

**THE EFFECT OF ANOMALY DETECTION ACCURACY IN VARYING
THE ANGULAR RESOLUTION OF SONAR USING REPETITIVE
OBSERVATION STRATEGY**

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The Effect of Anomaly Detection Accuracy in Varying the Angular Resolution of Sonar Using Repetitive Observation Strategy

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Abstract—This paper presents the feasibility study of implementing Repetitive Observation Strategy (ROS) using a sonar sensor array. ROS is a method that collects observation data taken from different observer positions for anomaly detection purposes. This strategy had never been implemented using sonar sensor. The study is conducted using simulation in MATLAB. The simulation is run by varying the angular resolution of the sonar sensor array which covered 180 degrees. The performance of anomaly detection is analyzed using Receiver Operating Characteristic (ROC) curve. Result shows that the performance of anomaly detection decrease as the angular resolution of sensor increases.

Keywords- Repetitive Observation Strategy (ROS), sonar array, anomaly detection, simulation.

I. INTRODUCTION

Nowadays, the importance of surveillance and inspection systems increased due to the occurrence of unwanted situations such as natural disasters, radiation incidents and also piracy crimes [1]. As example, mobile robots are used as a part of surveillance system for searching, rescuing and monitoring task during the Japan's tsunami incident in March 2011 [2]. These robots were trained to alert with any anomaly events in an environment that are inaccessible or dangerous for human. The most importance device on the system is sensor, which provides physical information for the robot to understand its environment. Most of the mobile robot applications using directional information type sensor such as laser range finder, sonar and infrared, especially for its navigation.

For a long time, sonar sensors known as an economical solution for a mobile robot for navigation, mapping and localization because its provide distance measurement at low cost. It is also relatively easy to control and detectable with most objects, solids and liquids. In spite of it, there are several comments from researchers [3] that mention its poor angular resolution because of its cone beam pattern. However, depends on applications, the capability of sonar operates whether in dark or bright condition make its more useful in a surveillance system. Furthermore, the capability

of sonar had been proven by animals such as bats to detect, localize and hunting in bright and complete darkness [4].

Motivated by this capability, sonar sensor is chosen to be implemented on Repetitive Observation Strategy (ROS) which initially used laser range finder by it researchers [5] during its introduction. ROS is a method that collects observation data, which are capture from different sensor positions repeatedly at different time and location. The 270 degree laser scans area is divided into 8 regions which each region consists of 85 laser scan point. The distance measurement in each region is the average of laser readings in each sector. This information is then used as inputs on Regional Habituable Self Organizing Map (RHSOM) which finds scan area with the highest dissimilarity. The RHSOM details can be found in [6].

This paper studies the feasibility of ROS using a sonar sensor array. Sonar sensor has the same operating principle as laser range finder. However the sensitivity of sonar sensor is not uniform and depends on the reflection angle of sound within its cone beam pattern [7]. Reading measurement other than 90 degrees reflection can be anywhere within its beam range. Different method and technique to model sonar sensor was done by several researchers. Elfes [8] modelled sonar sensor beam using probability profiles to provide occupancy information of sonar beam. Fonseca et al [9] used principle of Polaroid sonar range finder while Kuc and Seigel [10] used both principles of acoustics and Polaroid Range Finder. Harris and Recce [11] analyze gained data with Polaroid sonar to obtained average and deviation of reading for rough and smooth surface. In this paper, sonar sensor measurement is modelled by assuming that measurement is taken directly to the obstacle straight from its beam centerline.

The objective of the study is to find optimum possible angular resolution of a sonar sensor array within 180 degrees covered area by considering the limits of 'crosstalk' angle between nearest sensors. The study is believed to implement other fewer expensive directional information sensor and validate its feasibility on ROS. The contribution of this study is to implementing ROS using a sonar sensor

array on novelty detection where a mobile robot used as a platform.

II. REPETITIVE OBSERVATION STRATEGY

Repetitive Observation Strategy (ROS) is a method that collects observation data that taken many times from a different sensor pose. This strategy was utilized a mobile robot ability by carrying sensors to different positions hence enable it observes in different sites. The reason of repeating the observation is to provide more information about the anomaly and thus increase the accuracy of estimation position.

The strategy was implemented on Pioneer 3 mobile robot with on board Hokuyo URG 400 laser range finder for data collection. The 270 degree of laser scans area is divided into 8 sectors which each sector contained 85 laser scan points. Eight distance measurements are produced by averaging the distance measurement from each sector and become the directional information for the robot.

The robot was first trained with a normal environment using wall following behaviour. During the inspection, the current sensor measurements are compared with learning sensor measurements. By using RHSOM, the robot finds the highest dissimilarity of the scan areas to estimate the anomaly event. Anomaly can be a missing object or appearance of a new object.

The estimated anomaly points are then clustered into groups according to their distance from each other. The clustering method used on-line clustering approach and based on Euclidean distance method. Error ellipse is then used for represent the clustering groups created. Based on center of the ellipse, the position of the anomaly event was estimated.

The experiments were repeated several times by changing the size of the cluster and the sensitivity of the RHSOM network. By comparing a RHSOM network with and without ROS, the performance of the ROS was depicted by using ROC curve. The results show that, the higher the sensitivity, the higher true positive rate was achieved.

III. METHOD

A. System Overview

The system can be divided into two sections; mobile robot navigation system and novelty detection system. Sonar sensor used as mobile robot's perception for navigation and data mining. The 'brain' of the robot is PIC microcontroller which processes collected data from sensor the array and also for robot navigation. Data processing composed of data mining, clustering and estimating anomaly position. The robot is used wall following algorithm on its navigation because it is the simplest way to do inspection in a surveillance system. Fig. 1 shows the overall system on this study.

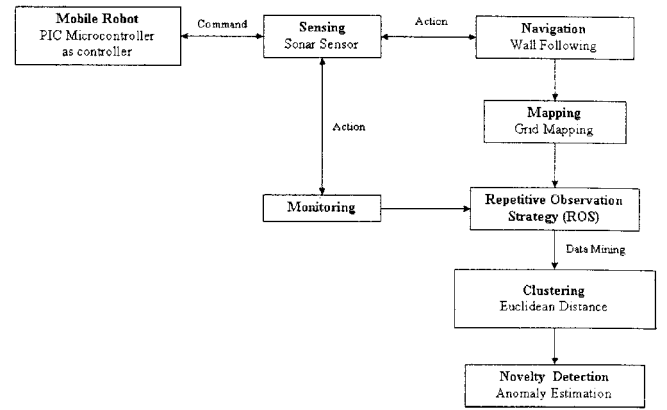


Figure 1: Overall system overview.

B. Simulation Modelling

Mobile robots used as a platform in novelty detection gives some advantages on a surveillance system. The system will overcome the limitation of using static sensor such as a sonar sensor. With on board sonar sensor, the novelty detection task can be done continuously along the route in an environment. The challenge of using mobile robot is that the performance of novelty detection is affected by robot navigation error which causes by odometry error. In this simulation, the odometry error and sensor measurement error is modelled based on Gaussian error model. Depends on the value of measurement, the error is higher when the measurement is high. For sensor if there is no detection, the sensor will not give any readings. Using these assumptions, the sensor measurement error is modelled for by using (1),

$$Error, \varepsilon_i = \begin{cases} \pm D_i \times \% error & \text{if true reading} > 0 \\ 0 & \text{if true reading} = 0 \end{cases} \quad (1)$$

where D_i is the true current sensor distance measurement while the percentage of error is the variance of error and depends on the distance of measurement. Thus, the sensor measurement equation for each sensor in an array is shown in (2),

$$d_i = D_i + \varepsilon_i \quad (2)$$

where D_i is the sensor distance measurement for each sensor and i is the sequence of sonar sensor. The other assumption for modeling sensor measurement is that the measurement is taken directly to the obstacle straight from its beam centerline.

The total number of sonar sensor in the array depends on the maximum viewing angle of the sonar beam. The typical angle is around ~ 20 degrees [3]. This step is taken to prevent sonar from detecting an echo which produced by the nearest sonar sensor. On this study, the covered angle of the array is 180 degrees, thus the maximum number that can be

occupied by the sonar sensor is 10. The number of sonar sensor sets the angular resolution and can be calculated using (3),

$$\alpha = \frac{a}{n-1}, \quad n = 3, 4, \dots, 10 \quad (3)$$

where α is the angular resolution, a is covered angle of the sonar array and n is the total number of sonar sensor.

During the inspection, current sensor measurement which deviates from normal measurement will be highlighted as an anomaly. The highlighted are relying whether on the appearance of new object, missing object or cause by sensor error measurement. The anomaly points are then clustered into unknown number of groups based on their distance between each other. Further analysis of the clustered data continued to the estimation of anomaly position.

C. Data Analysis and Anomaly Position Estimation

Clustering is an unsupervised classification process which separate unlabelled data set into unknown number of groups based on their similarity [12]. On this project, the similarity between the anomaly points is measured based on their quantitative feature. There are several clustering methods based on quantitative feature such as Euclidean distance, Mahalanobis distance, Minkowski distance, Point Symmetry distance and others. The most commonly used method is Euclidean distance [12] and has been used on this project.

By using (4), the distance between all anomaly points can be calculated as

$$r_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (4)$$

where r_{ij} is the Euclidean distance between two anomaly points. The similarity of the anomaly points is determined by the maximum allowable distance, d_{max} between group members. All anomaly points which have nearest distance between it neighbour below d_{max} is clustered into the same group. If the latest point has a larger distance between all points of each group than d_{max} , a new group is created consist of that point.

The chosen of value d_{max} gives the sensitivity value of the system. All points will be clustered into one group if a large value of d_{max} is chosen. On the other hand, if d_{max} value is sets too low, each anomaly point will be clustered into a single group. However, the minimum value of d_{max} should be more than the robot step size. This is because, in case there is no error on sensor measurement, the different between current and previous measurement is equal to the robot step size.

After the anomaly point data was clustered into groups, error ellipse is used to represent each group created. The covariance matrix, Q_{xx} (5) for each group is used to obtain

the information of ellipse formation. The orientation of the ellipse can be calculated using (6) which produce two solutions, where θ is the angle between x-axis and the semi-major axis of the ellipse. These two solutions then substituted into (7) and (8) to get the semi-major q_{uu} and semi-minor q_{vv} axes of the ellipse.

$$Q_{xx} = \begin{bmatrix} q_{xx} & q_{xy} \\ q_{xy} & q_{yy} \end{bmatrix} \quad (5)$$

$$\tan 2\theta = \frac{-2q_{xy}}{q_{yy} - q_{xx}} \quad (6)$$

$$q_{uu} = q_{xx} \cos^2 \theta + 2q_{xy} \cos \theta \sin \theta + q_{yy} \sin^2 \theta \quad (7)$$

$$q_{vv} = q_{xx} \sin^2 \theta - 2q_{xy} \cos \theta \sin \theta + q_{yy} \cos^2 \theta \quad (8)$$

Based on these solutions, the parametric equation shown in (9) and (10) are then used to form an ellipse as illustrated in Fig. 2. Note that \bar{x} and \bar{y} are the mean of x and y while parameter t varies from 0 to 2π .

$$x = \bar{x} + q_{uu} \cos \theta \cos t - q_{vv} \sin \theta \sin t \quad (9)$$

$$y = \bar{y} + q_{uu} \cos \theta \sin t + q_{vv} \sin \theta \cos t \quad (10)$$

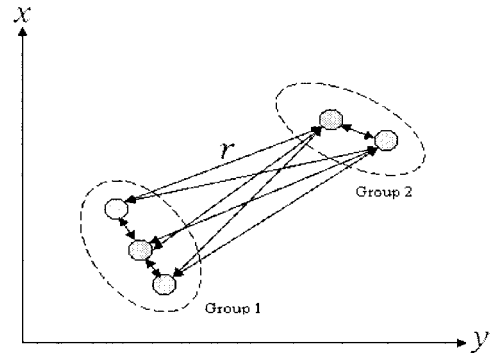


Figure 2: Group forming based on Euclidean distance method.

Next, the anomaly points are classified into four types of detection which are true positive, false positive, true negative and false negative. All anomaly points owned by an ellipse consisting more than five points and nearest to the novel object are assumed as a true positive detection. The rests of anomaly points are pointed as false positive detection. Whereas, if the system unable to detect an anomaly event, it is considered as false negative detection. None detection point which is not shown in the simulation is reflected as true negative detection. Finally, the center of

ellipse which consist of true positive detection are expected as position estimation of anomaly events.

IV. SIMULATION

The simulation was done by using MATLAB. As illustrated in Fig. 3, a corridor environment was modelled as the mobile robot inspection environment. The objectives of the simulation are:

1. To study the effect of changing the angular resolution of sonar sensor array on anomaly detection accuracy.
2. To evaluate the performance of ROS and determine the optimum number of sonar sensor in a 180 degree array.

Initially, the robot was run into the environment from point A to point B as shown in Fig. 3 to obtain the normal sensor measurement with sequential 3 to 10 total number of sonar sensors using wall following algorithm. All the measurements then stored and mapped using Grid Map technique.

During the inspection period, a box is placed into the environment and Door 1 is opened as depicted in Fig. 4. Each step of measurement is then compared with the normal data measurement. The measurement that deviates from normal measurement was highlighted as an anomaly. The criterion of anomaly definition was explained in section III.

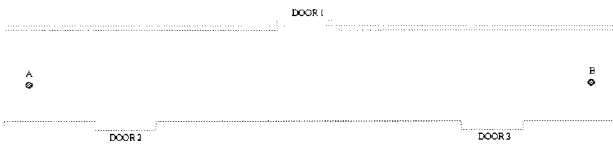


Figure 3: Normal environment for the robot navigation.

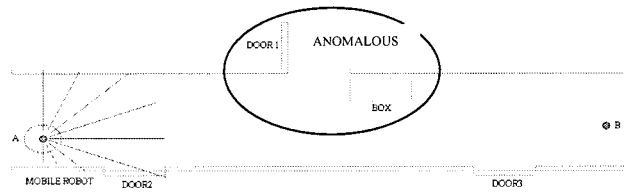


Figure 4: Inspection environment for the mobile robot.

All of the anomaly points are then classified and listed in Table 1. The simulation is repeated for varies value of angular resolution. Then for each case, by referring Table 1, the data was analyzed using (11) and (12).

$$Specificity = \frac{TP}{A} \quad (11)$$

$$1 - Specificity = \frac{FP}{B} \quad (12)$$

TABLE 1 CONFUSION MATRIX TABLE

Anomaly Presence Observation	Actual		Total
	Yes	No	
Yes	True Positives (TP)	False Positives (FP)	C
No	False Negatives (FN)	True Negatives (TN)	D
Total	A	B	E

The observation which correctly detects the existence of an anomaly is called true positives otherwise it is a false negatives. Whereas, the observation which correctly detects the absense of anomaly is called true negatives otherwise it is false positives. To get a better result, the total number of actual and observation data should be the same.

V. RESULT

By referring Fig. 5, anomaly points in the biggest ellipse are identified as true positive detection. Since the small ellipse consists of 5 anomaly points, it is also considered as true positive detection. The other points far from the novel object are identified as false positive detection. Some of the detection occurred inside the wall shows the error of sensor measurement. Large value of sensor measurement produces a large error of detection as mention in section III.

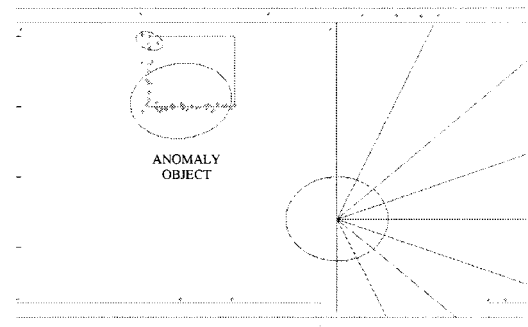


Figure 5: Examples of detection result from the simulation of 9 sonar sensors.

The main objective of this project is to study the effect of changing angular resolution of a sonar sensor array on anomaly detection using ROS. The sensitivity of each case of angular resolution is then varied by adjusting the threshold different of normal measurement and current measurement, $D_{identified}$. Fig. 6 shows the variety of anomaly detection with different value of $D_{identified}$ for angular resolution 22.5° . As represent in Fig. 6, lowering the value of $D_{identified}$, more anomaly points are detected. This means that, the sensitivity is increased when the $D_{identified}$ is lowered. By increasing the value of $D_{identified}$, the false positive filter becomes decreasing and position estimation of anomaly event becomes easier. Note that, some cases of

setting to high $D_{identified}$ value can make the system less sense and unable to detect an anomaly.

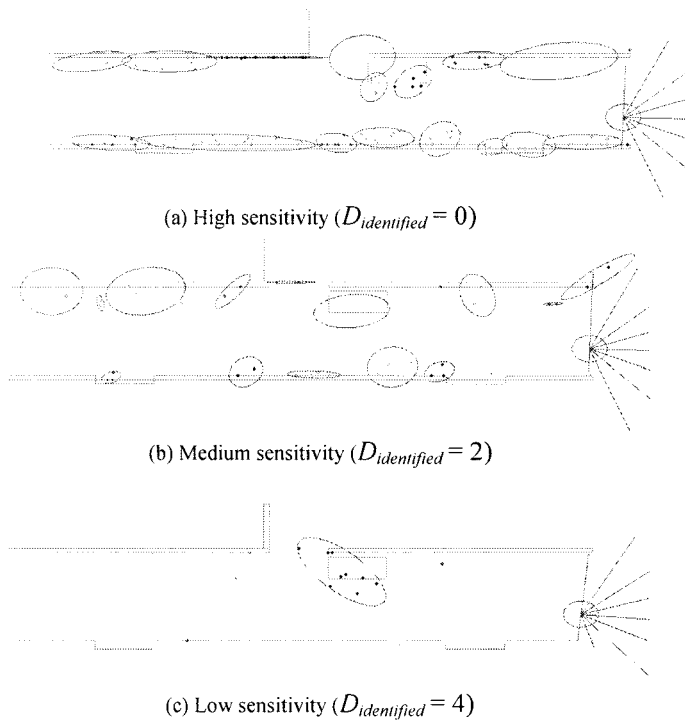


Figure 6: Example of anomaly detection with different angular resolution value.

By using ROC curve, the performance of ROS on each angular resolution is shown in Fig. 7 and Fig. 8. Each angular resolution is represented by varying the value of $D_{identified}$ from 0 to 5 units distance. The performance of ROS is measured by the sensitivity and specificity of the system. High sensitivity and high specificity of detection make the system performance become better.

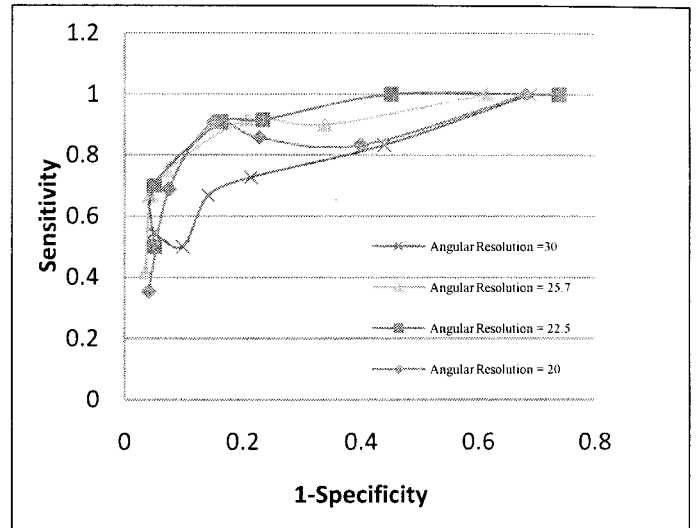


Figure 8: Sensitivity vs. 1-Specificity for Angular Resolution 30, 25.7, 22.5 and 20.

According to sensitivity and 1-specificity graph, the relationship between these two parameters is slightly improper because of the existence of noise or error sensor. More number of sonar sensor used, more error was generated.

VI. CONCLUSION

ROS is a method that collecting data repeatedly from different position observation. The method aims to reduce false alarm during an inspection by increase the confidence level of true detection. The simulation results show that the feasibility of implementing ROS using sonar sensor is possible. From Fig. 7 and Fig. 8, it can be concluded that angular resolution of 90 degrees has the best performance among others. Adding the number of sonar sensor makes the true rate detection of the system decreases. Future improvement of this study is to reduce the false positive detection by filter out the small groups of anomaly points.

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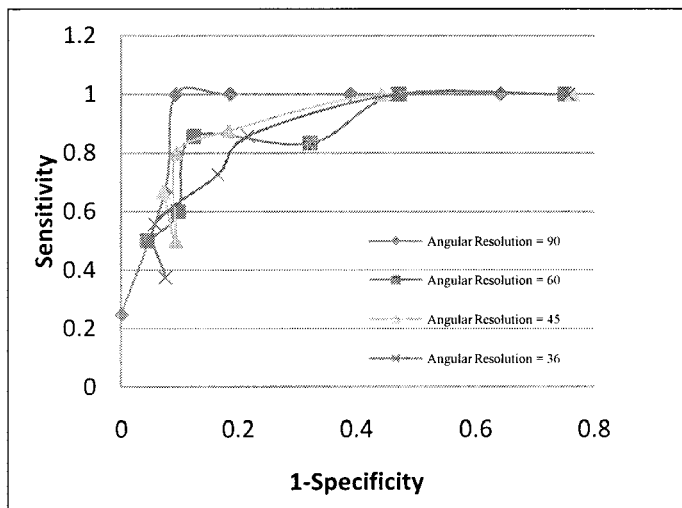


Figure 7: Sensitivity vs. 1-Specificity for Angular Resolution 90, 60, 45 and 36.

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