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***Research paper***

# 3D Indoor Mapping System Using 2D LiDAR Sensor for Drones

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## Abstract

Most 3D scanners are heavy, bulky and costly. These are the major factors that make them irrelevant to be attached to a drone for autonomous navigation. With modern technologies, it is possible to design a simple 3D scanner for autonomous navigation. The objective of this study is to design a cost effective 3D indoor mapping system using a 2D light detection and ranging (LiDAR) sensor for a drone. This simple 3D scanner is realised using a LiDAR sensor together with two servo motors to create the azimuth and elevation axes. An Arduino Uno is used as the interface between the scanner and computer for the real-time communication via serial port. In addition, an open source Point-Cloud Tool software is used to test and view the 3D scanner data. To study the accuracy and efficiency of the system, the LiDAR sensor data from the scanner is obtained in real-time in point-cloud form. The experimental results proved that the proposed system can perform the 2D and 3D scans with tolerable performance.

***Keywords***: *3D mapping; LiDAR; 2D sensor; indoor; drone.*

## 1. Introduction

For many years, building a three-dimensional (3D) model of real-world object has become a vital task in many applications including unmanned aerial vehicles (UAVs) autonomous navigation, street view and cartography [1]. 3D scanning also has been widely used in industrial sector for reverse engineering and fault inspections. Apart from that, the decreasing cost of 3D equipment over the past few years has led to the increasing usage of 3D scanning for many other applications such as fast prototyping, modelling and development of realistic computer graphic in the video gaming industry [2].

3D scanners and cameras generally are almost similar in terms of functionality and concept. Like cameras, 3D scanners have a cone shaped field-of-view and it can capture and analyze the data of the surface just like a camera. On the other hand, a camera analyzes the colour information of a surface while a 3D scanner calculates the distance of a surface in its line-of-sight. The image produced by a 3D scanner shows the distance of a surface to every interior point in the image. This information later allows three-dimensional position of every point to be identified. In most situations, a single sweep scan from the 3D scanner could not produce complete surface characteristics. Instead, multiple scans from various locations are needed to obtain complete and accurate information and surface characteristics.

## 2. Methodology

### 2.1. Introduction

This paper highlights the development of a low-cost 3D indoor mapping system using a 2D LiDAR sensor for drones. The general flowchart of the 3D indoor mapping system is illustrated in Fig. 1.

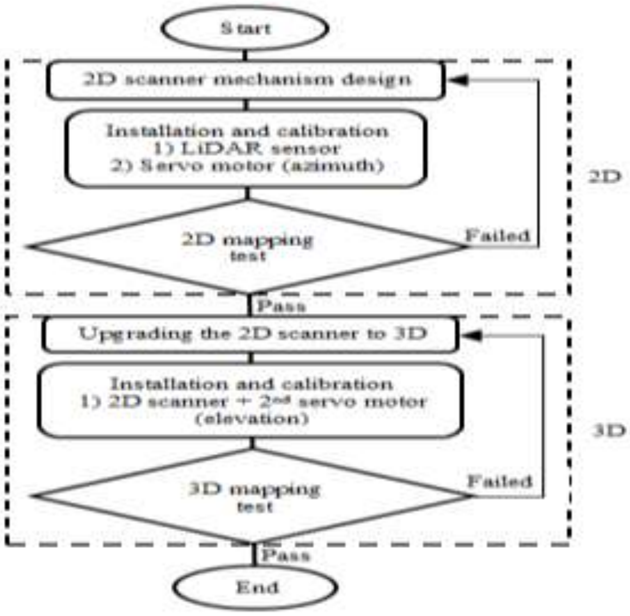


**Fig. 1:** Flowchart of the 3D indoor mapping system

The development of the 3D indoor mapping system consists of two main stages. The first stage is the design of the 2D scanner mechanism. A 2D mapping verification will be carried out to test the functionality of the system after being installed and calibrated. If the system failed the test, the design will be improved until it passed the test before moving on to the second stage. The second stage is the design of the 3D scanner mechanism. The proposed system will also go through the 3D mapping verification to find out the accuracy of the scanned image in comparison to the image of the real object.

## 2.2. Components

The 3D indoor mapping system consists of several electronic components which include the LiDAR Lite v2, the Arduino Uno microcontroller board and the standard direct current (DC) servo motor. A complete block diagram showing the component connections is shown in Fig. 2. The LiDAR sensor is connected to a servo motor to coordinate the scanning pattern, which is controlled by the Arduino Uno microcontroller. The output scanning pattern is displayed on a Point-Cloud Tool software which receives the inputs from a computer connected to the microcontroller.

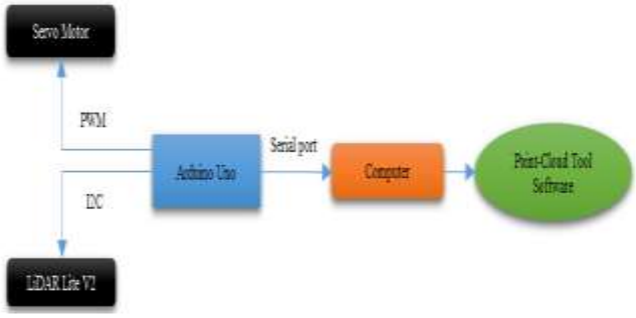


**Fig. 2:** System block diagram

### 2.2.1. LiDAR Lite v2

The proposed system uses the LiDAR Lite v2 from PulsedLight which is a low-cost and high performance light detection and ranging device. This sensor is suitable to be used with robots or UAVs such as drones due to its small size and light weight. In addition, the ability to detect an object up to 40 meters makes it suitable for indoor usage. There are two ways users can interact and communicate with this LiDAR sensor namely via Inter-Integrated Circuit (I2C) and Pulse Width Modulation (PWM). The technical specifications of LiDAR Lite v2 are listed in Table 1.

**Table 1:** Technical specification for LiDAR Lite v2

| General | Technical Specification |
|---|---|
| Power | *4.75-5.5V DC Optimal, 6V Maximum* |
| Weight | 22g including housing and optics |
| Size | 20 x 48 x 40mm |
| Current consumption | <2mA at 1Hz, <100mA during continuous usage |
| Maximum range | ~40 meter |
| Accuracy | +/- 2.5cm |
| Refresh rate | 50Hz |

LiDAR operating principle is quite similar to radio detection and ranging (RADAR), but it transmits and receives laser beams instead of radio waves. The photons created by the laser are emitted and reflected back to the receiver. Thus, this principle allows the LiDAR to measure distances in (1), where *d* is the measured distance in terms of the speed of light and time of flight, which is the time it takes for the light to travel to and from the detected object.

$$d = \frac{Speed\ of\ Light\ \times Time\ of\ Flight}{2} \quad (1)$$

### 2.2.2. DC Servo Motor

DC servo motor is one of the main components in an automated system. Every automated system has an actuator module which enables the system to move by itself. Most commonly used actuator module to perform this task is a servo. This servo motor device consists of several electrical and mechanical parts where these components are integrated to make it functional.

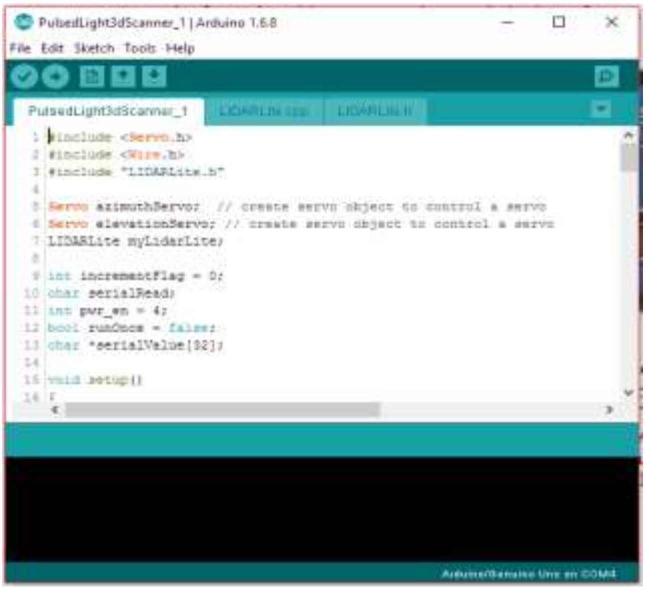
A standard servo motor can be controlled precisely but it has limited rotations. Most servo motors can only rotate from $0^0$ to $180^0$, controlled by a microcontroller. The microcontroller uses Pulse Width Modulation (PWM) to turn the servo to a specific angle precisely. In this project, Arduino Uno is used to control the servo motor and it has a specific library, Servo, in the programming language. The technical specifications of the servo motor used are shown in Table 2.

**Table 2:** Servo motor technical specification

| General | Technical Specification |
|---|---|
| Modulation | Analog |
| Torque | 4.8V: 3.17 kg-cm<br>6.0V: 4.10 kg-cm |
| Speed | 4.8V: 0.23 sec/$60^0$<br>6.0V: 0.19 sec/$60^0$ |
| Weight | 37.0 g |
| Dimension | 39.9mm (L) x 20.1mm (W) x 36.1mm (H) |

### 2.2.3. Arduino Uno Microcontroller

The main board for this project is the Arduino Uno which is based on the Atmel Atmega 328 microcontroller with 32KB flash memory, 1KB EEPROM, 2KB SRAM, 23 lines of input and output, programmable serial Universal Synchronous/Asynchronous Receiver/Transmitter (USART) and a few selectable power saving modes in the software. This smart board operates at 1.8V to up to 5.5V. Fig. 3 shows the Arduino programming user interface.



```
#include <Servo.h>
#include <Wire.h>
#include "LIDARLite.h"

Servo azimuthServo;  // create servo object to control a servo
Servo elevationServo; // create servo object to control a servo
LIDARLite myLidarLite;

int incrementFlag = 0;
char serialRead;
int pwr_en = 4;
bool runOnce = false;
char *serialValue[32];

void setup()
{
```

**Fig. 3:** Arduino programming user interface

Both of the main components in this project will be connected to the Arduino Uno. The LiDAR Lite v2 is connected to the Arduino Uno via I2C using the Serial Data Line (SDA) and Serial Clock Line (SCL) port while the servo is connected via PWM using the digital output port. This main board also provides a 3.3V and 5V line that is required by both components. The open-source Arduino Software integrated development environment (IDE) makes it very easy and simple to write a code and upload it into the smart board. It can operate in Windows, Mac OS X and also Linux. The Arduino environment is written in Java and based on Processing, AVR-GCC and other open source.

### 2.2.4. Point Cloud Tool Software

Point Cloud Tool is a software created by PulsedLight, Inc. for research and experimentation in point based visual system for robotics application. By using a point-based distance sensor such as the LiDAR Lite v2 together with two servos for both the azimuth and elevation axes, a point cloud data is collected and can be exported to a comma separated value (CSV) file and geometry definition file (OBJ). Fig. 4 shows the graphical user interface of the Point Cloud Tool software.

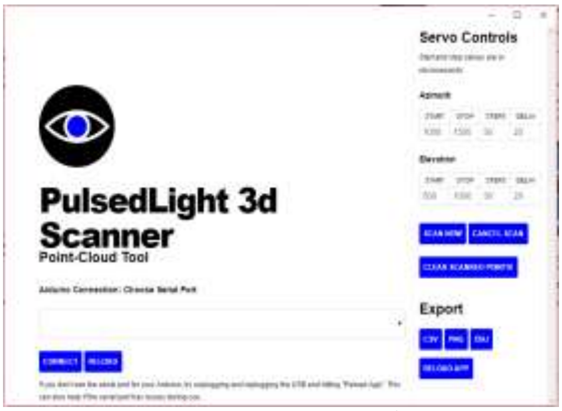


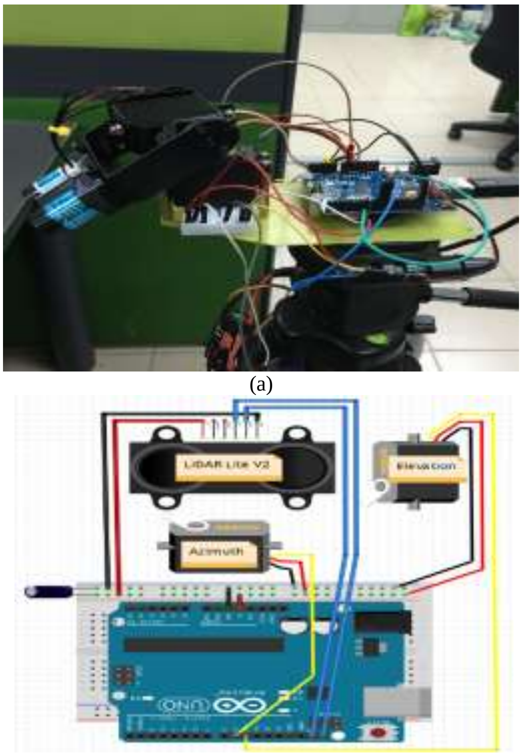
**Fig. 4:** Point Cloud Tool interface

This software is an extension that needs to be used with Google Chrome App. After uploading the code into Arduino Uno and connecting it to a computer via serial port, the software is ready to be used. There are several important parameters that need to be configured before starting the scanning process as shown in the right panel in Fig. 4. The servo motors can be controlled by adjusting the START and STOP for both of the axes. This parameter refers to the range of the angle that the servo needs to rotate. STEPS and DELAY is very important as it will determine the resolution of the scanned image.

# 3. Results and Discussion

## 3.1. Introduction

Fig. 5(a) shows the prototype of the 3D mapping system and Fig. 5(b) illustrates its schematic diagram. The complete system is mounted on a tripod to ensure it remains static and does not move while staying at a fixed position. Thus, it helps in adjusting the height and position of the scanner while performing the scanning tests. The proposed system is able to perform a 2D and 3D scan with tolerable results.



(a)

(b)

**Fig. 5:** The proposed 3D indoor mapping system, (a) 3D scanner prototype, (b) its schematic diagram

## 3.2. 2D Scanning Test

The 2D indoor scanning test takes place in an indoor office environment with a simple setup. An object is placed at the center of the office cubicle to act as an obstacle as shown in Fig. 6. Using the optimised parameters that have been decided earlier as listed in Table 3, the 2D scanning result has been successfully obtained as presented in Fig. 7.

**Table 3:** 2D scanning parameters

| Parameter | Value |
|---|---|
| Refresh rate | 50Hz |
| Scan time | 4 second |
| Scan speed | 50 points/s |
| Azimuth range | $180^0$ |
| Elevation range | $1^0$ |

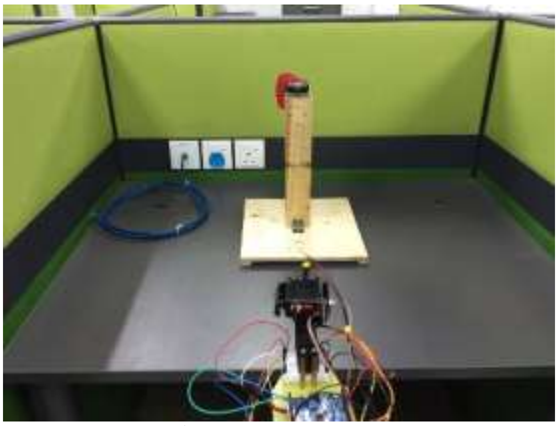
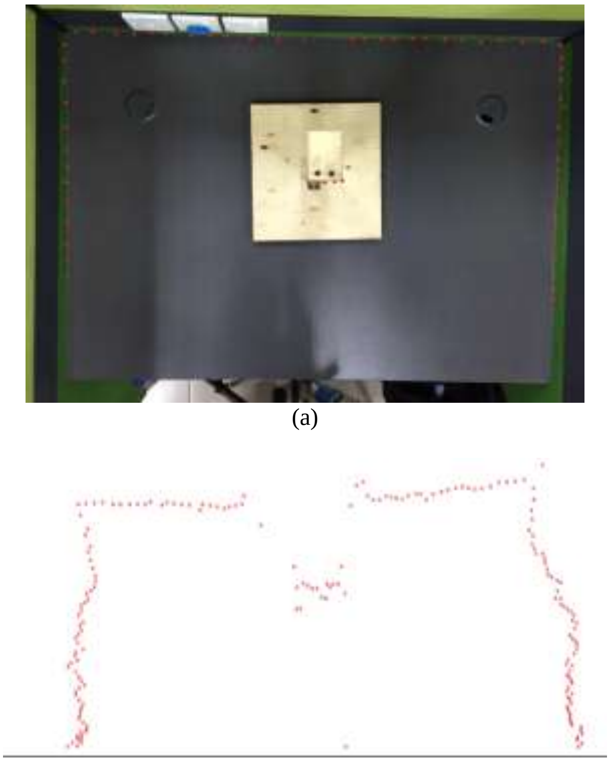


**Fig. 6:** 2D scanning setup



(a)

(b)

**Fig. 7:** 2D scanning test result, (a) expected results, (b) scanned result

## 3.3. 3D Scanning Test

For the 3D scanning test, several scans are run with different number of servo motor’s steps. The step number is an important parameter as it will determine the quality of the scanned image.

From this experiment, the most important tradeoff to consider is the time versus resolution. Using a small step number results in a slower scanning process, but better image resolution. Table 4 shows the 3D scanning parameters used in this experiment. Fig. 8 shows the 3D scanning test setup where an office chair is placed at the centre viewing field of the sensor. The obtained 3D scanning test results using different step numbers are shown in Fig. 9. As can be seen, the longest scanning time (1,376 seconds), with the smallest step number (2), results in the highest resolution of the office chair, while the shortest scanning time (15 seconds) with highest number of steps (20 steps) results in the lowest resolution.

**Table 4:** 3D scanning parameters

| Parameter | Value |
|---|---|
| Object distance | 1 meter |
| Refresh rate | 50Hz |
| Azimuth range | $60^0$ |
| Elevation range | $60^0$ |

**Fig. 8:** 3D scanning setup

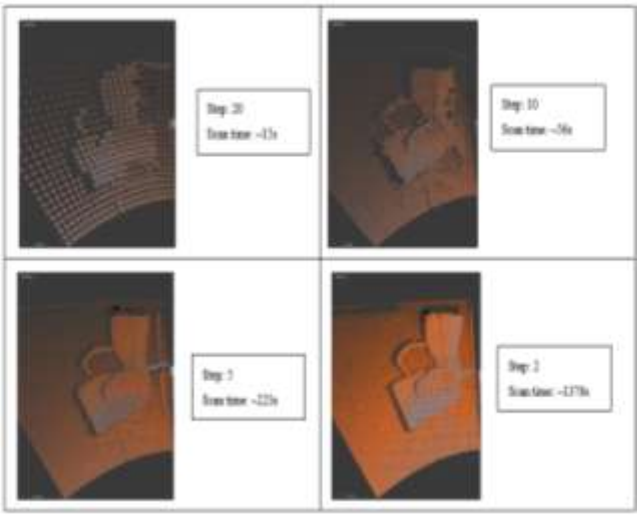


**Fig. 9:** 3D scanning test result

Fig. 10 shows the scanning time versus number of steps plot for the 3D scanning test. From the graph, it is clear that for a small number of steps, a large amount of time is needed to complete the scanning process. The LiDAR sensor used has a pulse repetition frequency (RPF) of 50 Hz. In theory, a 50 Hz RPF means the sensor could record 50 scanned points in 1 second. Therefore, by using a large number of steps, the number of scanned points recorded per second could be significantly reduced. This concludes that the number of scanned points per second is inversely proportioned to the number of steps as shown in Fig. 11. With this, it is conclusive that by combining both the azimuth and elevation axes, a 3D scanning mechanism could be realized using a 2D LiDAR sensor [9, 13].

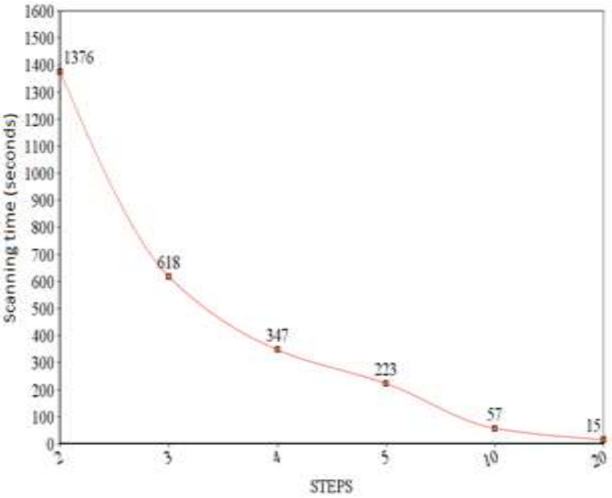


**Fig. 10:** Scanning time versus number of steps

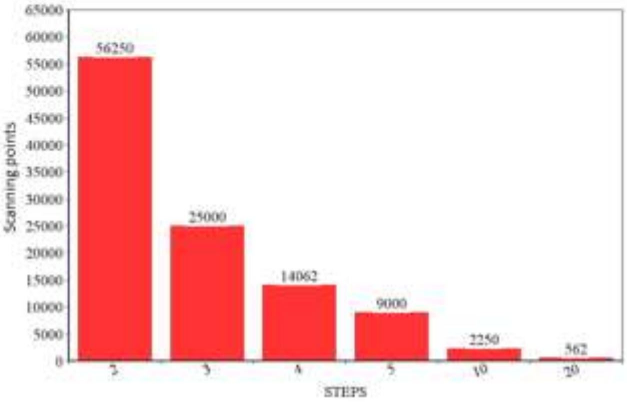


**Fig. 11:** Scanning points versus number of steps

# 4. Conclusion

The main objective of this project is to develop a low-cost 3D indoor mapping system using a 2D LiDAR sensor. The experimental results show that the objective was achieved, as the proposed system could perform a 2D and 3D scan with good results. However, there are many aspects that can be further improved for future work. For example, a higher quality servo motor could be implemented to reduce the vibration while performing the scanning test in order to reduce the noisy data. Furthermore, a smaller servo and LiDAR sensor should be considered to reduce the overall weight of the system as it is the most crucial factor for drone application.

In conclusion, the accomplishment of this project proves the reliability and accuracy of a low-cost LiDAR sensor to perform an indoor 3D scanning. However, there is still plenty of room for further improvement. This project reveals a great potential of low-cost LiDAR sensor for other robotic applications namely for the visual system.

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