Semester 1 Final Report

Team No. 10

Mariana Cave LIDAR Mapping System

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Abstract

Researchers at the department of Earth, Ocean, and Atmospheric Science at FSU are seeking help in the development of a LiDAR mapping device to map out the dry-land portions of the Mariana Caves. The main purpose of the device is to provide freelance cavers and hobbyists with a tool to map their explorations. The device must be small enough to be easily transported by hand. It should map the area surrounding its location within a few hours, then convert the data into a pount-cloud image for the user to view later.

Acknowledgements

We would like to express our deepest appreciation to Dr. Steven Kish and Mr. Bob Broedel whose support and guidance have allowed us to complete this report. We would also like to thank Dr. Victor DeBrunner, Dr. Rodney Roberts, Dr. Shonda Bernadin, and Dr. Jerris Hooker for their critiques and recommendations on our designs.

1. Problem Statement

The purpose of this project is to create a portable cave-mapping device for freelance cavers. Cave mapping can be a very expensive undertaking. The most widely-used method involves the use of notepads and tape measure, and can be tedious and time consuming. There are LiDAR devices on the market that map caves; unfortunately, these products are very expensive, costing upwards of $20,000. Ultimately, we aim to make LiDAR cave-mapping devices more accessible by providing a DIY-style, open-source project that allows cavers to construct their own mapping devices at an affordable price.

2. Background Research

LiDAR

Figure 1: LIDAR LITE 3, www.sparkfun.com

LIDAR is a remote sensing technology often used for geographical mapping and surveying. The word LIDAR is an abbreviation for Light Imaging, Detection, And Ranging although originally a portmanteau of light and radar. LIDAR technology typically utilizes ultraviolet, visible, and near infrared light imaging in conjunction with GPS. LIDAR sensing methods employ light pulses to measure variable distances and other data along terrestrial surfaces. These systems, commonly mounted on aircrafts are useful in the mapping of broad areas with high accuracy and precision.

LIDAR is widely used in the fields of geodesy, meteorology, geology, atmospheric research, geography, and more. It is often used to create high-resolution maps because of its ability to target a very wide range of materials with very high resolution (typically around 30 cm resolution or better). Two main types of LIDAR systems are topographic, which uses near-infrared laser, and bathymetric, which uses a water-penetrating light to measure underwater areas.

The LIDAR-Lite Rangefinder is a compact and user-configurable optical distance sensor developed by Sparkfun and Garmin. Thanks to its compact size, it is optimized for use on drone and robot applications. It utilizes a 40-meter laser-based optical ranging sensor and boasts a low power consumption of less than 130mA while operating. Because of these features, the LIDAR-Lite is the optimal choice for a portable mapping technology.

Cave Mapping

Caves represent a unique and intriguing challenge for explorers and researchers alike because they are extremely difficult to get to. LANDSAT imagery, topographical mapping, and aerial photography often fail to even identify that a cave is present. As it is, caves provide an unparalleled opportunity for explorers and the scientific community to discover what is hidden in the depths of our planet.

Figure 2: Cave in Florida Caverns State Park,

Cave mapping has traditionally consisted of choosing a centerline in a cave and taking a series of measurements from that centerline to the walls of the cave. The data would then be entered into a computer, which could produce a 2D/3D representation depending on the extent to which the researchers collected measurements. This approach usually requires a team of at least four people, and can take hours, days, or even weeks. In recent years, technology has allowed for quicker, more accurate mapping of caves using LIDAR, but the apparatuses can cost upwards of $50,000. This is why a small, affordable LiDAR mapping device is desired.

3. Needs Statement

Traditional cave mapping can be costly, limiting participants to professionals. There exist some examples of simple mapping systems online using LIDAR and Arduino programming, but the resolution is typically low. Our client wants a high-resolution system, so he contracted us to build this device. The whole system must be very small, and light compared to professional systems so as to be easily portable. It must be fully involved with its own motor control and autonomous mapping of the surrounding caves.

Needs and Wants list

- High-resolution data encoding software
- light weight and easy to carry
- Full rotational motion with micro-stepping abilities
- Small size (facilitates portability)
- Durability (resistant to shock / damage from natural elements)
- Low cost

We need a compact, durable, high resolution LIDAR system that can be carried, or mounted, to accurately depict the inside walls of any cave system.

	High Resolution	Portable	Low Cost	Durable	Geometric Mean	Normalized Weight
High Resolution	1.00	2.00	3.00	4.00	1.78	0.30
Portable	0.50	1.00	2.00	3.00	1.59	0.27
Low Cost	0.33	0.50	1.00	2.00	1.39	0.23

Durable	0.25	0.33	0.50	1.00	1.20	0.20

Table 1: NeedsMatrix for the LiDAR Mapping System

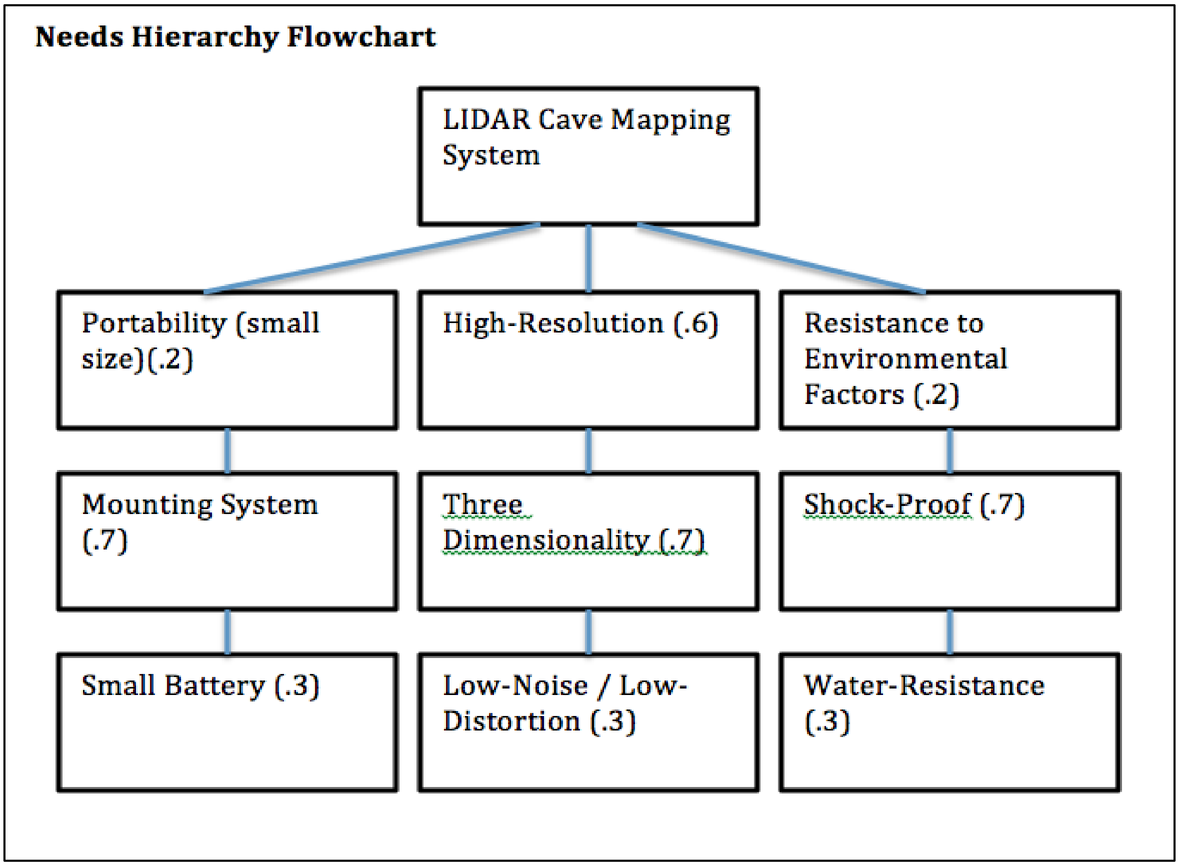


Figure 3: Needs Hierarchy Flowchart for LIDAR Mapping System

4. Project Objectives and Goals

The goal of the LIDAR Mapping System is to create a durable, high-resolution device that can be easily deployed to map an above ground cavern. The device must be small enough to be carried into a cave and potentially mounted on an autonomous vehicle. The mounting system will be a quick connect/disconnect and will be rigid enough to stabilize the measuring device as it traverses over obstacles. The device will be in an enclosure making it resistant to the rugged and wet environments of caverns.

Once set in position, the device will run autonomously to capture measurements of the targeted area. To acquire reliable data, stepper motors will be used to change the angles of the measuring system in micro steps. Full rotational motion in the x, y and z plane will allow the device to accurately measure a targeted area. The data will be correlated to true north and a high-resolution 3D image of the cave will be created. It may be necessary to create an external software to process the point-cloud data into a viewable image.

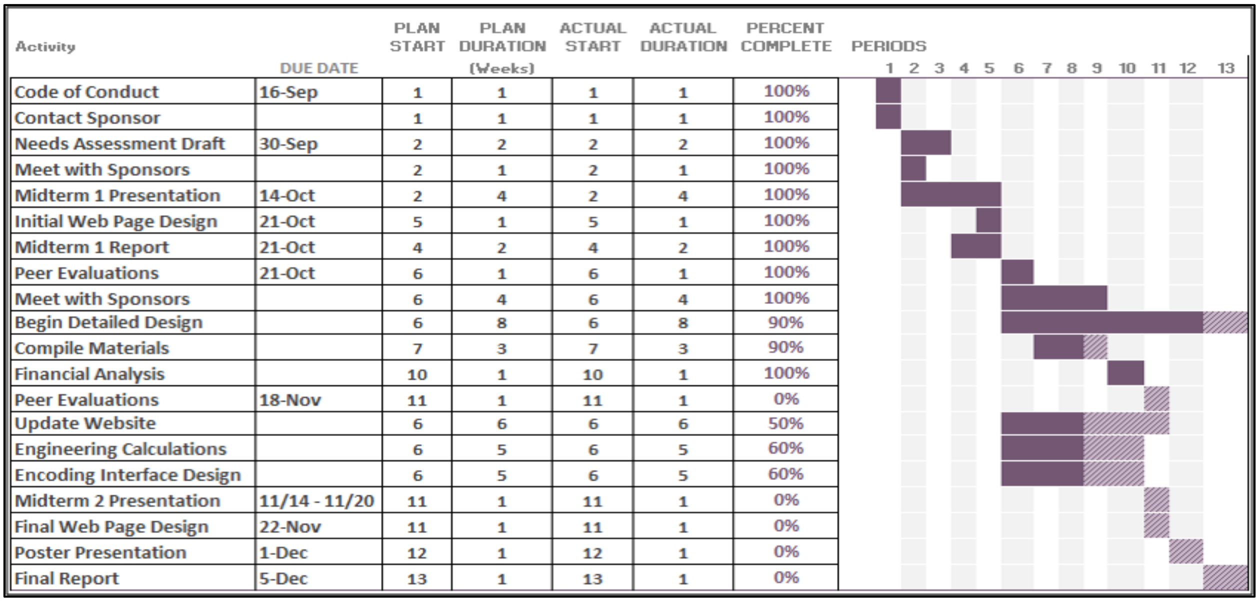
This device will be made with readily available parts to keep cost low while data encoding will ensure reliability. Inexpensive parts make upgrading or repairing the device easy. Batteries will be used to provide the system with ample power to perform measurements at multiple target areas. An automatic “off” feature will be added to reserve the batteries in dormant conditions. In case of a system failure, the data will be saved in memory to be exported when the system is retrieved.

5. Project Constraints

LIDAR device must be fully rotational in x, y, and at least 270 degrees in z plane to map surrounding area. It should be able to map up to 0.5 m in accuracy at 40m away and convert the data into a 3D image. It may require development of a small software app to convert the point-cloud data into a viewable image. The total weight should be no more than three to five pounds. It should be easily portable and small in height, no more than 2 feet tall. It will need to rest firmly on the ground and have a waterproof case for when not in use.

The device must be operational in dark caves. It should operate with little initial user input, then run autonomously for the duration of the scan. There must be indicator lights to alert user if mapping is finished, running, or fails at any time during the run. The device must have enough battery power for at least one complete scan, preferably two. The total cost of the finished device should not exceed $500.

6. Deliverables



Activity	DUE DATE	PLAN START	PLAN DURATION (Weeks)	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Code of Conduct	16-Sep	1	1	1	1	100%
Contact Sponsor		1	1	1	1	100%
Needs Assessment Draft	30-Sep	2	2	2	2	100%
Meet with Sponsors		2	1	2	1	100%
Midterm 1 Presentation	14-Oct	2	4	2	4	100%
Initial Web Page Design	21-Oct	5	1	5	1	100%
Midterm 1 Report	21-Oct	4	2	4	2	100%
Peer Evaluations	21-Oct	6	1	6	1	100%
Meet with Sponsors		6	4	6	4	100%
Begin Detailed Design		6	8	6	8	90%
Compile Materials		7	3	7	3	90%
Financial Analysis		10	1	10	1	100%
Peer Evaluations	18-Nov	11	1	11	1	0%
Update Website		6	6	6	6	50%
Engineering Calculations		6	5	6	5	60%
Encoding Interface Design		6	5	6	5	60%
Midterm 2 Presentation	11/14 - 11/20	11	1	11	1	0%
Final Web Page Design	22-Nov	11	1	11	1	0%
Poster Presentation	1-Dec	12	1	12	1	0%
Final Report	5-Dec	13	1	13	1	0%

Figure 4: Project Gantt Chart

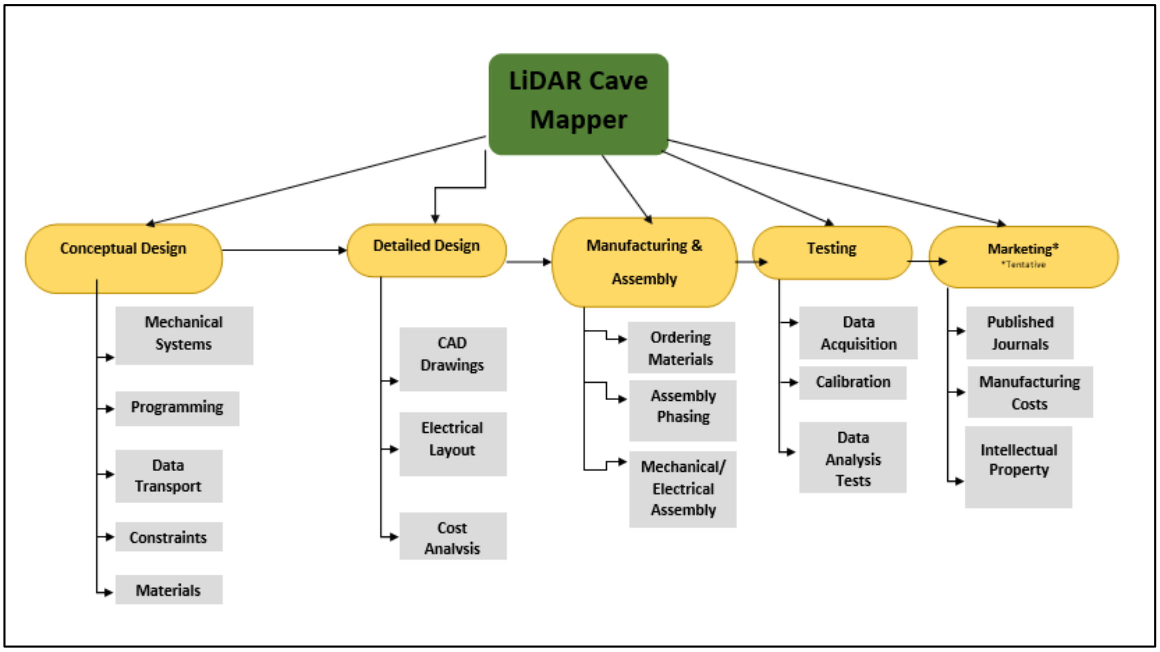


Figure 5: Project Flow Chart

7. Assign Resources

The project manager, Alisha Hunt, will delegate to both ME and ECE leads as needed. She will oversee general project deadlines and keep contact between project sponsors and our design group. She is also responsible for accounting for the LIDAR mapper device timing. She must calculate the total run time of the device based on a per/sample point time estimate.

The lead ECE, James Oliveros, will be responsible for dividing and delegating the ECE work amongst electrical and computer engineers within the group. He is personally responsible for the memory management of the LIDAR mapper device. This means calculating the memory usage per mapping point and then total usage of data. On this project all of the electrical and computer engineers will be partly responsible for coding the microprocessor. When it comes time to code, James will have to delegate this work.

The lead ME, Spencer Day, will be responsible for dividing and delegating the mechanical work within the group. With the assistance of Hunter he will design the concept frames and wiring/physical layout of the device.

The financial advisor, Cesar Rivas, will be responsible for budgeting and cost comparison. Since the team does not directly manage funds for this project, these will be based on publicly available cost data and estimated taxes/shipping.

The webmaster, Hunter Hayden, will be responsible for upkeep of the website. Website should contain general information about our project and team. It may also contain documents from presentations or reports compiled by the group.

The power engineer, Jake Ogburn, will be responsible for calculating power consumption of the device. This includes the individual consumption of various sensors and the microprocessor. He must be sure that consumption is within the constraints of the batteries.

8. Conceptual Design

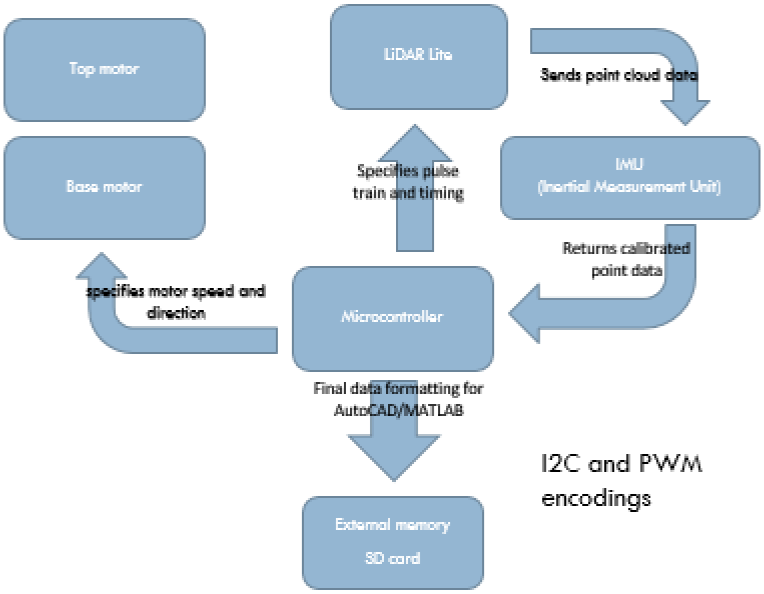


Figure 13: Illustration of Data Flow

Data flow in the device will be controlled by the Arduino Microcontroller. For each point scan the microcontroller will rotate the motors into the next position, then send a pulse train to the LiDAR lite device. It will have to poll the LiDAR lite device until position data is retrieved, then calibrate it using the Inertial Meaurement Unit (IMU). Once the data point is calibrated the microcontroller can store the data point in series with previous points to form the point cloud data of the image. When compiled, the data must be reformatted by the Arduino to be viewable on an external computer. Alternatively, this data may just be stored in arrays and formatted by an externally developed applet.

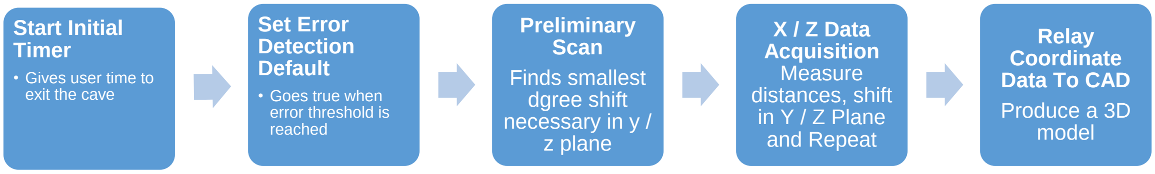


Figure 12: Pseudocode outline

Above is a top-level flowchart describing the functionality of the LIDAR scanning module. The LIDAR module will utilize the digital pins eight and nine on the Arduino module. These pins will be active high and will be designated as direction control and step control, respectively. Through the setup of the stepper motor driver, a microstep of 1/8th a step will be established. At the beginning of the scanning process, the user will start a countdown timer, which counts down a few minutes of time to allow the user to exit the cave so as to not interfere with the data acquisition process. The time allotted is still to be determined and will likely change during the experimental development process. Following this step, the LIDAR scanner will initialize the error detection function to a Boolean false value. This value will switch to true once a threshold of 15% error is read during the data acquisition process. This error detection will be linked to an LED output, which will notify the user that the data acquisition was faulty and needs to be repeated for a proper scan of a single point.

Two basic classes of objects will be established for this code. The first simply being an class containing data for x, y, z, and reflection coordinates for a single data point. The second class of object is an array of data point objects representing a horizontal circle of data points at a certain angle in the y / z plane. The first step of the data acquisition process after the initial timer and error check initialization involves a preliminary scan, which will quickly assess the surrounding area by scanning vertical circles while moving three microsteps in the horizontal direction in between vertical collection of data. This initial scan will find the smallest angle shift necessary in the y / z plane based on the following expression:

$$\tan^{-1}\left(\frac{0.5}{z}\right)$$

Where z is a measurement of distance in the z direction. The half-meter constant represents the desired unit of precision. The value from this equation represents the required degree shift based on the z distance. This minimum value, found in the preliminary scan will be used as the standard unit of degree shift in the y / z direction during the next stage of data acquisition.

The following stage of data acquisition involves the collection of arrays of data points in concentric circles starting at the horizontal plane. Using the above expression, but this time finding degree shifts in the x / z plane, the scanner will perform a full rotation, storing these data point readings. After this, the scanner will perform a degree shift in the y / z plane the amount of shift collected in the preliminary scan and perform a similar concentric circle revolution at the new position in the y / z plane. After a full data acquisition at one point, the scanner will store a group of arrays containing values collected in respective horizontal concentric revolutions. This data will be relayed to an CAD program to develop a three-dimensional point-cloud representation of the surrounding cave area.

9. Product Specifications

A. Design Spec

Electrical Design

The hardware components of the LIDAR system design include one LIDAR Lite v3 module, an Arduino mega 2560 microcontroller, two stepper motors (one for vertical motion and one for horizontal motion), two stepper motor drivers, one Sparkfun inertial measurement unit, batteries, external memory data storage via SD card, and status LEDs. The status LEDs will be used for error checking and notifying the user of issues during the data acquisition process. The inertial measurement unit includes an embedded Accelerometer, Magnetometer and Gyroscope for orientation purposes. The Arduino microcontroller was selected for its ease-of-use, and open-source modular nature.

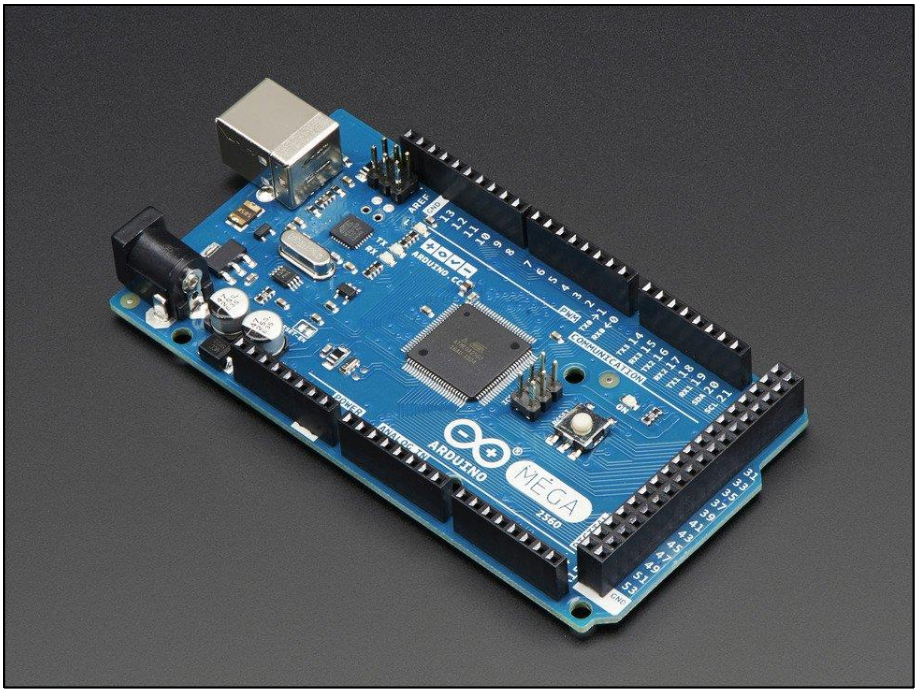


Figure 6: Arduino Mega 2560 R3 www.arduino.com

The software for the LIDAR system will be developed on the Arduino integrated development environment. Since the Arduino IDE is freeware, and it supports C and C++, our software will be open-source and easily modifiable for future iterations of design. Data from the LIDAR module will be collected and stored in local memory as a series of arrays including data for distance, orientation, and light measurements. This will be implemented into the AutoCAD part of the software design for the development of three-dimensional cave models.

Mechanical Design

The final mechanical concept design has been chosen from the three mentioned in the last report update. Concept one, seen below in Figure 9, gives us the most inexpensive and easiest to assemble design.

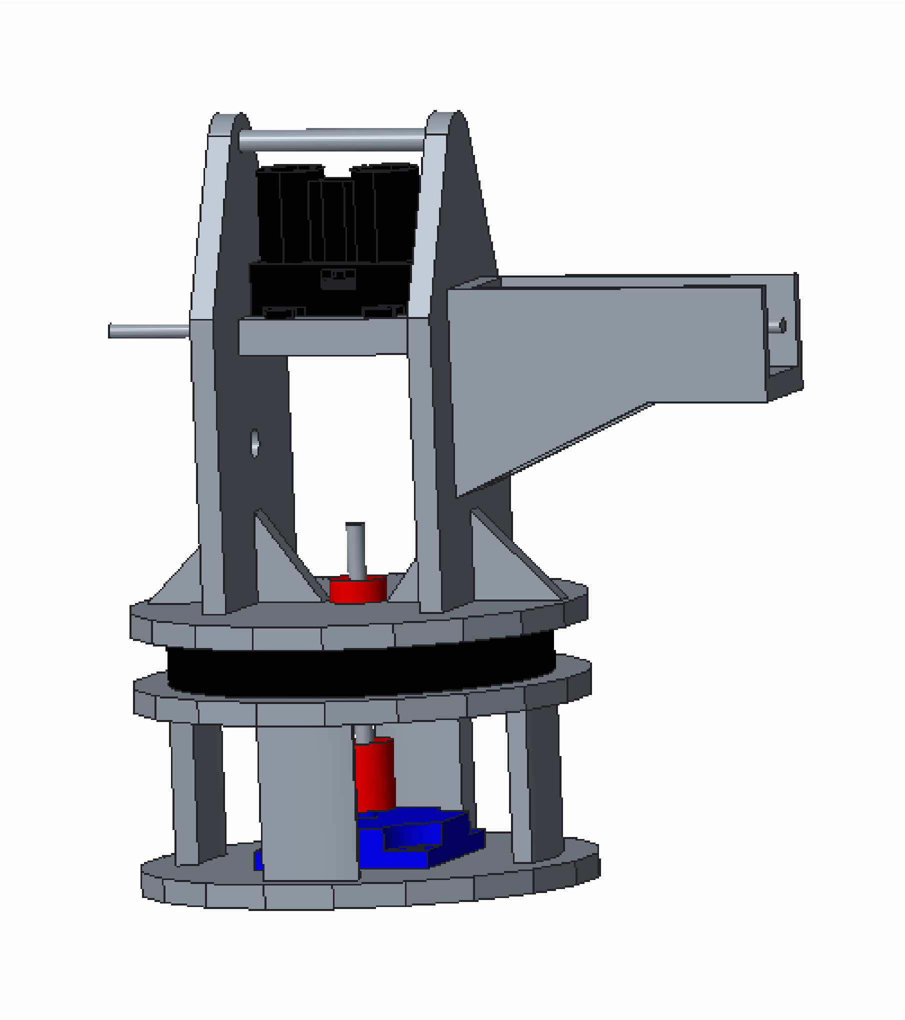


Figure 7: Rendered model of mechanical concept 1

The LIDAR will have a 270 degree view in the YZ plane and a 360 degree view in the XY plane. This 90 degree loss will be from the floor of the cave and this is where all of the electrical components, drivers, and batteries will be stored while a scan is in process. This design also limits the complicated twisting movements that will lead to tangled power wires.

The frame of the LIDAR mount will be constructed from ABS thermoplastic. We have chosen a thermoplastic because it is durable, light, non-magnetic, and 3D printable. All components of the frame will be 3D printed because it gives us opportunity to reprint in case of error or in case we want to alter the design slightly. If we were machining this out of aluminum, any changes to design would require us to re-machine the whole mount and it would get very expensive very quickly.

The thermoplastic frame will sit on a circular lazy-susan bearing in order to limit friction while turning. The whole frame will be rotated using a Sanyo 200 step pancake stepper motor (Figure 8). This motor provides a large thin base that will fit nicely underneath the bearing and will ease in assembly. The motor shaft will be connected via coupler to a much longer 4mm diameter shaft that will run through a hole in the base of the frame. The LIDAR base will be rotated by a NEMA 8 stepper motor (Figure 9) which is much smaller than the pancake motor. It will be much easier to design a small extending frame that will hold the NEMA 8 steady and make sure no stress is put on the shaft. Both motor shafts will also be fitted with bushings to eliminate wear on the thermoplastic over time.

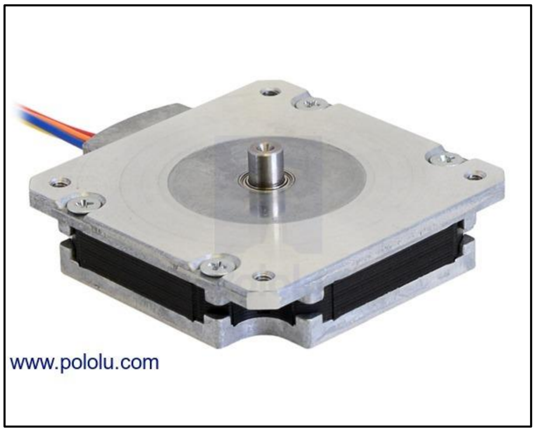


Figure 87: Pancake Stepper Motor

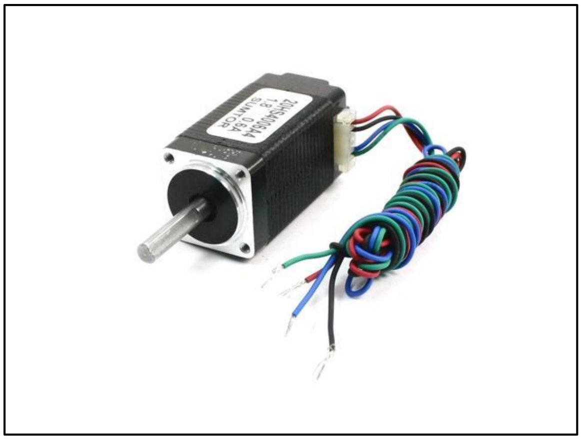


Figure 98: NEMA 8 Stepper Motor

All components; tripod, LIDAR, frame, motors, batteries, electrical components; have been measured to fit inside a portable water tight container. When it comes time to run a test, the user will remove the tripod and LIDAR mount and place it on top of the box. The starter and electrical components will remain in the box while the system runs in order to keep them safe. While operating, the system will be set up like it is below in Figure 10.

Figure 10: Physical setup of test device

Power will be supplied to the device by two separate battery systems. The total current consumption of the mapping system is 1.1 A. The two stepper motors require the majority of the power and will need to be supplied a constant current to uphold the required torque. Two EZ Drive motor drivers will be used to control the voltage and current to each motor. The total current consumption for both motor systems is 0.85 A. A 12 volt battery with at least a 9 amp-hour rating will be use to provide both motors continuous power. An additional 6 volt battery with at least a 2 amp-hour rating will be used to supply power to the Arduino microprocessor and the LIDAR Lite3. The total current consumption of the two electronics is 235 mA. The Arduino Mega has an onboard power supply which will be used to supply power to the IMU device. The two power systems will be small enough to remain portable while supplying ample power to map two target areas. The batteries will also be removable for easy recharge or replacement.

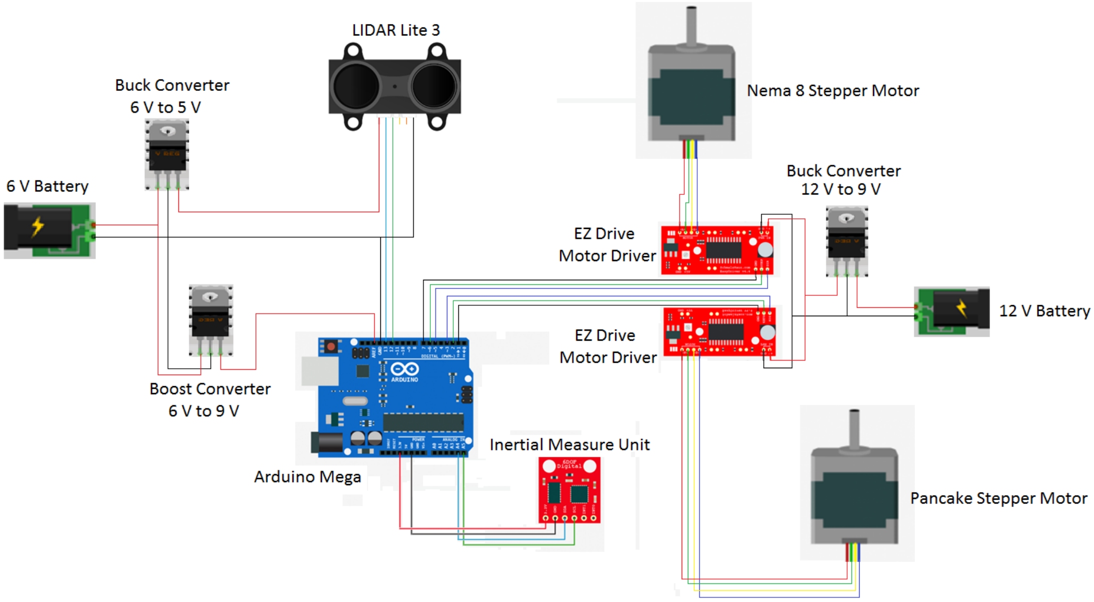


Figure 11: Top-level Wire Diagram

B. Performance Spec

The operation range of the LIDAR mapping system will be the maximum distance of the LIDAR Lite v3 module, which is the distance of 40 meters. The system will have the precision of at least 0.5m at 40m, its maximum distance. It will be able to gather distance data at this level of accuracy and feed it into AutoCAD mapping software to develop a three-dimensional representation of the surrounding cave area.

The operator of the system would begin the surveying process by placing the system on a stable section of the cave floor. They would then adjust the system such that the LIDAR Lite module is level to the horizontal plane. The LIDAR system will also have an error-detection feature which will contact the user remotely if there are any problems during the data collection process. Data acquisition at a particular point is projected to take around two hours, though this time estimation may vary during the developmental process. Therefore, the battery life of the LIDAR system should be able to span the time it takes to perform two points of data acquisition, which is about 4 hours.

According to the LIDAR Lite V3 specifications, distance measurements will be read in as two byte strings of data. In a worst-case scenario for data acquisition, the LIDAR design would be reading a data point at every increment on each respective stepper motor on the horizontal and vertical axes. Because each stepper motor has 200 steps, a worst-case-scenario run (taking in the most data points possible) would yield 40,000 data points. At two bytes each, this takes up 80,000 bytes or 80 kB of data. Ideally, the system would be able to collect data for two locations at a time, so the maximum amount of memory necessary for two runs would be 160 kB. This figure is significantly less than the available flash memory on the Arduino Mega 2560 R3. Although this figure does not account for the memory required for the program itself, it appears that the on-board flash memory is sufficient for the maximum load of data and that the Arduino Mega 2560 should have adequate data storage capabilities for the purposes of the Cave Mapper design.

C. Budget Spec

Item	Quanity	Source	Unit Cost	Total Cost
Lidar Lite 3 Range Finder	1	Sparkfun Electronics	$149.99	$149.99
Arduino Mega 2560 R3	1	Sparkfun Electronics	$45.95	$45.95
9 Degrees of Freedom IMU SM9DS1	1	Sparkfun Electronics	$24.95	$24.95
Sanyo 200 Step Pancake Stepper Motor	1	Karlson Robotics	$49.95	$49.95
NEMA 8 Stepper Motor 1.8°	1	McMaster Carr	$17.95	$17.95
Data Logging Shield for Arduino	1	Jameco Electronics	$18.95	$18.95
Proto Screw Shield Assembled	1	Jameco Electronics	$15.95	$15.95
Sandisk 4GB SD card	1	Amazon	$7.00	$7.00
Dry Storage Box	1	Cabellas	$9.98	$9.98
Plastic Submersible Cord Grip	2	McMaster Carr	$2.48	$4.96
Kapro 1-5/8" Bulls Eye Surface Level	1	Home Depot	$2.95	$2.95
Split Loom Tubing (1/4 ") - 10 ft	1	All Electronics	$1.20	$1.20
Slip Ring - 12 wire	1	Sparkfun Electronics	$19.95	$19.95
22 Gauge wires	1	Amazon	$10.00	$10.00
Dry Running Sleeve Bearings (4 mm)	1	McMaster Carr	$1.82	$1.82
Polulo Universal Aluminum Mounting Hub	1	Polulo	$7.49	$7.49
Strut Gears for Stepper MOtorPinion	1	Servo City	$8.00	$8.00
Light Duty Turntable (4'25 OD)	1	Global Spec	$7.16	$7.16
Flex Shaft Couplers (4mm)	1	Studica	$7.49	$7.49
Flex Shaft Couplers (5mm)	1	Studica	$7.49	$7.49
Aluminum Rod (4 mm) (1 ft)	1	McMaster Carr	$7.21	$7.21
Aluminum Rod (5 mm) (1 ft)	1	McMaster Carr	$7.99	7.99
Tripod	1	Amazon	$10.00	$10.00
Powersonic 6V 4.5 Ah Battery (Electronics)	1	Batter Clerk	$4.99	$4.99
GPS 12V 4.6 Ah Batter (Stepper Motors)	2	Big Time Battery	$20.00	$20.00
UPG D1724 6V or 12V/500 mA Battery Charger	1	1000 Bulbs	$9.65	9.65
TOTAL				$479.02

Table 2: Design Budget Breakdown

10. Conclusion

Cave mapping has been a specialized field utilizing expensive technology only few people can afford to use. Our LIDAR Cave Mapping System aims to provide an inexpensive, portable, and reliable device, easily obtainable to all cave-mappers. The open source project will allow cavers to construct their own LIDAR Cave Mapping system for around $500.00. Using this device, the user will be able to place the LIDAR system in a cave, initiate scanning, and scan the entire area within a couple of hours.

During the early stages of the design process, three potential frames were proposed. The initial frame design has since been selected as it will allow for the most stability and simplicity of calculations. Although not a formal requirement, the Arduino microcontroller was selected as ideal by the project sponsor. From these two specifications the other hardware including the Nema stepper motors and batteries, were chosen. All of these components have since been acquired and there is still some emergency funding left in the budget. This puts the project fully into the testing and development phase.

Now, in the development phase the work of assembling all of the hardware and compiling code begins. After establishing an initial scan, our team focus will be on optimization of device performance. This means analyzing data error from scans, testing alternate mapping patterns, changing pulse length and error responses, and reformatting point cloud data. We may revise the frame design and wiring as needed to best serve the environment and user accessibility.

Once our project is fully functional we expect to test it out in the scientific portion of the Mariana Caverns. We’ll make both the scans from this field test and the device specifications freely available through our sponsor and online. We also expect to present the project and results to people within, or interested in, the earth-space, geology and oceanography departments at FSU.

1. References

[1] "About - ILMF." ILMF. N.p., n.d. Web. 11 Oct. 2016.

[2] "Caving Projects." Southern Arizona Grotto. N.p., n.d. Web. 10 Oct. 2016.

[3] "LIDAR-Lite V3." - SEN-14032. N.p., n.d. Web. 4 Oct. 2016.

[4] "Slamtec's RPLIDAR A2 Has a Range of 6 Meters And Can Take Up To 4000 Samples of Laser Ranging per Second ($480)." Into Robotics. N.p., n.d. Web. 4 Oct. 2016.

[5] "Underwater Cave (low Poly)." 3D Model :. N.p., n.d. Web. 10 Oct. 2016.

[6] "Vermont Center ForGeographic Information." VCGI LiDAR Program. N.p., n.d. Web. 11 Oct. 2016.

[7] "What Is LIDAR." US Department of Commerce, National Oceanic and Atmospheric Administration. N.p., n.d. Web. 6 Oct. 2016.

[8] England, Emily. "The Effigy Mounds and Mallam | Anthropology | Luther College." The Effigy Mounds and Mallam | Anthropology | Luther College. N.p., n.d. Web. 13 Oct. 2016.

[9] Nguyen, Quyen. "Running a Raspberry Pi from 6 AA Batteries." Tutorial Raspberry Pi :. N.p., 1970. Web. 12 Oct. 2016.

[10] S. Kish and B. Broedel, "Introduction to Cave Mapping Design Project," 2016.

[11] S. Kish, "Mapping of the Mariana Springs Conduit-Cave System Using LIDAR and Inertial Navigation Sensor System– Prototype Modeling,”.