Leveraging Available Components: Low-cost Solutions for 3D Environment Reconstruction

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***Abstract*—This research explores a cost-effective alternative to 3D LiDAR technology, using the RPLidar A1 and an essential servo motor. The RPLidar A1 and a Raspberry Pi3 are operated using Python programming. The method achieves precise 3D environmental representations, which can be used for surface mapping, scene classification, and basic robotic functionalities like autonomous navigation and collision avoidance. The research demonstrates the potential of this approach in various applications, including robotics, autonomous vehicle safety, industrial surveillance, and environmental modeling and mapping.**

***Keywords*—3D Environment Reconstruction, Laser scanner, 3D LiDAR, 2D LiDAR.**

I. INTRODUCTION

Robots' versatility has transformed industries, enabling them to perform diverse tasks independently. They outperform humans in dangerous professions and precision tasks. Their mobility and dynamic environment reconstruction are crucial for their operation.

2D LiDAR technology is widely used for accurate distance and angle measurement, aiding 3D data reconstruction and offering cost-effective alternatives to 3D LiDAR for various applications.

Reconstructing dynamic environments, especially in high-traffic zones, presents challenges due to rapid transformations and impediments. Innovative methodologies are needed for efficient 3D reconstruction to overcome these challenges.

The study presents a cost-effective 3D reconstruction prototype using a swing-mount RPLidar A1 and two servo motors managed through a Raspberry Pi platform. This innovative configuration offers precise and adaptable environment reconstruction, improving robotic technology implementation in various sectors. Its potential extends to a broader range of applications and researchers.

The article provides a brief overview of the research, details the design and construction of a 3D scanning apparatus and the point cloud processing chain, details the materials and methods used, outlines experimental configurations and findings, and concludes with a perspective for future work.

II. RELATED WORK

LiDAR technology is widely used for acquiring 3D data through laser pulses, but its cost and accessibility limit its widespread use in some areas. However, advancements in 2D LiDAR technology have made it more cost-effective, prompting researchers to explore its potential applications in 3D reconstruction. in [1], The authors propose a low-cost RPLidar A1 2D LiDAR system for an FPGA-based 3D LiDAR system. Despite its flexibility, this method can be time-consuming and error-prone due to the numerous potential error sources. The authors highlight the need for a more robust and efficient debugging approach for FPGA-based systems. [2].In [3], The system's design involved a 2D LiDAR, DC motor, motor driver, rotating platform, angular measurement subsystem, and ROS-enabled computer. In [4], The authors developed a three-dimensional laser range finder using a Hokuyo URG-04LX-UG01 two-dimensional laser scanner, Arduino nano motion controller, and computer. Calibration was performed using MATLAB and ROS for precise performance. In [5], Integrating a 2D LiDAR sensor with reflectors creates a cost-effective 3D imaging system, enhancing precision and scope. This technique is particularly useful when reverse laser beams are ineffective, like vehicle exteriors.

III. MATERIALS AND METHODS

The proposed system in this paper intends to reconstruct a dynamic environment using two-dimensional LiDAR and a servo motor. The 2D LiDAR is connected to the Raspberry Pi to collect distance and angle data for each point in the environment. Steps include connecting components, using necessary libraries, programming to collect data from different servo rotation angles, creating a map of the environment using mapping algorithms, and reconstructing a 2D or 3D image.

A. LiDAR

LiDAR is a technology using Time of Flight (ToF) laser rangefinders to measure the duration of a laser pulse to reach an item, enabling object detection and range determination Fig 1. [6] using the following equation [7].

$$TOF = (2 * Distance)/C \tag{1}$$

The system uses a rotating mirror to discharge a laser beam, scanning 360 degrees and detecting objects obstructing its trajectory, using the beam's round trip duration to determine distance Fig. 2. This allows for precise information collection about the distance between target objects, the light source, and their velocity [8]. RoboPeak, a robotic sensor production company, developed the RPLidar A1 M8 laser scanner, a widely used 360-degree scanning technology in robotics and automation. Table .I shows the main characteristic of RPLidar A1 m8.

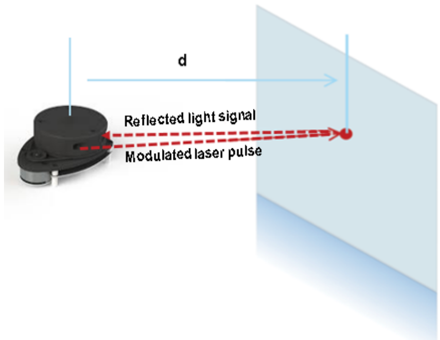

Fig. 1: RPLidar A1 ranging schematic.

TABLE I: Main characteristic of RPLidar A1 m8

Characteristic	Description
Scanning Frequency	Up to 8000 samples per second
Laser Type	Amplitude Modulated Continuous Wave (AMCW)
Compactness	Compact and lightweight design
Compatibility	Compatible with various operating systems and platforms
Maximum measurement range(m)	6
Measurement error (mm)	±50
Scanning angle (deg.)	360
Angular resolution (deg.)	<= 1
Scanning time (ms/cycle)	180
Measurement resolution (mm)	<0.5
Data interface and transfer rate	USB 2.0
Supply voltage (VDC)	5± 5%
Weight (kg)	0.2
External dimensions (WxLxH in mm)	90 × 70 × 60
Cost	Affordable compared to high-end LiDAR alternatives

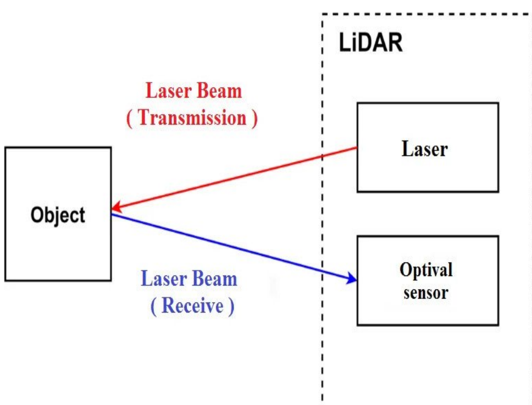

Fig. 2: Basic principle of LiDAR

This study presents a cost-effective 3D LiDAR technology using a two-dimensional LiDAR motor and Raspberry Pi, generating a real-time environment map using distance and angle data, allowing real-time monitoring of dynamic variations.

B. The Raspberry Pi 3

The Raspberry Pi is a microcontroller developed in the United Kingdom by the Raspberry Pi Foundation [9]. The Raspberry Pi 3 is a compact Linux-based, Python-based computing device with a 1.2 GHz quad-core CPU, 16GB SD card, and enhanced performance, making it a popular choice.

C. Servo motor

The Futaba S3003 servo, a medium-sized motor with a commendable power-to-weight ratio, was used in applications like aeromodelling, automotive modeling, robotics, and drone control, with a transit speed of 0.23 seconds per 60 degrees.

IV. EXPERIMENTAL

A. LiDAR Calibration

The initial phase focused on developing a LiDAR code to depict a two-dimensional scene using LiDAR coordinates accurately. The RPLidar provides a dataset with 360 values representing a 360° rotation, determined by equations (2) and (3). [10]; Fig .3 shows the configuration step.

$$x_i = d_i \cdot \cos\theta_i, \quad \theta \in [0, 360] \tag{2}$$

$$y_i = d_i \cdot \sin\theta_i, \quad \theta \in [0, 360] \tag{3}$$

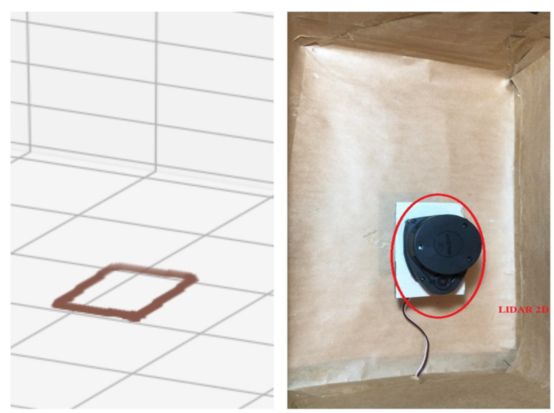

Fig. 3: Configuration of LiDAR

B. Data collection

The LiDAR system stores coordinates in voxels, three-dimensional storage units. Initial values are 0, and the system scans and assigns numerical values to coordinates. Reflection causes 1 numerical value, while no reflection results in 0.

. The servo motor adjusts the angle of the z value after recording 360 pairs of coordinates, then iterates through six cycles to capture fresh coordinates.

C. Data fragmentation

The voxel is generated, and environmental data is collected using equation (7). If the distance between two obstacles is less than 20 cm, they are considered a unified barrier and assigned a distinct color. If the distance exceeds 20 cm, a new color is introduced.
As shown in the illustration [11]:

$$x_i = d_i \cdot \sin\phi \cdot \cos\theta i, \quad \theta \in [0, 360], \quad \phi \in [0, 45] \tag{4}$$

$$y_i = d_i \cdot \sin\theta \cdot \cos\phi i, \quad \theta \in [0, 360], \quad \phi \in [0, 45] \tag{5}$$

$$z_i = d_i \cdot \cos\phi i, \quad i \in [0, 360], \quad \phi \in [0, 45] \tag{6}$$

$$\text{distance}_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2} \tag{7}$$

Where (x,y,z) is the coordinate of voxels, (d,θ) data from LiDAR, and (ϕ) is the rotated angle of the servomotor.

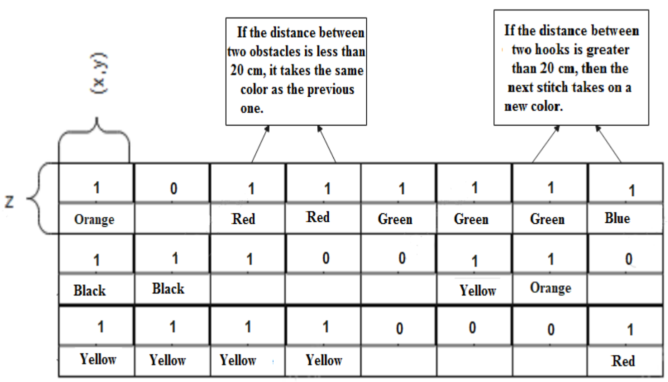

Fig. 4: Data Fragmation

V. Result and Discussion

A protective enclosure was designed for a three-dimensional environment reconstruction system, housing the LiDAR sensor and servo motors, connected to the Raspberry Pi 3 microprocessor for ease of transportation Fig .5.

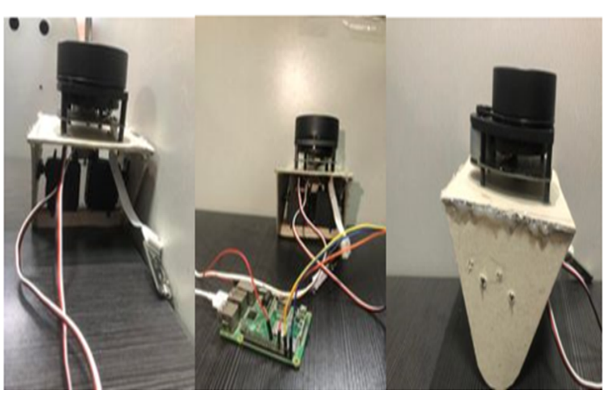

Fig. 5: The proposed system

The RPLidar A1 M8, a budget-friendly 2D LiDAR device, was used to assess the effectiveness and precision of a 3D LiDAR configuration. The device can generate up to 8000 measurements per second and has a scanning frequency of up to 10Hz. The RPLidar was connected to a USB adapter, which provided power and facilitated the conversion of the inbuilt UART serial interface to a USB interface. The Raspberry Pi was connected via a micro-USB cable. Two servo motors were interfaced with GPIO ports, and Python code was built. This technique enhances the system's portability across different platforms and provides a versatile solution without specific hardware architectures.Fig .6. We determine the height (z dimension) using a motor servo, where we define a maximum angle of 45 degrees. Every 5 degrees, we record LiDAR information to obtain a three-dimensional environment.

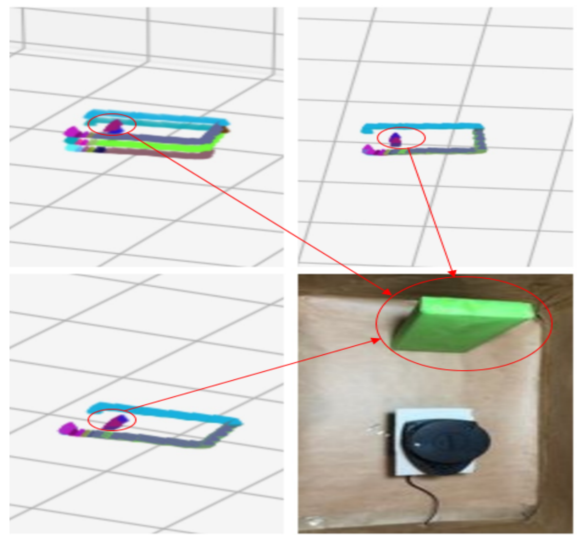

Fig. 6: Reconstruction of the 3D map as a point cloud for different real situations

VI. Conclusion

This paper outlines the successful development of a low-cost 3D laser scanner using a 2D LiDAR and a servo motor. Integrating a box containing the LiDAR and servo motor enabled synchronized movement, ensuring precise adjustment of the LiDAR's angle during rotation to capture height information in the Z dimension. Consequently, we acquired three-dimensional coordinates (X, Y, and Z) of the environment, visualizing them in a three-dimensional Voxel. The combination of horizontal coordinates (X, Y) from the 2D LiDAR and vertical coordinates (Z) from the servo motor contributed to the generation of comprehensive point cloud data.

In conclusion, our proposed system exhibits promising capabilities for low-cost 3D scanning, representing a valuable contribution to 3D sensing and reconstruction. The advancements achieved in this study represent a significant step towards more sophisticated and practical implementations, empowering researchers and professionals with accessible tools for three-dimensional data acquisition and analysis. For future work, we will focus on organizing the point cloud data into obstacles and endowing them with three-dimensional geometric structures. This continued research effort will further enhance the utility of our system, opening up new avenues for applications in various domains, such as robotics, environmental mapping, and autonomous navigation. We are optimistic that our work will inspire further advancements and foster collaborations within the scientific community, ultimately driving the evolution of low-cost 3D scanning technologies for broader adoption and practical applications.

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