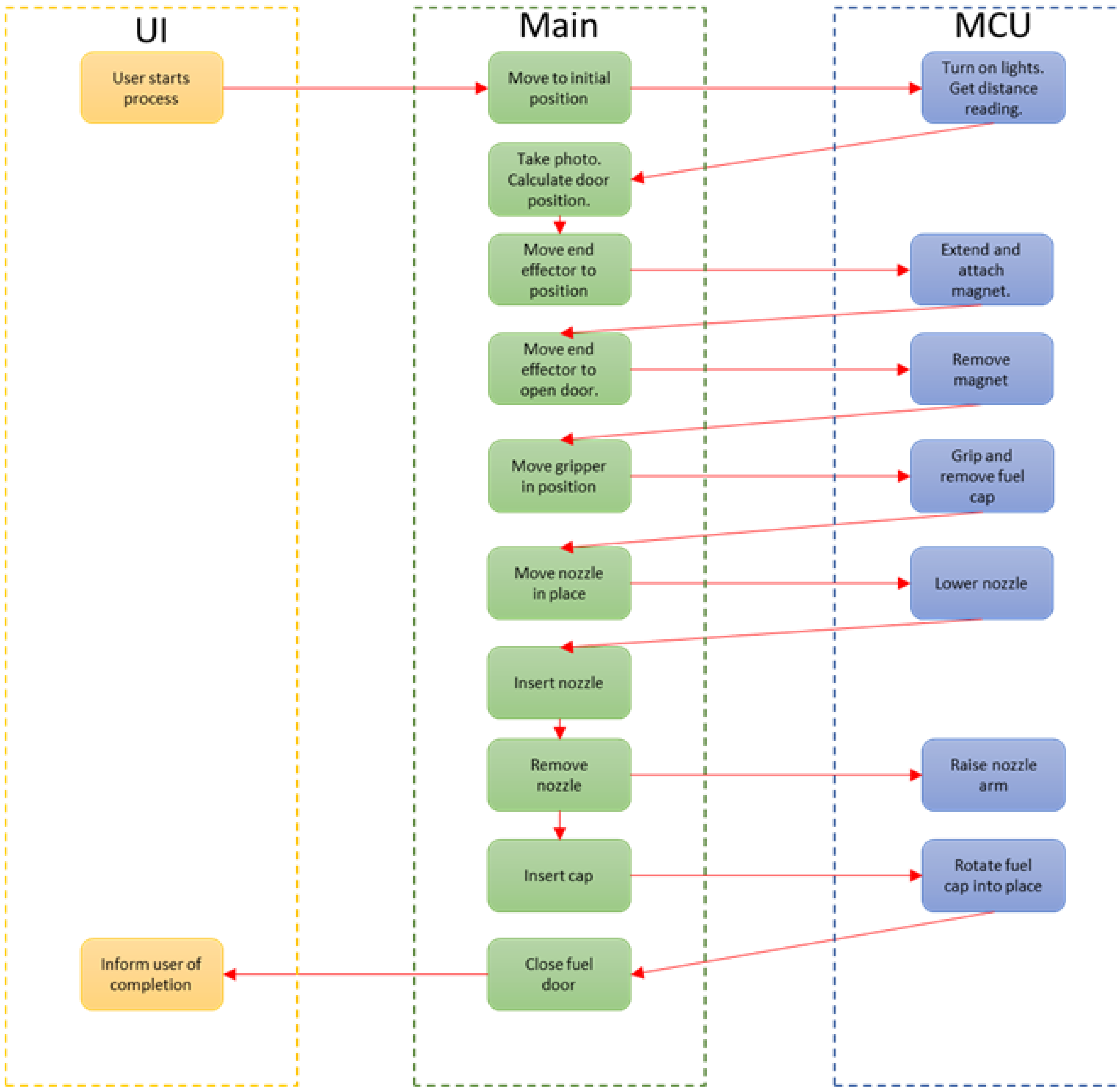

Figure 38: General Flow of the program

5.2 Fuel Door Detection

Once the user has started the refuelling process, and the end effector is moved to the general location of the fuel door, the exact location can be determined using image processing. For this project, OpenCV is the chosen library to handle computer vision.

OpenCV is an open-source computer vision library that can be used on multiple platforms. The image processing in this project is done in C++ on a personal computer.

In order to locate the fuel door, a snapshot of the image is taken through the web camera. The processing is done on this still image, rather than a stream of frames. The captured image is then thresholded and masked to detect sharp changes in contrast, which provides the outline of the fuel door. The center of this shape can then be determined. Figure 39 shows an example of the captured and thresholded images.

Figure 39: Original and processed images showing outline of fuel door

Once the door has been located on the image, the pixel position can be converted to a position in global workspace. There are three main steps for doing this.

The first step is to convert the pixel position on the image into a position on the camera's sensor plane. Equations 1 and 2 define the relationship between the two points.

$$u = \frac{(i)(px)(fi - w)}{fi} \qquad \textbf{(1)}$$

$$v = \frac{(j)(py)(fi - w)}{fi} \qquad \textbf{(2)}$$

$where:$
$i = pixel\ position\ in\ x - direction$
$j = pixel\ position\ in\ y - direction$
$px = pixel\ width$
$py = pixel\ height$
$fi = focal\ length\ of\ camera$
$w = distance\ of\ the\ point\ to\ the\ image\ plane$
$u = position\ in\ the\ x - direction\ on\ the\ sensor\ plane$
$v = position\ in\ the\ y - direction\ on\ the\ sensor\ plane$

Once the point is known on the camera's sensor plane, it can be transformed to the global frame to get the position with respect to a known point, as shown by Equation 3 below.

$$[p^0] = [T][p^s] \qquad \textbf{(3)}$$

$where:$
$[p^o]\ is\ the\ coordinate\ in\ the\ global\ frame$
$[T] is\ the\ tranformation\ matrix\ from\ the\ global\ frame\ to\ the\ sensor\ frame$
$[p^s] is\ the\ position\ in\ the\ sensor\ frame.$

5.3 User Interface

The user’s interaction with the system is enabled through a mobile-app. From the user’s perspective, whole process flow starts and ends with the mobile-app, as he is close by the system he opens the app and starts the process and when the process is done, he closes the app and get back on his way.

The features include,

- Displaying the car information and checking if it’s correct with the user
- Prompting the user to do the safety checks
- Processing user’s payment option and method selections
- Entering the fuel type
- Showing a real-time status screen while refuelling
- Telling the user when the fuelling and the disconnection is done and let them call for assistance if required

The main focus of the user interface is to create an easy to use and fluent experience while minimizing the time spent using the app. The process flow along with the designed screens is shown below, in Figure 40.

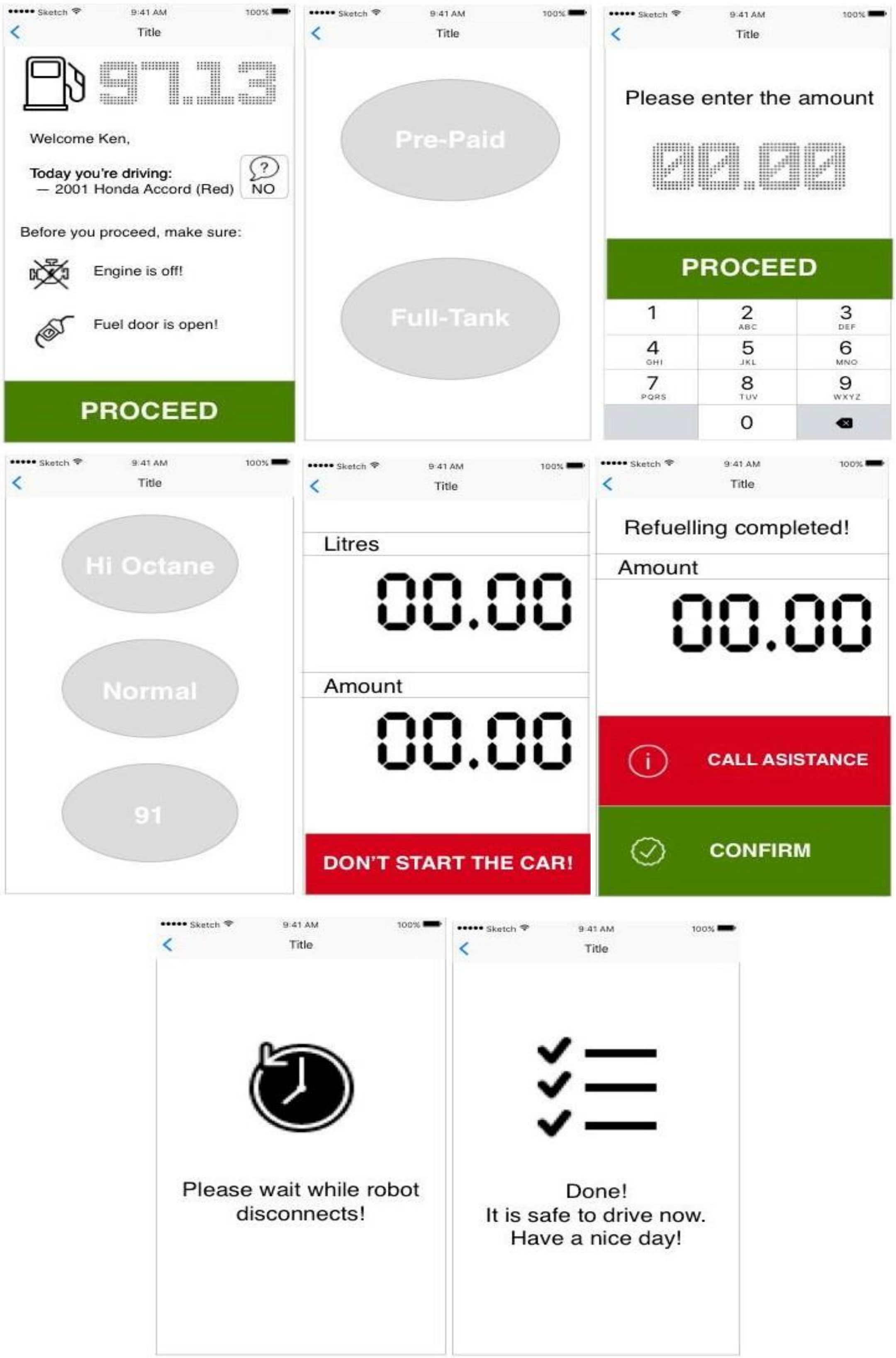

Figure 40: Screenshots of app for user interface

6.0 Design Review

The detailed design was explained in the previous sections, with the selection of the components and analysis of the system. Now the design has to be checked if it meets the design objectives and constraints that were outlined in Sections 1.3 and 1.5 respectively.

For the objectives, the project is able to meet all of them. The system is able to locate the a fuel door using image processing, open/close a fuel door with the electromagnet, remove/replace the fuel cap using the gripper and insert/remove the fuel nozzle.

The most important thing is that the design should meet the criteria that were outlined; otherwise the proposed solution needs to be changed. The first criteria was the ease of implementation, which is easily met by the system as it is constructed using linear rails and from the solid work renderings it can be seen that there isn't that much complexity. For the percentage of vehicles accommodated, an end effector was used that has the tools required to work on the scope that was outlined. The electromagnet is able to work on vehicles with metallic fuel covers and open them. The gripper is able to grasp the fuel cap and rotate it up. Also, the system can work on cars with rectangular or circular fuel doors, which can be seen by the image processing results as the system can detect circular or rectangular contours.

The image processing also shows that the positioning system is accurate and reliable since it's able to detect the fuel doors and be able to know where they are. So the three main criteria are met. As for the minimum processing time, an estimate can be made and not match the actual performance. The calculations for this can be seen in section and it can be seen that this criteria is also met.

From Section 4, the total amount the group spent is $1327.47 and within budget, with the total being under $2000. This means the design maximizes cost efficiency currently unless unexpected costs occur. Finally, the mass of the system is 27.25 kg and is less than the 30 kg constraint that was placed on the system. So the system is minimizes mass and meet the criteria. It should also be noticed that a conservative weight of 20 kg was used for the payload and can change when actually made, so the mass can further decrease or increase. Overall, the system meets all the objectives and criteria that were outlined in the project.

7.0 Expected Performance

The expected performance of the design is decided by two tasks, location of the fuel door and completion time. In the previous sections it can be seen that the image processing does a good job of locating the fuel door and the same results can be expected for the actual performance. The completion time has to be calculated and is done in this section.

In Section 3.2.2.1, a conservative time of 5 seconds was used to calculate the torque requirements for how long it would take to go across each linear rail. Based on a worst case scenario that the system needs to travel the full lengths of the x, y and z beam and the 5 seconds dwell time of each motor, the movement time of the system is 30 seconds.

The finding the location of the fuel door involves image processing and transformation calculations. The image processing time was found by timing the process several times and the average time was found to be 2.4 seconds. A buffer was added to increase the time to 5 seconds. The same was done with the transformation calculations, which took 5 seconds. This gives locating the fuel door a total time of 10 seconds.

Next is the opening of the door and the timing for this can be used for closing the door. This value was calculated based on how long it takes the linear actuator to extend to its full length. The actuator has a speed of 15 mm/s [38] when a load is attached, so in order to extend to 10 cm it would take 6.67 seconds. A buffer of 10 seconds is added to this time to take into account the turning on of the electromagnet and other processes occurring during this operation. So the opening of the fuel door and closing the door will take a total time of 33.34 seconds.

The inserting/removal of the nozzle and the removing/replacing of the fuel cap are controlled by motors. So the timing for these two tasks will be based on the performance of the motors. The nozzle motor is given a speed of 10 rpm and the fuel cap motor is given a speed of 20 rpm, which ensures that there is control over the motors. For the movement of the nozzle it needs to turn up to 135 degrees, which is 0.375 revolutions, and doesn't require making a full half circle movement. Multiplying 0.375 revolutions by the rpm and converting into seconds, a time of 2.25 seconds is given and a 5 seconds buffer is added. So the total time for inserting and removing the nozzle is 14.5 seconds. The removal of the fuel cap involves 4 revs and based on this a total time of 12 seconds is found for the removal of the fuel cap. The replacing of the fuel cap is also 12 seconds.

An additional buffer of 1 minute is added to the completion time to take into account other tasks that need to be performed. So the total expected completion time of the system is 2 mins and 52 seconds. The completion time that was found is less than the 3.5 minutes stated in the constraints. This time can increase even though buffers were added during the time calculations, but it should still stay below 3.5 minutes as the expected time right now isn't very close to that value in the present.

8.0 Schedule and Budget

This section discusses the timeline for the project with all the important dates and milestones. It also calculates the total cost of the components and compares it with the initial budget set.

8.1 Schedule for manufacturing, commissioning and testing

The project started in early September with doing research in various fields to come up with a solid idea and several brainstorming sessions were held to identify the best idea, which was found to be the automated refuelling system. In order to confirm that the idea was a problem solver, we spent some time for validation, conducting surveys and doing market research. In early October, our mechanical design period started and in late November it's finalized and the required parts are ordered. Throughout November, the electrical design is completed and the ordered parts are started to being assembled, this process will end in late December. After we have our mechanical system functioning, for the rest of the time, till the mid-March, we are expecting to focus on the software, integration, calibration and testing. Figure 40 provides a visual insight of the project timeline.

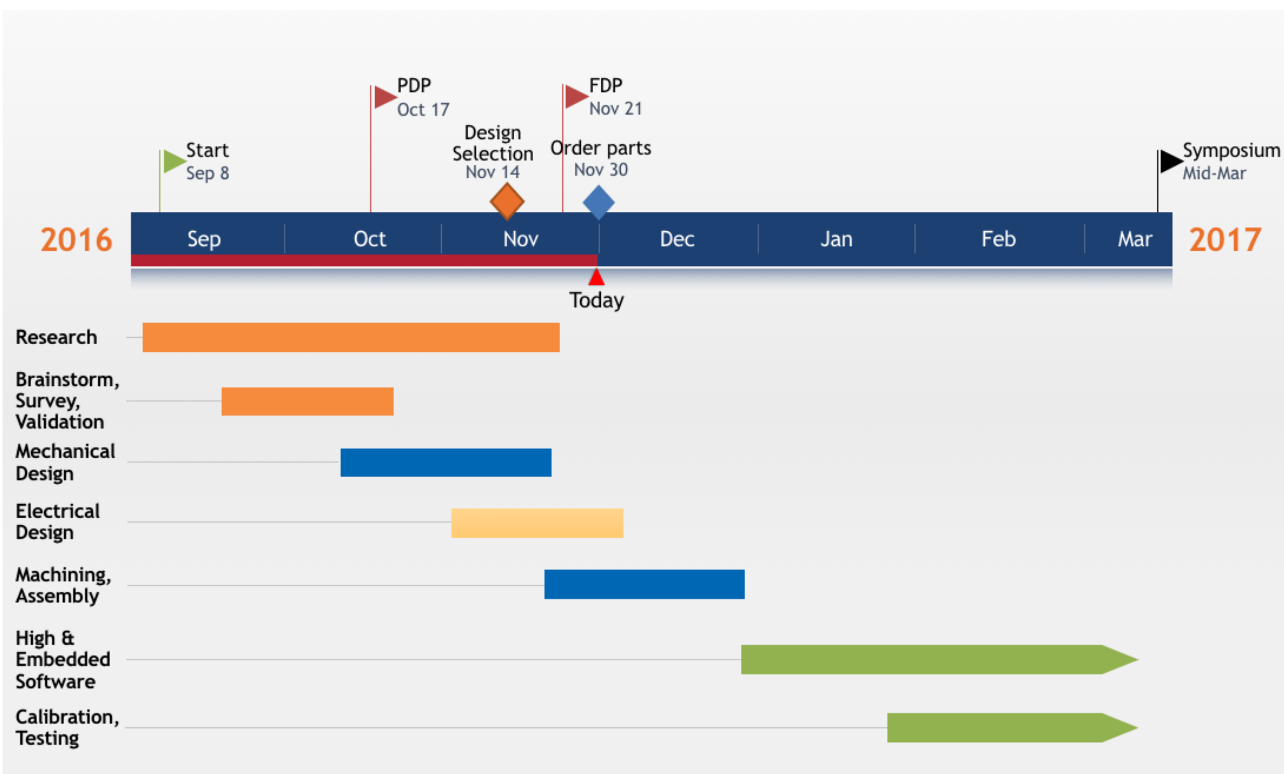

Figure 41: Project Timeline

8.2 Budget

The cost of all the components mentioned in this report required for the project are summarized in Table 9 below and the total cost has been calculated. Most of the parts in this table have already been ordered.

Component	Unit Price ($)	Quantity Needed	Cost ($)
Nema 23	32.58 [23]	5	162.90
Nema 17	23.27 [24]	1	23.27
Geared DC motor	6.15 [25]	1	6.15
CNC xPRO V2 Stepper Motor Driver	172.85 [29]	1	172.85
Arduino Mega	57.09 [30]	1	57.09
VNH2SP30-E based motor driver	3.94 [31]	1	3.94
HC-SR04	3.59 [26]	1	3.59
Logitech c310	52.56 [32]	1	52.56
5 mm white leds	1.87 (40 pack) [28]	10	1.87
MakeBlock Robot Gripper	34.99 [8]	1	34.99
Uxcell	12.19 [15]	1	12.19
L16-P linear actuator	102.56 [27]	1	102.56
C beam Linear Rails 500 mm	18.62 [9]	3	55.86
C beam Linear Rails 1000 mm	37.23 [9]	1	37.23
Threaded Rods 500 mm	27.59 [11]	3	82.77
Threaded Rods 1000 mm	41.89 [11]	1	41.89
Flexible Motor Coupling	9.11 [12]	5	45.55
Locking Collar	1.20 [19]	8	9.60
Linear Rail Bearing	1.33 [21]	8	10.64

C beam end mount	11.66 [17]	2	23.32
Black Angle Corner	3.66 [16]	10	36.60
C Beam Gantry Plate X large	9.92 [10]	3	29.76
Tee nuts	6.58 (25 pack)	20	6.58
Hex nuts	0.15 [33]	54	8.1
Xtreme Solid V Wheel	2.17 [34]	54	117.18
Jog Knob	6.58 [35]	1	6.58
Spring Loaded T nuts	1.60 [36]	4	6.4
6 mm spacers	0.27 [18]	47	12.69
3 mm spacers	0.20 [18]	30	6
40 mm spacers	0.73 [18]	8	5.84
Eccentric Spacers	2.66 [20]	17	45.22
Anti-backlash nut block	13.10 [13]	4	52.40
Precision Shims	0.33 [37]	10	3.3
Y Plates	25	2	50
Total Cost			**$1327.47**

Table 9: Component Cost

The total cost of all components comes out to be $1327.47 and is less the $2000 budget that has been set for this project.

9.0 Conclusions and Recommendations

The mechanical design of the proposed solution consists of a 3 axis linear rail system that is made from C beams. The electrical design includes the selection of stepper motors, power supply unit and other electrical components that are required for the system. The software design uses image processing for detecting the shape of the fuel door cover and an app for the user to interact with.

The system is able to meet the objectives and criteria that are outlined in the report. The expected performance of the design meets the standards of being able to have a complete process time under 3.5 minutes and be able to locate the fuel door using image processing.

Some recommendations in order to improve the design and efficiency of the system involve critical thinking about different methods for each task, if it fails during testing. The next steps that need to be taken are to machine the Y plates for the system and start assembling the 3 axis rail system. Then the electronics should be integrated with the system and the basic functionality should be tested. After this, more detailed testing should be done to polish the image processing and correct any mistakes in the mechanical, electrical or software side.

10.0 Teamwork effort

The project was broken into four main areas, and each of the team members were given responsibility of one of them. This was determined by their skills and general area of interest.

Ben Mendis

Ben has some prior experience in designing electromechanical systems through co-op. He is in charge of mechanical design and analysis of the system. Ben will be leading the construction of the system once all components are received.

Jasdeep Dhillon

Jasdeep was responsible for most of the electrical aspects of the systems, and acted as a bridge between the mechanical and the electrical systems of the design. He was also in charge of the component selection and ordering.

Ahmed Syed

Ahmed has worked in software for most of his work terms. He is charge of the low level systems, and interfacing the embedded components of the system with the main software system. He is also responsible for the image processing required for fuel door detection.

Atakan Kanman

Atakan is in charge of the main software system. This includes the user interface application, and the main controls software required for managing the main tasks of the system. Atakan will also be sharing the responsibility for the image processing system with Ahmed.

11.0 References

[1] https://www.google.com/patents/EP2053015A1?cl=en

[2] https://patents.google.com/patent/US5609190A/en

[3]https://www.google.com/patents/US8393362?dq=US8393362+B1&hl=en&sa=X&ved=0ahUKEwiz4LLh-eDPAhUM4YMKHYLlDUcQ6AEIHjAA

[4]https://www.google.ca/patents/US3169407?dq=3169407&hl=en&sa=X&ved=0ahUKEwjqjdSXp93QAhVK8WMKHdgGDEMQ6AEIHTAA

[5]https://www.google.ca/patents/US20140265401?dq=robotiq+2014&hl=en&sa=X&ved=0ahUKEwiQ_raxp93QAhVJ4WMKHfmICMgQ6AEINDAD

[6]https://www.google.ca/patents/US6237647?dq=william+pong&hl=en&sa=X&ved=0ahUKEwim27DBp93QAhUBT2MKHYBCAyUQ6AEITjAH

[7] http://openbuildspartstore.com/c-beam-linear-actuator-bundle/

[8] http://www.makeblock.com/robot-gripper/

[9] http://openbuildspartstore.com/c-beam-linear-rail/

[10] http://openbuildspartstore.com/c-beam-gantry-plate-xlarge/

[11] http://openbuildspartstore.com/8mm-metric-acme-lead-screw/

[12] http://openbuildspartstore.com/1-4-x-8mm-flexible-coupling/

[13] http://openbuildspartstore.com/anti-backlash-nut-block-for-8mm-metric-acme-lead-screw/

[14] http://openbuildspartstore.com/xtreme-solid-v-wheel-kit/

[15] https://www.amazon.com/a13120300ux0142-Connector-Electromagnet-Solenoid-Holding/dp/B00HR8M4QQ

[16] https://makerparts.ca/products/black-angle-corner-connector?variant=6660975876

[17] http://openbuildspartstore.com/c-beam-end-mount/

[18] http://openbuildspartstore.com/aluminum-spacers/

[19] http://openbuildspartstore.com/lock-collar/

[20] http://openbuildspartstore.com/eccentric-spacer/

[21] http://openbuildspartstore.com/ball-bearing-688z-8x16x5/

[22] http://machinedesign.com/motorsdrives/how-pick-motors-linear-motion

[23] http://openbuildspartstore.com/nema-23-stepper-motor/

[24] http://openbuildspartstore.com/nema-17-stepper-motor/\

[25] http://www.banggood.com/N20-DC-Gear-Motor-Miniature-High-Torque-Electric-Gear-Box-Motor-p-924377.html

[26] https://www.amazon.ca/niceEshop-Ultrasonic-Distance-Measuring-Sensor/dp/B00F167T2A/ref=sr_1_4?ie=UTF8&qid=1480946710&sr=8-4&keywords=hc-sr04

[27] http://www.robotshop.com/ca/en/linear-actuator-l16-100-150-12-p.html

[28] https://www.amazon.ca/SODIAL-White-Round-Emitting-Diodes/dp/B00V4Q8OAC/ref=sr_1_3?ie=UTF8&qid=1480947461&sr=8-3&keywords=5mm+white+leds

[29] http://openbuildspartstore.com/cnc-xpro-v3-controller-stepper-driver/

[30] http://www.canadarobotix.com/arduino-microcontroller/arduino-mega-2560-3

[31] http://www.ebay.ca/itm/Mini-VNH2SP30-Stepper-Motor-Driver-Monster-Moto-Shield-module-30A-For-Arduino/161297896765?_trksid=p2047675.c100011.m1850&_trkparms=aid%3D222007%26algo%3DSIC.MBE%26ao%3D1%26asc%3D39923%26meid%3D2503ac69115449e79f5d0495bc426dd9%26pid%3D100011%26rk%3D3%26rkt%3D10%26mehot%3Dag%26sd%3D310780916584

[32] https://www.amazon.ca/Logitech-960-000585-HD-Webcam-C310/dp/B003LVZO8S/ref=sr_1_1?ie=UTF8&qid=1480946737&sr=8-1&keywords=logitech+c310

[33] https://makerparts.ca/cart

[34] https://www.aliexpress.com/item/Strong-Solid-Derlin-V-Wheel-Kit-for-Openbuilds-V-Slot-rail-OX-CNC-V-Slot-solid/32315153844.html?spm=2114.13010608.0.0.oWU1CO

[35] http://openbuildspartstore.com/jog-knob/

[36] http://openbuildspartstore.com/spring-loaded-tee-nuts/

[37] http://openbuildspartstore.com/precision-shim-10x5x1mm/

[38] http://www.actuonix.com/L16-Linear-Actuators-p/l16-p.htm

Appendix

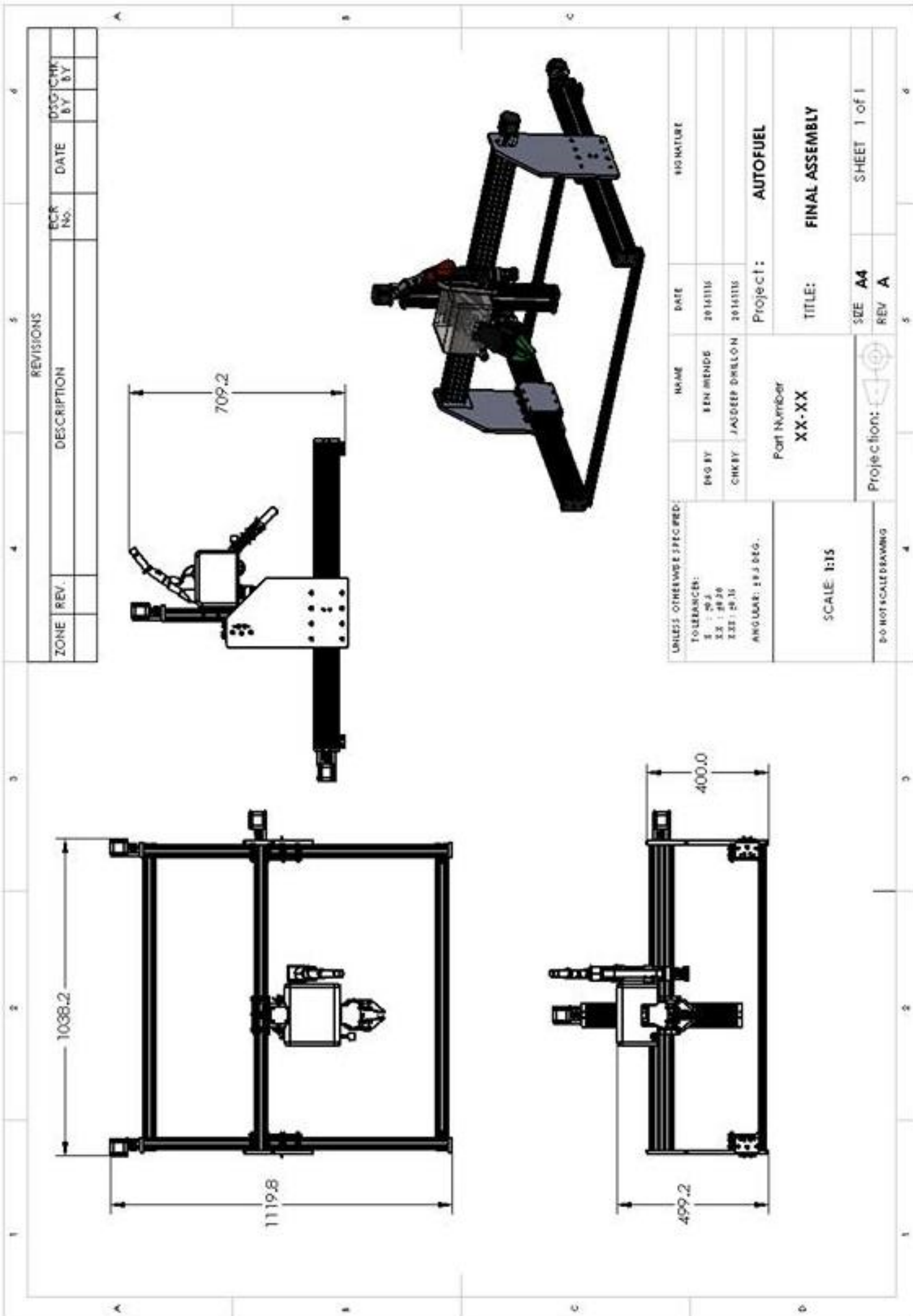

Figure 42: Detailed Drawing of Final Assembly

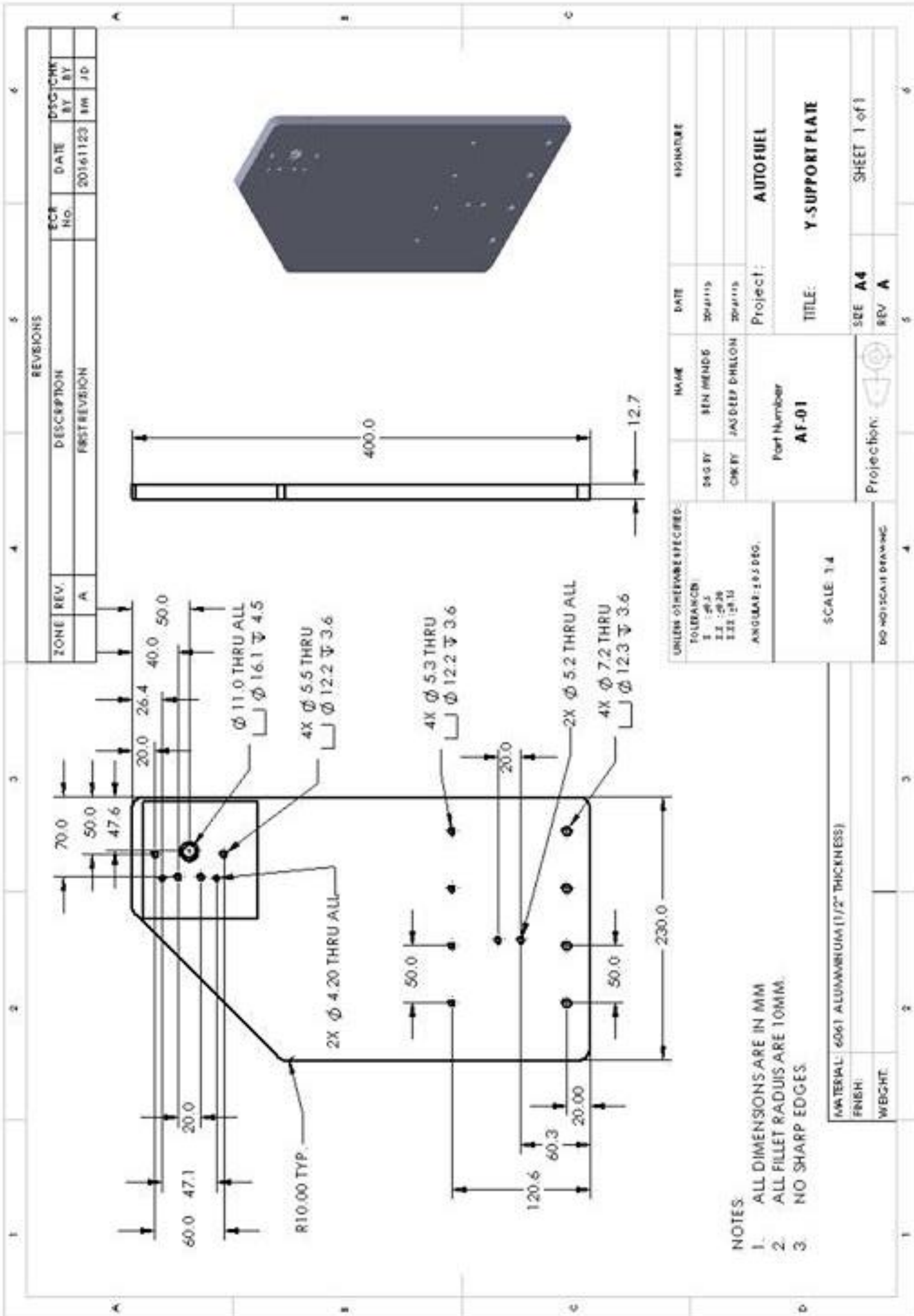

Figure 43: Detailed Drawing of Y-Support Plate

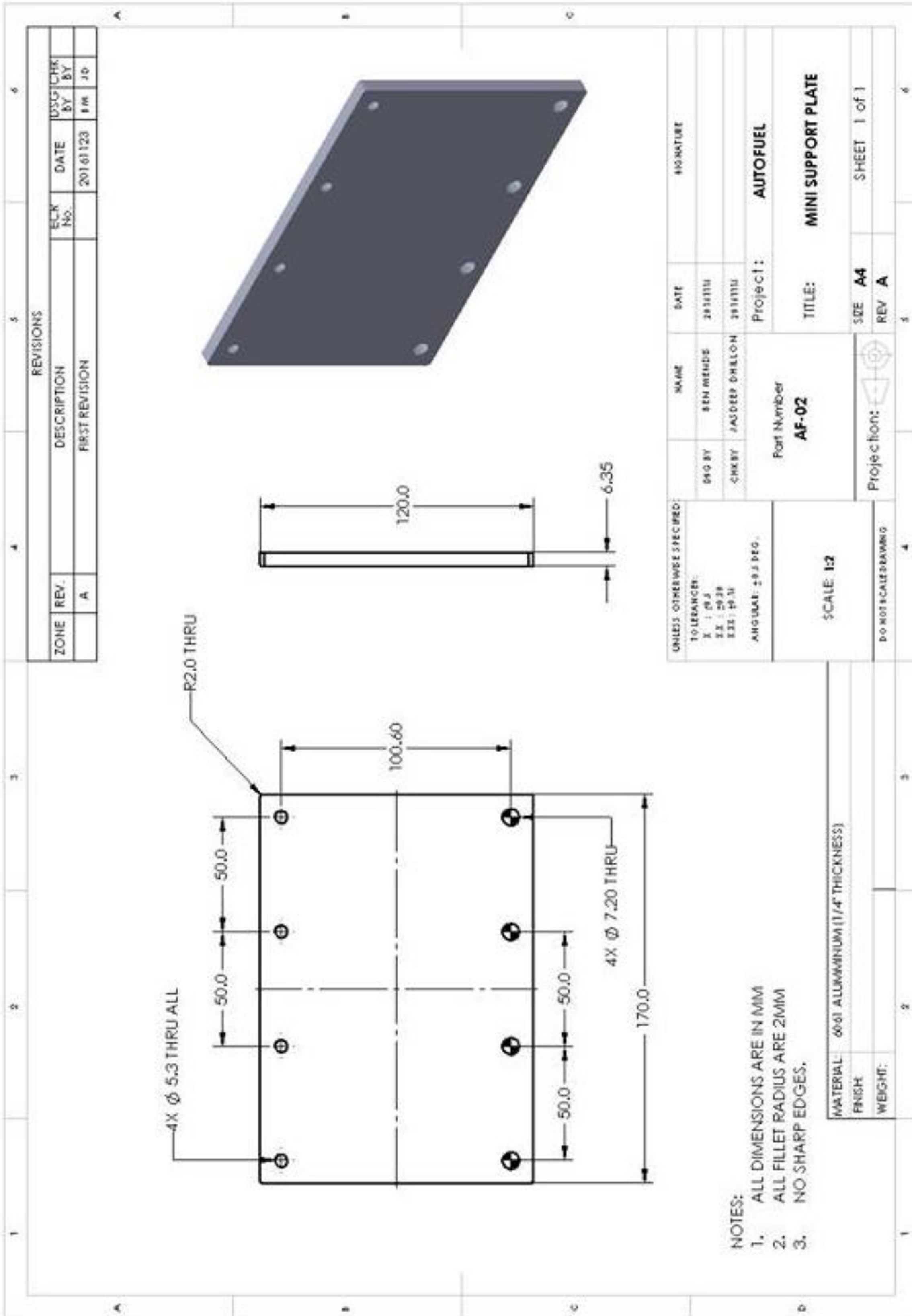

Figure 44: Detailed Drawing of Mini Support Plate

BILL OF MATERIALS

Item Number	Component	Quantity	Cost	Source
1	Nema 23	5	162.90	Openbuild
2	Nema 17	1	23.27	Openbuild
3	Geared DC motor	1	6.15	BangGood
4	CNC xPRO V2 Stepper Motor Driver	1	172.85	Openbuild
5	Arduino Mega	1	57.09	CanadaRobotix
6	VNH2SP30-E based motor driver	1	3.94	CzB Electronics
7	HC-SR04	1	3.59	Amazon
8	Logitech c310	1	52.56	Amazon
9	5 mm white leds	10	1.87	Amazon
10	MakeBlock Robot Gripper	1	34.99	Amazon
11	Uxcell	1	12.19	Amazon
12	L16-P linear actuator	1	102.56	Robotshop
13	C beam Linear Rails 500 mm	3	55.86	Openbuild
14	C beam Linear Rails 1000 mm	1	37.23	Openbuild
15	Threaded Rods 500 mm	3	82.77	Openbuild
16	Threaded Rods 1000 mm	1	41.89	Openbuild
17	Flexible Motor Coupling	5	45.55	Openbuild
18	Locking Collar	8	9.60	Openbuild
19	Linear Rail Bearing	8	10.64	Openbuild
20	C beam end mount	2	23.32	Openbuild
21	Black Angle Corner	10	36.60	Openbuild
22	C Beam Gantry Plate X large	3	29.76	Openbuild
23	Tee nuts	20	6.58	Openbuild
24	Hex nuts	54	8.1	Makerpart
25	Xtreme Solid V Wheel	54	117.18	Aliexpress
26	Jog Knob	1	6.58	Openbuild
27	Spring Loaded T nuts	4	6.4	Openbuild
28	6 mm spacers	47	12.69	Openbuild
29	3 mm spacers	30	6	Openbuild
30	40 mm spacers	8	5.84	Openbuild
31	Eccentric Spacers	17	45.22	Openbuild
32	Anti-backlash nut block	4	52.40	Openbuild
33	Precision Shims	10	3.3	Openbuild
34	Y Plates	2	50	Openbuild

Table 10 Bill of Materials