Remote Excavator Team

Final Proposal

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DISCLAIMER

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EXECUTIVE SUMMARY

The project explained in the following report is a fully electric, remotely operated, small scale excavator. The client has required that the excavator dig a trench that is a foot in depth and six inches in width. The client has also required that the batteries used will be able to operate for a full workday. The base design of the excavator is designed to be low to the ground in order to keep the center of gravity low. The base is also designed to be as small as possible so that it can be used effectively in small areas, such as residential yards. Due to the small size, tank tracks will not be necessary for operation and store-bought wheels will be used instead. The excavator will be powered by lead acid batteries, which were chosen primarily because of the low cost. Additionally, the lead acid batteries are heavy, and they double as counterweight to the arm. The arm of the excavator is powered by hydraulic systems instead of electronic actuators because the client is providing the team with a hydraulic system. The team has calculated that the arm will produce a breaching force of 7000 N given the hydraulic system provided. Due to the machine being fully electric, it would increase battery life if the machine were as light as possible. The weight of the batteries is acceptable because the arm needs counterweight, however there are other ways to reduce overall weight of the machine. The team has decided to make the base from hollow square steel tubing and make the center with cross beams instead of one solid piece.

In order to remotely operate the excavator system, Arduino will be used to create the Electronic Control Unit (ECU). Remote operation will be done through an Android device, that will connect to the ECU using a Bluetooth module. User interface will allow the operator to use the remote controller to control the rear wheels, which will independently be powered by two motors that will control and power the direction of the excavator's movement. A potentiometer and relays will be used in coordination with pulse-width modulation to control the hydraulic system.

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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.

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 (ECU)	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 Functional Decomposition

2.3.1 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.

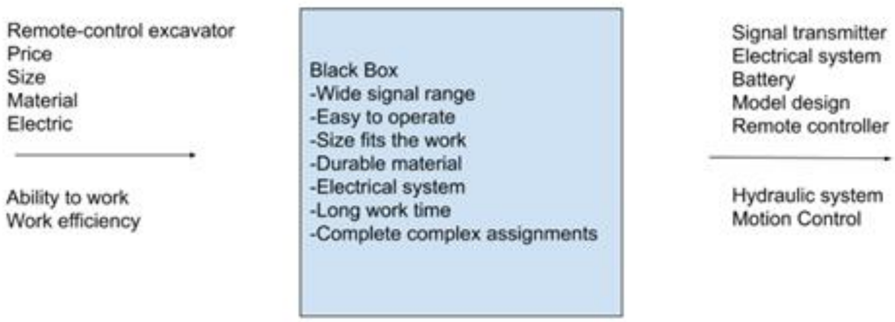

Figure 1: Black Box Model

2.4 House of Quality (HoQ)

Creating a Quality Function Deployment (QFD) 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.

Updates to the QFD include added testing procedures, and their quantitative relationship to the engineering requirements. Tests are listed below the customer requirements section, including four tests that ensure the operation of all main components. Relationship correlation between tests and engineering requirements are depicted in red, following the same format noted above that relates customer requirements and engineering requirements.

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
1	4	Remote Operation	3	9	3		1
2	5	Electrically Operated	9	3	1	1	
3	3	Full Work Day	9			3	1
4	5	Digs 1'x6" Irrigation Trench	3	1	3	9	3
5	1	Ground Penetrating Radar	3	1			
6	4	Durability	1	1	1	9	9
	Test Procedures	**Testing Objectives**					
7	Test 1	Charge, Recharge, and Battery Compatibility	9	3	3		
8	Test 2	ECU Operational Testing	1	9	9	1	
	Test 3	FEA				9	9
9	Test 4	Hydraulic Compaitbility Testing	3	9	9	1	

Figure 2: Updated QFD

2.5 Standards, Codes, and Regulations

Arizona law requires underground utilities to be marked before the excavation process. Locators will come out to the property if utility lines are buried in the dig area and mark them for you before the excavation process begins. Welding and electrical codes are also relevant to our project as we need to weld the base, battery box and arm together as well as wire the batteries to the hydraulic pump to have a completed product.

Standards of Practice as Applied to this Project

Standard Number or Code	**Title of Standard**	**How it applies to Project**
Flagstaff Municipal Code SECTION 13-18-004-0001.1	ENGINEERING DESIGN STANDARDS AND SPECIFICATIONS FOR NEW INFRASTRUCTURE: Excavation Section	Provides municipal regulations on excavation projects in the city of Flagstaff, AZ.
AWS D9.1	Sheet Metal Welding	Welding the base, battery box and arm/bucket of the excavator
A.R.S. 40-360.21-31	Pre-digging identification of underground utility lines.	Requires anyone who is excavating on public or private property for any reason to determine, in advance, whether underground facilities will be encountered

Table 3

[1-3]

3 Testing Procedures (TPs)

In this section, testing procedures are discussed that will ensure each main system of the excavator will reliably work according to the team's designs. Testing categories include the hydraulic system, ECU, battery capacity, and FEA, respectively.

3.1 Testing Procedure 1: Hydraulic System Testing

The hydraulic system test is a test to test whether the hydraulic system works in the remote-control excavator. For the project, hydraulic testing mainly includes hydraulic pressure testing, hydraulic pump testing and valve testing. The test will control the workmanship of the remote-control excavator arm by studying the pressure parameters of the hydraulic system, debugging the hydraulic pumps and valves, so as to meet the engineering requirements for remote control excavator motion control.

3.1.1 Testing Procedure 1: Objective

In order to test the function of the hydraulic system, first pass the hydraulic pressure test, connect the pressure measuring device to the hydraulic system, turn on the switch of the hydraulic system, and observe whether the pressure parameters meet the standard by measuring the measured pressure of the hydraulic system. Secondly, the pressure of the hydraulic system is controlled by moving the hydraulic control rod. If the pressure parameter can change normally, the pressure parameter of the hydraulic system is normal. Next, the hydraulic flow test is performed. The fixed displacement pump can be tested by checking the flow through the safety valve. The fixed displacement pump can be tested by checking the flow through the safety valve. Turn on the pump and record the flow out of the safety valve tank line. After about one minute, reduce the safety valve setting to the minimum setting. If the flow rate difference between the two tests should be less than 10%, it means that the hydraulic flow parameters are normal. Finally, connect the hydraulic system to the electric system and arm of the remote-control excavator, and observe whether the hydraulic system can control the movement of the remote-control excavator arm by controlling the joystick to determine whether the hydraulic system meets the standard.

3.1.2 Testing Procedure 1: Resources Required

Hydraulic system testing requires a hydraulic tester to test the pressure and flow of the hydraulic system. At the same time, the hydraulic system test needs to complete the arm model of the remote-control excavator, and it needs to be connected to the electrical system of the remote-control excavator.

3.1.3 Testing Procedure 1: Schedule

The hydraulic system test needs to be tested after the hydraulic system, electrical system and the remote-control excavator model are completed. The specific time will be carried out after the campus is open.

3.2 Testing Procedure 2: ECU Operational Testing

Testing the functionality of the ECU will include Bluetooth compatibility between the remote control (Android device), and the Arduino UNO board. Ultimately, this testing procedure investigates the operability of the remote control with the wheel motors and hydraulic system. The main engineering requirement this regards is a working ECU, with an intuitive user interface, while satisfying the customer's requirement of remote operation.

3.2.1 Testing Procedure 2: Objective

To test that the ECU will be functional, first Arduino's sketch validation can be utilized within Arduino's web programmer. This validation will confirm if all written code will upload onto the Arduino board. Next, Bluetooth connection will be established between the Android device and the ECU, confirming that the Bluetooth module is working. Motor control will then be tested by the Android device, using a community created app on the Android app store, to ensure that inputs on the remote controller will produce expected results from the motor i.e. both motors producing forward motion. Last, compatibility between the hydraulic system and the remote controller must be tested. This will be attempted in isolation from other components to ensure expansion and contraction of the hydraulic system can successfully be controlled by the potentiometer and relay modules via the remote-controlled device.

3.2.2 Testing Procedure 2: Resources Required

Resources required to attempt and achieve these tests will be durable and reliable potentiometers and relays to test the hydraulic system. Furthermore, the Arduino board will need the Bluetooth module and a corresponding Android smartphone or tablet for all ECU testing. Lastly, the wheel motors, and all components of the hydraulic system will be required to complete the remaining tests.

3.2.3 Testing Procedure 2: Schedule

While preliminary testing has commenced in order to test individual modules of the ECU, such as the potentiometer and motor control, these tests are rudimentary compared to the actual modules that will be used on the excavator. Once all needed resources are sourced, testing can be expected to begin at the beginning of September, once the NAU campus is open. Ideally, testing will be finished in two weeks, although the team expects delays due to technical issues, as electrical engineering is a secondary forte for all team members.

3.3 Testing Procedure 3: Battery Capacity

Testing the capacity of the battery system will require the full assembly of the excavator and using the machine until the batteries need to be recharged. This will allow us to determine if the battery capacity is correct for all day usage of the hydraulic system and movement motors. After the batteries are depleted, we can test the charging system and document the full recharge time.

3.3.1 Testing Procedure 2: Objective

The objective of this test is to ensure the batteries have the correct capacity to run the electronics, and to make sure the recharging will be fast enough to use the next day again. To ensure these tests are done without error we must begin the test with a full charge and start recharge when the batteries are completely depleted.

3.3.2 Testing Procedure 2: Resources Required

The test will require a 4-bank battery charger and a battery percentage indicator to inform the team when the batteries are dead. We intend to plug in the battery charger to a 110-volt outlet to allow a full recharge of all four batteries overnight.

3.3.3 Testing Procedure 2: Schedule

Testing of the battery system can begin when we complete the build of the excavator and it is fully operational. It will most likely be on NAU campus where the testing takes place so the campus will need to be open and available for us to use.

3.4 Testing Procedure 4: Finite Element Analysis

The testing procedure for the Finite Element analysis firstly requires a basic understanding of what we are looking for in our results. To be more specific we are seeking to calculate the digging force that is required to dig in varying terrains There is a number of ways to calculate this force however in our study we will be focusing on the SAE standard SAE J1179. In this SAE standard we will be analyzing 2 forces produced by our excavator. The forces that we will analyze both act on the tip of the bucket and can be classified by the motion that produces them. These force classifications are the Bucket curling force which is a generated due to the motion of the bucket cylinder and the arm crowd force which is generated due to the motion of the arm cylinder. Generally speaking, the digging force will be taken as the maximum of these 2 forces and it is commonly referred to as maximum breakout condition of the linkages. The key to this calculation will depend on the hydraulic cylinders used, as they apply the forces to the boom, arm and bucket which propels our mechanism to move. It is at this point where the Finite Element Analysis becomes a very useful tool to have at our disposal. The reason being is because depending on Excavator arm position, the applied force and the diameter of the hydraulic cylinders will have a huge impact on the digging forces we calculate. The methodology for the Finite element analysis is as follows, conduct a Rigid Body Dynamics analysis in order to calculate the maximum digging forces, compare them to the hand calculations as a way to verify, optimize the hydraulic cylinders depending on the resistive force calculations and lastly conduct a stress and strain analysis on the bucket, arm, and boom to see where are weak points are.

3.4.1 Testing Procedure 2: Objective

The objective of this analysis will be to study and compute the digging forces our excavator arm generates. Then we will compare these digging forces to the resistive forces experienced while in the motion of digging as a way to ensure we will have sufficient digging power. Once we have these preliminary results, we will analyze the stress and strain experienced in the bucket, arm, and boom in order to optimize the arm design so that we are as efficient as possible with our design.

3.4.2 Testing Procedure 2: Resources Required

At the moment the only thing that we require to proceed with our finite element analysis is the final specifications of our hydraulic system. Once we have this in place, we will have everything needed to conduct the analysis and generate accurate results that fit our model. Other things that we need but have already crossed of our list include a reliable connection to the Ansys platform and the force calculations needed to generate these results by hand.

3.4.3 Testing Procedure 2: Schedule

The schedule for the finite element analysis is currently on track we plan to have this study complete with in the first third of the second semester. At the moment the only thing that is holding us back is the specifications of the hydraulic system, in the meantime we have been focusing our time on setting up the study so that when we do get these final specifications we will be able to plug values in and move on from there.

4 DESIGN SELECTED – First Semester

Chapter 4 discusses the current design the team has decided on at the end of the summer semester. A description of the design, and photos of the CAD models created so far, featuring an altered base compared to the preliminary design, is discussed in section 4.1. Section 4.2 elaborates on the plan the team has in order to reach a final product, discussing the team's expected timeline and order of assembly.

4.1 Design Description

The team's current design provides an expected solution that theoretically satisfies all customer requirements. The design consists of 5 subcategories: Base design, arm design, ECU, power supply, and the hydraulic system.

Base Design

The base design did not have many changes from the original design up to this point. The original design was 30 inches long and 24 inches wide with the square steel tubing being 4 inches wide. The design modifications made after battery choice and arm design resulted in the steel square tubing reducing to 2 inches, the length increasing to 36 inches and the width increasing to 30 inches. The first and second designs both featured 3 inch axels. The only modification made to go to design number three was decreasing axel size to 1 inch and stepping it down to .625 inches to accommodate the chosen wheels.

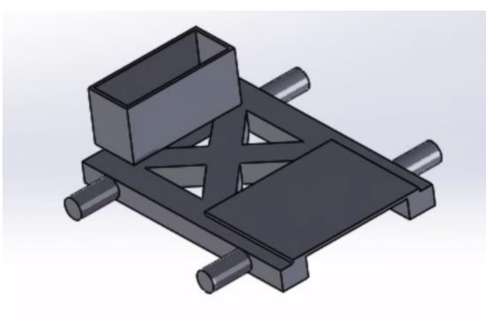

Figure 3: Design 1

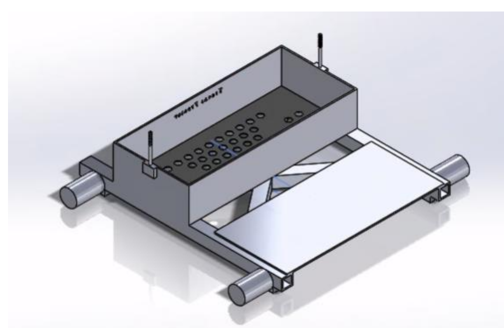

Figure 4: Design 2

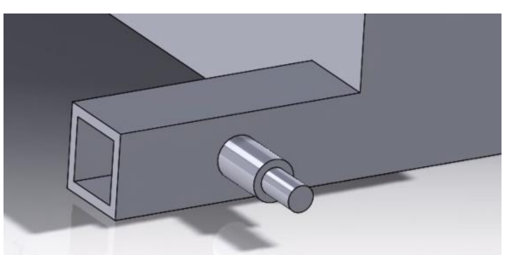

Figure 5: Design 3

Arm Design

Our current arm design was reversed engineered from a model obtained from GrabCad. At the moment the bucket is 6 inches wide and is roughly 6 inches in depth. We modeled our mechanism in a robust manner so that when we finally analyze any results from the FEA study we will be able to reduce material instead of figuring out ways to add material. In the current state of our design the lower, middle, and upper actuators respectively have travel lengths of 7.5 inches, 10.5 inches, and 5.5 inches. These travel lengths allow our excavator arm to have a maximum reach of roughly 75 inches. With these preliminary dimensions we have initially estimated our maximum digging force at right around 7000 Newtons which is more than enough force needed to overcome our initial resistive force calculation of 4000 newtons. As this is only an initial design all of the dimensions and calculations are bound to change as our component specifications become more readily available to us and thus these dimensions and calculations should only be used as an estimate to the range of values we are seeking.

ECU

The design for the electronic control unit relies on the use of an Arduino UNO, utilizing an Android device for a remote controller, connected to the Arduino board via a Bluetooth module. A breakout shield expansion module that interfaces flush with the board will allow extra voltage and ground pins to be able, which will be used to connect the potentiometer, relay, and wheel motors. This expansion module will also provide an open voltage pin to connect to an extra motor, should the team alter the design in favor of a rotating excavator arm. The wheels of the excavator will be used to position the arm, providing turn radius from powering the rear wheels in opposite directions. The current user interface option chosen is the Android app, MjRoBot BT Remote Control, which allows users to connect wirelessly to their Arduino board and control motor systems through the app. Another option, should this application provide issues, would be creating an application using MIT App Inventor, which the previously mention app was created on. While this option would be more time consuming, the team would be able to develop the user interface to be tailored directly towards this project.

Power Supply

The design of the power supply box is located near the rear of the excavator to counter act the weight of the arm. The batteries are 12 volts that weigh 60 pounds each and there will be 4 batteries that fit in the battery box to drive the hydraulics and motors. The batteries will be connected in series to create a 48-volt system. A 48-volt system allows the wires on the excavator to be thinner than that of a 12-volt system. A 300o watt inverter will be connected to the batteries which will allow a calculation of the wire thickness required to support the amperage. A 12-volt system calculation would result in: 3000 Watts/12 Volts= 250 Amps, finding a wire that will support 250 amps of current is very difficult and expensive therefore the 48-volt system is ideal for our situation. The 48-volt system calculations result in: 3000 Watts/48 Volts=62.5 Amps, this is a more reasonable amperage and will only require a 10-gauge wire for power transfer. The batteries will be equipped with battery percentage indicators to allow the user to know when the machine is not fully charged along with a 4-bank battery charger that will charge the batteries over night when not in use.

Hydraulic System

The design of the hydraulic system of the excavator is shown in the figure below. First, the energy is transferred to the hydraulic pump of the hydraulic system through the engine of the excavator, and the output liquid passes through the main control valve of the hydraulic system, and is divided through the hydraulic manifold to three valves. The arm of the excavator can be controlled by the valve joystick. Finally, the liquid flows through the circuit of the hydraulic system to the hydraulic accumulator for storage.

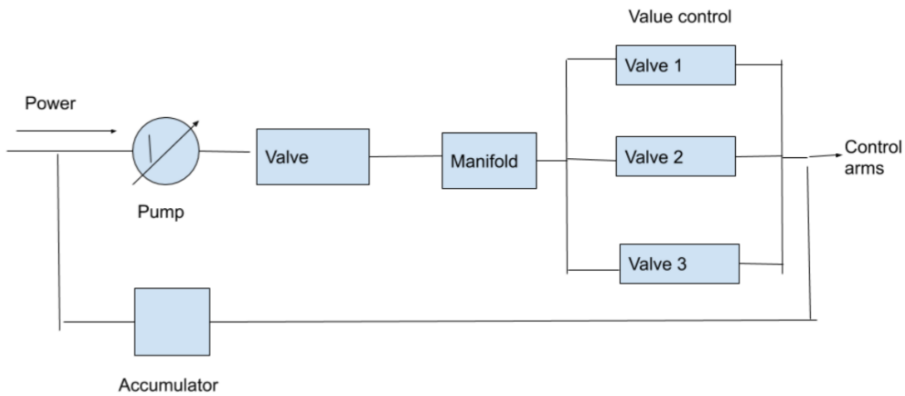

Figure 6: Hydraulic System

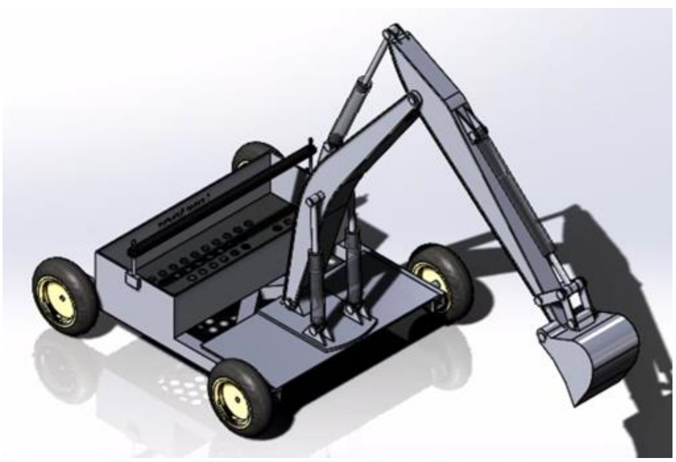

Figure 7: Final Assembly

4.2 Implementation Plan

Implementation of the customer requirements and design decisions require some fabrication, programming, wiring and assembling the purchased parts. Arm construction will require a 9 cubic foot sheet of stainless steel and will require fabrication to create the arm shape along with the bucket and base. The hydraulics and hydraulic pump will be provided to the team by NAU which will control the arm of the excavator. Four deep cycle batteries will be purchased from Walmart and installed in the fabricated battery bucket on the base of the excavator. Wire, battery percentage indicators, an inverter and a 4-bank battery charger will all be purchased from amazon to wire up and maintain the excavator batteries. The wheels that attach to the base of the excavator along with motors to move the wheels will be purchased at harbor freight, this will allow the excavator to be mobile to allow for digging in different spots. The Arduino board and android tablet that will control the motions of the arm and wheels will be purchased from amazon as well.

To begin the manufacturing process following the sourcing of material and components, it can be expected that the beginning stages of testing and building will begin at the start of September, shortly after the expected opening of NAU's campus. During this time, testing will occur and as verification of design success results from testing procedures, manufacturing will begin. It is unclear how the pandemic will affect the team's manufacturing timeline, as regulations on the number of team members in the machine shop might be expected. With expectations that tests are completed swiftly, manufacturing of the excavator will start the second week of September, starting with the construction of the frame and arm of the excavator. Machining, welding, and other manufacturing processes will take place, largely in the machine shop at NAU. During this time, the ECU can also begin preparation for attachment to the frame. Once the frame is mostly complete, the ECU can be fixed and attachment of the wheel motors, wheels, and wiring can be done. Last, the hydraulic system and power supply assembly onto the excavator will commence, and then be connected to the ECU. A detailed gantt chart, can be viewed in figure 8 below, depicting expected start and finish times of the excavator's components. Although it would be ideal for the team to adhere to this strict schedule, it is understood that the pandemic can cause unexpected hurdles for the team to complete tasks as forecasted.

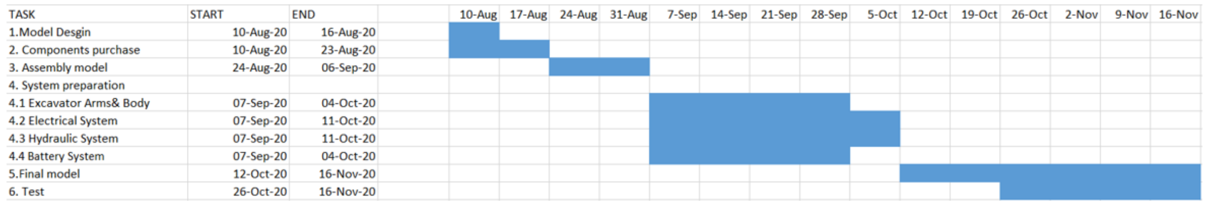

Figure 8

System	Name	Quantity	Cost($)
Excavator Arms& Body	9 cubic feet stainless steel	1	30
	Wheel motors	4	80
	wheels	4	27.96
Electrical System	Arduino UNO	2	50
	Bluetooth Module	1	10
	Potentiometer & Relay	1	40
Hydraulic System	Hydraulic pump	1	50.99
	Hydraulic valve	5	300
	Hydraulic manifold	1	69.99
	Hydraulic accumulator	1	48.76
	Motor	1	230.93
Battery System	12 volt battery	4	360
	48 volt Inverter	1	323
	battery percentage level screen	1	17
	10 gauge wire (50 feet)	1	44
	4 bank battery charger	1	178
		Total	1860.63

Figure 9

5 CONCLUSIONS

The client's requirement of a remote operated, electric powered, excavator suitable for digging garden-sized irrigation ditches, is the primary goal of the team's design. To begin the design process, customer requirements were specified, clarified and prioritized, allowing the team to then create quantifiable engineering requirements. The two were then organized into a QFD and assigned weighted relationships during the preliminary design process. The QFD was then updated to include testing procedures, in which each engineering requirement would be ensured functionality through testing. Conceptually, these tests include investigating operability of the ECU, hydraulic system, and power supply, while also using FEA to theoretically test stress and strain values of the frame and arm of the excavator.

Although the design is still open to change, the current iteration uses Arduino to remotely operate the excavator. The hydraulic system, powered by the lead acid batteries, will allow an operator to remotely dig an irrigation trench, approximately 1 foot deep and 6 inches wide. Currently, the design proposes a fixed arm, with rotation being provided by the wheels of the excavator, but this feature can be amended if the team decides that operation would be much more difficult than a rotating arm. In order to provide a rotational arm instead of a fixed arm, the design would place the arm on an elevated platform, which would allow rotational movement powered by an additional motor specifically for the platform. For now, the current design is expected to meet all required customer needs.

6 REFERENCES

[1] Flagstaff Municipal Code Title 13 ENGINEERING DESIGN STANDARDS AND SPECIFICATIONS FOR NEW INFRASTRUCTURE, https://www.flagstaff.az.gov/DocumentCenter/View/13743/2017-COF-Engineering-Standards-and-Details?bidId= SECTION 13-18-004-0001.1

[2] Kelechava, Brad, AWS D9.1-2018 – Sheet Metal Welding Code, 3/08/18: https://blog.ansi.org/2018/03/aws-d9-1-2018-sheet-metal-welding-code/#gref

[3] "Professional Excavators," *Arizona 811*, 11-Feb-2020. [Online]. Available: http://www.arizona811.com/excavators/. [Accessed: 05-Aug-2020].

7 APPENDICES

[Use Appendices to include lengthy technical details or other content that would otherwise break up the text of the main body of the report. These can contain engineering calculations, engineering drawings, bills of materials, current system analyses, and surveys or questionnaires. Letter the Appendices and provide descriptive titles. For example: Appendix A-House of Quality, Appendix B- Budget Analysis, etc.]