# Grading-Surveying Tower (GST)

**Senior (Capstone) Design Project Final Report**


**College of Engineering**

**Department of Electrical Engineering**

**Team Members:**

Angie Abdelbaky
Mohammad Rashiqul Alam
Ryan Garvin
Jose Molina

**Faculty Advisor:**

Dr. Arash Takshi

**Poster:**

# Grading Surveying Tower

Electrical Engineering Senior Capstone Design (Spring 2019 – Fall 2019)

Angie Abdelbaky, Mohammad Rashiqul Alam, Ryan Garvin, Jose Molina

Faculty Advisor: Dr. Arash Takshi

## Problem Definition

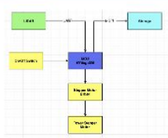
Concrete floors and foundations require a smooth and level surface to pour concrete. Grading subtractors are hired to make a rough grade at job site. Rough grades are routinely given at +/- 1.2" of the final fine grade. The fine grade requires movement of excess material (sand, soil, etc). This +/- 1.2" is often only spot checked by concrete subcontractors. This often results in inconsistencies.

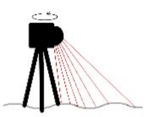
## Solution

Design a device and software that can measure and display the average terrain elevation to within +/- 1.2". Design should automate what was previously a manual task.

## Proposed Design

Using a LiDAR (Light Detection and Ranging), radial distances can be measured. The LiDAR will be mounted on an adjustable height on a rotating tower system. These measurements will then be saved onto a removable SD card, from which the user can process the stored data using the supplied MATLAB script. This script will process the given information into a 3D map of the scanned terrain, inform the user if the terrain is within rough grade, and various other useful statistics.





## Design Considerations/ Methodology

We want the device to be easily transported to and from different construction sites. As a result, the design for the tower legs are telescopic and fold inwards. A bubble level will be included to ensure the enclosure sweeps a level plane.

## Requirements

Hardware:

- Tower platform must rotate in steady and controlled manner.
- Final assembly must be able to autonomously rotate and record topographical data.

Software:

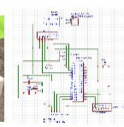
- LiDAR data must be normalized for vertical reference and plotted in three dimensions.
- LiDAR data must be recorded and stored on an SD card for mobility.
- The scan resolution (number of sweeps) should be an accessible setting to the user.

## Simulation & Calculations

- The Design utilizes a 5000 mAh LiPo battery.
  at an average current draw of ~ 930 mA the tower should be able to scan continuously for over 5.3 hours.
- Each LiDAR datapoint returns 8 Bytes of floats.
  Typical sweeps are comprised of ~ 100 data points.
  One gigabyte of storage space could hold over one million sweeps i.e. effectively infinite resolution.

## Prototyping

A prototype circuit was constructed on a breadboard to test each individual hardware component, including the LiDAR, the motor, and the SD card module. A PCB was then designed based on this circuit. A prototype enclosure was also created for testing.

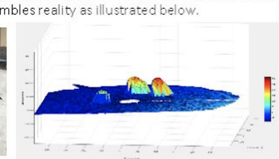


## Testing

The individual components were soldered onto the PCB and were tested individually and then together as a whole.

## Analysis of Results

The device is capable of sweeping an area and returning a plot which perfectly resembles reality as illustrated below.



## Conclusion

To increase the accuracy of the terrain elevation as well as the area that can be swept, the use of a higher quality LiDAR device can further improve this project. The hardware enclosure can also be further improved by designing it with a more reliable material than PLA.

## Timeline


## Work Division

Angie – Mechanical & System Documentation Lead, 3D Design of Enclosure
Mohammad – Hardware & Software Design Lead, PCB Design, MCU Software
Ryan – Data Interpretation & Software Lead, Data Visualization from LiDAR on MATLAB
Jose – MCU Software Lead, Data Acquisition from LiDAR, System Controls

## Project Description:

The Grading Surveying Tower is intended to survey, record, and report the 'grading' of a cleared and leveled plot of land. The product in question is intended to be a freestanding platform which will sweep a 30 sq ft area of land, plotting the topographical information. The device will be placed at a certain point and report the elevation along the surface to ensure appropriate conditions prior to land development or to plot an object of interest.

Concrete floors require a smooth and level surface to pour onto and rough grades are routinely given at +/-1.2" of the final fine grade elevation. The fine grade requires movement of any excess materials (sand, soil etc). This +/- 1.2" is often spot checked by concrete contractors and the current method often results in inconsistencies therefore, resulting in higher material and labour costs.

The Grading-Surveying Tower is intended to be a relocatable platform supporting a rotating assembly. This rotating component will house all of the electrical components, primarily the LiDAR (Light Detection and Ranging) which the objective is centered around. The LiDAR will record and map the terrain surrounding the perimeter of the device and save this data on an SD (Secure Digital) card. This data will then be processed and plotted to display the topographical model of the terrain and return critical data to the user.

The list of individuals involved in the project are as follows:

1. Angie Abdelbaky
2. Mohammad Rashiqul Alam
3. Ryan Garvin
4. Jose Molina

## Technical Design:

The following image shows the high level overview of the system. The primary components of the system include an ATmega 328 MCU (Micro-controller), SD Card Module (Storage Unit), LiDAR (Scanning Device) and a stepper motor to rotate a 3D printed enclosure containing the electrical components (including the battery).

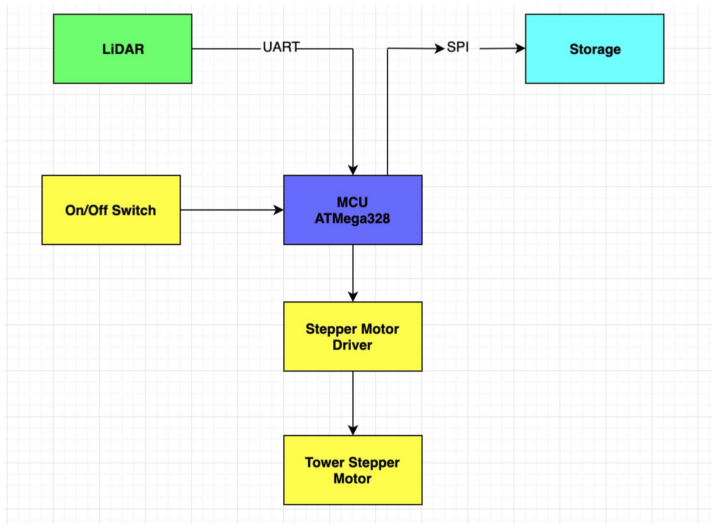



Figure 1: Shows the high level block diagram of the system

The following figure shows the PCB (Printed Circuit Board) schematic and the layout of the system. The circuit involved a DC - DC converter, ensuring 5V is maintained throughout the circuit and that necessary current is provided to the stepper motor driver (LM298N) to drive the motor. Other components include necessary crystal, capacitors, resistors to drive the ATmega328 MCU chip in the center of the board. The power rails on the PCB were designed to be wide enough to support 4A of current incase the system experiences a current surge.

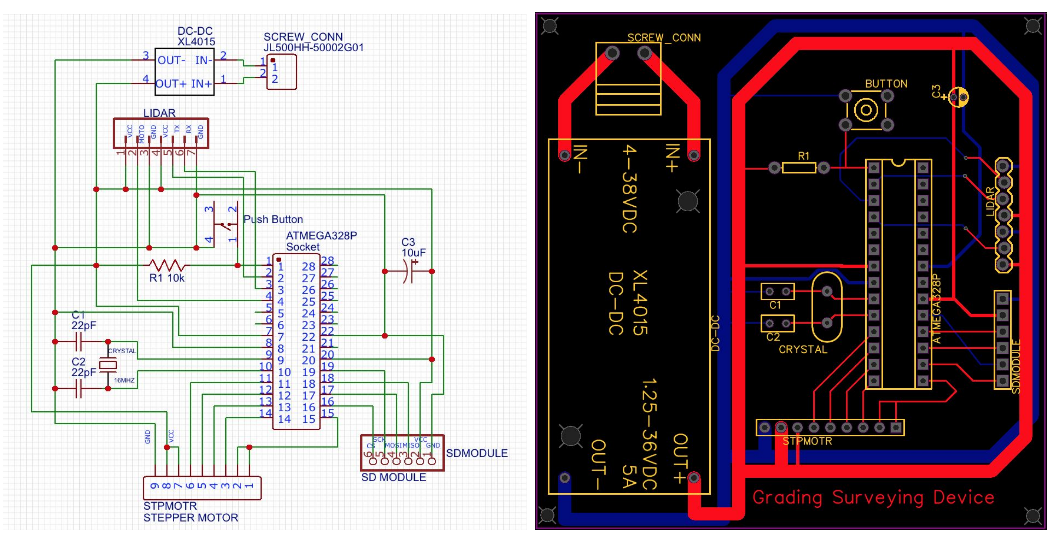



Figure 2: Shows the PCB Schematic and Layout

The flowchart above shows the program flow of the MCU unit when interfaced with the LiDAR and the SD Card Module. The program requires requiring communication protocol to be set up for the respective components. The parameters of interest include 'Distance' and 'Angle' hence, the LiDAR data acquisition begins by creating two one dimensional arrays that can contain 50 elements each. Due to the memory restrictions of the ATmega328 MCU, it was necessary to capture the data in two different streaks i.e. populating the array once and having as a CSV file on the SD card. This was followed by appending the file with new data obtained from the second streak. To keep consistency in all the data sets, it was important to acquire data from a starting angle hence, such an angle was set and once this was detected in the algorithm, only then it triggers to populate the array with distance and angle values and sets a flag. Once the arrays are filled a function is called where the MCU proceeds with creating a file that stores the contents of the array. In doing so, the last element of the array is saved such that the program knows where to start gathering the next set of measurements from and clears the flag. An important part of the program takes the number of sweeps as an  input from the user. This number is then used to calculate the increment angle required to turn the stepper motor.

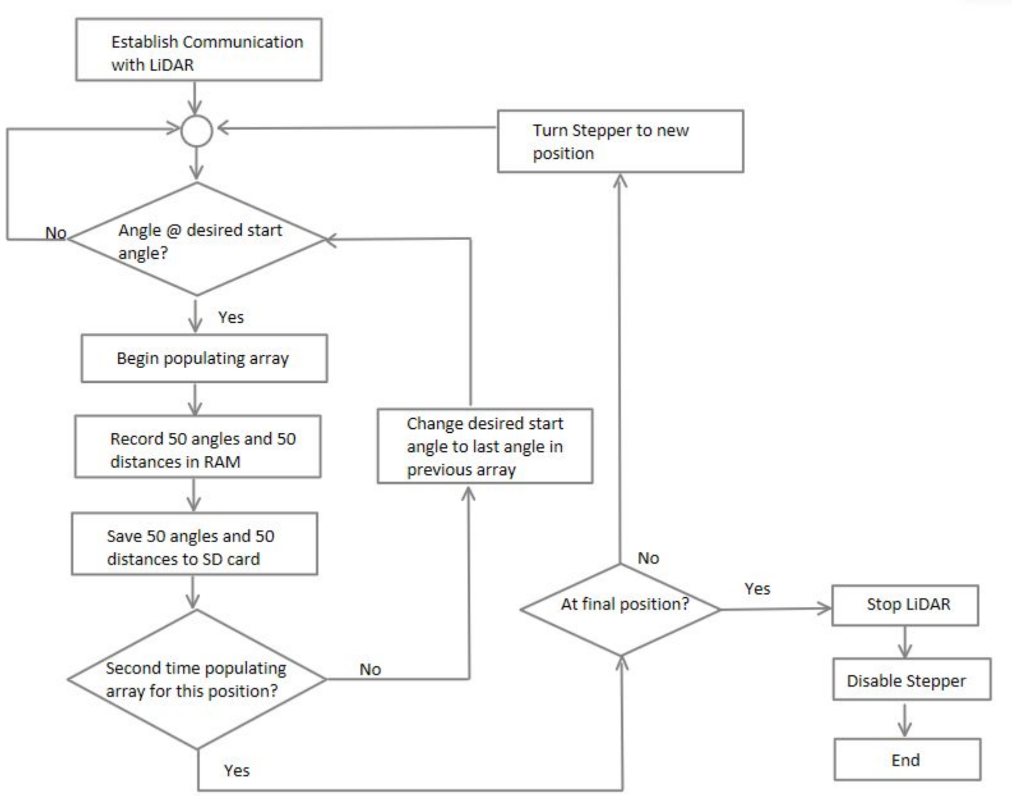



Figure 3: Shows the Program Flow/System Flowchart of the MCU unit

The MATLAB plot is the final output of the project. The data collected by the LiDAR sensor is managed and stored by the microcontroller using the process described above. The 50 element arrays require four rows of data to fully store the information of one sweep. The MATLAB script must begin by collating the distance rows and angle rows together, creating a pair of rows (angles and distances) that fully describe each sweep. The data must be analyzed for two critical values prior to accurate plotting. The first and most important calculation to be made by this script is the “vertical angle” to the ground. This is the angle read internally by the LiDAR that corresponds with the “normal” angle to the earth. To find this value, the angles and distances of each sweep are individually fit with a sixth-order polynomial of best fit. The derivative of each of their polynomials are found and then their zeros. The locations of these zeros correspond to local minima, indicating the shortest distance point measured by the LiDAR. This index is used to find both the vertical angle and vertical distance of each sweep, which are then averaged for the most accurate result. From there, the polar coordinates inherent to the LiDAR and the rotating box assembly are converted to Cartesian coordinates with simple trigonometry. This allows the plot to be produced, with the height values normalized to the elevation of the LiDAR. Other than this most critical function, the script is also capable of collecting and calculating various useful statistics, from LiDAR elevation, average elevation of the terrain, standard deviation of the terrain, and the pass or failure result of the terrain for the “tenth of a foot test” that the project is intended to answer.

The approach to the code was multifaceted and involved techniques at many levels of abstraction. The Atmega code was written at a lower level, for example the individual data points had to be printed to the SD card with commas and spaces expressly included to generate our csv file. The MATLAB script has access to a higher level of abstraction, with powerful functions available to quickly perform laborious tasks. For example, the polynomial for the line of best fit in the data and its subsequent derivative. This was useful in writing robust and readable code once the data had been transferred to a computer with relatively infinite time to process. This is in contrast to the necessity to make the Atmega code lightweight in order to perform all necessary operations in the microcontroller before  the next datapoint was collected. In fact, the code had to be changed specifically to accomodate the time delay involved in writing an array to the card. The lowest abstraction level of code that we interacted with was Bash terminal commands. This level was used to write directly to the SD card from a laptop, allowing the team the power to create txt files with sweep settings or even to change the extension of a csv file to a text file when convenient. In the end, the team had to combine their sum experiences with writing software to accomplish the project. The problems to be solved required a wide variety of techniques and approaches, which allowed each member of the team to contribute to the overall problem solving strategy.

The main box was designed to account for all the hardware components necessary for this tower to operate. The size of the box was made to account for the amount and sizes of the individual components. In the middle of the box is a compartment for the motor. This compartment was sized with the precise measurements to make sure that the motor fit snugly enough to rotate the entire box. A compartment was also made for the battery to make sure that while the box rotates it will not destroy any other components. There are two holes on opposite sides of the box. The first hole was made for easy access of the SD card module. The second hole in the box was made to account for the wires from the side attached box with the LiDAR.

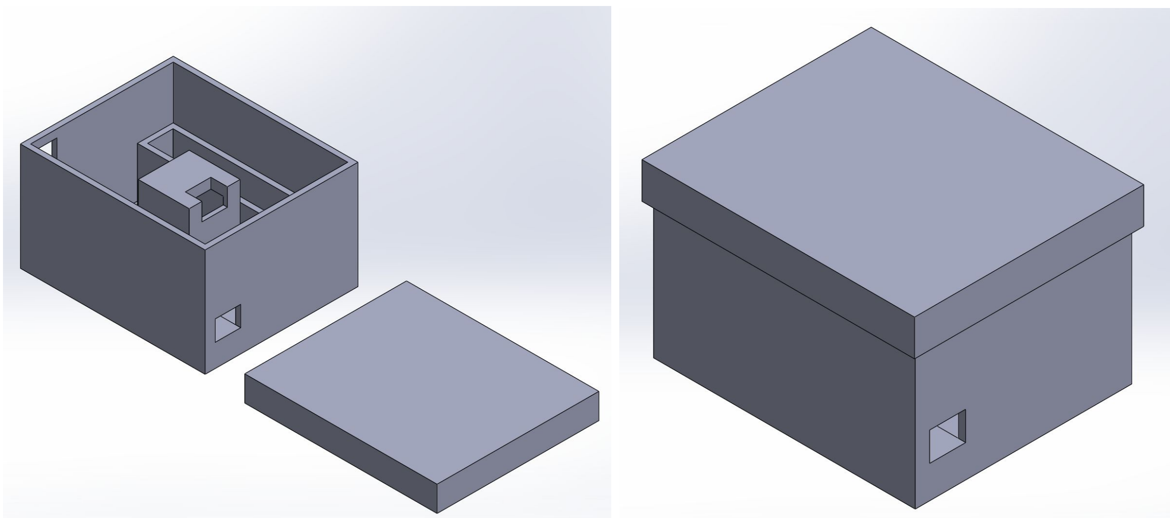


Figure 4: Shows the main enclosure with the lid on and off

The second enclosure that was designed was to account for the LiDAR's unique shape and size. The LiDAR has wires that will have to run through from this enclosure to the main enclosure, so there is a cutout to account for that. This enclosure was designed with two components that would be attached after printing them separately. The reason being, was so that the LiDAR could be mounted on the base of this enclosure. Finally, the protective lid was attached.

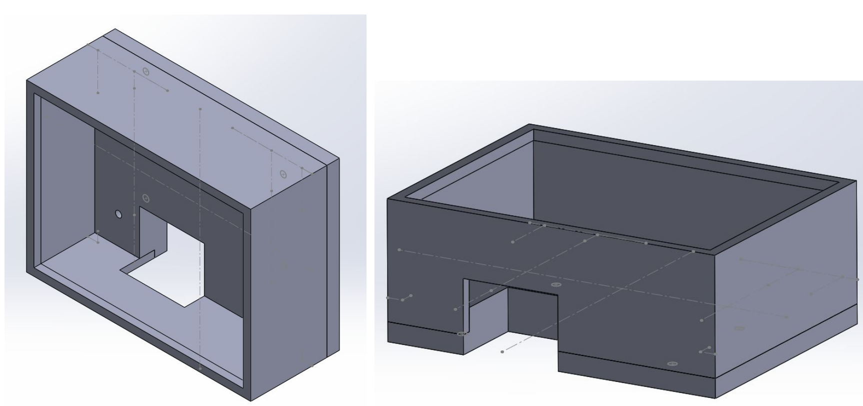


Figure 5: Shows the LiDAR enclosure

## Bill of Materials (BOM)

### Assessed

| | |
|---|---|
| HRB 11.1V LiPo Battery | $40.99 |
| Battery Connector | $7.00 |
| GPS Module | $11.99 |
| Magnetometer (Compass) Module | $8.60 |
| Photodiode | $15.72 |
| RPLiDAR | $99.00 |
| Arduino Mega 2560 | $14.99 |
| Micro SD Module for Arduino | $6.99 |
| Nema 17 Geared Stepper Motor Gear Ratio 5:1 | $45 |
| Nema 17 Stepper Motor 1.5A 12V | $10.50 |
| Uxcell Deep Groove Ball Bearings | $6.73 |
| ATmega328 Chips x3 | $14.44 |
| 16MHz Crystal for MCU x10 | $5.42 |
| 5V Voltage Regulator x15 | $6.99 |
| A4988 Stepper Motor Driver x5 | $9.49 |
| Basswood Sheet | $10.66 |
| Total | **$314.51** |

Table 1: Shows the assessed BOM

### Updated

| | |
|---|---|
| HRB 11.1V LiPo Battery | $40.99 |
| Battery Connector | $7.00 |
| RPLiDAR | $99.00 |
| Arduino Mega 2560 | $14.99 |
| Micro SD Module for Arduino | $6.99 |
| Nema 17 Geared Stepper Motor Gear Ratio 5:1 | $45 |
| ATmega328 Chips x3 | $14.44 |
| 16MHz Crystal for MCU x10 | $5.42 |
| 5V Voltage Regulator x15 | $6.99 |
| A4988 Stepper Motor Driver x5 | $9.49 |
| 3D Printed Enclosures | $60.00 |
| Total | **$310.31** |

Table 2: Shows the updated BOM

## **Executed Project Plan**

To meet the requirement of the project, there were several tests that needed to be conducted. The device needs to operate in a reasonable amount of time. While running the GST, the average sweep time was measured to be between 4 & 5 seconds, meaning that a high resolution sweep at 100 angles would take only 7 or 8 minutes. This is a reasonable time for such high resolution, especially considering the inordinate amount of time it would take a human operator to take the ~ 8000 point measurements. This requirement passes.

Another test that needed to be conducted was the amount of storage space this device is capable of handling. It was found that each sweep stores around 80 data points, each of which are 8 Bytes. If the user provides 1 GB of storage space on the SD card, over one million sweeps could theoretically be saved meaning the upper limit to resolution is effectively infinite. This gives the user more freedom to specify resolution than they would ever reasonably required. This requirement passes.

In addition to timing and storage space, the MATLAB plot of the topographical information was important. The MATLAB script returns a plot with only $^{+}/_{-}$ 2mm deviation for a "smooth" test surface, which could actually be accurately matching the physical reality of a professionally poured concrete floor. Considering that the "tenth of a foot test" that the project was designed to evaluate is a deviation of over 30 mm, the device clearly passes this test.

It was also important to make sure that the lighting based on what time of day does not affect the quality of data. As a result, the sweeps were performed indoors and outdoors, in both full daylight and in dimmer evening conditions. The LiDAR shows no adverse effects on scanning accuracy, regardless of lighting conditions. The LiDAR passes this test.

The most important part of making sure this tower will operate for the entirety of the plot of land was by choosing the appropriate battery. The GST operates at a power rating of 5V * 0.93 = 4.65W. Therefore, using a 5000 mAH LiPo battery, it gives runtime of about 5.37 Hrs.

Once the PCB was designed, each individual component had to be tested. After they were confirmed as working components, they were tested together. The working PCB was accomplished after soldering in the components indicating it passed the test. This put the project schedule ahead of time allowing the team to work on different parts of the project. It was important to ensure that the board would be able to sustain high current during the design phase. Using an online width calculator, the width of the power traces were made thick enough to withstand 4A of current, most of the high current was drawn to power the coils of the stepper motor during operation.

The final test involved making sure the tower was level. The bubble level was placed on the box, which successfully assured the GST of being completely level. This helped make sure that the data being measured was as accurate as possible.

## Design Learning Experience

Different aspects were taken into consideration during the design phase of the project. Concepts and skills acquired from courses were enough to propose a 'method,' but not necessarily a solution for a problem. The team used material from physics, C programming, embedded systems, electronics, and MATLAB courses to aid in mechanical design, microcontroller programming, power conditioning, and data visualization components of the project respectively. These courses offered the technical background necessary to give the team confidence to embark on initial designs, but the implementation and system testing presented challenges not anticipated by initial designs.

The team was afforded opportunities to develop critical and analytical thinking skills through the challenges that arose during the design and iteration cycles. One major challenge was the development of what would become our final product given the time constraints placed on the team by the brevity of the course. After concerted efforts with the team and team advisors, though, the team agreed on the tower design that is being presented. This challenge was not a test of the team's technical skills, but it was a test of the team's ability to mitigate a potential project management risk. The team gained experience and knowledge in project management. This ranged from deadline management using organizational tools such as the Gantt chart, to team meeting management where design approaches were pitched, critiqued, and either accepted or rejected democratically. The team meetings occurred both face-to-face and digitally, with design and work allocation typically occurring in person and document completion primarily completed using internet tools.

## Appendix:

The following consists of a list of documents turned in at different stages of Design II:

1. Critical Design Requirement (CDR) presentation
2. Test Plan
3. Critical Assessment Document

# Grading Surveying Tower

**Team Members**
Angie Abdelbaky
Mohammad Rashiqul Alam
Ryan Garvin
Jose Molina

**Project Advisor**
Dr. Arash Takshi




# Problem Statement & Goal

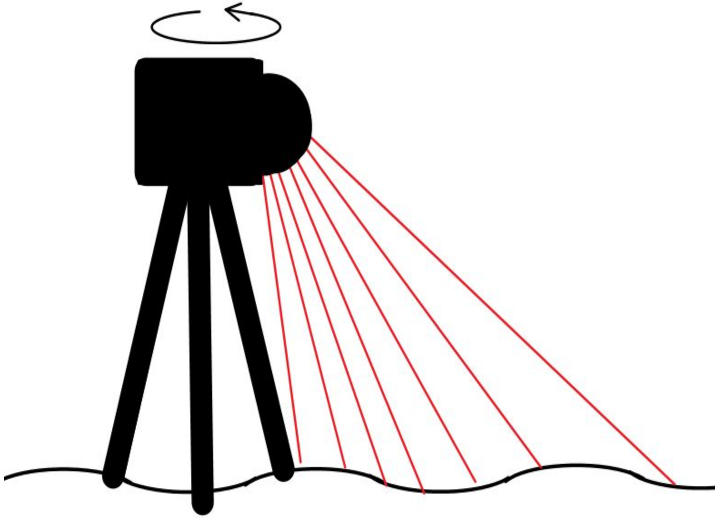
- Concrete floors require a smooth and level surface to pour.
- Grading subcontractors are hired to make a rough grade at job site.
- Rough grades are routinely given at +/- 1.2” of the final fine grade.
- The fine grade requires movement of any excess material (sand, soil, etc).
- This +/-1.2” is often only spot checked by concrete contractors.
- Often results in inconsistencies.

**Project Goal:**

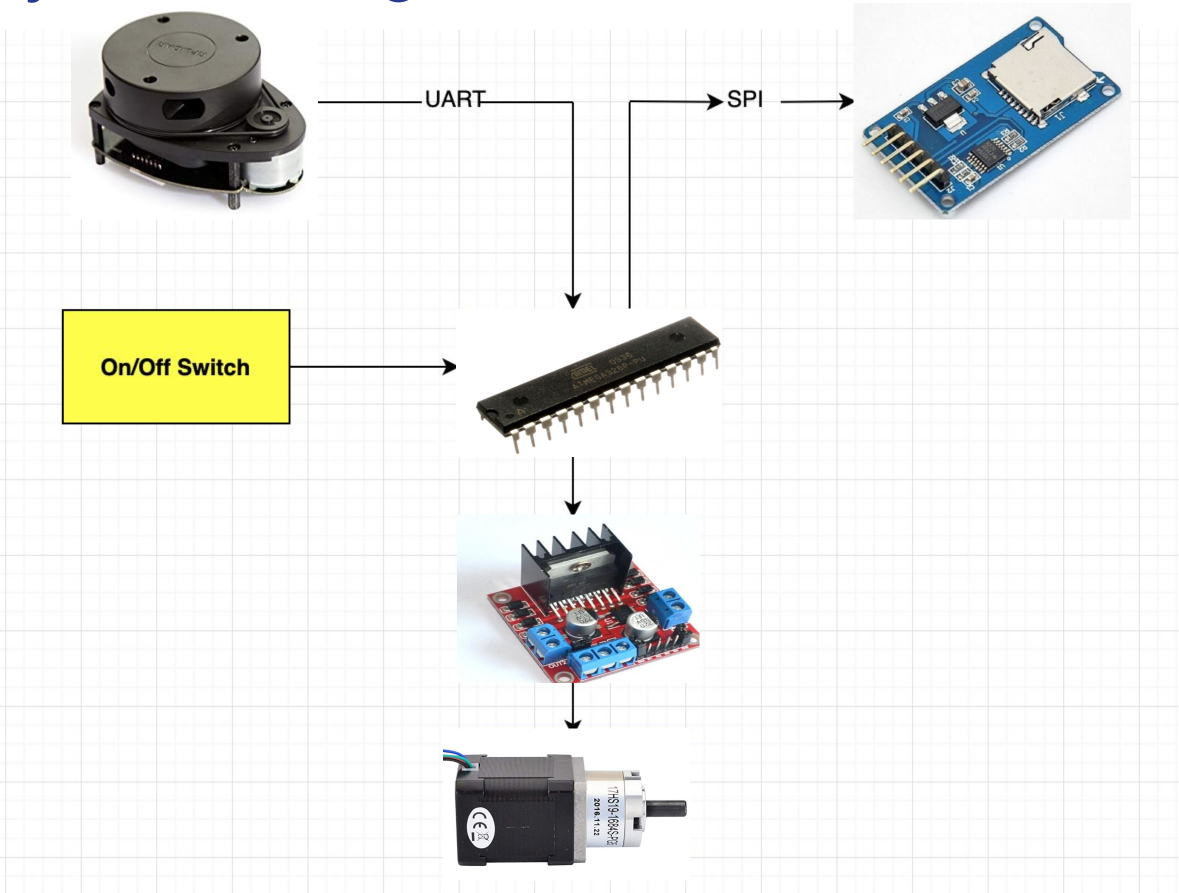
- Device and software to measure and display average terrain elevation to within +/- 1.2”

# Design Approach

- Use Lidar to make radial distance measurements
  - LiDAR Error: +/- 1% of radial distance
- Will mount Lidar to 5 ft. rotating tower system.
- LiDAR measurements will be saved to SD card
- SD card data will be processed in MATLAB script to output:
  - 3D map of scanned terrain
  - Average terrain elevation deviation



# System Diagram

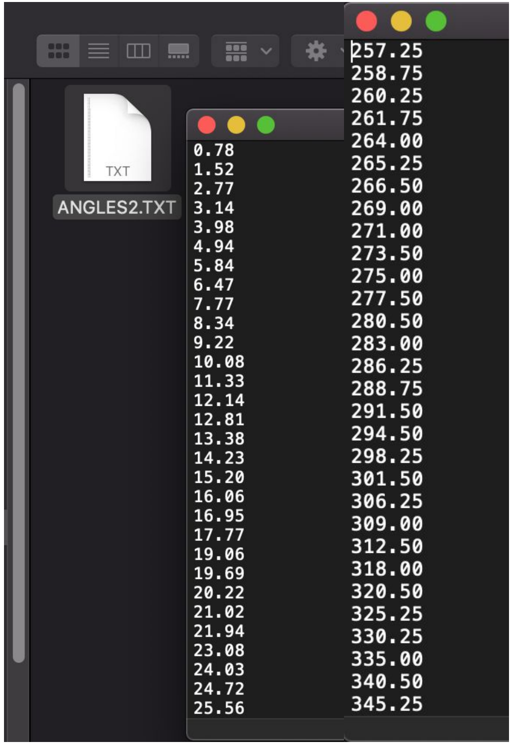


# Subsystem 1: LiDAR Data Acquisition

Spec: Data delivered in .txt format

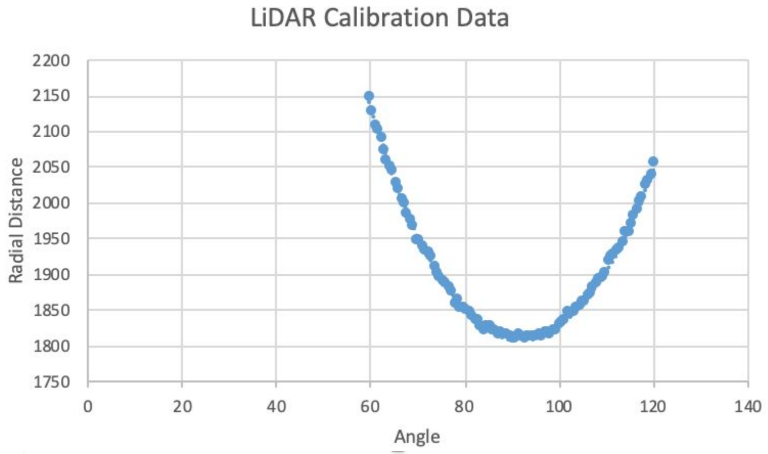
Values on Serial Monitor

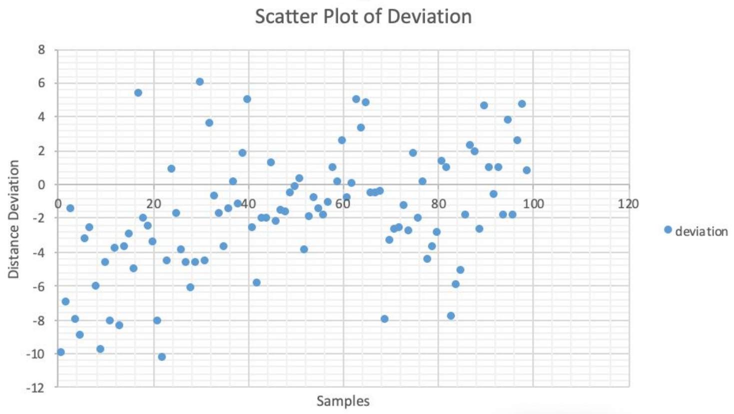

Values on SD Card in .txt File



# Subsystem 1: LiDAR Calibration

- Spec: +/- 1.2” elevation error
- Data acquired from LiDAR needs to be calibrated to determine the angle at which the LiDAR is normal to the ground
- LiDAR data was collected after running a scan along a flat surface
  - Plotting this data, gives us an idea where the minimum distance point is located
  - Taking the derivative of the polynomial tells us exactly which angle corresponds to the shortest distance
  - Sweep angles are then normalized to this vertical reference
  - Using trigonometry the deviation on the surface can be determined from the radial distance measured from the LiDAR



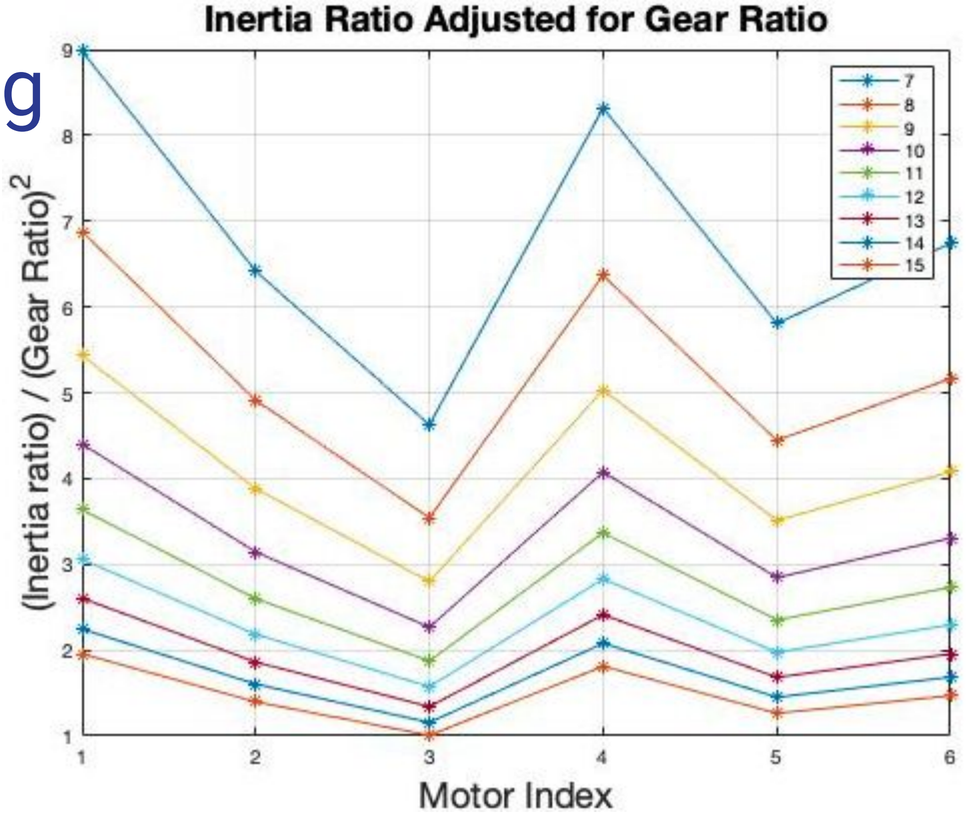



# Subsystem 2: Motor Sizing

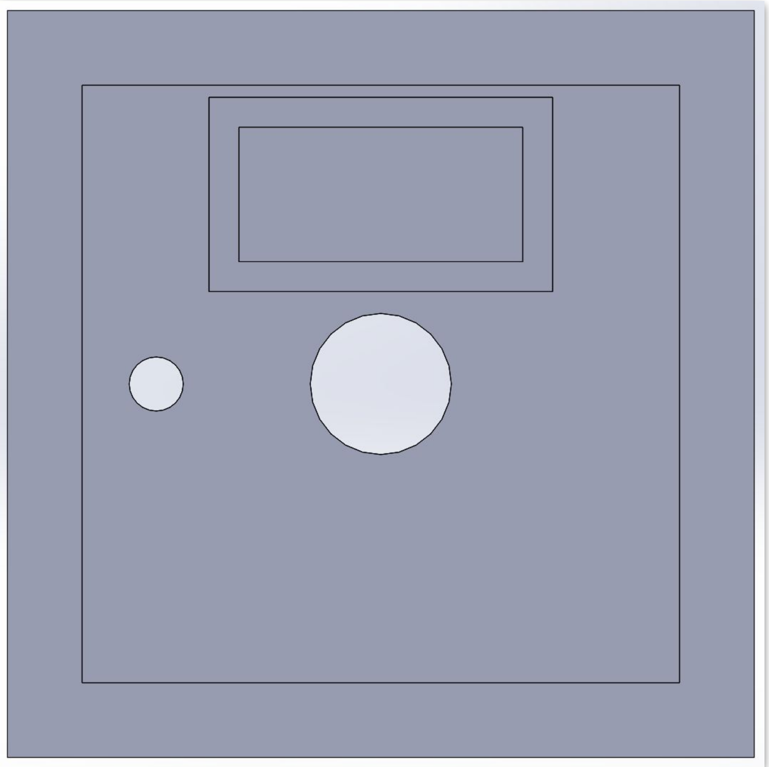
- Spec: Rotation granularity of 1 degree or better
- Stepper motor controlled systems are most stable and easily controlled when the *inertia ratio* is less than 10:1
- *Inertia ratio* is taken from the moment of inertia of the driven load over the inertia of the motor rotor
- Each object of the rotating load has an inertia of its own ($I_{cm}$), which is increased as the center of mass is moved farther from the axis of rotation ($I_{axis}$)
- The *parallel axis theorem* was used to calculate the accurate load inertia according to:

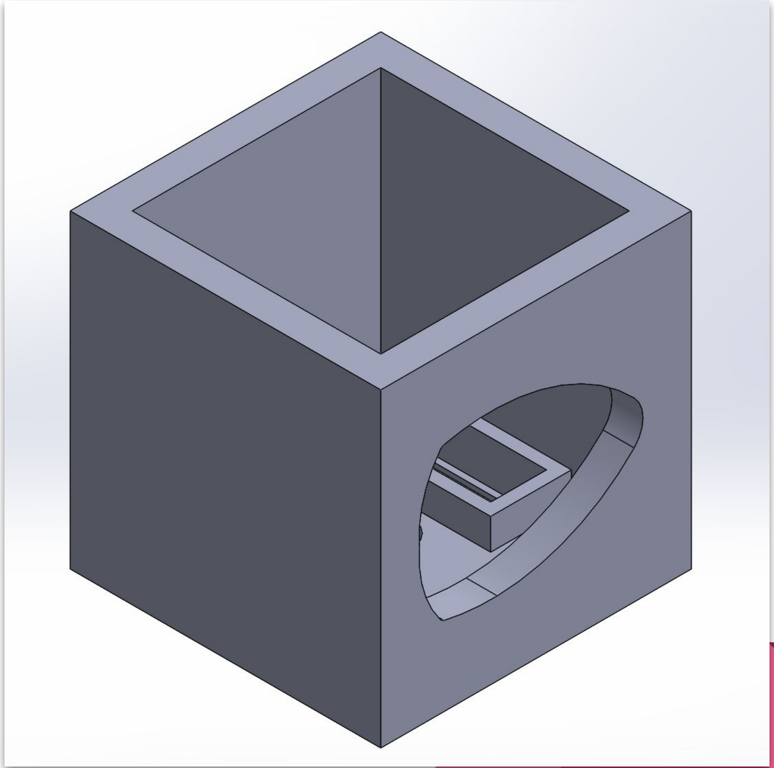
$$I_{axis} = I_{centerMass} + mass*(dist_{cm\text{-}axis})^2 \quad \& \quad I_{total} = \Sigma(I_{axis})$$

- Introducing gears between the motor and load reduces the load inertia seen at the rotor by the square of the gear ratio
- Adjusted inertia ratio = $I_{total}$ / (gear ratio)$^2$



# Subsystem 2: 3D Design





# Power Calculation

<u>Power by element:</u>

- ATMega368 Microcontroller through regulator: 11.1 V @ 30 mA = 333 mW
- NEMA 17 Stepper Motor: 12 V @ 550 mA = 6.6 W
- RPLiDAR: 5 V = 350 mA = 1.75 W

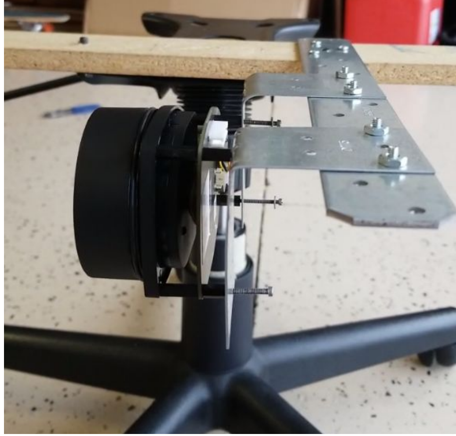
Using the 5000 mAh battery:

5000 mAh / ($\Sigma$ currents) = run time

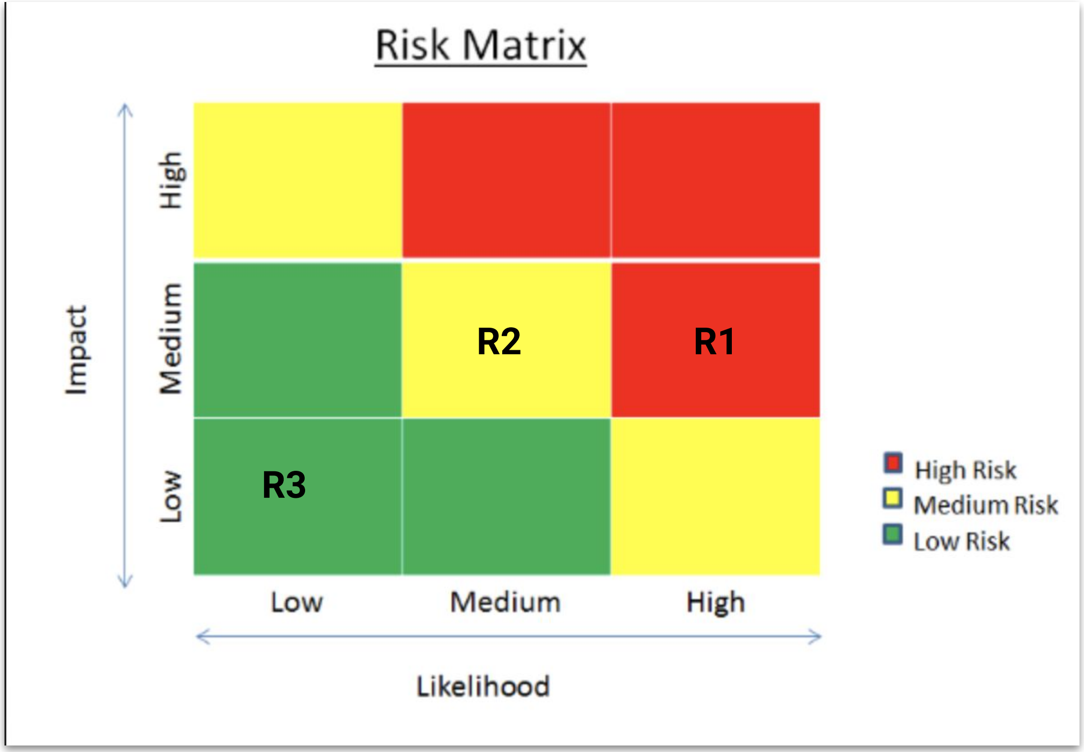
5000 mAh / (930 mA) = 5.37 hours

# Testing Plan

| Requirement | Test Description |
|---|---|
| LiDAR data must be normalized for vertical reference and plotted in three dimensions | Data will be recorded manually prior to the completion of the tower and program will be written for plotting |
| LiDAR data must recorded and stored on SD card for mobility | LiDAR data will be recorded and stored on SD card prior to tower completion |
| Tower platform must rotate in steady and controlled manner | Platform will be rotated only considering fidelity of angle setting |
| Final assembly must be able to rotate independently and record accurate topographical data | Finished tower assembly will be tested on a “sandbox” to compare sweep results with known terrain |



# Project Risks & Mitigation




**R1** - LiDAR feeds noisy data to the SD card
**Mitigation** - Software solutions for data filtering
**R2** - Too much sunlight can affect the LiDAR data
**Mitigation** - Avoid using device during peak sun-hour
**R3** - Battery might run out while the LiDAR is scanning the plot of land
**Mitigation** - Make sure to test the power consumption with relation to time to know how long the battery will last

# Work Division

| Member | Responsibilities |
|---|---|
| Angie | 3D Design of hardware enclosing & PCB Design |
| Jose | Mechanical Design of the Tower |
| Rashiqul | Data Acquisition from Lidar to SD Card |
| Ryan | Displaying data to user as topographical map |

# Project Timeline

| | | | | |
|---|---|---|---|---|
| **Mapping of LiDAR information** | | | | 45% |
| Formatting of LiDAR data for export | 9/16/19 | 11/1/19 | 35 | 80% |
| Development of topographical map | 9/16/19 | 11/1/19 | 35 | 10% |
| | | | | |
| **LiDAR Data Acquisition** | | | | 75% |
| Development of coordinate system | 9/16/19 | 10/21/19 | 26 | 50% |
| Formatting of LiDAR data for import | 9/16/19 | 10/21/19 | 26 | 100% |
| | | | | |
| **Tower Hardware Design** | | | | 30% |
| Rotating platform design | 9/16/19 | 10/18/19 | 25 | 90% |
| Motor & gear interfacing between stationary and rotating components | 9/16/19 | 10/18/19 | 25 | 0% |
| Motor control/power electronics permanant installation | 9/16/19 | 10/18/19 | 25 | 0% |
| **Hardware Enclosing & PCB Design** | | | | 50% |
| 3D design of the hardware enclousre | 9/16/19 | 10/7/19 | 16 | 100% |
| PCB Design | 9/16/19 | 10/18/19 | 25 | 0% |

# Project Test Plan

**Project Name:** Grading Surveying Tower

**Team Members:**

- Angie Abdelbaky
- Mohammad Rashiqul Alam
- Ryan Garvin
- Jose Molina

**Test Method:**

- **Analysis**
  Analysis is the use of established technical or mathematical models or simulations, algorithms, or other scientific principles and procedures to provide evidence that the item meets its stated requirements. Examples of such tasks are listed below:
- **Demonstration**
  Demonstration is the actual operation of an item to provide evidence that it accomplishes the required functions under specific scenarios. Examples of such tasks are listed below:
- **Test**
  Test is the application of scientific principles and procedures to determine the properties or functional capabilities of items. Test is similar to demonstration, but is more exacting, generally requiring specialized test equipment, configuration, data, and procedures in order to verify that the item satisfies the requirement.
- **Inspection**
  Inspection is observation using one or more of the five senses, simple physical manipulation, and mechanical and electrical gauging and measurement to verify that the item conforms to its specified requirements.

# <u>Test Requirements Matrix</u>

| Req# | Function | Requirement | Test Method | Brief Test description | SME /Faculty Reviewed / Approved |
|---|---|---|---|---|---|
| 1 | EE/ME | Mounted motor on the tower must be strong enough to rotate the arm that contains the LiDAR | Analysis | • Measure the weight of the contents and compare it to the motor load-torque curve to understand what type (specification) of motor might be required<br>• Streak measurement and recording scheme and effects on motor speed (RPM) | ✓ |
| 2 | EE | LiDAR must not exceed concrete contractor required error range | Test | • Manufacturer's datasheet will be referred for degrees of error.<br>• Will measure the maximum angle allowing for the identification of a 1.2” object. | ✓ |
| 3 | Software | Must provide average error, and a 3D visual representation of the pad | Demonstration | Run sample data through a script | ✓ |
| 4 | ME | Tower motor must have sufficient power in order to help the device with LiDAR rotate to scan the plot of land. | Analysis | System weight, field coarseness, and system speed (TBD) will be used to choose the appropriate motor power rating from motor datasheet | ✓ |
| 5 | ME | Rotating assembly must be leveled. I.e., there must be no deviation in elevation from one end of the rotating arm to the other due to terrain differences | Test | The legs must be adjusted to make a level platform. Bubble levels may be used to assist in this. | ✓ |

| | | | | | |
|---|---|---|---|---|---|
| 6 | EE/ME | Rotating assembly must smoothly rotate LiDAR to avoid transient movements and/or unintended errors in the LiDAR measurements | Inspection | Program will be run without the LiDAR data reliability examined. Software will be adjusted until performance conforms to desired speed | ✓ |
| 7 | EE | LiDAR data must be processed and displayed in a topographical map. This will be the final deliverable to the user. | Demonstration | • Sample readings from the LiDAR can be taken prior to project completion to be used for test plotting. Polar to Cartesian coordinate conversions will be examined.<br>• Anticipated storage file type should be used and read into MATLAB script | ✓ |
| 8 | EE | LiDAR data must be saved onto local hardware during normal operation. This data must be readable by a computer for later use. | Test | LiDAR readings should be read and saved onto local hardware using the Atmel MCU. These files should be accessible for later users. | ✓ |
| 9 | EE | PCB design must be robust and useful for processing, control, and data movement. | Test | Simulation software should be used prior to placing PCB order to ensure proper design function. | ✓ |
| 10 | EE | Data storage requirements calculation | Analysis | Will need:<br>• Memory occupied by single data point<br>• Number of data points per streak<br>• Number of streaks per sweep | ✓ |
| 11 | EE | Battery and DC converter requirements | Analysis | • Sum of individual modules' power consumption: LiDAR, motor driver, ATmega PCB | ✓ |

| | | | | | |
|---|---|---|---|---|---|
| | | | | ● Corresponding DC converter requirements | |
| 12 | EE | Assessment of ambient light interference with system | Demonstration | ● The LiDAR's 'quality' measurement must be interpreted<br>● System will be tested in a dark/light environment. | ✓ |
| 13 | Software | Serial communication workaround | Test | ● Initiate communication protocols for selected storage module and LiDAR separately, then integrate both modules. | ✓ |
| 14 | EE | Build and test ATmega microcontroller before printing PCB | Test | ● Identify components and wiring diagram for PCB.<br>● Test on breadboard before printing PCB | ✓ |
| 15 | ME/EE | Data acquisition with ATmega microcontroller | Test | ● Column with leveled swivel will be moved manually<br>● Data will be taken and saved as .txt/.csv for MATLAB processing | ✓ |
| 16 | ME/EE | System operations and output accuracy | Test | ● Sandbox, sand, and spectra laser will be set up to test accuracy of system measurements | ✓ |

Table 1: Table showing the test matrix

## Empirical Analysis

The final testing of the device has been completed. The average sweep length is between 4 & 5 seconds, meaning that a high resolution sweep at 100 angles would take only 7 or 8 minutes. This is a reasonable time for such high resolution, especially considering the inordinate amount of time it would take a human operator to take the ~ 8000 point measurements. This requirement passes.

Each sweep stores around 80 data points, each of which are 8 Bytes. If the user provides 1 GB of storage space on the SD card, over one million sweeps could theoretically be saved meaning the upper limit to resolution is effectively infinite. This gives the user more freedom to specify resolution than they would ever reasonably required. This requirement passes.

The MATLAB script returns a plot with only $^{+}/_{-}$ 2mm deviation for a “smooth” test surface, which could actually be accurately matching the physical reality of a professionally poured concrete floor. Considering that the “tenth of a foot test” that the project was designed to evaluate is a deviation of over 30 mm, the device clearly passes this test.

Sweeps have been performed indoors and outdoors, in both full daylight and in dimmer evening conditions. The LiDAR shows no adverse effects on scanning accuracy, regardless of lighting conditions. The LiDAR passes this test.

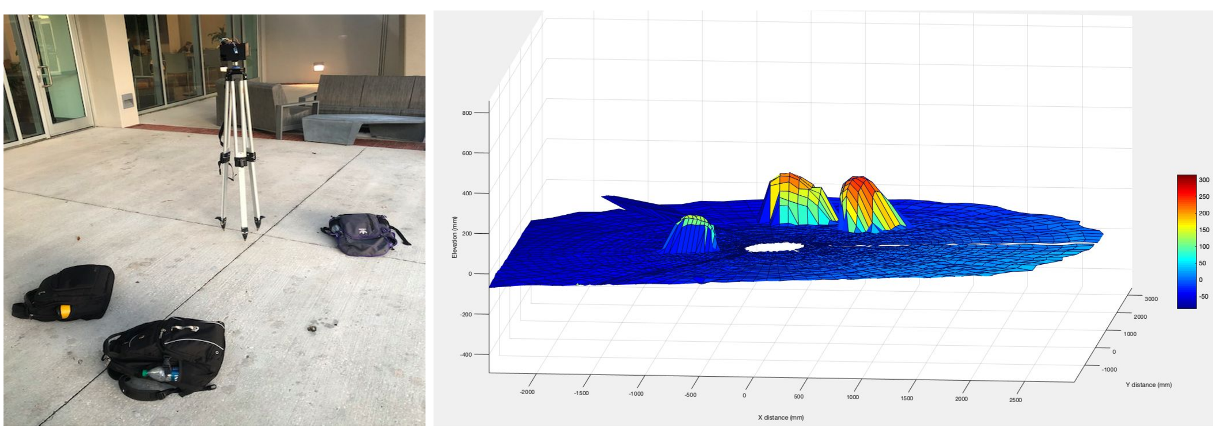



Figure: Shows a plot of the LiDAR scan of the environment, represented on the picture to the left.

The GST operates at a power rating of 5V * 0.93 = 4.65W. Therefore, using a 5000 mAH LiPo battery, it gives runtime of about 5.37 Hrs.

A working PCB was accomplished after soldering in the components indicating it passed the test. This put our project schedule ahead of time allowing us to work on different parts of the project. It was important to ensure that the board can sustain high current during the design phase. Using an online width calculator, the width of the power traces was made thick enough to withstand 4A of current, most of the high current was drawn to power the coils of the stepper motor during operation.

# Grading-Surveying Tower

**Critical Assessment Document**


**College of Engineering**

**Department of Electrical Engineering**

**Team Members:**

Angie Abdelbaky
Mohammad Rashiqul Alam
Ryan Garvin
Jose Molina

**Faculty Advisor:**

Dr. Arash Takshi

## Introduction

The Grading-Surveying Device is intended to be a relocatable platform supporting a rotating assembly. This rotating component will house all of the electrical components, primarily the LiDAR sensor which the device is centered around. The LiDAR sensor will record and map the terrain surrounding the perimeter of the device and save this data on an SD card. This data will then be processed and plotted to display the topographical model of the terrain and return critical data to the user.

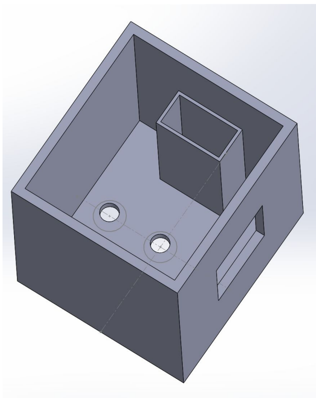
The realization of this project will be accomplished through the completion of the "four pillars" of this design. Each of the four pillars plays a critical role in accomplishing a subtask of the final goal, and the project will see final success once all four subcomponents are integrated into a single functional unit. The four pillars are:

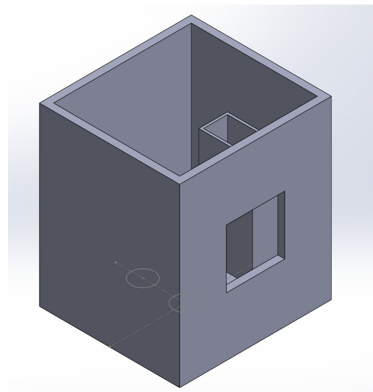
1. Design and construction of both the box that is housing the hardware components and the PCB which controls the overall operation.
2. Interfacing with the LiDAR sensor to accurately collect data and store this information on a removable SD card for transport by the user.
3. Generating a topographical map using the collected data and performing data processing to return information of interest to the user.
4. Mechanical design and construction of a stand-alone tower which supports a rotating assembly at the head.

## Enclosure & PCB Design

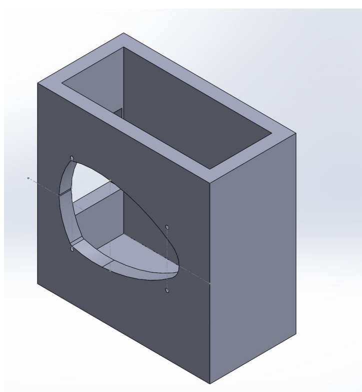
For the rotating platform of this tower, it is important to have a properly designed enclosure for the hardware components. It was also important to make sure that the enclosure, which is a box will not tip over during the duration of operation. To mitigate the potential issue of the box tipping over, the group thought of having a metal rod that runs through the middle of the box. Another potential problem that needed to be accounted for was to make sure a compartment for the battery was designed to prevent damage to the other hardware components in the box such as the motor and the PCB, when the box rotates. The design of how tall and wide this box was to be was dependent on the hardware components that were being put inside the box. The tallest component was the battery, so the height of the box was made to account for that. An attachment was also designed for the LiDAR to be drilled into. This attachment was designed to be joined with the main box with a 3D designed part. The LiDAR is to record data from exactly the same plane as the one at the center of the main box. As a way to limit the amount of times the boxes needed to be printed to make sure the measurements are as accurate as possible, a 3D designed part was created to be used as a binding tool.

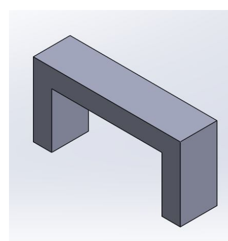
The way the enclosure was designed to be tested was by placing all the hardware components in their respective areas inside the box. If the components fit well then there was no error with the design.





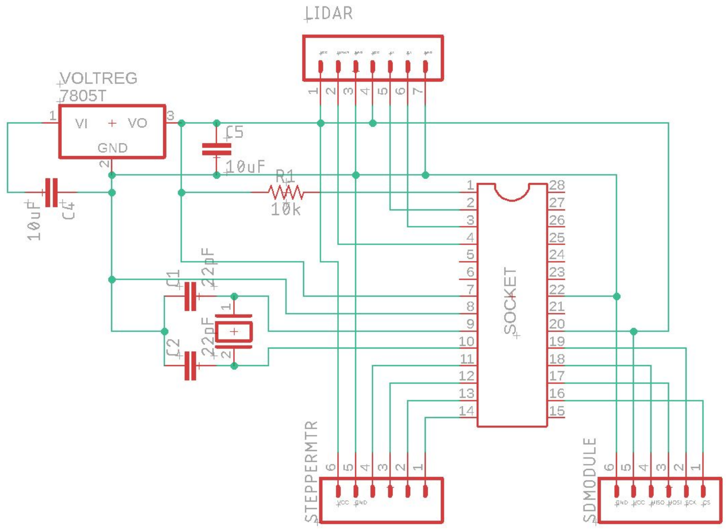
Main box with battery compartment, cutout for LiDAR wires to run through, and motor shaft and metal rod holes.





Attachment box for the LiDAR and the 3D part to bind the two boxes together

Before designing a PCB it was vital to be able to create a working circuit that was tested using lab bench equipment and a circuit on a breadboard. The major components necessary for the PCB design include headers for the LiDAR, stepper motor driver and a socket for the ATmega328 microcontroller. Once it was confirmed that the prototype circuit was functioning properly, the PCB was designed in EAGLE. The following picture is a schematic made on EAGLE.



Shows the schematic of the PCB with headers for respective components

**Data Acquisition by LiDAR**

This part of the project involved interfacing the microcontroller with the LiDAR and the SD Card Module therefore, requiring communication protocol to be set up for the respective components. The parameters of interest include 'Distance' and 'Angle' hence, the LiDAR data acquisition begins by creating two one dimensional arrays that can contain 50 elements each. Due to the memory restrictions of the ATmega328 chip, it was necessary to capture the data in two different streaks i.e. populating the array once and having the data saved as a CSV file on the SD card. This was followed by appending the file with new data obtained from the second streak. To keep consistency in all the data sets, it was important to acquire data from a starting angle hence, such an angle was set and once this was detected in the algorithm, only then it triggers to populate the array with distance and angle values and sets a flag. Once the arrays are filled a function is called where the microcontroller proceeds with creating a file that stores the contents of the array. In doing so, the last element of the array is saved such that the program knows where to start gathering the next set of measurements from and clears the flag. An important part of the program follows the concept of modular (clock) arithmetic, the concept revolves around the hours on a clock and the program is initially set with a count of 12. Every time a sweep is completed the arithmetic is done and the count is replaced by the next number (count = (count+5)%12), this ensures that a sweep can cover 150° instead of certain angles by incrementing the steps of a stepper motor. Overall the process is faster, and takes the system about 16 seconds for 12 measurements. The figure below shows the CSV file that was created from data off the LiDAR on the SD card module.

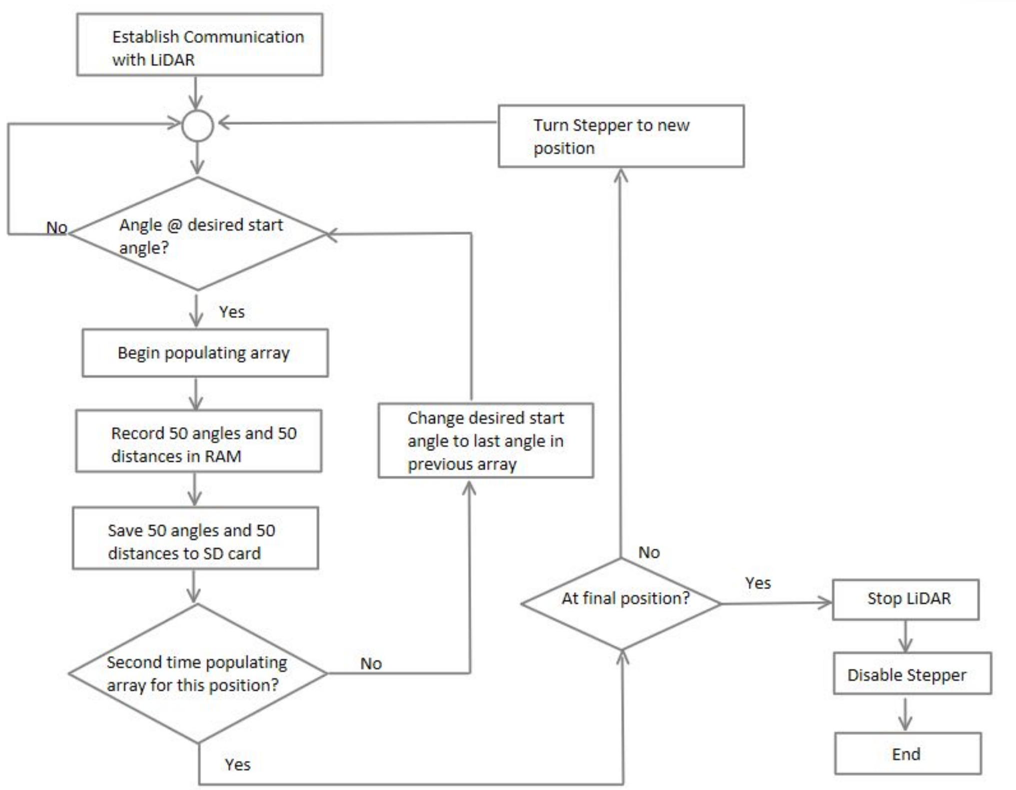
First 50 angles (20-81 degrees)

Second 50 angles (82-145 degrees)

fx | 20.56

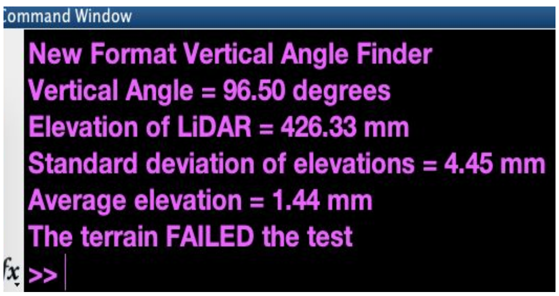
| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | 20.56 | 21.73 | 22.8 | 23.84 | 24.95 | 26.16 | 27.23 | 28.23 |
| 2 | 755 | 761.75 | 762.25 | 764.25 | 769 | 773.5 | 777.5 | 787.25 |
| 3 | 82.2 | 83.33 | 84.45 | 85.59 | 86.73 | 87.78 | 88.92 | 90.06 |
| 4 | 1657.5 | 1646.75 | 1639 | 1637 | 1632.75 | 1631.25 | 1628 | 9734.75 |
| 5 | 20.86 | 21.98 | 22.98 | 24.19 | 25.19 | 26.22 | 27.36 | 28.47 |
| 6 | 759 | 759.25 | 762.5 | 763.5 | 769.5 | 773 | 778.5 | 781.25 |
| 7 | 82.19 | 83.28 | 84.39 | 85.52 | 86.66 | 87.7 | 88.84 | 89.95 |
| 8 | 1658 | 1652.75 | 1639 | 1637 | 1633 | 1631.25 | 1627 | 7119.5 |

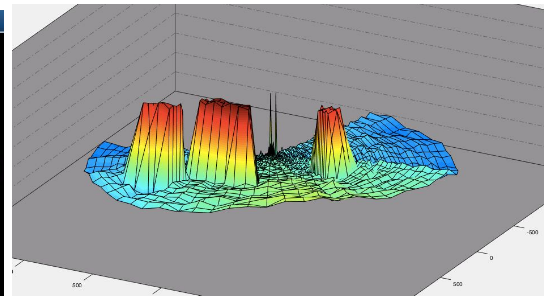
The figure above shows a flowchart that shows the flow of control of the program.




## Processing and Plotting

To accomplish the task of both calculating critical data points and plotting a topographical map of the area surrounding the tower, the team elected to use Matlab. The team's prior familiarity with the software allows quick prototyping and informed us that Matlab is capable of simultaneously performing the necessary calculations and generating high-quality plots in three dimensions. Some of the values returned to the user will be important points such as the current elevation of the LiDAR, the mean elevation of the surrounding terrain, the standard deviation of the terrain elevation from the mean, and whether or not the land passes the 'tenth of a foot test' for construction.





A LiDAR sweep was performed of a floor with 3 objects placed around the axis of rotation. It can be seen above that the floor was plotted as a smooth surface: the ripples found in the flat areas of the sweep are only a couple of millimeters in magnitude. The three objects places around the sweep location were all very clearly displayed in the plot. As the quality of collected data improves, the produced plots will similarly gain clarity and resolution.

On the left, critical data has been output to the user. Even with the objects present, the standard deviation of the elevation data was less than half a centimeter. This indicates that the LiDAR can collect topographical data with a very high degree of accuracy. The most important result that the script returns to the user is the outcome of the ‘tenth of a foot test.’ It can be seen displayed above as a failed test, which is exactly what was expected due to the presence of the large objects in the sweep area.

## <u>Mechanical Design & Tower Structure</u>

The tower structure is to rotate 360 degrees to complete a full scan. A prototypical arrangement was constructed for the designed tower. The prototype swept 360 degrees in 36 increments and the microcontroller was then run to record the LiDAR data and save it to an SD card. The prototype worked as expected, and the data was run through the MATLAB script for plotting. The final mechanical design building is still in process.