Development of a Low-Cost SLAM Radar for Applications in Robotics

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Abstract

The current state of SLAM radar is quite advanced, featuring various methods of data retrieval. One of the methods used is that of video telemetry to locate "common spots" in the surrounding environment which provide positional information during motion. Another method is that of using high-speed high-resolution laser measurement tools which provide a 360° horizontal field of view and a 90° vertical field of view. These systems create vast amounts of point cloud data and are expensive, ranging from £1,000 upwards. These systems are often unsuitable for small competition robots due to these reasons.

The developments discussed in this paper describes various alternative measurement technologies, such as ultrasonic and infra-red and how these can be adapted with the addition of a mechanical drive to provide an almost real-time 360° horizontal field of view and an adjustable vertical field of view.

Keywords: *Mobile Robotics, SLAM, Mapping.*

Introduction

What is SLAM

Simultaneous Localisation And Mapping (SLAM) is a well known problem in robotics research [1]. *"It asks if a mobile robot, put in an unknown location, can incrementally build a consistent map of the environment and simultaneously determine its location within this map"* [2]. The concept of SLAM in mobile robotics, if implemented properly can prove to be a very comprehensive and accurate form of localising a robot in relation to its environment, also providing real time information. A solution to the SLAM problem has been seen as a "holy grail" for the mobile robotics community as it would provide the means to make a robot truly autonomous [1].

Kalman Filters (KF) and Extended Kalman Filters (EKF) are tools that provide an estimation of the current dynamic state vector of a system and are used as a recursive tool to provide parameters from indirect, inaccurate and uncertain observations [3]. In essence the filter corrects the noise associated with inaccurate readings over time, estimates the current state of observed models and allows for theoretical prediction of future dynamics and outputs. The Bayesian estimation is another model which can be used in conjunction to estimate the spatial relationship of objects in comparison to the robot [4]. Once the prototype has achieved a stable iteration the algorithms can then be applied for localisation and mapping.

The concept is for a self-contained, low cost SLAM radar unit which could be used in conjunction with any mobile robot. Currently there is nothing like this on the market. It will consist of a number of distance sensors with a linear sensing range of less than 1.5 m, spinning around 360° and will communicate data in real time.

The sensing tool will translate three numbers to the robot system using one wire. Information given will be:

- The relative angle from horizontal plane (y-axis)

- The relative angle from vertical plane (x-axis)
- The measured distance to the obstacles

These three numbers specify a point in space. Multiple sets of this data can form a 3D point cloud.

Table 1. Existing SLAM systems

SLAM System	Roomba [5]	HOKUO URG-04LX-UG01 [6]	Neato vacuum robot [7]
cost	$200 - 430	$1,576	$399
Sensors used	2 bump switches	laser range finder	Laser triangulation
Sensor range	Contact only	5.6m	over 6m
Angle of sight; X-axis	Minimal	240deg	360deg
Angle of sight; Y-axis	Minimal	minimal	minimal

The Concept

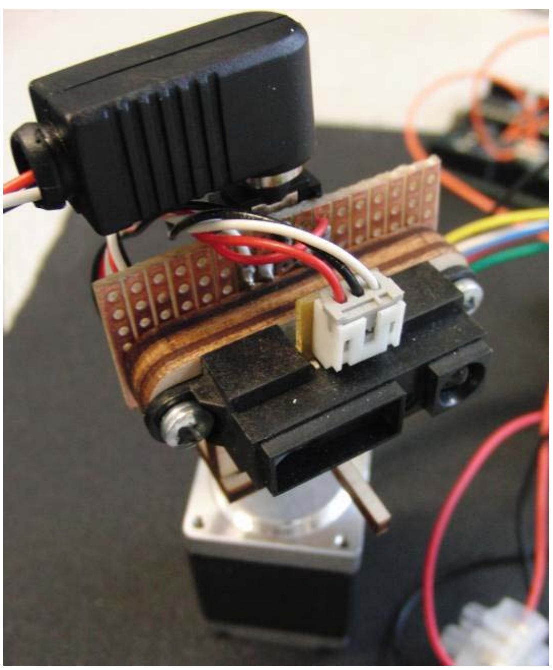

Figure 1. First 360° IR system iteration

Figure 2. Hokuyo Laser Range Finder [6]

The concept will be designed and prototyped completely from scratch using, where possible, existing components which can be purchased and integrated. When the concept is proved, the designs will be published as open source.

Starting point

Laser range-finders provide more accurate range data over a longer detection range but are more expensive, bulkier, and heavier than ultrasonic and infra-red. Ultrasonic sensors use a wide beam angle, this results in greater uncertainty. We will use infra-red sensors as they provide a low cost measurement of linear distance [8].

The first step in the development process was to find the most simple way to map the surrounding environment. A guide featured at www.luckylarry.co.uk presented two effective solutions to provide mapping. The first featured an Ultrasonic sensor and the second featured an infra-red sensor. The IR sensor presented better data due to the smaller beam width. The system was limited to 180° and used a servo motor for positional data. The project also used the programming language 'Processing' to visualize the data received as a dynamic graph (See figure 3).

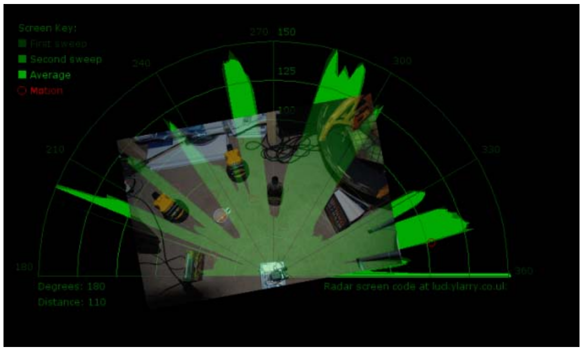

Figure 3. Plotting of measured distances [9]

360° rotation

The following stage was to feature continuous 360° rotation. The servo, as discussed earlier has a maximum angle of 180°. It is possible to adapt any servo to rotate continuously, however position control is lost. Other low cost alternatives include an encoded DC motor or a stepper motor. The stepper motor was chosen as it provides accurate angular positioning as well as ability for full 360° continuous rotation. Shown in figure 1 the stepper motor is introduced to the system.

Connectivity

Connectivity between static parts and rotating parts was now an issue. A 3.5 mm headphone jack connector was used for this as it could be rotated continuously. The connector had three terminals. One terminal carried the analogue sensor reading, the second was power for the sensor (+5V) and the third was ground.

Rotation Calibration

Before use, the stepper motor must always be calibrated so that it starts rotating from the same position every time. This will ensure that the horizontal angular measurements are always accurate. This will be done using an infra-red emitter on the rotating part and an infra-red receiver on the static part. When the system is switched on the stepper motor will rotate slowly until the IR receiver and emitter are aligned accurately. Every angular measurement taken after this will be relative to this starting position.

Accuracy of Results

The default speed for the motor was too slow, it took around ten seconds to retrieve a full set of readings, however if the speed was increased then the accuracy and consistency of results was reduced. The program was altered to stop rotating while taking the IR readings. The data was now gathered several times at each step of rotation then the average reading could be calculated. Following this, the consistency of results increased. There are now two new variables; the number of readings at each stage and the speed of rotation of the motor. As the speed is increased, the accuracy and consistency of results is proportionally lost. A compromise was made between these two variables resulting in the fastest speed possible while still keeping accurate, useful results.

The next stage will be to increase the number of IR sensors in the system, therefore substantially increasing the number of readings that can be achieved at each stage during rotation, firstly by implementing four IR sensors to give four simultaneous readings at each step during 360° rotation.

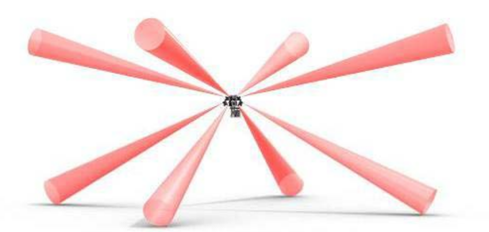

Figure 4. The tilting concept

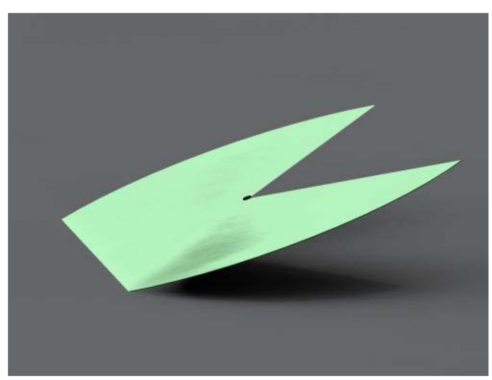

Figure 5. Hokuyo laser sensor, tilted

Pivoting mechanism

Previously, measurements were taken on only the horizontal plane. The Hokuyo laser sensor (See figure 2) measures 250° using a single horizontal plane. It is possible to tilt this system to gain a three dimensional point cloud however it will see up at the back. This will not provide useful data. An image to demonstrate this is shown in figure 5. In order for our concept to create a 3D point cloud, it will be necessary to tilt the IR sensors perpendicular to the direction of rotation by up to 45°. This will allow sight of objects below and above the horizontal plane and give an almost spherical sensing field (See figure 4).

Shown in figure 6, all four sensors are linked to a central servo horn which controls the tilting angle of all sensors simultaneously.

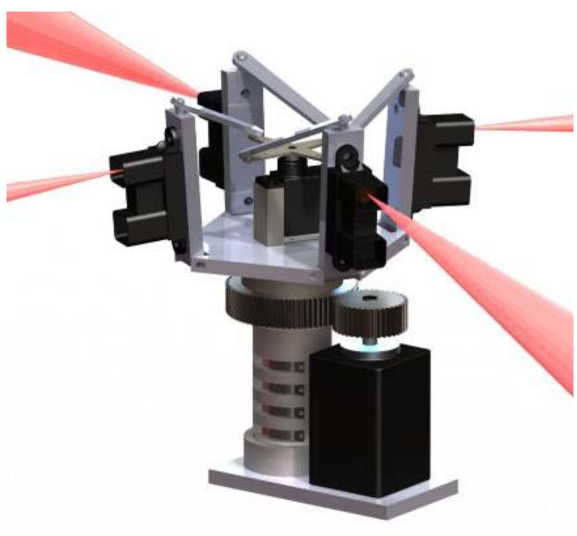

Figure 6. Proposed assembly

Components

For the initial setup the Sharp GP2Y0A02YK IR Sensor is used to provide an effective radius from 20 cm to up to 150 cm. Ultimately because of the design of the hardware, the sensor can be easily substituted by other sensors to adapt the range required. The Microprocessor used is the Arduino Pro Mini 5V. For the pivoting motion a Protech 150 Servo motor is used and for the drive system the Astrosyn MY3002-01 stepper motor is used. Figure 7 shows the layout and connections between components of the system.

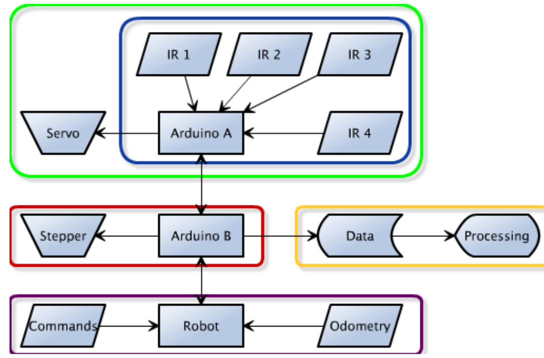

Figure 7. System layout

The Sharp IR sensor uses an infra-red transmitter and a position sensing detector (PSD). The basic procedure is that the emitter emits a very narrow beam through a condenser lens whilst the PSD calculates the incoming angle of return which passes through another lens. Using triangulation the length is measured and the output signal is measured through the rate of the voltage.

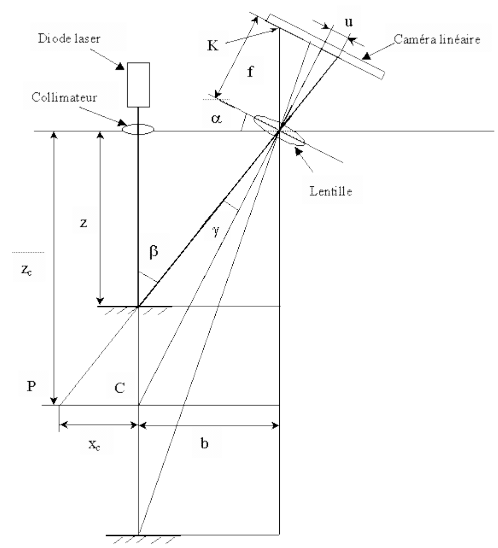

Figure 8. Triangulation methods for distance measurement [10]

Rotary Connector

The rotary connector (See figure 6) presents the key mechanism for the hardware solution to function. The concept for this connector is the same as the 3.5 mm jack, however with the introduction of a servo to operate the tilting mechanism and three additional sensors, three connecting terminals is insufficient. A small microprocessor will be placed on the rotating part and collate all information and communicate with the static part using two way serial communications. The rotary connector provides four connections i.e. GND, +5V, Serial in and Serial out. The mechanism is geared to the stepper motor. Two bearings provide stability and low friction rotation.

Figure 7. Rotating connector mechanism

Drive System

The drive system consists of a geared stepper motor which drives the rotary connection mechanism. The advantage is an accurate stepping sequence which can be geared to reduce the stepping angle which creates a higher resolution.

Microprocessing

Microprocessing presents a cost and time effective solution to interface with all components. Two Arduino Pro Mini 5V boards communicate via the rotary connector mechanism. Arduino is an Open Source platform which is easily available to the hobbyist community and provides an entry point to SLAM application processing. The "Arduino A" sitting on the rotating section provides control of the servo, four IR sensors, IR calibration LED and sends and receives data via serial communication. "Arduino B" controls the stepper motor and relays the data to the robot control unit.

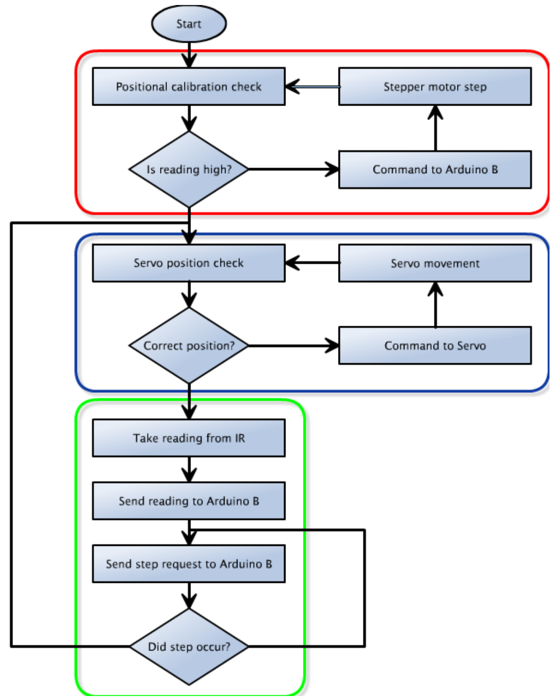

Figure 8. Arduino A flow chart

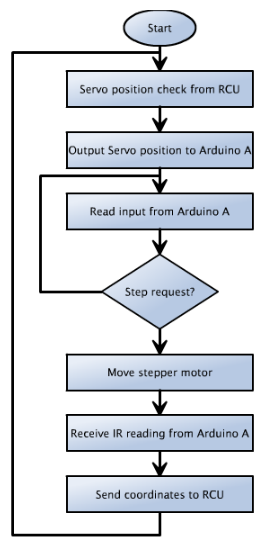

Figure 9. Arduino B flowchart

Code process

Figure 10 and figure 11 both illustrate the process for procedure described below:

- The first step in the procedure is to calibrate the servo for the desired angle of operation.
- The second step is the calibration between course heading and initial positional reading.
- The next segment compiles data for each degree (X) in the horizontal plane (Y) in the

vertical plane and in the length (Z). Before the next degree point is reached Arduino (A) takes several readings of (Z) and then averages them to provide more accurate readings.

- Arduino (A) sends to Arduino (B) the value of Y as well as the command for next stepping motion.
- Arduino (B) stores the values and provides the data to the robot control unit.
- After the desired steps to complete 360° (i.e. 360; 720; etc.) are completed the measurement for (X) starts at zero again.
- Proposed is a calibration check after x amount of rotations for reliability purposes.

Conclusion

Currently, the only completed testing was explained in section "Starting Point". The majority of this paper is in the form of a proposal for future testing.

The prototype provides the opportunity for people new to robotics to build and experience 360 degree radar systems at low cost with the advantage of the robot using comprehensive obstacle avoidance.

Integration

Following the introduction of more complex code, obstacles can be classified through measurements in the x and y axis also integrating the pivoting of the sensor. This can be used to measure the width of the gap between objects and would also allow for the exploration of tunnels or cluttered surroundings.

Future Testing

Some questions need to be answered such as:

- Number of IR sensors needed based on best performance and low cost
- The optimal speed of motor (RPM) based on accuracy and speed
- Will lighting conditions affect readings?
- Will different surfaces affect readings?
- Will the system deliver information quickly enough for a mobile robot to use?

A test platform must be made in order to measure:

- Motor speed (RPM)
- Error in results (%)
- Consistency in results (%)
- Time taken to complete a 2D scan (s)
- Time taken to complete a 3D scan (s)
- Current draw (A)

After the test results have been analysed, the test platform can be configured for the optimal performance. The feasibility of practical use of the system in collaboration with a mobile robot will be considered. A jump to a low-cost laser range finder is another option to increase the accuracy and speed of the system.

Finally, miniaturisation of the components and the reduction of power requirements will greatly improve the efficiency of the Radar.

References

[1] T. Bailey, H. Durrant-Whyte (2006). *Simultaneous localization and mapping: part I* IEEE Robotics & Automation Magazine, 13(2), pp. 99 - 110.

[2] J, Callmer, K. Granstöm, J. Nieto, F. Ramos (2008). *Tree of Words for Visual Loop Closure Detection in Urban SLAM, Australasian Conference on Robotics and Automation 2008,* Canberra, Australia

[3] S. Huang (2010). *Understanding Extended Kalman Filter*. University of Technology Sydney.

[4] S. Roumeliotis, G. Bekey (2000). "Bayesian estimation and Kalman filtering: A unified framework for mobile robot localization," *in proceedings of the Conference on Robotics and Automation, ICRA'00 IEEE International.*

[5] B, Tribelhorn et al. (2006). *Roomba and Mac OS X: Cross-platform Vision and Robotics for AI, American Association for Artificial Intelligence (AAAI)*

[6] Active Robots - *HOKUYO URG-04LX-UG01 Scanning Laser Range Finder* - UK. Available: http://www.active-robots.com/products/sensors/urg-04lx-ug01.shtml [Last accessed 30/10/2010, 2010].

[7] K. Konolige, J. Augenbraun, N. Donaldson, C. Fiebig, P. Shah (2008). "A Low-Cost Laser Distance Sensor," *in proceedings of IEEE International Conference on Robotics and Automation.* Pasadena, CA, USA, pp. 3002 – 3008.

[8] Hyun seung Choi, Woong keun Hyun (2008). "A low cost map building sensor system for mobile robot," *in proceedings of The 6th IEEE International Conference on Industrial Informatics, Daejeon, South Korea..* pp. 448 - 452.

[9] Lucky larry Visual illustration http://luckylarry.co.uk/wp-content/uploads/2009/11/Sharp-IR-radar.png [Last accessed 09/11/2010].

[10] Triangulation visualization http://diwww.epfl.ch/lami/expo/zufferey.html [Last accessed 09/11/2010].