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Low cost solution for 3D mapping of environment using 1D LIDAR for autonomous navigation

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Abstract. The mobile robotics industry is booming rapidly and this demands low cost alternatives to autonomous navigation. Perceiving the unknown environment is of utmost importance for the robot to navigate. In this paper, a low cost indoor navigation system for mapping of stationary environment and object detection has been presented. Algorithm to convert 1D LIDAR (Light Detection and Ranging) into 3DLIDAR has been developed. Profile of the objects that are obstacles has been plotted using a simple, one dimensional point LIDAR. The system will detect the presence and shape of the object as quickly as possible using the adaptive scanning approach.

Keywords: LIDAR, Point cloud, autonomous navigation, 3D mapping

1 Introduction

The future of autonomous industry depends on Light Detection and Ranging (LIDAR) technology. LIDAR sends light pulses that are reflected back by the objects to measure the distance of obstacle. The depth information is calculated either by Time of Flight (TOF) measurement, phase shift or triangulation methods. Three dimensional perception of the environment is necessary for autonomous navigation of aerial vehicles (UAV's), self-driving cars, Automated Guided Vehicles (AGV's), etc. Apart from autonomous navigation the other applications of 3D mapping include entertainment industry like video games and virtual reality, industrial design, healthcare, reverse engineering, prototyping and quality inspection. For navigation purposes LIDAR data is fused with GPS unit or some inertial sensor for localization. LIDAR is a tried and tested method to capture accurate 3D point clouds. Cameras are used along with LIDAR data for mapping[1]. This is done since LIDAR is incapable of providing color information and combining camera and LIDAR data makes it easier to recognize the objects. Many 3D sensing technologies are available in the market. Each of them have their own advantages and drawbacks. The most popular 3D LIDAR that is being used in Google's self-driving car (Waymo) is the Velodyne LIDAR (eg.HDL-64E, VLP-16, HDL-32E). These different models differ in the number of lasers rotating. They have very high resolution and high acquisition rate and therefore are suited for vehicles driving at high speeds. These different models differ in the number of lasers rotating. They have very high resolution and high acquisition rate which make them suitable to for vehicles driving at high speeds. The data generated by these sensors is huge and can be processed only on particular higher end platforms. The cost of this LIDAR is approximately $75,000 which is highly expensive. Many companies are investing into bringing down the cost of these sensors so that they can be used in lower end cars and autonomous robots. Recently Solid state LIDARS have gained popularity due to their compact size since they are entirely built on a single silicon chip. But still the cost of these LIDARs remains high. Their cost can be brought down only by mass production. RGB depth cameras are being used as an alternative to 3D LIDARs. These cameras provide color as well as depth information[2].They are low cost but are limited in their sensing range (0.5 to 4m), precision and also affected by lightning conditions. Stereo camera has similar characteristics[3]. The stereo camera output is highly affected by lighting conditions and textural appearance of the objects.

Obstacle avoidance and identifying the object to transverse is of utmost importance[4]. All these aspects lead to the need for a customized low cost LIDAR sensor for 3D mapping of environment. This can be achieved by means of rotating a laser scanner in horizontal (yaw) and vertical (pitch) planes. A 2D LIDAR is used to generate 3D map using two methods[5]: One by generating 3D map at known locations and secondly by using one 2D LIDAR for mapping and another for localization. The maps thus generated are evaluated based on their proposed metrics. The above system is time consuming and can be used only for low speed platforms. The customized 3D LIDARS mainly differ in driving mechanisms: passiveand active. In passive mechanism the range sensor is connected to a passive linkage like a spring. The vibrations in the vehicle will cause the spring to propel the laser scanner and extend its field of view [6]. This type of mechanism will not be feasible for flat surfaces. Active mechanisms[7] on the other hand use a motor for driving the sensor in the required planes (roll and pitch). This type of system requires precise control of motors and accuracy depends on the accuracy of the motors.The system realized in [8] describes 3D mapping with different step sizes of servo motor and analyze the output based on number of scanning points and scanning time required.

We hereby try to evaluate the possibility of generating a map of the environment using a single low cost 1D LIDAR. In this way we try to bring down the cost of conventional 3D LIDAR in the market for perceiving the environment. A single 1D LIDAR (Lidar Lite v3) and two servo motors have been used. The LIDAR will measure distances and the motors will drive the sensor in two planes horizontal(yaw) and vertical(pitch) to generate a point cloud. This 3D point cloud is further used to plot a graph of the environment.Profile of the objects that are obstacles has been generated using a simple, low cost LIDAR.

The paper is structured as follows: Section 2 describes the proposed system with assumptions; Experimental results are presented in section 3. Section 4 concludes the paper.

2System Design

The system is designed mainly for small autonomous bots or Automated Guided Vehicles (AGV's) where speed of the vehicle is not a major consideration. The major assumption is that the environment is stationary with respect to the sensor and rest of the items other than the obstacle are immaterial. The prototype designed in scans for 150° horizontal and 120° in vertical directionusing fast scan method and determines the co-ordinates of the obstacle. Based on the co-ordinates received the sensor will scan only the obstacle and generate a map of the obstacle. This will help the vehicle to know the profile of the object in front of it. The system also gives directions to navigate.

2.1 Mechanical Setup

The mechanical setup designed includes the following components:

1. Lidar Lite v3
2. Two servo motors
3. Pan-Tilt mechanism

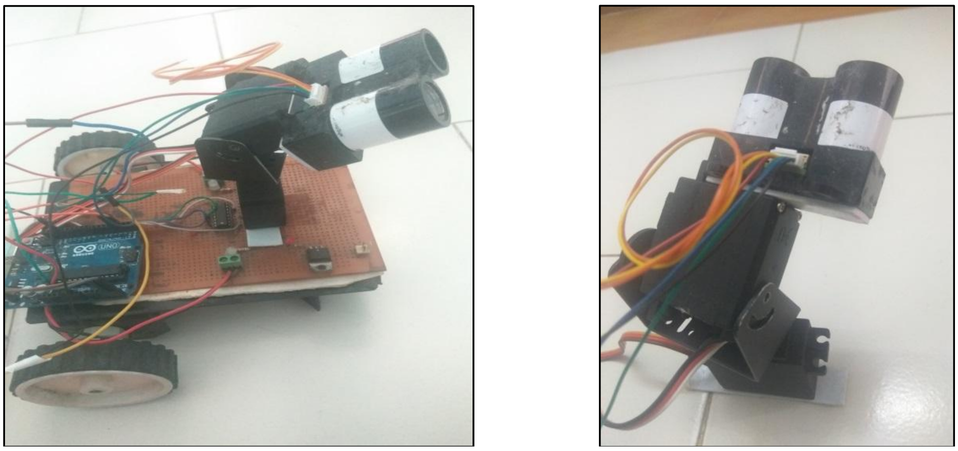
The sensor used (Lidar Lite v3)is a light weight point LIDAR whose technical specifications are as mentioned in Table.1. Time of Flight method is used by the sensor to calculate the distance to obstacle. The formula used is as given in (1).

$$\text{Distance} = (\text{Speed of light} * \text{Time of flight})/2 \quad (1)$$

Table 1. Technical Specifications of LIDAR Lite v3

Parameter	Specification
Max range	40m
Resolution	+/- 1cm
Acquisition time	5-20ms
Current Consumption	135mA
Accuracy <5m	±2.5 cm
Accuracy >5m	±10 cm
Resolution	1cm
Interface	I2C

The servo motors fitted into a pan-tilt mechanism are the most important part of this system. They need to be precisely positioned in order to get accurate point cloud.The potentiometer connected to the rotary shaft inside a servo motor helps to give feedback of the angular position. This feedback is used to calculate the present orientation of the LIDAR. To convert the 1D LIDAR into 3D LIDAR we need to give an extra degree of freedom to the LIDAR. This is achieved by using a pan-tilt mechanism that will sweep the sensor in horizontal and vertical planes. The setup is mounted on a robot chassis as shown in Fig.1.



(a) (b)

Figure 1.(a)Setup mounted on chassis (b) Pan-tilt mechanism with LIDAR

2.2 Point Cloud generation

The ability of a mobile robot to self-navigate requires to have information about its current position[9] and map of surrounding area. The algorithm to convert the sensor data into 3D point cloud is implemented on Arduino UNO and the generated point clouds are visualized using the MATLAB software. The commands to drive the servo motors are also given by Arduino UNO. The Schematic overview of the experimental setup is given in figure 2. The processor, in our case which is Arduino Mega, receives data from the LIDAR Lite and the two motors. The LIDAR gives the distance information in centimeters and the yaw servo gives yaw angle while pitch servo gives pitch angle.

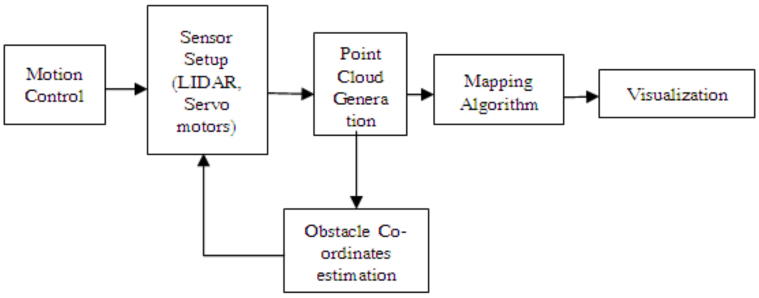


Figure 2. Schematic Overview of System

The processor receives data from the sensor in the form of bytes which contain range information. The sensor communicates with the processor through I2C protocol. At the same time the processor also receives the angular measurement that is the servo motor position. Let the distance be ρ, yaw angle be θ and pitch angle δ.The received information has to be converted into point cloud[10], for which some computation is required. The whole co-ordinate systems are shown in figure 3.These polar co-ordinates need to be converted into Cartesian (*x*,*y*,*z*) co-ordinates.Any point P in (*x*,*y*,*z*) 3D space will be as visualized as in figure 3. The equations to convert polar co-ordinates to Cartesian are given as in (2) (3) (4).

$$x = \rho \sin\theta \cos\delta \quad (2)$$

$$y = \rho \sin\theta \sin\delta \quad (3)$$

$$z = \rho \cos\theta \quad (4)$$

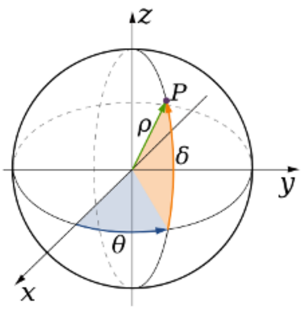


Figure3. Polar to Cartesian conversion

2.3Reducing the Scan time

The quality of the map generated depends upon parameters like visualization technique used, mapping algorithm, speed of robot, etc. In the proposed system it greatly depends on step size of the servo motors. Lower the step size of servo motors,better is the quality of map generated. Lower step size results in lower speed of scanning. This issue is addressed in the proposed system using an approach similar to Raster Scanning. The entire range (horizontal 150° vertical 120°) is scanned using higher step size (high speed) with raster scanning. The technique involves scanning horizontally from left to right (0° to 150°) and coming down by one step and repeat until vertical span is completed. The step size used in this approach is 5°. This takes only 25sec to scan the entire region in front and gives information about presence or absence of obstacle within 1m. The co-ordinates of the obstacle are also derived at the same time. These co-ordinates are used to restrict the scanning range to the obstacle. Now the profile of the object is obtained using smallest step size of motors (0.5°) giving best possible resolution of map. This approach has reduced the scan time from 16min to 6min 25sec.The methodology followed for the above approach is illustrated in figure 4.

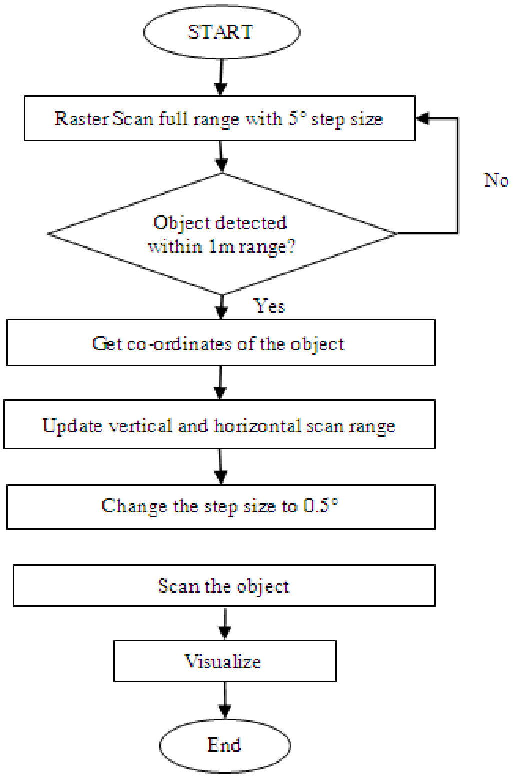


Figure 4.Algorithm for Adaptive Scanning

3 Results and discussion

The mechanical setup described above is mounted on a robot chassis. The processor used to drive motors and generate point cloud isArduino UNO. The map is visualized on PC and point cloud processing and registration is done using MATLAB. The experiment is conducted in an open corridor with objects such as box and dustbin to map. The snippet of 3D point cloud generated using 1D LIDAR and the assembly is as shown in figure5.The point cloud data will logged and further given to MATLAB. First entire scan of the corridor was performed which took 16min. After implementation of the adaptive scanning approach the time considerably reduced to 6min 25sec. To improve the quality of map generated the point cloud data was interpolated. This was done to improve the visualization of the objects mapped by inserting points in between the points generated.

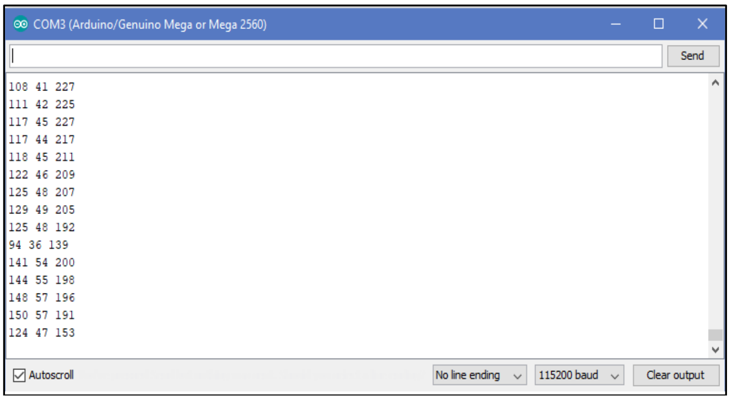


Figure 5. Generated Point Cloud

The camera images and the obstacles and the profiles generated of different objects is as shown in figure 6. The objects are present at a distance of 1m from the sensor. The different planes are colored differently in the generated maps. This makes it easier to identify the object.

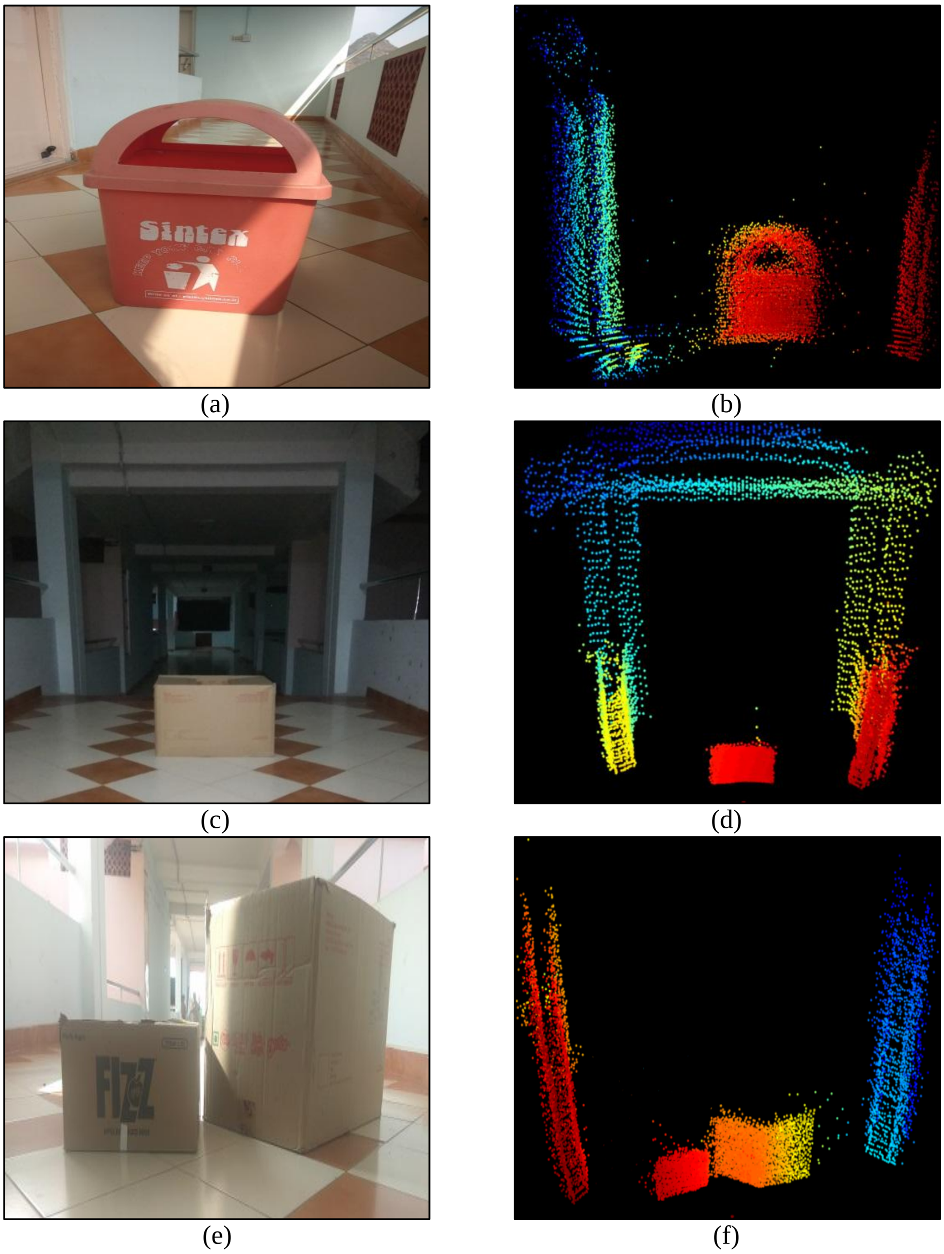


Figure6. Maps of the obstacles generated: (a)(c)(e) Original Camera image (b)(d)(f) Object profile

4 Conclusion

A low cost alternative for the commercially available 3D LIDARS has been implemented and evaluated. The proposed system performs scanning and good results are achieved. The obstacles within the range of 1m are successfully detected followed by creating a profile of the objects. The time required to scan is considerably reduced to more than half by implementation of adaptive scanning algorithm. In the experiment conducted, items other than the obstacles are of least importance. The primary aim is to detect the presence and shape of the object as quickly as possible which was tried and tested on different objects with different shapes, orientations and sizes. This system works well with stationary environment. The project displays great ability for application in self -driving bots like AutomatedGuided Vehicles (AGV's). It can be concluded that the system is capable of 3D object detection and scanning in indoor environment with the use of low cost LIDAR.

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