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Line Integration LiDAR (LILi)

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Abstract

Autonomous navigation is becoming a norm in all kinds of transport system and robotics, and the primary component of such system is the proximity sensors or rangefinders for creating the localized map of the environment they are in to avoid obstacles. The processing and computational power required to perform such an in the current technology is too high to be feasible for every day applications or unmanned aerial vehicles. In this report, we present an affordable low resource consumption 3 dimensional range sensor that provides a comparable performance with commercial grade range sensors which is easy to implement and scalable.

Keywords: Laser; SLAM; Autonomous; Navigation; LiDAR, Computer Vision;

1. Introduction

Robotics in a static environment to be autonomous don't need the sensors to propagate from point A to B or for that matter anywhere in the given field where all the landmarks are pre-plotted and provided for the robots navigational system in advance. The reality is for from the above instance where the robots are meant to explore uncharted territories and create the map of the given surrounding which assists both humans to explore in detail of other bots and vehicles to navigate autonomously. The problem with the above task is that the robot / UAV need to sense its surroundings in an effective way, while there are many range detection sensors available, laser distance sensors are currently the standard sensor in closed as well as open space environments.

LIDARs or Light Detection and Ranging Sensors, could be considered as a superior light-based type of radar. Yet, that belittles the radical effect of rapidly getting itemized separation estimations from a vertical cluster of turning lasers sending and accepting a beam of light more than a million times each second, to frame a complete photo of a vehicle's surroundings at a casing rate that matches feature's 30 times each second. In contrast to camera, which has a plenitude of data, however needs an intensive pattern recognition programming to convey intended information to each one of those pixels. On the other hand LIDAR frameworks convey a strong stream of point-mists that is effortlessly absorbable by a system. These quick shoot precise 3D depictions of each item encompassing the vehicle can happen day or night, no matter what.

The most commonly used LIDAR SICK LMS 200 [1], UAM-02LP-T302 and the Hokuyo UTM-30LX [2] cost more than the robot / UAV designed to use those LIDARs by 10 Folds. The preliminary work on using triangulation has been proposed very early by many innovators and a working prototype was brought out in 2008 by Kurt Konolige and his team members under the title A Low-Cost Laser Distance Sensor.

Although the above technology has been applied widely there has been very less effort that has been put in order to improve this simplistic yet powerful method of measuring depth of space.

2. Methods

A. Design Technology

The science behind LiDAR is truly very basic. Sparkle a little light at a surface and measure the time it takes to return to its source. The point light on a surface we see is the light being reflected and coming back to our retina.

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Fig 1: Typical Time of Flight LIDAR used in high end applications.

Light travels very quickly around 300,000 kilometers for every second 186,000 miles per second or 0.3 meters per 10^{-9}S so turning a light on shows up to be spot on which it is not. The hardware needed to gauge this needs to work amazingly quick. Just with the advancements in advanced processing innovation has this get to be conceivable.

All single-point scanning sensors, such as the SICK and Hokuyo devices, use Time of Flight sensor.

B. Proposed Solution

In this work we present a low power, low-cost that is comparable with standard devices, yet can be designed for fraction of their cost. The Device we are proposing has the following specifications.

1. Uses a Class I / II Laser < 5mw which is safer for the Eye
2. Works with standard indoor lighting conditions, and non-extreme outdoor conditions
3. Provides a 360 degree view of the surrounding area
4. Accuracy range varies from 1mm to 10cm in respect to objects distance from the device
5. Provides distance measurement from 5cm to 3m
6. Point cloud count is virtually infinite
7. Small size the circumference of the device is 10cm
8. Uses OTS (Off the Shelf) components
9. Scalable design in case of accuracy and distance that can be measured
10. Low Cost implementation

C. Triangulation Methodology

LILi is a built upon the idea of triangulation to measure distance. Triangulation is an alternative way of measuring distance: separation to an article is measured by the edge of the reflected light. Figure 1.1 demonstrates the essential geometry of triangulation. A laser creates a little purpose of light, which reflects off an article and onto the picture plane of the camera. A perfect pinhole camera is situated so that the laser bar is parallel to the beam through the focal point of centre to the edge of the picture. This gives a separation estimation from max at one edge of the picture to the separation min at the other edge. A pinhole camera is places such that the laser beam passes through the center of focus to the edge of the image. This gives a distance measurement from infinity (at one end of the image) to the distance qmin (at the other end). From similar triangles, the perpendicular distance to the object is

$$M=\frac{f}{x} \qquad (1)$$

In the below figure 2, **M** refers to the displacement of the actuated pixel from the edge of the sensor. **f** represents the focal length or perpendicular distance of the aperture from the CMOS sensor surface and **x** represents unknown i.e actual distance of the object from the point of consideration in this case the aperture of camera.

The distance along the laser ray depends also on the angle of the laser with respect to the image axis.

$$d=\frac{q}{Sin(\alpha)} \text{ Meters} \qquad (2)$$

From the basic trigonometry we can easily visualize that the distance is not a linear quantity and is dependent on the angle at which the camera and lasers are placed, for the below given arrangement the angle formed between the laser and the camera is α, perpendicular distance between the laser and CMOS camera aperture is **q**, the actual distance of the object from the laser.

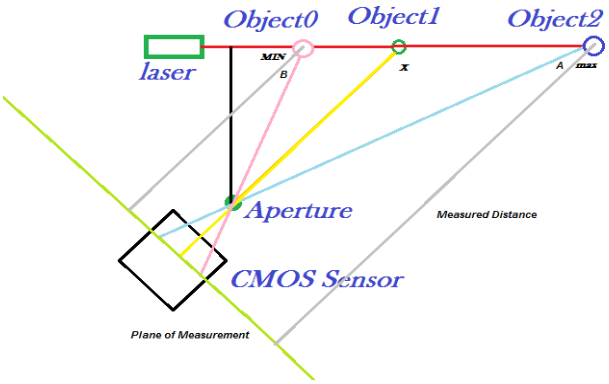

Fig 2: *Graphical image illustrating triangulation method used to localise three objects using a line laser and a CMOS pinhole camera*

These mathematical statements demonstrate the hyperbolic relationship between picture separation and item remove that is a property of triangulation. This nonlinear relationship postures issues for deciding longer separations. Example: if a 1-pixel picture uprooting compares to a 1 cm separation relocation at 1m, then it relates to a 4 cm dislodging at 2 m.

Fig 2-2: LILi captures the data in two dimensions as shown figure 2-2 when compared with one dimension capturing using a dot laser as in Figure2-1

D. Lasers

Lasers are sorted by their wavelength. 600-1000nm lasers are all the more regularly utilized for non-exploratory purposes however, as they can be centered and effectively consumed by the eye, the greatest force must be restricted to make them 'eye-safe'. Lasers with a wavelength of 1550nm are a typical alternative as they are not engaged by the eye but for our experiment to know the proper location of the line falling on the object in question the laser with 550nm is used.

E. Hardware Integration

The following block diagram represents the present hardware integration of the LILi board,

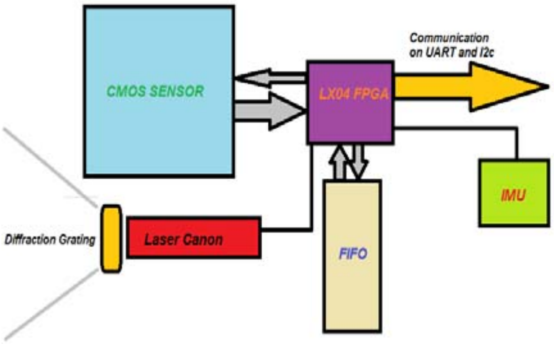

Fig 3: *Bloch diagram illustrating the implementation of the LILi*

The design of the hardware went through many phases, as given below. **Phase 1**: In this phase Logitech webcam was used in the place of CMOS sensor and the image manipulation was done in MATLAB as shown, the laser was operated with a PWM output of the Arduino UNO board as it can be seen from the diagrams. The frame rate of the webcam used was 30FPS at 720p resolution.

Fig 5: *Design of digital camera along with line laser to capture the images*

Phase 2: In this phase the Logitech web camera has been replaced using the arducam ov5642 which is a 5MP RGB Camera, although the camera runs with a maximum rate of 120FPS at 640*480 resolution the Arduino computer interface done through serial cable was unable to handle this bandwidth and since the Arduino UNO and Mega are not powerful enough to handle the image manipulation on the board itself the serial interface was considered as the bottleneck and was discarded from further implementation.

Fig 4: *ArduCam used with Line Laser for LILi phase 2*

Phase 3: The current phase of this project being phase 3 uses the Lattice FPGA and an On-board FIFO of 256Mb to perform image processing on the board and transmit the point cloud / line data only through the UART / I2C Bus.

Fig 5: *Lattice FPGA LX04 with LineLaser for LILi Phase 3*

F. Operation

The LILi operation to generate the distance data from the images involves several steps:

1. Strobing the Laser Canon.
2. Opening the CMOS shutter
3. Perform Rows read operation
4. Close Shutter of the CMOS Sensor
5. Processing the rows to determine the position of laser dot
6. Calculating the distance corresponding to the image centroid
7. Store the distance value as a rows X 1 matrix
8. Format and transmit the distance measured using the UART and I2C protocol.

The device energy requirements are under 2W, since the laser canon is strobed at a very high speed, this also eliminates any artefacts that would otherwise appear. Induction power transfer technology is used to power-up both the Lattice-Flea FPGA-Board and the Laser this effectively removes the usage of slip rings to transfer energy. Since the no of points on the CMOS sensor directly

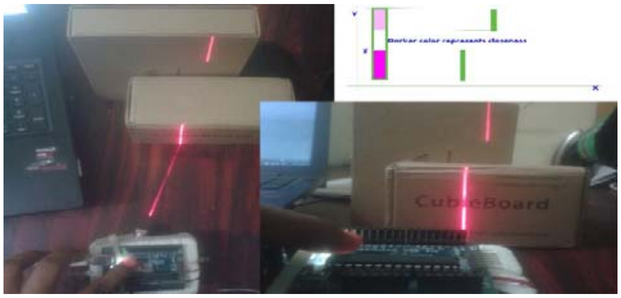

Fig 6: *Image showing qualitative analysis of laser intensity as a function of distance from the camera*

relates to the resolution the LILi is a very scalable platform, also the frame rates of the CMOS sensor directly co relates to the livelihood of making such a sensor real-time when it's rotating on a geared motor.

Fig 7: *Induction charging used to provide portability for the camera and to ease the rotation and orientation of the camera and laser*

3. Results and Discussion

The following table lists out the comparison based on the actual distance of the object under consideration and the pixel being activated by the reflection of the laser in LILi.

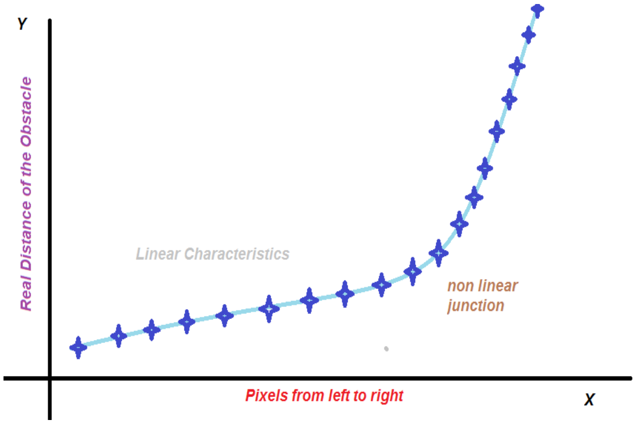

Fig 8: *The X axis represents the pixels and Y axis represents actual distance of the object from the sensor.*

From the table it can be inferred that the mapping of the objects distance to its reflection is not linear but rather it's hyperbolic in nature.

The below table provides a comparison study of all the three LILi Prototypes and their specific highlights.

Table 1: *Comparison study of various LILi implementation*

Platform	Pure Software	Embedded Microcontroller	FPGA Hardware
Processing Speed	Medium	Slow	Quick
Cost of Implementation	Less	Medium	High
Data Manipulation	Floating Point Manipulation	Fixed Point and Floating-point	Fixed Point Only
Transmission Protocol	USB	UART I2C	USB, I2C and UART
Flexibility	Highly Flexible	Moderately Flexible	Very Rigid

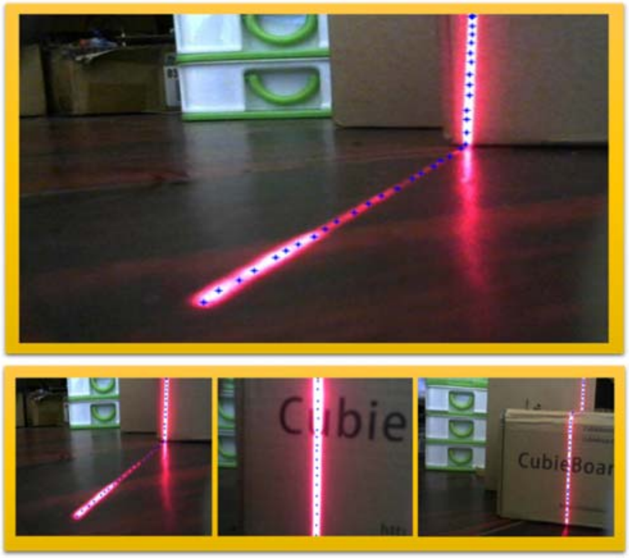

Fig 9: *The image representing the non-linearity of the Lidar.*

The above images show that the displacement on the x axis reduces non linearly as the object under the consideration moves farther and farther which ultimately reduces the resolution and accuracy of the LILi.

Min distance and Range resolution relative to fs. The design criteria is to keep min distance less than 20cm, and range resolution less than 40mm. The vertical line is a sweet spot

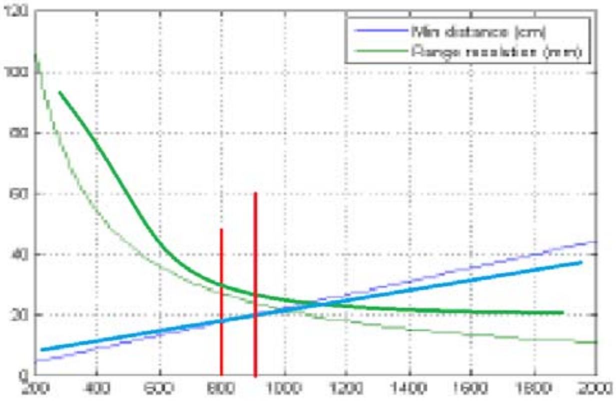

Fig 10-2: *Comparison study of the LILi performance with the available Neato XV 11 Lidar.*

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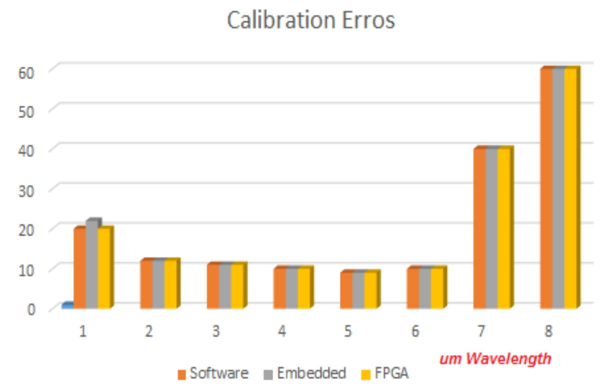

Fig 11: *Calibration Errors comparison between various implementation of LILi*

Since the device uses a CMOS sensor to know the orientation of it, the above graph show that the device requires the obstacle in the sweet spot of the color range around green this ensures proper detection of the light and hence the calibration is less erratic.

4. Conclusion

There are numerous difficulties in transitioning from a proof-of-concept of this device to a consumer product. The conversion of this linear LiDAR to a circular one is a huge task involving lot of calculations to be made. The key empowering agents for the LILi are the high unbending nature of the laser-to-imager interface and the fast sub-pixel confinement of the laser spot, all utilizing standard ease optics and hardware. The Future work includes the integration of IMU sensor to the device to register the angle of rotation and current position of the LiDAR once it starts rotating.

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