POINT FEATURES EXTRACTION: TOWARDS SLAM FOR AN AUTONOMOUS UNDERWATER VEHICLE

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ABSTRACT

Simultaneous Localisation and Mapping (SLAM) is a process by which a mobile robot maps the environment and concurrently localises itself within the map. Feature extraction is a technique by which sensor data is processed to obtain well defined entities (features) which are recognisable and can be repeatedly detected. These features are then used to aid navigation. In this paper, Mechanically Scanned Imaging Sonar (MSIS) is used to perform scans of the environment. The information returned is then used to detect point features from data collected in a swimming pool. Artificial landmarks were introduced into the environment to obtain identifiable and stable features. This work is part of our efforts to develop a SLAM system to be utilised in an Autonomous Underwater Vehicle (AUV).

Keywords: SLAM, Point Features, Imaging Sonar, Feature Extraction.

1 INTRODUCTION

Feature extraction is a process by which sensor data is processed to obtain well defined entities (features) which are recognisable and can be repeatedly detected. The extraction of reliable features is a key issue for autonomous feature based navigation systems and Simultaneous Localisation and Mapping (SLAM) [14] and [15]. The extracted features are used to aid navigation. Underwater navigation is especially challenging because of the limited sensorial modes. Acoustic devices are the most common choice in underwater domains while the use of cameras and laser scanners is limited to applications where the vehicle operates near the surface, in clear waters or very near the sea floor [3].

Most of the previous work using MSIS has focused on the use of point features assuming the robot remains static or moves sufficiently slowly [5], [6] and [7]. Line extraction algorithm to take advantage of structured elements typically present in common underwater scenarios like drilling platforms, harbours, channels, and dams has been proposed [3], [10] and [11]. Algorithms for blob extraction from acoustic data have also been used [4], [9] and [13]. A much more general idea of a feature (blob) is introduced in [12], where data from sonar and camera is fused together so that the two sensors can complement each other.

This paper describes the extraction of point features from scans taken in a swimming pool using a MSIS. The data was first segmented by selecting bins with the highest intensity return value over a threshold along each beam. This would filter out the noise without loss of significant information and reduce the computational cost of processing the data. The

vehicle is equipped with a Mechanically Scanned Imaging Sonar (Micron DST Sonar) which is able to perform user selectable scan sectors up 360 degrees [8].

The paper is structured as follows: section 2 explains the imaging process and the principles of operation of the MSIS, section 3 & 4 presents the interpretation of sonar images and sonar data respectively, section 5 describes the feature characteristics sought, section 6 describes the feature extraction procedure, section 7 outlines the experimental setup, conclusions and future works are found in section 8.

2 UNDERSTANDING MECHANICALLY SCANNED IMAGING SONARS

This section gives a brief introduction on the operational principles of Mechanically Scanned Imaging Sonars (MSIS) by explaining the basics behind the acquisition of acoustic images as well as providing tools to understand and interpret the information they contain. Detailed information on sonar theory can be found in [1] and [3].

2.1 Imaging

In Imaging a fan-shaped sonar beam scans a given area, by either rotating or moving in a straight line, through a series of small steps. The beam's movement through the water generates points that form a sonar image of the given area [1]. Figure 1 below shows such an image taken in a water tank.

2.2 Principles of operation

An MSIS performs a scan in a horizontal 2D plane by rotating a mechanically actuated transducer head at pre-set angular increments. For each one of the resulting angular positions, an acoustic fan beam with a narrow horizontal beam width and a wide vertical one is produced. When this emitted acoustic signal travels through the water and encounter an object in its path, part of the energy transmitted as a mechanical wave returns to the transducer. Using the time of flight of the returning wave and assuming a known value for the speed of sound in water, the range at which the signal originated can be determined. Similarly, if the signal returning to the transducer head is analysed for a period of time, a series of echo amplitude vs. range measurements is produced. Each of these measurements is referred to individually as a bin, while the set of bins obtained from a single emitted wave is called a beam. So, when a transducer head oriented in a particular direction emits a pulse, a beam is produced. This beam is composed of a set of bins, each one representing the echo returning from a specific place along the transducer axis [3].

3 INTERPRETATION OF SONAR IMAGES

In many cases the sonar image of a target will closely resemble an optical image of the object. In other cases the sonar image may be difficult to interpret and quite unlike the expected optical image. A sonar image will always have less resolution than an optical image, due to the nature of the ultrasonic signals used to generate it [1]. Figure 1 below shows an image of a scan taken in a water tank. Darker areas depict no echo return and lighter areas shows high echo intensity returns from objects. The water tank walls are shown by the linear lighter sections.
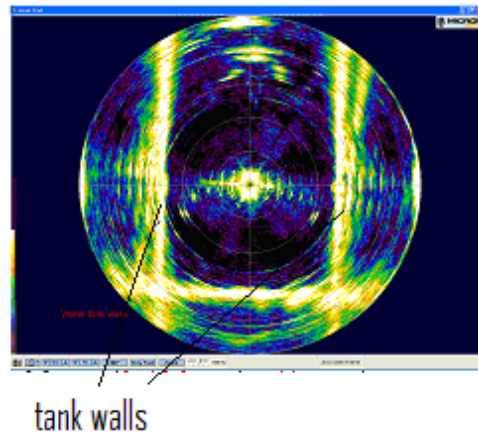
Figure 1: Sonar Image from a water tank

Generally, rough objects reflect sound well in many directions and are therefore good sonar targets. Smooth angular surfaces may give a very strong reflection in one particular direction, but almost none at all in other directions. As with normal vision, it is often useful to scan targets from different positions, to help identify them. A target which is unrecognizable from one direction may be quite easy to identify from another. The relative elevations of the targets are not known, only the range from the transducer. Therefore two targets, which are displayed in the same location in the image, may be at different elevations. A target at the bottom and a target floating on the surface will be displayed in the same place. The height of targets above the bottom can be inferred by analysing the shadows [1].

4 INTERPRETATION OF RAW SONAR DATA

This section explains how the Micron DST Sonar onboard the vehicle is used to detect landmarks within the swimming pool. The sonar produces a 'ping' consisting of a series of N_s echo amplitude bins with 8 bit resolution. The sonar is configurable to sense objects from 2m up to a maximum range, R_s. The nth echo amplitude bin is mapped to a discrete distance r_n from the transducer head according to:

$$r_n = n\delta_r \qquad (1)$$

δ_r is the distance between samples and it is given by:

$$\delta_r = R_s / N_s \qquad (2)$$

This echo amplitude/distance information is used to detect landmarks and obstacles within the environment.
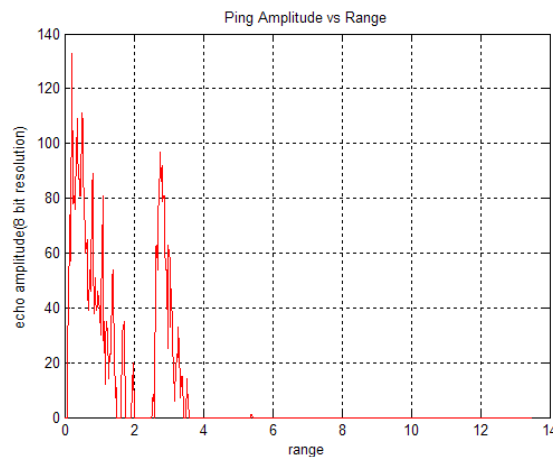
Figure 2: Echo amplitude for a ping in a swimming pool

Figure 2 above shows echo amplitude within a swimming pool. The large amplitude return at low range results from the sensor self noise. Large amplitude returns are ignored if they are below 2 meters from the sonar. The peak at a range of about 3m corresponds to a reflection from the swimming pool wall.

5 CHARACTERISTICS OF POINT FEATURES

The development of autonomous map based navigation relies on the ability to extract appropriate and reliable features with which to build maps. Point features are identified from the sonar scans returned by the imaging sonar and are used to build up a map of the environment. The following characteristics are desirable for point features:

Spatial Distinctiveness: To reduce the possibility of features becoming occluded or indistinguishable at different viewing angles, the navigation features should not be close to other strong sonar reflectors.

Spatial Compactness: The feature should be observed over a narrow bearing range when observed with a range bearing sonar for it to be small enough to approximate to a point.

6 POINT FEATURE EXTRACTION

This section describes the processing of raw sonar data. Sections 6.1 and 6.2 describe the segmentation process and aspects of the algorithm used to extract features respectively.

6.1 Data Segmentation

Objects in the environment appear as high echo amplitude returns. Only part of the information stored in the scan-line vector is useful for feature extraction. Hence a segmentation process can be carried out to get the more significant information from the scan; this would also reduce the computational cost of processing the data as less data has to be processed. This process is complicated by such issues as multiple and / or specular reflections in the pool but less so in a natural environment [5], [6] and [7].

(a) Threshold

The measurements with an intensity value lower than 80% of the typical maximum value are discarded. Only the bins with values above this threshold are selected. This filters out background noise and receiver self noise without loss of significant information.

(b) Highest Intensity Return Selection

The bin with a maximum value over a threshold along each scan line is selected. This corresponds to returns from objects in the environment.

6.2 Feature Extraction Procedure

Following Highest Intensity Return Selection, the first task in extracting reliable features is to identify a Highest Intensity Returns (HIRs) along scan line. HIR is considered to be a bin with a maximum value over a threshold. Next, ranges corresponding to HIR are determined according to equation 1 and 2 above, and accumulated into a buffer (Range Buffer, R_i) until a required number has been stored. These ranges correspond to ranges to objects in the environment. The bearing information corresponding to HIR scan line and the current vehicle pose is also stored. The Range Buffer is then differentiated to form a new buffer (Difference Buffer, D_i). The ith element of the Difference Buffer D_i is given as follows:

$$D_i = R_{i+1} - R_i \qquad (3)$$

Point features appear as narrow (spatially compact) and steep edged (spatially distinct in range) clusters in the Difference Buffer. Such clusters are detected using the Difference Buffer then gated to ensure that they are not too wide as a result of large non point like reflectors (swimming pool walls) or too narrow as a result of spurious pings. Qualifying clusters are validated by applying a simple clustering algorithm to ensure that only approximately spatially compact clusters are outputted as point features. The range and bearing to the feature is taken to be the average range and average bearing of the validated cluster [2], [5], [6] and [7]. This approximation is reasonable since the cluster produced by the target is required to be small. The position of the ith target is then estimated according to:

$$x_{f,i} = \begin{bmatrix} x_r + r * \cos(\theta + \psi_r) \\ y_r + r * \cos(\theta + \psi_r) \end{bmatrix} = \begin{bmatrix} x_f \\ y_f \end{bmatrix} \qquad (4)$$

x_r, y_r, ψ_r is the current pose of the vehicle, r, θ is the range and bearing to the ith target respectively.

7 EXPERIMENTAL SETUP

This section gives details about the experiment setup. Section 7.1 describes the swimming pool environment in which the experiment was carried out. Sections 7.2, 7.3, 7.4, 7.5, 7.6

and 7.7 describe the Sonar Targets, Laser Scanner, Robotic Platform, Underwater Sonar, Trilateration System and the Electronic Compass respectively used during the test.

7.1 Swimming Pool

The tests were performed in a 15m by 15m, and 5m deep public swimming pool located in Pretoria-Hatfield area. Figure 3 below shows a section of the swimming pool where the data was collected.
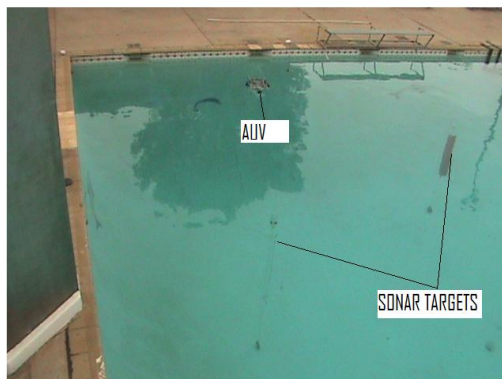

Figure 3: Swimming pool where data was collected

7.2 Artificial Landmarks

In order to develop and test the feature extraction algorithm, two sonar targets were placed in the swimming pool to obtain identifiable and stable features. The sonar targets are constructed from Perspex sheets such that they are visible from all angles of incidence. They are anchored to the swimming pool floor by a weight and a bottle buoy holds them in a vertical mode. The targets are assumed to have different widths. Figure 4 below shows one such a sonar target used for this purpose.
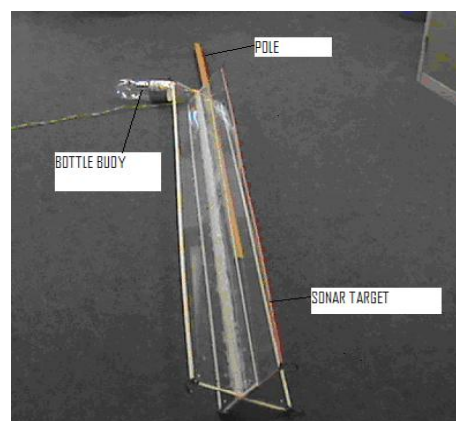

Figure 4: Sonar Target

7.3 Laser Scanner

To get ground truth about the position sonar targets, a pole is mounted on top of each target erecting outside the water surface. A laser scanner (Figure 5) was then used to determine their absolute positions. The laser scanner used is a SICK LM200 laser

rangefinder, maximum range setting of 150m at a resolution of 7.5mm, and an angular resolution: 100 degree scan: 0.25/0.5/1 degrees, 180 degrees scan: 0.5/1 degrees.
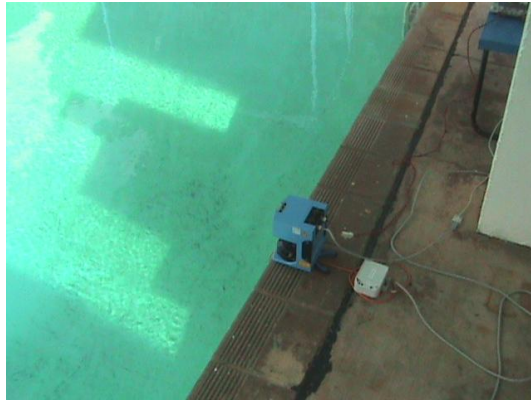

Figure 5: SICK LM200 Laser Range Finder

7.4 Robotic Platform

The experimental platform used for the work reported in this paper is a small submersible robotic vehicle designed and built at CSIR-MSM (see Figure 6 below). The vehicle is equipped with underwater sonar described in section 7.5 below.

Figure 6: AUV developed at the CSIR-MSM

7.5 Underwater Sonar

Sonar is the primary sensor of interest for this work. A small, cheap Mechanically Scanned Imaging Sonar (Micron DST Sonar) by Tritech International is mounted underneath the vehicle and is used to scan the environment in which the vehicle is operating. It is able to perform user selectable scan sectors up to 360 degrees continuous using a fan beam with a variable step angle at ± 1.5 degrees; it has an inverted mode sonar operation. Its range settings are 2m to 75m at ± 7.5mm, an operating frequency of 650 kHz to 750 kHz and a depth rating of 750m. It has a vertical beam-width of 35 degrees and a horizontal beam-width of 3 degrees. The sonar uses a digital CHIRP system. The sonar receiver accepts signals in the region of 0 to 80 decibels.

7.6 Acoustic Transducers for Trilateration System

A trilateration system was used to estimate the position of the vehicle. It uses four sonar transducers, three to transmit and one to receive. The system has a maximum 2D position

error of 0.21m. This was verified by the use of a laser range finder tracking the X and Y position of a vertical pole attached to the top of the vehicle. These positions were then compared to the Trilateration System [16].

7.7 Magnetometer (Electronic Compass)

An electronic compass was used to estimate the heading of the vehicle. The device used is HMC6343 from Honeywell [16].

8   RESULTS

This section presents the results of the experiment carried out at a public swimming pool mentioned in section 7.1 above. The experiment was carried out using the sonar described in section 7.5 above. Its operating range was set to 13.5m at a step angle of 0.9 degrees, and 360 degrees scan sectors were taken. The vehicle was submerged to a depth of 1m. In this experiment two sonar targets described in section 7.2 above were placed in the pool. The vehicle was assumed to be static during scanning process. The vehicle position was estimated using the trilateration system described in section 7.6 and the vehicle heading was estimated using the electronic compass described in section 7.7. Figure 7 below shows the raw data scan in Cartesian coordinates. The scan data was colour coded to distinguish between strong and weak sonar returns. The bluish sections indicate stronger intensity returns while the weak returns are depicted in black. A distance of 2m is ignored from the sonar. The actual pool perimeter wall is shown by the green line. The absolute target position is shown by the red cross (+). As can be seen from the scan, the pool walls cause a considerable amount of additional sonar noise as well as multiple reflections that appear behind the walls [5], [6] and [7].
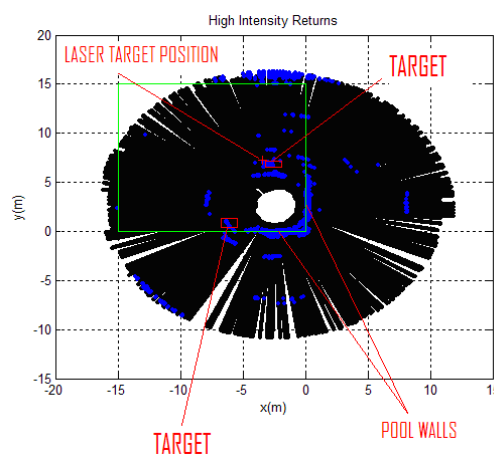

Figure 7: Raw Data Scan

Figure 8 below illustrates the results after applying the (80% of maximum value) threshold. This filters out noise without loss of significant information.
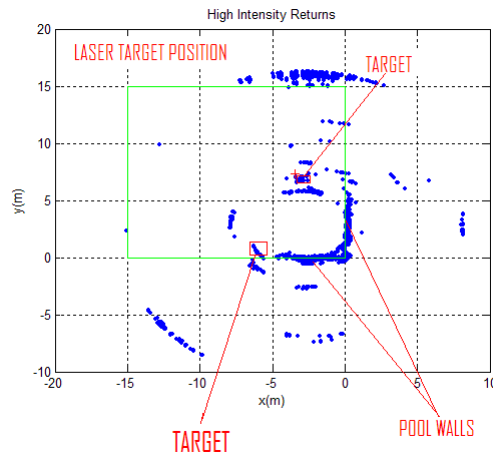
Figure 8: Thresholded Data

Figure 9 below shows the resulting image when bins with a maximum value above a threshold are selected along each scan line. Sonar targets returns are now distinguishable from other returns in the scan.
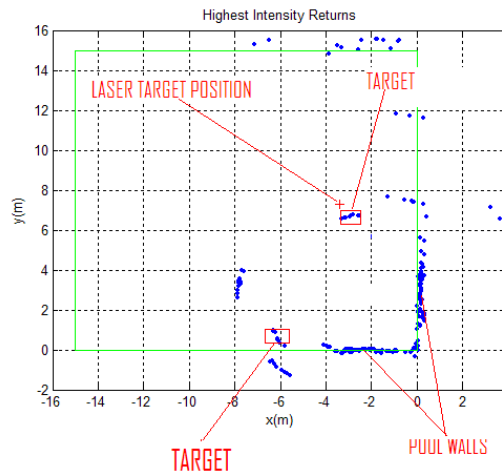

Figure 9: Highest Intensity Return Selection

Figure 10 below shows the extracted features. Potential features are shown in red. Features that are validated are shown by the green star (*), these corresponds to the sonar targets introduced into the swimming pool. For the target with ground truth available, the combined position (x, y) error was found to be 0.45m. This is a reasonable error if one considers both the uncertainty in the sonar sensor and the vehicle position.
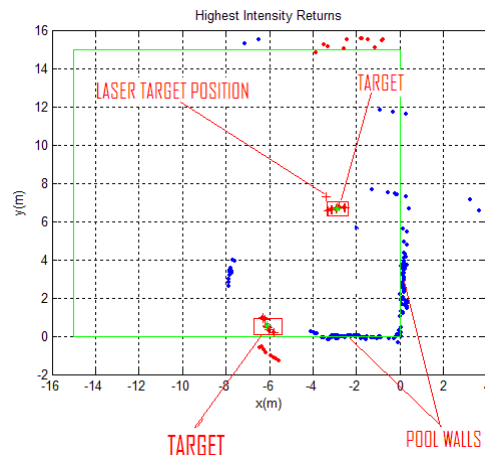
Figure 10: Features extracted

9 CONCLUSIONS AND FUTURE WORK

In this paper point features are extracted from scans taken in a swimming using a MSIS. Artificial landmarks were introduced into the environment obtain identifiable and stable features. The data was first segmented by selecting bins with the highest intensity value above a threshold from each scan-line. The algorithm has been tested on several data sets collected from the swimming pool and it proved useful at least for the scans collected.

Future work will focus on incorporating the algorithm into SLAM system and towards real time implementation. The algorithm will also be modified to extract more complex underwater natural features such as coral reefs and natural variations of the sea floor. This will allow the vehicle to be deployed in a wider range of environments without the need to introduce artificial beacons.

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