ND EE Senior Design: High Level Design

LiDAR Object Mapping

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1 Introduction

The idea for converting LiDAR data into an STL file for 3D printing emerged as a response to several project ideas that failed to meet budget and availability constraints. Originally, the goal was to create an autonomous boat that would feature a sonar array taking depth measurements. These soundings would then be stitched together to create a depth chart for any given body of water. However, underwater sonar sensors proved to be unavailable, extremely pricey, and bulky; as a result, the team decided that a potential project idea would be to build our own sonar sensor instead. Once again, adding an aquatic element to the project made the task too complicated and expensive to pursue. Thus, it seemed natural to transition to an alternative measurement tool: LiDAR. The team found for on-land applications, LiDAR sensors possessed superior range, lighter weights, positive availability, and cheaper prices than sonar alternatives. Based on these findings, the group decided that pursuing a project with this technology would be significantly more fruitful.

LiDAR technology has many potential applications, but it is best suited for acquiring range measurements from objects. For this project, we will capitalize on the advantages of this technology by developing a device that takes thousands of unique measurements and stitches them together to model an entire object.

2 Problem Statement and Proposed Solution

Corporations spend millions of dollars designing products and then ensuring that manufactured results match the original design specifications. Using computer-aided design (CAD) software, nearly any part or product can be digitally modeled. However, this is a laborious process, and there is no guarantee that the CAD engineer will execute the task perfectly. If even one dimension is incorrect, the CAD model will need to be updated, and parts already sent to the 3D printer will need to be scrapped. Thus, replication of parts and products in CAD is time-consuming and error-prone. In addition to CAD, there are other methods that are employed to examine the specifications of parts and products. For example, companies hire individuals to take measurements of various manufactured parts rolling off an assembly line. Today, some companies even utilize computer vision to take images and implement edge detection algorithms that measure distances in 3D space. These methods, however, can be unreliable and incredibly costly. If a simple, cost-effective solution to this problem could be implemented, it would increase the efficiency and accuracy of designing and manufacturing all sorts of products.

In order to solve this problem, product and part measurements could be verified with a LiDAR scanner. This scanner would employ a LiDAR array that continuously takes distance measurements. This array will be capable of moving to varying heights to record the full dimensions of a part. As the LiDAR sensor moves up, the part of interest – placed on a 360 degree rotating tray – will spin, and the LiDAR sensor will capture measurements. This method will enable the scanner to take thousands of measurements at nearly every point around a part. The measurements data will be collected, exported to an SD card, and used to generate a corresponding STL file. Additionally, upon completing the measurements, the LiDAR scanner will quickly perform simple error computations to determine whether or not a part's dimensions are within an acceptable tolerance.

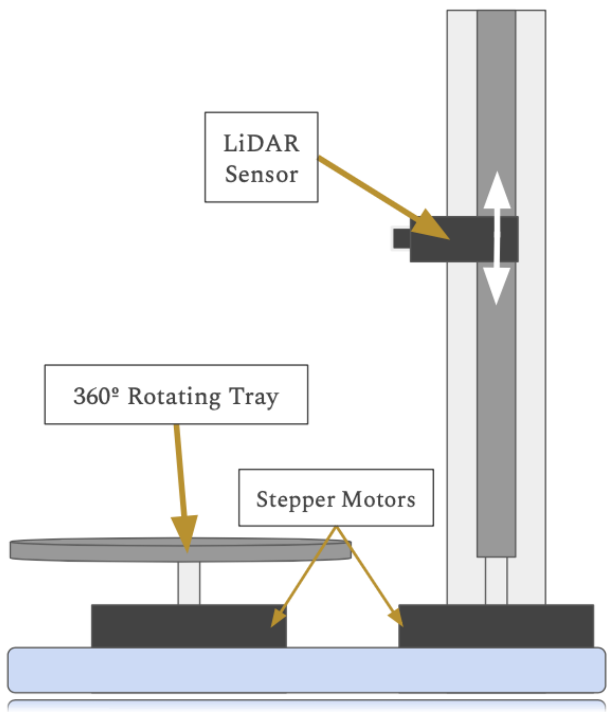


Figure 1. Proposed Design Layout of Sensor and Motors

3 System Requirements

Features of the Design:

3.1 Precise Stepper Motor Control

- The driver for this controller needs approximately 20 - 50 V DC. To meet this voltage requirement, a voltage regulator will be used to convert AC power from an outlet to 24 V DC. The device user will not be exposed to any of these voltages, so no user safety features will need to be implemented.

3.2 Functional LiDAR Sensor

- The LiDAR sensor requires 5V and 85mA of current to operate. This cannot be supplied directly from the ESP32; however, a transformer can take the 24V DC from the motor controller and convert it to 5V DC. The chip will then get power from a final regulator that converts 5V DC to 3.3V DC. We will use the same regulator used in the class board design for this aspect of the project.

3.3 Stable Frame

- The frame will need to be able to support both the weight of the LiDAR sensor and part being scanned. Neither of these components are excessively heavy, so a well-constructed frame should be sufficient.

3.4 STL File Creation

- This step will be executed by running a dedicated program on the ESP32. Thus, as long as the ESP32 is powered appropriately, it will have sufficient computing power to accomplish this step.

3.5 STL File Storage on a SD Card

- The ESP32 will use SPI to write the LiDAR measurement data onto an SD card. Again, assuming the ESP32 is appropriately powered, no other features are needed to accomplish this task.

3.6 Wireless STL FIle Preview

- We will create a remote, wirelessly supported software application to start scans and to view them in real-time. This feature requires the scanning system and user to be connected to the same network. To implement this feature, the ESP32 will write the measurement data to an SD card and wirelessly transmit it through the internet.

3.7 Part Quality Evaluation

- This project will use software to perform part quality evaluation. Provided that all subsystems are powered correctly, nothing to fulfill this requirement. The result of the part quality evaluation will be output to the wireless interface.

User Interaction Requirements:

This device will be powered from a connection to a wall outlet. The device will have a switch used to turn the device on or off. Although the device is not portable, it will be appropriately sized so that it can be easily transported from location to location. Once the device is plugged in, all systems on the device will receive DC power from their respective DC voltage regulators.

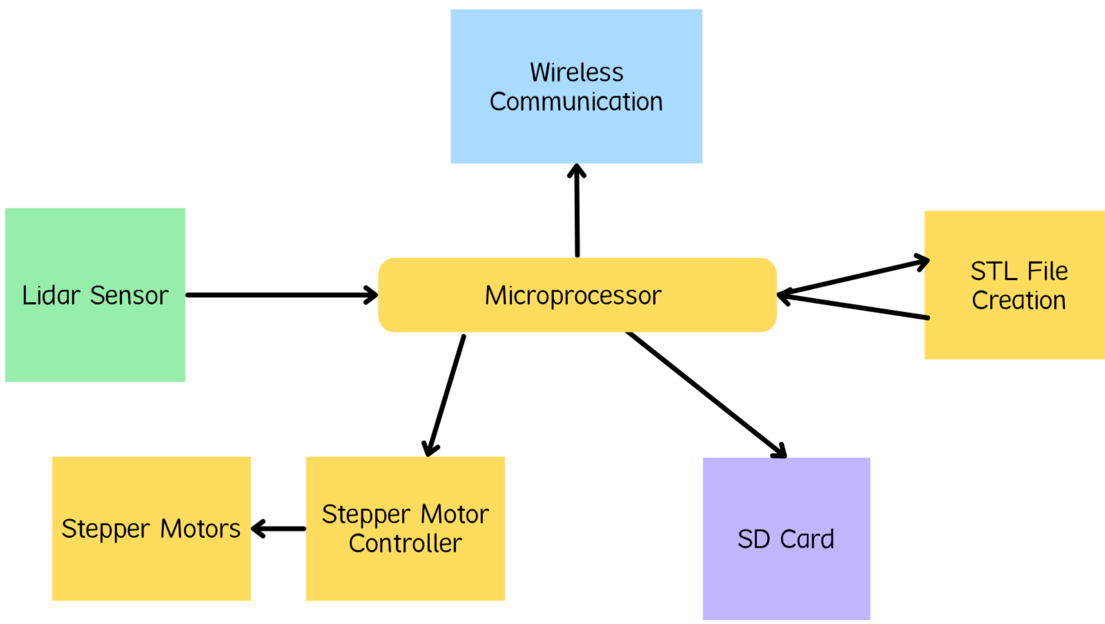
In order for the user to start a scan, he or she must complete the following steps. First, he or she must place the part to be scanned on the circular platform. This platform will be capable of supporting a two to three pound object. Second, once the part is placed on the platform, the user will go to a web address in order to wirelessly interact with the ESP32. Upon connecting to the web address, the user will be presented with an option to start a scan. Additionally, if the user wishes to perform an error analysis on the part, he or she can upload the desired dimensions of the part and click to enable the error detection feature. Third, once this preference has been recorded, the user should press the start button. The platform will begin rotating and the LiDAR sensor will take measurements. Once this process is complete, the user will see the 3D scan of the object updating in real-time on the website. Finally, if the error detection feature was enabled, the web application will display whether or not the part passed the error detection algorithm.

Safety Concerns:

This project team holds safety as its top priority. The user of this product will not be directly exposed to any harmful voltages or currents. Also, all of the sensitive electronics and moving parts will be enclosed in a casing, thereby protecting the user from any damage. Specifically, there will be a protective barrier around the rotating screws. In this manner, the customer cannot get caught in the system's moving parts and injure themselves.

4 System Block Diagram

4.1 Overall System:



4.2 Subsystem 1 and Interface Requirements: LiDAR Sensor

The LiDAR sensor is required to measure, with high accuracy, distances to an object. These distances will be used to create an STL model of the object, which can be used to 3D-print or evaluate the object for quality control. The LiDAR sensor uses I2C to communicate with the microcontroller. There are importable Arduino libraries that specifically support LiDAR based projects. Such libraries will enable the microcontroller to transmit, receive, and interpret data from the LiDAR sensor.

4.3 Subsystem 2 and Interface Requirements: Stepper Motors

The stepper motors will provide slow, precise mechanical motion for the system. One motor will be used to rotate the platform supporting the object being mapped. Another motor will raise and lower the LiDAR sensor to incrementally capture the entire object. The stepper motors interface through the stepper motor controller.

4.4 Subsystem 3 and Interface Requirements: Stepper Motor Controller

The stepper motor controller will interface with both the microcontroller and the stepper motors. It will provide the necessary voltage to the motors (12V) to allow for safe operation. The motor receives command pulses from the microcontroller serially. Then, the controller outputs the corresponding amperage and voltage required to the motor. By doing so, the motor is able to turn a specified, precise amount. The motors in consideration for this project will not require substantial amounts of voltage or current to successfully operate; thus, there are no safety or regulatory concerns with this aspect of the project.

4.5 Subsystem 4 and Interface Requirements: SD Card

The SD card system is required to store the generated STL files after they have been created. This allows the customer to take the files from the SD card and plug it into a 3D printer to print out the model. The SD card interfaces with the microcontroller via the SPI communication protocol.

4.6 Subsystem 5 and Interface Requirements: Wireless Communication

The goal of the wireless communication feature of this product is to provide the customer a preview of what the generated model looks like. This allows the customer to see the scan – in real-time – without needing to manually access the data stored on the SD card. The ESP32 utilizes a native wireless communication standard, which will be used to transmit the preview to a website.

4.7 Subsystem 6 and Interface Requirements: STL File Creation

This system processes the measurement data provided by the LiDAR sensor and converts it into an STL format. The interface requirement for this system does not exist, as it will be handled by the ESP32 processor.

4.8 Future Enhancement Requirements

The largest future enhancement that could be performed is the use of an extremely high quality LiDAR sensor. Sensors that have an accuracy of ± 1mm are available for purchase; however, the cost is in the neighborhood of tens of thousands of dollars. If a well-funded corporation decided to pursue a project concept similar to this, such a sensor could reasonably be acquired. However, due to the budget constraints of this senior design project, this enhancement is not feasible at this time.

Another future enhancement includes the implementation of higher quality stepper motors. Motors with the ability to control movements in smaller increments, which could increase the resolution of the image map generated by the LiDAR sensor. Additionally, more powerful motors would allow for larger, heavier objects to be scanned.

Both of these enhancements would require little modification to the existing design. Merely installing the new equipment and making some small software changes would prove sufficient to implement these enhancements.

5 High Level Design Decisions

5.1 Subsystem 1 Design Decision: LiDAR Sensor

The LiDAR sensor was selected to optimize cost and resolution considerations. We selected a sensor that was within our budget and possesses a resolution of 1cm. The sensor requires 5V and 85mA; these voltage and current requirements do not pose any problems, as a transformer can be used to convert 24V DC to 5V DC.

5.2 Subsystem 2 Design Decision: Stepper Motors

The stepper motors were selected for their ease of use, simple design, relatively low cost, and smooth interface with the stepper motor controller.

5.3 Subsystem 3 Design Decision: Stepper Motor Controller

The stepper motor controller was selected as the intermediate interface that allows for communication between the ESP32 and the stepper motors. It supplies 12V to the stepper motors, and once again, price was not prohibitive.

5.4 Subsystem 4 Design Decision: SD Card

The SD card was selected for its status as a well-established method of storage and compatibility with many computers, as well as the ESP32. The SPI protocol capability of the ESP32 makes the SD card module a neat solution.

5.5 Subsystem 5 Design Decision: Wireless Communication

Wireless communication will be executed via a Wi-Fi interface, and the data will be transmitted to a webpage. Wi-Fi will allow for significant data transfer speeds, and the ESP-32 already has built-in Wi-Fi capabilities.

5.6 Subsystem 6 Design Decision: STL File Creation

This subsystem was chosen as an area harnessing the capabilities of the ESP32 to process data. We are currently unsure of exactly how to implement this, but we are reasonably confident that we will be able to come up with some kind of workable solution within the system we have set up around it. For now, the most logical approach seems to involve implementing an algorithm that computes errors across the object and determines if the errors are within an acceptable range.

6 Open Questions

The biggest open question, in relation to this product, is the accuracy that the LiDAR sensor will be able to provide. While it has a stated accuracy of ±1 cm, it will be necessary to test this accuracy on real world objects. This will give the team an idea as to the scale of objects we should be seeking to model.

Another open question is the process related to taking the measurements from the LiDAR sensor and converting them into a 3D map. Furthermore, that 3D map then has to be converted into an STL file. No group members have undertaken a project like this before, so there are many open questions relating to how the multidimensional measurements should be processed. Additionally, due to an unfamiliarity with developing web applications, the team will need to experiment with the process of writing the LiDAR data to a user-friendly interface.

Finally, questions regarding the accuracy of the stepper motors and how precisely they can be tuned remain unanswered. Also, we are also unsure of the speed(s) at which the platform holding the object will need to rotate. Properly controlling the speed at which the platform rotates is essentially to produce accurate models. It's possible that variable speeds will be needed depending on how dramatically the edges, curves, and points of the object change. Additionally, we will have to test the maximum weight that the stepper motors are capable of lifting. If it is not sufficient, the motors will need to be replaced with more powerful ones capable of supporting larger, heavier objects.

Despite the potential challenges associated with the multitude of unanswered questions, our team is confident that through ample amounts of testing and experimentation, we will be able to find solutions to the problems that arise.

7 Major Component Costs

7.1 LiDAR Sensor: $80.00
7.2 Stepper Motors: $14.00 x 2 = $28.00
7.3 Circuit Board and Processor: $50.00
7.4 Frame Screws: $10.00
7.5 SD Card Module: $7.99
7.6 Stepper Motor Controller: $28.00

7.7 24V DC Regulator: $24.00
7.8 5V DC Regulator: $4.00
7.9 3V DC Regulator: $3.00

8 Conclusions

This project implements a vertically moving LiDAR sensor to record distances to a rotating object. The distances can be utilized to render a 3D model of an object, generate a STL file, and verify certain dimensions for quality assurance.

This particular design has several applications and considerations. First, if there is a part that an individual or a corporation would like modeled, there is no need to spend valuable time making a CAD model. Instead, the part can simply be placed on a scanning tray, and a 3D model with ±1cm accuracy will be generated. Due to cost constraints, a LiDAR sensor with greater accuracy and resolution cannot be implemented for this project; however, in a corporate setting with increased funds, a sensor with extremely high accuracy and fine resolution can be obtained. Finally, the model generated from the LiDAR measurements can be used for quality control purposes. By setting a specific tolerance between an actual measurement and reference measurement, this system could easily accept or reject parts. Therefore, this LiDAR scanner can ultimately serve several purposes, and it can be modularly outfitted with several different sensors depending on the desired resolution and accuracy.

9 References

Garmin LiDAR-Lite v4 LED | Distance Measurement Sensor

Hooshing 3PCS M2 x 100mm Stainless Steel Fully Threaded Rod, Long Threaded Screw Right Hand Threads: Amazon.com

STEPPERONLINE Nema 17 Stepper Motor Bipolar 2A 59Ncm(84oz.in) 48mm Body 4-Lead W/ 1m Cable and Connector Compatible with 3D Printer/CNC - - Amazon.com

Amazon.com: HiLetgo 5pcs Micro SD TF Card Adapter Reader Module 6Pin SPI Interface Driver Module with chip Level Conversion for Arduino UNO R3 MEGA 2560 Due

Digital Stepper Driver 1.0-4.2A 20-50VDC for Nema 17, 23, 24 Stepper Motor - DM542T STEPPERONLINE

CFM70S240-P Cincon Electronics Co. LTD | Power Supplies - Board Mount | DigiKey

B2405S-1WR3, Isolated Module DC DC Converter 1 Output 5V 200mA 21.6V - 26.4V Input