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Development of Low-cost LiDAR Scanner for Indoor Mapping

Serena Parve[1], Om Gaikwad[2] Poorvi Sidhapura[3], Sanket Chaudhary[4] and Shrikar Nakhye[5]

[1] Hardware Programming Researcher, LearnByResearch, Mumbai, India

[2] Hardware Development Researcher, LearnByResearch, Pune, India

[3] Hardware Development Researcher, LearnByResearch, Pune, India

[4] Hardware Development Researcher, LearnByResearch, Nashik, India

[5] Hardware Development Researcher, LearnByResearch, Mumbai, India

Abstract

In this fast-paced world, which has a growing rate of robotics and automation technologies with increasing applications in the fields of self-driving cars, autonomous guided vehicles, and unmanned aerial vehicles, the use of Light Detection and Ranging (LiDAR) sensors is becoming vital. LiDAR scanners have proved to be the most efficient and extremely accurate technology for Simultaneous Localization and Mapping (SLAM) applications, but they are also expensive. Researchers and hobbyists who do not have good economic resources are unable to use these systems.

In this paper, a prototype of an inexpensive and more flexible design of a 3-Dimensional (3D) LiDAR scanner with the use of a single-point ranging LiDAR sensor is presented. The design consists of an electromechanical setup, an optical sensor and a microcontroller for data acquisition (TF-Luna Range Sensor and Arduino Module).
A python algorithm was developed to structure and process the collected data. The algorithm is further used to generate a Point cloud of the scanned area.

Since the cost of this model is economical, students, researchers and developers who do not have access to financial sources can use it. This LiDAR scanner can be used for development of autonomous mobile robots, vehicles or drones for navigating through the environment and scanning the area simultaneously (SLAM) to create a map and navigate independently. Such applications prove useful for mapping indoor regions where human intervention can be hazardous like situations of fire outbreak, navigating through underground mines or in difficult and risky terrains. ***Keywords:*** **LiDAR, Low Cost, Scanning, SLAM, 3D Mapping**

1. Introduction

Over the past decade, the world has seen unprecedented research in robotics and autonomous systems with the purpose of reducing human involvement in arduous and hazardous tasks. Robots are expected to work without being monitored continuously and perform tasks which include autonomous navigation, path planning and obstacle avoidance, for which the selection and utilization of sensors play a vital role.

The preeminent sensor, which could perform most of these tasks, is Light Detection and Ranging (LiDAR) sensor. LiDAR systems have become immensely popular for their ability to scan their environment and return data accurately and swiftly. This feature has promoted the use of LiDAR systems in various fields such as Indoor Mapping, Self - Driving Cars, Building Information Modelling, sensing Forest Structures, surveying Agricultural Landscapes, etc.

LiDAR sensors are available in two types- 1 Dimensional and 2 Dimensional LiDAR sensor. These sensors, depending upon its application, can be used for scanning multi-dimensional areas. A LiDAR scanner works on Time-of-Flight (TOF) principle to measure distance and repeats this process for various orientations of the electro-mechanical design to create a multi-dimensional map of the area. 2D and 3D LiDAR scanners are more advanced and provide flexibility for various use-cases.

The vast range of applications of LiDAR has increased the expectations of more and more innovations in the field. The highly efficient LiDAR systems used in these are well developed and expensive, limiting their applications to industries and research organizations. Given the current price range of LiDAR sensors and scanners, individual researchers, students and hobbyists who do not have the economic resources are unable to use these systems. In this paper, we present a prototype of a low-cost and more flexible design of a 3D LiDAR scanner with the use of a single-point ranging LiDAR sensor.

2. Literature Survey

Companies and researchers have already studied LiDAR Technology, being one of the most advanced technologies in the Robotics and Automation industry, extensively.

Juan Li, et.al, has developed a system using 2D line-scan LiDAR and a digital camera wherein they acquire transformation matrices using extrinsic calibration based on which they have performed sensor fusion [1]. Similar to our approach, they have also created a 3D scanning system using a basic robotics servo on which both the sensors are rigidly attached.

Mapping and Localization systems are open to a variety of sensors and sensor combinations as surveyed by the authors of “Sensors for Indoor Mapping and Navigation” [2], and choosing the right sensor is vital to create an inexpensive and accurate system.

LiDAR scanners are predominantly used in Simultaneous Localization and Mapping (SLAM) applications where a LiDAR sensor and a mechanical system are combined in a mobile robot with a microcontroller or microprocessor, a radio module, an IMU, servo motors, and power supply elements [cite incomplete].

Post-Processing is the most imperative step after designing the scanner and various techniques and algorithms are used in multiple applications. Some algorithms such as weighted parallel iterative closed points (WP-ICP) will first process corners and line features and then apply point registration to maintain precision in mapping its surroundings [3].

The research paper titled “A Survey on LiDAR Scanning Mechanisms” [4] surveys different mechanisms used for scanning in LiDAR technology. According to the authors of this paper, the most cost-effective method for developing a multidimensional laser scanning system is to use a single point LiDAR sensor along with an electro-mechanical system to map the other dimensions, similar to the mechanism developed by us for the purpose of our research work.

V. Sarker et al presented a way of generating 3D data using an electro-mechanical robot setup consisting of a 2D LiDAR and a varied angle mirror. The acquired data was processed and visualised in MATLAB [5]. Edge computing technique was also incorporated for efficient processing of data, which effectively increased the battery life of the robot.

Lukasz Sobczak, et.al have developed a LiDAR simulator, which delivers 3D point clouds in real time [6]. Their research uses SLAM algorithms to evaluate the efficiency of driving using data collected by the sensors in real time. They have created simulations for both physical real-world environments and vehicle simulation, which are fed to the development environment consisting of virtual sensors, which further is fetched to Robot Operating System (ROS) along with real-world data from sensors. While our approach is inclined towards an audience interested in low-cost LiDAR systems for 3D indoor mapping, it is based on similar principles of generation of point clouds in real time.

3. Methodology

LiDAR systems have quite comprehensive working encompassing the study of sensors, light deflection, computation involving data processing techniques and algorithms, making them ideal in SLAM technology. Combining a single point LiDAR sensor with a 2-DOF (degree of freedom) electromechanical system has allowed us to construct 3D LiDAR scanners at a considerably low cost. The data acquisition hardware of the system consists of the sensor and the servo motors and are controlled by a 32-bit ARM microcontroller allowing fast processing of the sensor data. This data is further processed using python wherein a 3D point cloud is generated using the array of data acquired by the sensor. This system is mainly developed for scanning indoor environments and objects, with the system itself being stationary throughout the scanning process.

3.1 Light Detection and Ranging Sensor

The scanner makes use of the TF Luna sensor, which is a single point LiDAR sensor. It works on Time-Of-Flight (TOF) principle. The sensor periodically emits near-infrared modulation waves that reflect back after hitting an obstacle. The time of flight is obtained by measuring the phase difference between emission and reflection of the wave, which is then used to

calculate the distance between the object and the sensor.
The main specifications of the sensor [7] are mentioned in table I.

TF Luna is capable of measuring distances from 0.2m to 8m with objects having 90% reflectivity. The high accuracy provided by the sensor makes it ideal for its application in low-cost 3D scanners.

3.2 Electromechanical Design

Fig.1 shows the prototype that was developed. The design consists of a 360° servo motor, enclosed within the 3D printed base along with other components that support the rotation of the platform in the horizontal plane (yaw motion). A bracket is attached to the platform, onto which the sensor is installed. Another servomotor, which is mounted on the bracket and fixed to the sensor, is responsible for the movement of the sensor in the vertical direction (pitch angle motion) allowing it to scan in all the 3 dimensions.
The servomotor, fixed to the base of the system, actuates a to-and-fro motion of the platform. It allows the scanning of the horizontal plane in 2 dimensions using a single point (1D) LiDAR sensor (if the pitch angle is kept fixed). The motion starts from 0° and rotates up to 359° and travels back. This process is repeated with an increment in the angle of the second servo. Continuing this increment of the pitch angle results in the scanning and mapping of the surrounding area in three dimensions.

3.3 Programming

The servomotors and the LiDAR sensor are controlled by Arduino, which is coded in embedded C language in Arduino IDE. The data collected from the serial monitor is converted into CSV. This data is read in Python Compiler and plotted using an embedded library.
Servo Motors were programmed such that it will make a sweep motion of a semicircular shape. Besides that, TF Luna will simultaneously start creating its array by sending the laser signal through its transmitter. After the base servo completes its one cyclic semi-circular rotation, the top-attached servo will make an increment. Subsequently the data set will be collected in memory of Arduino IDE and later extracted in a CSV file.

3.4 Post Processing

Post processing is done using various python libraries such as ‘Matplotlib’, Pandas, open3D. The data collected from the LiDAR sensor is converted into CSV format, which makes it easy to read in python. Once the data is collected the program is compiled to get an animation of the point cloud. The plot consists of angle and distance values of the LiDAR, which gives us the respective x and y-axis.

4. Results and Discussions

To test the system, an open room consisting of objects such as desks and industrial equipment was used. The range of the scan was limited to 100cm, to only plot the immediate vicinity for optimal results. After the CSV file of the scanned data was extracted, it was processed for graphical results. The aim was to obtain a 3D point graph or a Point Cloud of the room.
The figures, Fig.2, Fig.3, and Fig.4 show the attempts to plot a Point Cloud. The results were not as desirable as per the predictions. The scanner noticed some noisy data in addition to its surroundings. Additional improvements and data filtration would need to be made in some of the core aspects of the system to improve its accuracy and resolution.

5. Tables, Figures and Equations

5.1 Tables and Figures

TABLE I
SPECIFICATIONS OF TF LUNA

Parameter	Value
Range	0.2 m - 8.0 m

Accuracy	±6 cm (0.2 m - 3.0 m) ±2% (3.0 m - 8.0 m)
Range Resolution	1 cm
F.O.V.	2°
Frame Rate	1 ~ 250 Hz (Default 100 Hz)

Fig. 1. Prototype of the model developed

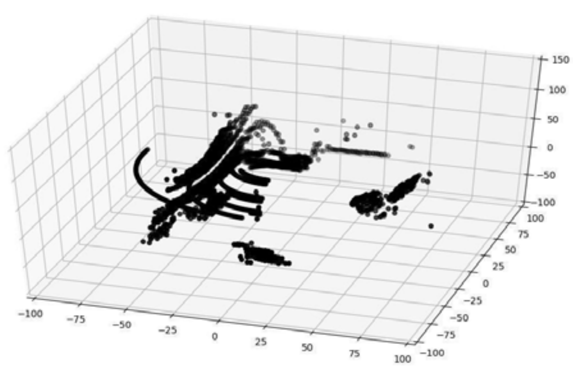

Fig. 2. 1st Attempt at plotting

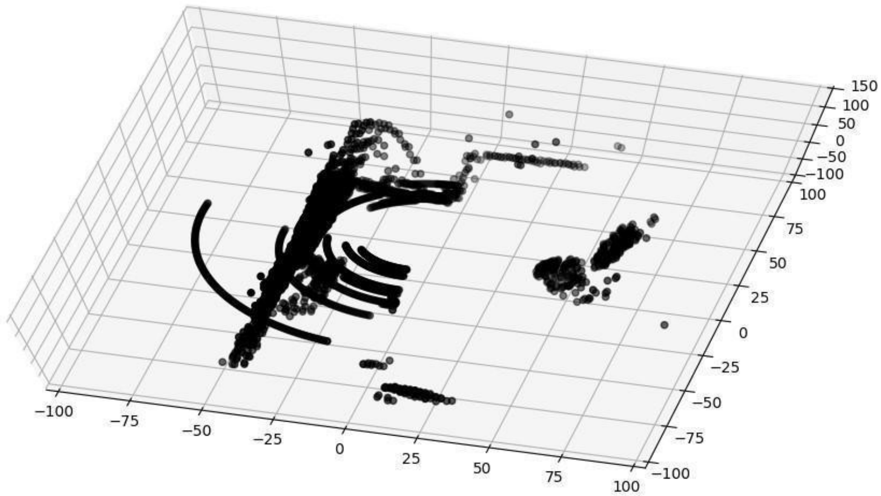

Fig. 3. 2nd Attempt at plotting

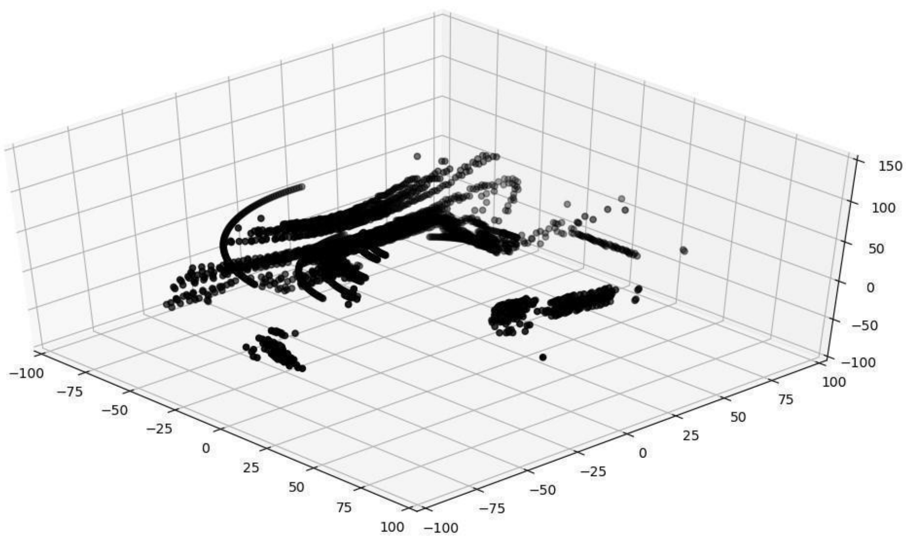

Fig. 4. 3rd Attempt at plotting

5.2 Equations

$$D = \frac{c}{2} \cdot \frac{1}{2\pi f} \cdot \Delta\phi \qquad (1)$$

D =Distance of between object and lidar sensor

c=Speed of light (3x10^8 m/s)

f=Frequency of light

$\Delta\Phi$=Phase difference

7. Conclusions

7.1 Summary

The average current market price of a 3D LiDAR scanner for an 8m to 12m range is $100. By using low-cost components such as 1D LiDAR sensor, rotary actuators such as servomotors, and an Arduino board, we have managed to bring down the cost of the system to $49. This is a more economically viable system for students and hobbyists.
A low-cost 3D LiDAR scanner model was built using TFLuna, Servomotors and an Arduino board. The model successfully makes a semi - circular sweep and collects distance and angle data of all points in its vicinity.
The post-processing results obtained were not as desired and threw light on some challenges we faced. These issues would need to be addressed before the model can be optimally used as intended.

7.2 Future Scope

In the near future, there is vast scope to avail integrity in code with proper algorithm and logic; also, to attain stability in mechanical design, especially by developing a rigid base to the assembly. The compiler used in the post-processing module can be a greater good for change and replacement for the system. Whereas the post processing algorithm is inchoate and can be improved.

Keywords:
1. LiDAR
2. Low Cost
3. Scanning
4. SLAM
5. 3D Mapping

Acknowledgments

1. LearnByResearch

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