Remote Operated Excavator

Preliminary Proposal

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2020

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DISCLAIMER

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1 BACKGROUND

1.1 Introduction & Project Description

As the current state of industry moves towards an industrially globalized landscape, the expansion of modernized infrastructure is inevitable. This expansion, as is the case with any form of change, will have both good and bad consequences. Our goal as future Engineers is to tackle these issues head on, and to the best of our abilities deliver a product that is on par with industry standards. In the short history of mankind there has been a handful of defining moments that have shaped the world to what it is now. Some defining moments include the Bronze Age, The Industrial Revolution, the invention of the combustion engine, and the harnessing of electricity just to name a few. These defining moments are few and far between and as the world transitions to renewable forms of energy we have the privilege of being witnesses to such transition. Today, it is no secret that electricity is at the forefront when it comes to renewable forms of energy. It is also true that in our not too distant futures, our dependency on fossil fuels will be a thing of the past.

As a result of these last two statements, we are beginning to enter the electric powered car revolution. which is gaining momentum very quickly, and some estimates predict that in 20 years there will be more electric vehicles than combustion powered ones on the road. As the movement grows its influence has managed to reach manufactures of heavy machinery such as caterpillar, Volvo as well as a few others. At the moment all of the electric excavators that are being prototyped and produced have applications that are most suited for professional use. Our team has been tasked with the capstone project of designing and building a small-scale, remotely operated excavator that is fully electric. The excavator's primary application will be to dig irrigation trenches that would otherwise be dug manually. Some of the requirements that our project demand include a durable design, capable of a full 8-hour workday, and the ability to dig at minimum 6-inch-wide and 12-inch-deep trenches. In the following report we will be defining the problem to be solved, the study conducted and the initial results.

1.2 Original System

The project is going to be a redesign of preexisting excavators to fit the customer needs. Traditional excavators are powered by a diesel engine and requires an operator to be within the cab. These excavators are also used for tasks such as digging, demolition, debris removal and hauling heavy loads.

1.2.1 Original System Operation

The standard excavators move on two parallel track systems and have a fully revolving cab. There is an arm attached to the cab consisting of a boom, stick, and bucket. The arm is moved by hydraulic systems attached to the arm segments which allows for precise control. The excavator is controlled by an operator that sits in the cab and uses a variety of joysticks.

1.2.2 Original System Deficiencies

The standard excavator design will not meet the customer needs for this project due to size, fuel, and operation. The standers excavator bucket is too large for the specified trench dimensions and the entire system is too large to access many residential areas. The customer requires that the excavator be fully electric, and the original designs are diesel powered. Lastly, the original system requires a human operator to be inside the cab for operation.

2 REQUIREMENTS

In the Following subsections we will provide the requirements that the customer requested in addition to all the Engineering requirements that we generated.

2.1 Customer Requirements (CRs)

The customer requirements, as relayed to the team from the client, provide the overall basis of the project. These requirements including creating a garden sized excavator, capable of digging a 1 foot deep by 6-inch-wide irrigation trench. The excavator must be remotely operated, and its power supply must be electric as opposed to a gas or diesel powered design. The client ideally wants the excavator to be able to work a full 8-hour workday and if possible, to equip and utilize ground penetrating radar. As always, staying within budget, providing a reliable and durable design, and safety are always requirements to prioritize. Last, the client has mentioned a "nice to have" feature would be ground penetrating radar, in order to detect cables, pipes, and pvc systems. Although, buying or creating a system will be wildly outside of budget and at this moment is not a priority. Below is *table 1* displaying each respective customer requirement with its appropriate weight and justification

Customer Requirements	**Weight**	**Justification**
Remote Operation	4	Remote operation is crucial to complete success of the project. The client will accept a wired control variation, but remote operation exponentially expands future operation possibilities.
Full Workday	3	Although it would be a luxury for the excavator to work 8 consecutive hours, it is not imperative, and 3-6 hours will be accepted.
Electrically Operated	5	A fully electric power supply has been designated as a "must have" feature by the client.
1'x6" Trench	5	The main goal of operation.
Ground Penetrating Radar	1	While this feature would be amazing to have for cable, pipe, and pvc detection, it is very expensive from every angle.
Durability	4	The excavator and all components must be durable enough to survive hundreds of hours of work, but it is not imperative to engineer the excavator for an infinite lifespan.
Safety and Reliability	5	Safety and Reliability are not included in Figure 1 because these are of the highest priority and have a strong relation to every engineering requirement.

Table 1: Customer Requirements

2.2 Engineering Requirements (ERs)

Engineering Requirements	**Justification**
Body/Base Design	The body design will be a key point of interest with respect to the durability and reliability of the excavator. A robust body design will prevent the excavator being stuck and protect other main components and systems.
Arm & Bucket Kinematics and Design	An optimized arm and bucket design are imperative for meeting the main objective of digging an irrigation trench. Over engineering these components may add unnecessary costs, while the opposite may produce failures during unusual circumstances.
Arduino: Electronic Control Unit	Arduino and the ECU will be the main bridge between the remote operator and all controls on the excavator. It is essential that the ECU is completely reliable with all functions, which include wheel motion, arm motion, and bucket motion. Tying in functionality to control all motor systems and hydraulics.
Electric Power Supply	The electric power supply achieves the goal of creating a fully electric excavator, but its role is critical. These batteries are the sole contributor to all operations of the excavator.
Motion Control Systems	Motion control relates to the hydraulic systems of the excavator. While the ECU is the median between the operator and the excavator, the motion control system is the median between the ECU and all hydraulic operations of the bucket and arm.

Table 2: Engineering Requirements & Justifications

2.3 House of Quality (HoQ)

Creating a Quality Function Deployment allowed the team to conceptualize the relation between customer requirements and engineering requirements. These relations were determined as strong (9), moderate (3), weak (1), or none (blank). Furthermore, as displayed above in *Table 1*, customer requirements were weighted between 1 and 5, with 5 having a high importance to the customer and 1 having a low importance. The customer requirements of reliability and budget restrictions are omitted from the QFD as both would have a strong relation to all engineering requirements. All components must fit within budget and their reliability is crucial.

Quality Function Deployment

Project Title: Remote Excavator
Project Leader: Davis Geniza
Date:

You need only to fill the white and blue cells.

1: low, 5: high Customer importance rating	Desired direction of improvement (↑,0,↓) Functional Requirements (How) → Customer Requirements - (What) ↓	Lead Acid Battery Power Supply	Arduino Programmed Electronic Control Unit	Motion Systems Control Unit	Arm and Bucket Kinematics and Design	Body Design
4	Remote Operation	3	9	3		1
5	Electrically Operated	9	3	1	1	
3	Full Work Day	9			3	1
5	Digs 1'x6" Irrigation Trench	3	1	3	9	3
1	Ground Penetrating Radar	3	1			
4	Durability	1	1	1	9	9

Figure 1: QFD

2.4 Functional Decomposition

2.4.1 Black Box Model

The black box model is an input factor, after the black box is transformed, it becomes an output factor. In the project, the team entered the black box according to the customer needs and engineering requirements of the remote-control excavator, so as to obtain the research direction needed for the remote-control excavator. As shown in the figure below, the input factors include remote-control excavator, price, size, material, electric, ability to work and work efficiency. After the black box transformation, the output factors include signal transmitter, electrical system, battery, model design, remote controller, hydraulic system, motion control. These output results guide the team's subsequent research direction.

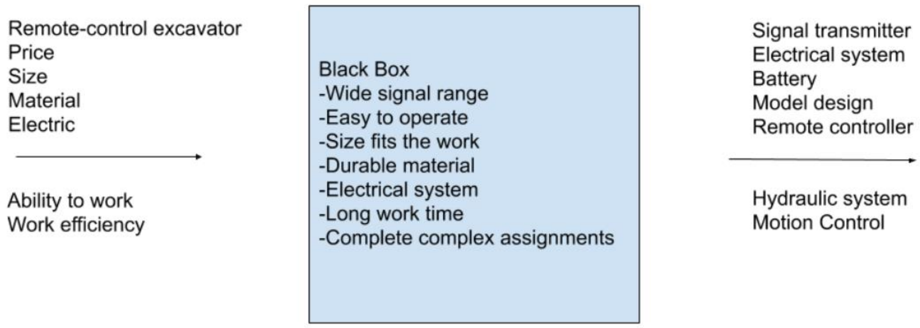

Figure 2: Black Box Model

3 DESIGN SPACE RESEARCH

2.5 Literature Review

In this section, each student provided a literature review pertaining to a system or component of the excavator.

2.5.1 Student 1

After doing research on excavators similar to our project scope Alec found some information on an excavator that would be similarly sized as ours and runs on electricity. The problem with this example is that it runs off 110-volt or 220-volt outlets rather than being battery operated but the electric motor used in this excavator was very similar to what our concept required. Using this example as reference I was able to find a motor that would work for our application. The requirements for a motor in an excavator include high torque and low amp hour usage due to the excavator being battery operated. The motor in the example excavator was a 110-volt or 220 volt, 2HP, 1750 RPM and was connected to power via 100-foot extension cord which limits the device to within 100 feet of a power source. Our device will be able to move anywhere with the battery packs on the back of the machine which makes it ideal for any situation. The device that was picked for our excavator project was a 1HP, 1800RPM, 48 Volt DC Leeson Electric motor which will not be as powerful as the example excavator but will be applicable to what our team is trying to achieve. The motor will be mounted below the batteries on the back of the machines. This motor should be able to run the hydraulics and have enough torque to penetrate the surface for the required size irrigation trench. Separate motors will be used to move the excavator on two wheels to be able to turn and maneuver to certain places. The excavator is intended for usage in the backyard of people's homes and is expected to have an 8-hour battery life.

The Greens Machines and Cycles. [Online]. Available: https://turbot-plantain-6xf6.squarespace.com/. [Accessed: 17-Jul-2020].

L. Ada, "All About Batteries," *Adafruit Learning System*. [Online]. Available: https://learn.adafruit.com/all-about-batteries/power-capacity-and-power-capability. [Accessed: 17-Jul-2020].

[1]"Serial and Parallel Battery Configurations and Information", *Batteryuniversity.com*, 2020. [Online]. Available: https://batteryuniversity.com/learn/article/serial_and_parallel_battery_configurations#:~:text=Adding%20cells%20in%20a%20string,the%20capacity%20remains%20the%20same.&text=If%20you%20need%20an%20odd,than%20what%20the%20device%20specifies. [Accessed: 17- Jul- 2020].

M. Stansberry, "How to Increase Battery Voltage," *Sciencing*, 02-Mar-2019. [Online]. Available: https://sciencing.com/increase-battery-voltage-7484078.html. [Accessed: 17-Jul-2020].

2.5.2 Student 2

The technical aspect of the project studied by Ryan was the kinematic model of the arm. By creating a kinematic model in SolidWorks, Ryan was able to see and analyze the full range of motion of the arm used for design. He was able to see how each individual hydraulic piston cylinders would move the arm segments. Furthermore, he was able to determine the maximum depth achievable by the arm.

With the current design, the arm was able to reach four feet below the lowest pin joint on the boom as shown in figure 3. Ryan was able to determine that the boom will be mounted onto the base eight inches above the ground. This means that once assembled, the current arm will be able to dig a trench that is forty inches deep. This depth is much greater than the customer needs and will be redesigned to better fit the customer needs.

The redesign of the arm will likely be the same design but scaled down to better fit the customers' needs. Although the trench only needs to be twelve inches in depth, the redesign will reach a depth a few inches deeper than necessary to account for sloping or other naturally occurring imperfections.

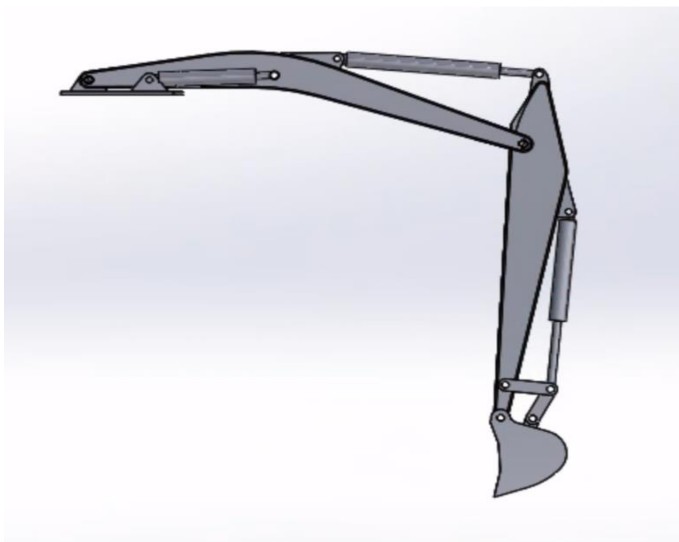

Figure 3: Kinematic model showing maximum achievable depth.

2.5.3 Student 3

The technical aspect Davis focused on was the creation of an electronic control unit, in order to remotely operate the excavator. At the advisement from Dr. Trevas, Arduino was chosen to be the platform utilized to remotely operate the excavator and establish electronic control. To begin the task of conceptualizing an Arduino based interface, research was first conducted on understanding what the platform is and how it could help with the goal of remote operation. Open sourced and easy to use, Arduino is a hardware-software platform that can provide an operator the ability to remotely use all aspects of the excavator, including the hydraulic systems and motorized wheels [1].

Arduino's open sourced libraries have provided a basis for implementing remote operation into the excavator design. One avenue Davis reviewed was a Roomba, a self-operating cleaning robot, being remote controlled by an Android phone through the use of an Arduino microcontroller. This method at the very least will aid in the process of operating the wheel system of the excavator [https://create.arduino.cc/projecthub/mjrobot/controlling-a-roomba-robot-with-arduino-and-android-device-56970d]. In order to replicate a similar system, an Arduino UNO microcontroller will be programmed by Arduino IDE software, where a Bluetooth module will be used to connect to a controller or Android device. Theoretically, user interface would be similar to the Roomba control in figure 4. Many Arduino projects involve robotics and many robotic kits exist for this purpose, which have provided a foundation that it is without a doubt possible to utilize Arduino for remote operation and electronic control of excavator actions and maneuvers.

Figure 4: Arduino setup

[1] Arduino Foundational: Getting Started Introduction

https://www.arduino.cc/en/guide/introduction#:~:text=Arduino%20is%20an%20open%2Dsource,an%20LED%2C%20publishing%20something%20online.

[2]October 21, 2016, MJRobot: Arduino Project Hub: "Controlling a Roomba Robot with Arduino and Android Device" https://create.arduino.cc/projecthub/mjrobot/controlling-a-roomba-robot-with-arduino-and-android-device-56970d

2.5.4 Student 4

Oscar's technical aspect focus was to conduct a Finite Element Analysis (FEA) of our Excavator project. The finite element method is not a new field and has been around for quite some time now. This method in summary is best described as a numerical technique that solves Partial differential equations [1]. The use of this method in recent times has been gaining popularity due to its practicalities and as a result of technology innovation, in short, this numerical method is only just now starting to reach its full potential.

In this study the Ansys platform was chosen to perform simulations on the excavator's arm, as it is readily available through the school. In addition to the Ansys software he has incorporated the use of existing engineering models from sources such as GrabCad to aid with the benchmarking design of our original model. The team will use the results that are generated through simulations as a way of checking mathematical computations and as a way of modeling and optimizing our final design. Through this method we will be able to generate and predict engineering parameters such as digging forces, stress calculations and strength calculations which will help us as a team determine the most viable design. The impact of finite element studies will ultimately prove most beneficial when optimizing the design.

[1]"What Is FEM and FEA Explained | Finite Element Method." https://www.simscale.com/blog/2016/10/what-is-finite-element-method/ (accessed Jul. 17, 2020).

2.5.5 Student 5

The technical aspect of Zhiyu is hydraulic pump, accumulator and valves and motion control. Hydraulic pumps, accumulators, valves and other hydraulic components constitute the hydraulic system of the excavator. Zhiyu's research mainly strives to study the respective functions of hydraulic pumps, accumulators and valves in the hydraulic system and the role of the hydraulic system on the operation of the excavator. During the working process of the hydraulic system of the excavator, the working oil is sucked from the working pump through the oil filter from the bottom of the accumulator, and the working oil of a certain pressure is output from the oil pump and enters a set of parallel distribution valves. Corresponding actions can be achieved through the handle-⟶ pilot valve-⟶ working valve group.[1]

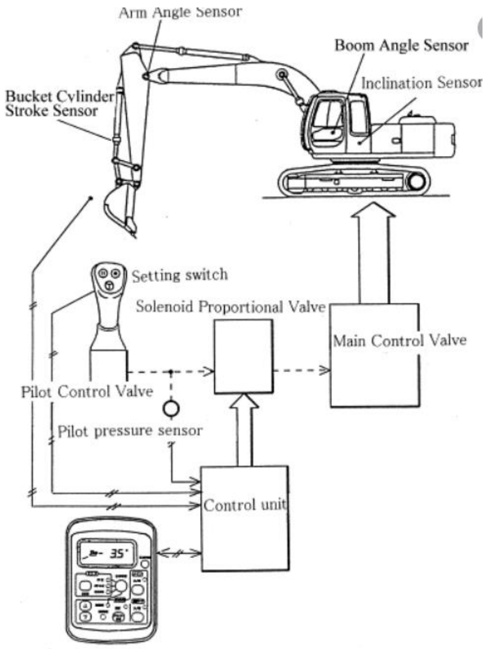

Figure 5: Excavator hydraulic control system

Motion control uses components such as controllers to control the force, pressure, power and other parameters of the hydraulic system of the remote-control excavator through a closed loop system to realize the normal operation of the remote-control excavator.[2]

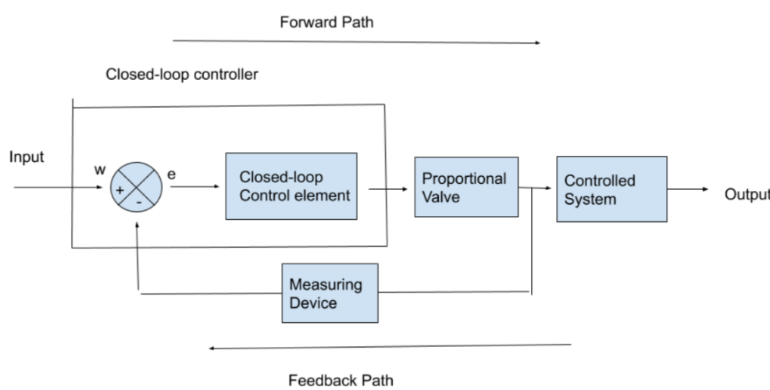

Figure 6: Motion control - Proportional valve cricuit

[1]R. Hidayat and L. lengkapku, "COMPONENT", Rahmadhidayat009.blogspot.com, 2020. [Online]. Available: http://rahmadhidayat009.blogspot.com/p/component.html. [Accessed: 20-

Jul- 2020].

[2]"What is Motion Control", MCMA - Motion Control Online, 2020. [Online]. Available: https://www.motioncontrolonline.org/blog-article.cfm/What-is-Motion-Control/91. [Accessed: 06- Jul- 2020].

2.6 State of the Art - Benchmarking

The benchmarking system consist of finding concepts and using parts of those concepts to create ideas for the new concepts for the team's design of a remote excavator. Excavators have been around for many years but the one the team is trying to build will be completely different from the rest. The benchmarking process allows us to use designs that have been previously created for reference while trying to create our own version. It allows us to visualize the product to get a better understanding of what the team is after. And once the team creates a concept we can see if its viable with the other pieces or concepts of the project.

2.6.1 System Level State of the Art - Benchmarking

The client requirements for the excavator project in-tail making it fully electric, eco-friendly, portable, and small enough for backyard usage as well as digging irrigation trenches wherever they may be. There are not many concepts out that fit all those requirements so the team will have to use different pieces from concepts to making something completely new.

2.6.1.1 Existing Design #1: Hitachi Remote Operated Excavator

The Hitachi remote operated excavator only pertains to our project with the implemented remote system that is used. The excavator that Hitachi showcased is substantially bigger than what or concept will look like and will cost thousands of dollars over our budget. It is also gas operated which is harmful to the environment, our concept will be electric and will produce no emissions. The remote system they use is exactly what we are looking for in our concept so reviewing it and using the technology to design our own remote system will be the goal.

Figure 7: Hitachi Remote Operated Excavator

2.6.1.2 Existing Design #2: Custom Builds Allen Savage

The website Green Machines and Cycles showcases customer built mini excavators. There are several builds on the green machine website that are similar to what our team is planning to build according to our client requirements. The requirements include being small, for backyard usage, being eco-friendly and being last for an entire working day without recharge. These models are mostly equipped with gas powered engines where our model will be fully electric. We believe that this size model will be prefect for what our client is looking for and perfect for portable backyard usage.

Figure 8: Custom Builds Allen Savage

2.6.2 Subsystem Level State of the Art Benchmarking

2.6.2.1 Subsystem #1: Hydraulics System & Motion Control

The hydraulic system of the excavator is a combination that organically connects various hydraulic components with pipelines in accordance with the transmission requirements of the excavator's working devices and various mechanisms. It mainly includes hydraulic oil tank, main pump, multi-way valve, various pipelines, cylinders and motors that perform various actions. Its function is to use oil or water as the working medium, use the hydraulic pump to convert the mechanical energy of the engine into hydraulic energy and transmit it, and then convert the hydraulic energy back to mechanical energy through hydraulic cylinders and hydraulic motors to realize various excavators action.

Motion control is the processing of various parts of the machine in a controlled manner. The basic architecture of a motion control system includes motion controllers, drives, moving mechanical components and feedback sensors. The motion controller achieves the function of controlling the entire machine by controlling other parts of the motion control system. Among them, common control functions of motion control systems include speed control, position control, pressure or force control, impedance control and Electronic gearing, etc. For the project, the remote controller inputs commands to the motion controller of the remote-control excavator by controlling the remote controller. The motion control system of the remote-control excavator is controlled by commands to make the remote-control excavator work.

2.6.2.1.1 Existing Design #1: RMC150 mid-range motion controller

RMC150 mid-range motion controller can be programmed using RMCTools to control various parameters such as force, pressure and power in the remote-control excavator. This controller needs to meet the specific parameters of the hydraulic system that controls the eight axes of the remote control excavator, which meets the requirements for independent operation of each arm of the remote control excavator, allowing the remote control excavator to complete complex operations and tasks. At the same time, it also has the function of communicating with most programmable logic controllers (PLCs), which makes this controller adapt to most PLCs.

Figure 9: RMC150 mid-range motion controller

2.6.2.1.2 Existing Design #2: EPD03 Series - Proportional Valves

The size specification of this proportional valve is D03. This size specification uses the remote-control excavator of the project. In addition, the fluid viscosity of this proportional valve is 17-65cSt, the fluid temperature is 5-70°C, the ambient temperature is -20 to 70°C, and the frequency response is 28 Hz @-3db. A wide range of parameter values allows the remote-control excavator to be suitable for general work scenarios. This proportional valve can use 2 or 3 modular static pressure devices to achieve more precise flow control.

Figure 10: EPD03 Series - Proportional Valves

2.6.2.2 Subsystem #2: Excavator Arms

As it pertains to this study, and as is the case with a majority of technical analysis the first step is to conduct the proper research and to understand your problem parameters. The first major problem that we wanted to answer was what are the forces associated with the digging motion of an excavator. These forces are broken down into 2 classifications, both of which are exerted or experienced at the tip of the bucket. These 2 forces are bucket curling force and arm crowd force. The bucket curling force is categorized as the force that is generated due to the pressure applied by the bucket cylinder, and the arm crowed force is the force generated due to the pressure applied by the arm cylinder.

2.6.2.2.1 Existing Design #1: Digging forces

The figure to the bottom illustrates the parameters that we will use in modeling our arm. The primary focus is the labeling and the location of both the bucket curling force and the arm crowd force, both of which are located at the tip of the bucket. With this simple diagram we were able to calculate the required forces needed to generate the adequate forces needed to dig our trench.

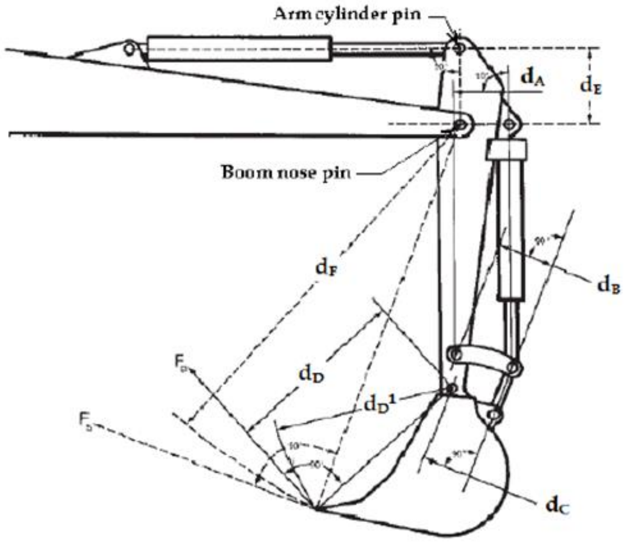

Figure 11: Digging forces diagram

2.6.2.2.2 Existing Design #2: Current Arm and Bucket Design

The current Arm and bucket assembly was sourced from GrabCad and it is currently being used as a way of benchmarking our final design. At the moment all of our results can only be used as a verification that the current design actually works, in the future we will take the current lengths of the joint locations and we will modify the design in order to reduce the material needed while at the same time optimizing the design to reduce cost. This also opens up the opportunity to run other analysis types on our model as finite element analysis is currently one of the best techniques for determining strengths and stresses on our mechanism as it moves from one point to another. This technique first requires that we solve all of our initial loading conditions and boundary conditions first.

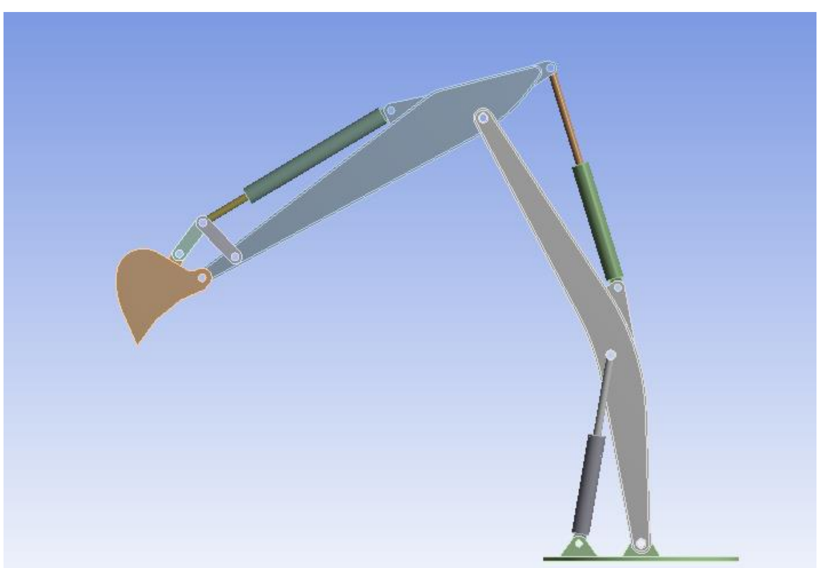

Figure 12: Current Arm design

3 CONCEPT GENERATION

3.1 *Full System Concepts*

In the following section we will discuss the pertinent systems that we deemed important in this first iteration of our design.

3.1.1 Full System Design #1: Excavator Arm& body design

This first iteration is a rendition of what our final model geometry will simulate. At the current level the model only demonstrates the body assembly with the addition of the battery tray and the arm assembly. As a team we decided to not include any of the components that will be used within the excavator as we have not fully determined their final placement and orientation. Examples of the components that will be included in future iterations include the motor, batteries, hydraulic assemblies, and all of the electrical components that will be used to remotely power the excavator. The present version of our design is demonstrated in the figure below.

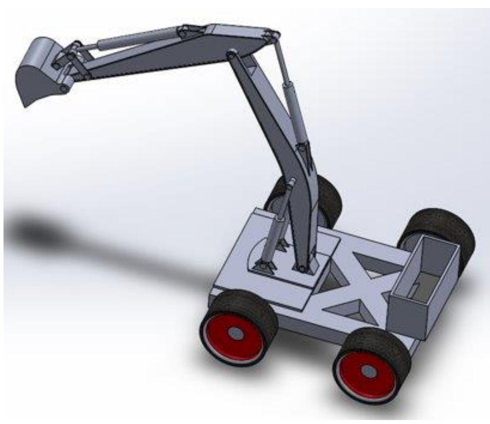

Figure 13: Current Excavator Design

3.2 *Subsystem Concepts*

3.2.1 Subsystem #1: Computer Aided Design Parts

3.2.1.1 Design #1: Arm Design

The current state of the Arm design has been generated as a scaled down version of a crane excavator arm attachment. Our team rationalized this design style due to the ease of how it would attach to our existing base. At the moment this is our initial design and the pros are that for our intended purposes it is overengineered by design to ensure us that it will function as intended. On the flipside the cons are that currently the design is not cost effective for its intended purposes and needs to be further optimized.

Figure 14: Preliminary Arm Design

3.2.1.2 Design #2: Base Design

The base is being designed to be minimal in size and optimized for counterweight. The base has an area at the rear to house the batteries which will provide counterweight as well. The team has decided to use wheels instead of a track system due to the loads that the excavator will handle. The team has designed two bases, one preliminary, and the second more optimized and scaled with proper measurements. Figure 15 shows the preliminary design without the wheels attached.

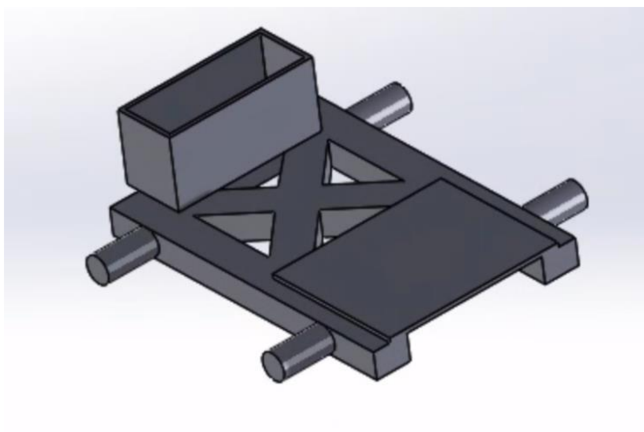

Figure 15: Isometric view of preliminary base design.

The box shape on the rear is the battery housing and at the bottom, there is a rubber mat to reduce the probability of damage to the batteries during operation. The frame has cross beams and a section of negative space in the front to accommodate for balance once the arm is attached. The preliminary base is fully solid, and has three-inch diameter axels. Figure 16 shows the second design of the body and is scaled to fit our current design.

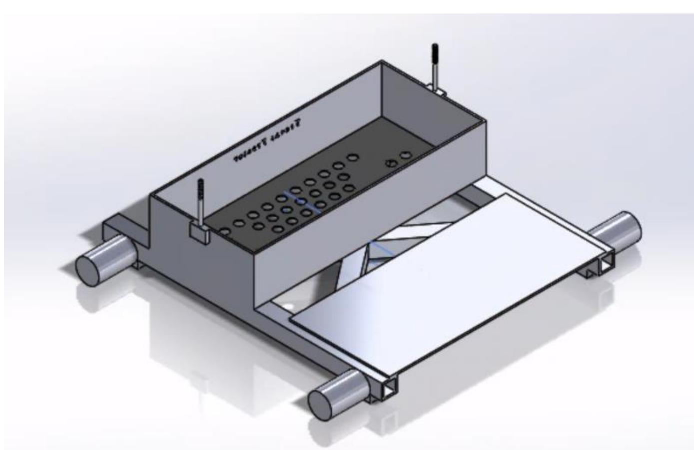

Figure 16: Isometric view of scaled base design.

This design of the base is scaled to fit the necessary components that have already been chosen, such as batteries and the mounting of the arm. The cross beams and the negative space at the front have remained, but there has been an added negative space at the rear to accommodate the mounting of the motors. The box has been enlarged to fit the necessary amount of batteries and has the rubber mat to protect the batteries as well. In a larger effort to lengthen battery life the floor has holes to drain out any dirt that may fall in, and to make it easier to clean the battery housing. We have also added two threaded rods on the outside to hold down a plastic battery fastener across the top of the batteries to prevent them from bouncing out of place during operation. Figure 17 shows a rear view of the base with the fastener in place.

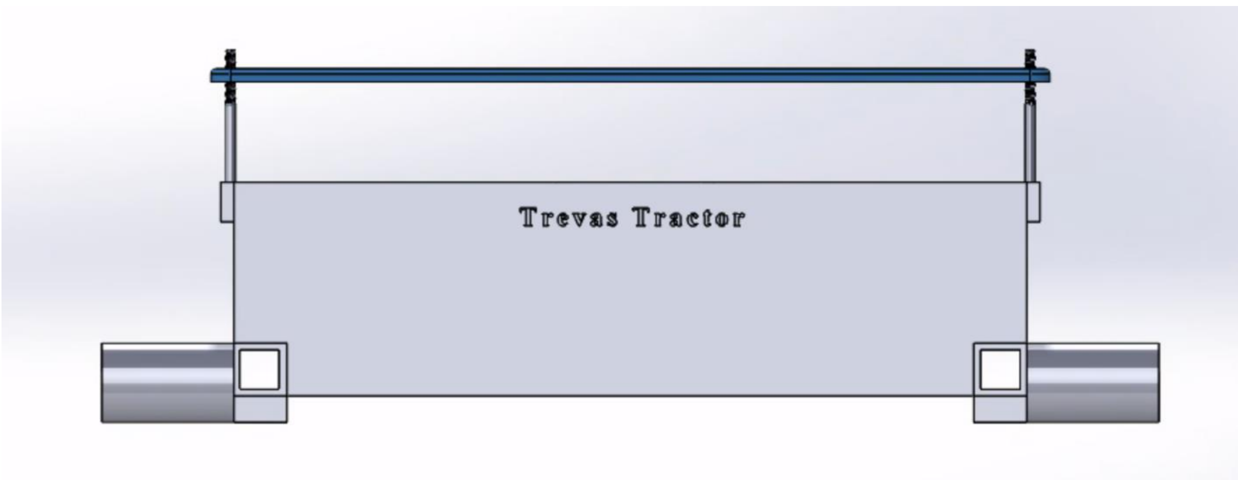

Figure 17: Rear view of base showing battery fastener in place.

The team has decided to make the base hollow and constructed using 2”x2”x1/4” steel tubing to reduce weight and cost to build. The axels have remained three inches in diameter to ensure that they can withstand loads while traveling over uneven surfaces. Lastly, the team has decided to add the name “Trevas Tractor” to the base to give credit to the project sponsor.

3.2.1.3 Design #3: Wheels

The wheels have a preliminary design, and the team has still not decided on a material.

Figure 18: Preliminary wheel design.

The team is still working through calculations of what size would be optimal for the wheel as well as tread pattern, lug pattern and operating psi. This design shown in figure 18 attaches to a three-inch diameter axel to show a full assembly in SolidWorks.

3.2.2 Subsystem #2: Systems Control

3.2.2.1 Design #1: Arduino: Electrical Control

The current iteration for the conceptualized electronic control unit, consisting of the Arduino UNO and its breadboard would be fixed by adhesion within a protective case nearby the battery storage unit. A polymer case would be low in cost and can be easily mounted to base, while also being non-disruptive to Bluetooth connection. Breakout boards will be utilized to accommodate the different components needing to be wired to the Arduino Uno. These components include the hydraulic controller, pumps, and motor, as well as the wheel motors. The Breakout boards ensure all electrical components can be grounded and provide enough analog, digital and power inputs, this module is shown in figure 19.

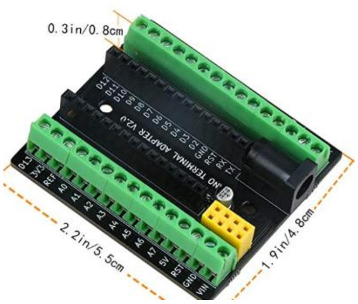

Figure 19: Arduino Breakout Board

Next, the design's Bluetooth connection will satisfy the feature of wireless remote operation. To achieve this, a Bluetooth module will be implemented into the Arduino board to establish a connection with the operator. Currently, an Android device is being prioritized as the main median of connection between the operator and the excavator using an application similar to figure 4 above. This system will provide flexibility with user control, allowing replacement due to malfunction of a controlling device to be done easily. Figure 20 below provides a depiction of the Bluetooth module that will be used with the electronic control interface. Overall, the main con regarding this aspect is the somewhat limited range which will have an absolute maximum of about 50 feet, although for demonstration purposes this will not be a main concern.

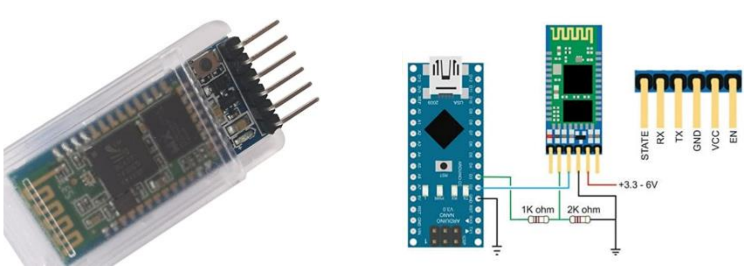

Figure 20: Bluetooth Module and Schematic

Ultimately, the key to a successful electronic control unit can be broken down to the programming.

Correctly diverting power to each system is reliant on the software. This is still a work in progress as there is much to learn in the world of Arduino, but optimism of successfully programming the system lies within robotic projects made by the community, setting a precedent that completing this project is possible. Although most of the programming that will be attributed to this project will not be able to be taken directly from Arduino's libraries, they help build a basis of understanding how to tackle the challenges ahead when constructing the excavator's electronic control unit. Steps taken to accomplish this have been powering a small 5-volt motor and attempting to replicate the Roomba project mention in the lit review.

3.2.2.2 Design #2: Valves in Hydraulic System and Motion Control

Valve is an important part of excavator hydraulic system and motion control. In the selection of valves, Zhiyu considered two electronic control valves. They are proportional valve and servo valve. The main difference between the two is the filtering level, accuracy, response time and cost. The proportional valve has no pressure feedback, which means that additional measuring equipment is required to maintain a relatively stable load condition in the closed loop of the proportional valve. Compared with proportional valves, servo valves have pressure feedback. In addition, servo valves have higher accuracy than proportional valves. However, the servo valve needs to be equipped with more electronic valves and hydraulic components, and better filters are needed to reduce the level of particulates in the liquid. This greatly increases the cost. In addition, the price of proportional valves is much lower than that of servo valves. Most of the servo valves are more than $1000, while most of the proportional valves are less than $500.

	Proportional Valve
Feedback	No Feedback
Accuracy	Error factor 3%
Response	<10 Hz
Cost	The price is lower than other valves
Auxiliary equipment	Other electronic valves and measuring equipment

Figure 21: Proportional Valve Sheet

Integrating the requirements of the remote-control excavator in the project for the hydraulic system, the remote-control excavator does not require high precision, requires a valve with a smaller space, and requires a valve with a low cost. Therefore, Zhiyu decided to use the proportional valve in the design of the hydraulic system of the remote-control excavator.

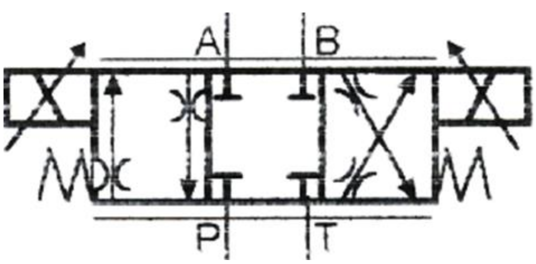

Figure 22: Proportional control valve

3.2.2.3 Design #3: Battery System: Power Distribution

The battery part of the excavator which is based off the motor selection is located in a steel basket above the motor near the back of the excavator to counter act the weight of the arm on the front of the excavator. Since voltage is directly related to torque for batteries and motors the decision was made to go with a higher voltage rather than a standard 12-volt battery motor system. This is due to the fact that this machine will require a significant amount of torque to penetrate the ground and remove dirt from a specific location. A 48-volt system was agreed upon and implemented into the excavator. The batteries that would fit this requirement are four 12-volt deep cycle marine batteries. Even though these are 12-volt batteries, hook them up in series and you get the 48-volts that we are after for our system. Hooking up batteries in series will increase the voltage of them while keeping the same amp hours. Hooking up batteries in parallel will result in the same voltage but increased amp hours. The deep cycle batteries were chosen over normal car batteries due to the fact that deep cycle batteries can be completely depleted of energy and not damage the batteries capacity to charge again. In other words, the deep cycle batteries are more durable than the regular car batteries and will last longer. The batteries were originally intended for usage in RVs and boats and has a 122-amp hour rating which should be enough to power the excavator for several hours depending on usage. The batteries weight 60 pounds each so a grand total of 240 pounds for the batteries will counteract the weight of the arm of the excavator located on the front for the machine. The basket for the batteries will be located above the motor on the back of the machine and will be designed to withstand that weight with steel brackets. The basket being located above the electric motor will allow for easy access of the batteries for charging and maintenance purposes.

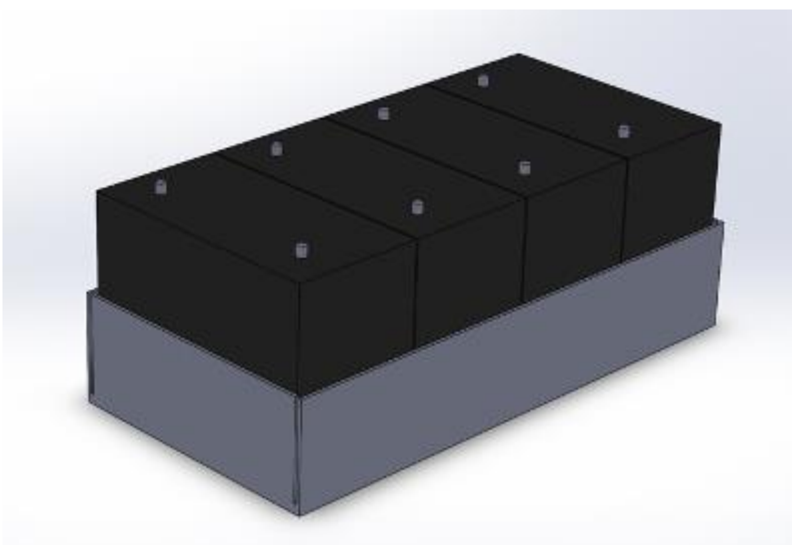

Figure 23: Battery System

4 DESIGNS SELECTED – First Semester

Chapter 4 discusses the main preliminary design for the excavator team and its upcoming changes.

4.1 Technical Selection Criteria

To select a final preliminary design, the team wants a design that will be most reliable, within budget, durable, and can accomplish the main task of digging an irrigation trench, ideally within a garden sized setting. This final design, while not fully assembled within SolidWorks, addresses the shortcomings of the preliminary design in section 3.1.1 and utilizes finals concepts in section 3.2.

4.2 Rationale for Design Selection

The excavator team's final design utilizes the base design in figure 16 and 17, in section 3.2.1.2. This design provides a more balanced center of gravity than the preliminary base shown in the full preliminary design in section 3.1. This base design is chosen due to its hallow cross section, for reduced cost and weight of the material. Furthermore, the power storage unit in this design allows dirt and debris to filter through in an attempt to preserve the life cycle of the battery units. The design accommodates mounting the motor and electronic control unit, while also providing easier maintenance and access for part replacements.

The excavator arm still requires optimization as two 45'' arm lengths is believed to be an overengineered design. Calculations to optimize the arm design are estimated to be finished by July 21st, with final arm design being estimated to be completed by July 25th allowing for a full body and arm assembly to be completed shortly after.

References

All cited works are section based, within literature reviews.