UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty Of Electrical Engineering

HIERARCHICAL SELF ORGANIZING MAP AND FOCUSING INSPECTION STRATEGY FOR MOBILE ROBOT NOVELTY DETECTION

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2014

DECLARATION

I declare that this entitled "Hierarchical Self Organizing Map and Focusing Inspection Strategy for Mobile Robot Novelty Detection" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :..

Name :..

Date :..

APPROVAL

I hereby declare that I have read this thesis and my opinion this thesis is sufficient in term of scope and quality for the award of Master of Science in Electrical Engineering.

Signature :..

Supervisor Name :..

Date :..

DEDICATION

To my beloved mother and father

ABSTRACT

Novelty detection is a process of recognizing changes based on learned knowledge. In this research, a novelty detection system was implemented on a mobile robot with an array of sonar sensors for surveillance application. In order to perform novelty detection, a map that stores normal information with respect to any particular robot pose in an environment is required. The map is needed to detect changes and determine the position of novel event. The challenges of mobile novelty detection system are that the false positive rate is usually high whereas the true positive rate is usually low due to mapping and monitoring problems. During mapping, errors due to robot localization and sensor measurement can reduce the quality of the map built. However, available methods in mapping assume perfect localization, hence error in localization is not taken into account in the process of mapping. During monitoring, inspection interval that is too small will consume a lot of time and energy but if the interval is too big, novelty could be missed, hence lower the true positive detection. On top of that, low true positive detection is also caused by the low reliability of sonar sensor measurement. Thus, the objective of this thesis is to utilize mobile novelty detection system by developing a mapping and monitoring strategy that has low false positive detection, high true positive detection and able to estimate the position of a novelty. This thesis proposed two methods regarding to mapping and monitoring process; a hierarchical Self Organizing Map (SOM) and a Focusing Inspection Strategy (FIS). Unlike other mapping methods, hierarchical SOM also consider localization error when associating the normal information with respect to the robot pose. FIS is a multi resolution monitoring strategy which works by changing the frequency of measurement depending on the detection of anomaly. In this thesis, two models were considered; a step (FS) and linear (FL) resolution models. The hierarchical SOM was validated by using simulation and experimentation of the inspection in environment with normal and novel event. False positive rate is measured to determine the map performance. The results show that hierarchical SOM is able to map the normal condition of the environment very well. The inspection results show the false positive rate occurred less than 0.1 at the higher sensitivity setting of 0.9 in either normal or novel condition. The performance of FIS was investigated by using experimentation of the inspection of novel objects of different sizes. The results show that by changing the frequency of measurement using the FS and FL models, the number of true positive detection increases up to 80% when compared to inspection with fix measurement frequency. FIS also reduced the error of position estimation by about 8.8% and 10.9% each for FS and FL and maintained the false positive rate lower than 0.1.

ABSTRAK

Pengesanan kebaharuan adalah satu proses mengenalpasti perubahan berdasarkan pengetahuan yang telah dipelajari. Dalam kajian ini, sistem pengesanan tersebut telah dilaksanakan pada robot boleh bergerak dengan jajaran beberapa sensor sonar untuk aplikasi pemantauan. Untuk melaksanakan pengesanan tersebut, sebuah peta yang menyimpan maklumat normal suatu persekitaran bersama dengan kedudukan tertentu robot diperlukan. Peta tersebut diperlukan untuk mengesan perubahan dan menentukan kedudukan peristiwa novel. Cabaran menggunakan sistem pengesanan kebaharuan bergerak ialah kadar positif palsu lazimnya tinggi manakala kadar positif benar adalah rendah disebabkan oleh masalah pemetaan dan pemantauan. Semasa pemetaan, ralat penyetempatan dan ukuran sensor boleh merendahkan kualiti peta yang dibina. Walaubagaimanapun, kaedah pemetaan sedia ada menganggap penyetempatan adalah sempurna, maka ralat penyetempatan tidak diambil kira dalam proses pemetaan. Semasa pemantauan, selang pemeriksaan yang terlalu kecil akan memakan masa dan tenaga yang banyak tetapi jika terlalu besar, kebaharuan mungkin tidak dapat dikesan. Selain itu, pengesanan positif benar yang rendah juga berlaku kerana kebolehpercayaan ukuran sensor sonar yang rendah. Oleh itu, objektif tesis ini adalah untuk memanfaatkan sistem pengesanan kebaharuan bergerak dengan membangunkan strategi pemetaan dah pemantauan yang mempunyai pengesanan positif palsu yang rendah, pengesanan positif benar yang tinggi dan mampu menentukan posisi kebaharuan. Tesis ini mencadangkan dua kaedah berkaitan dengan proses pemetaan dan pemantauan; hierarki Peta Swaorganisasi (SOM) dan Strategi Pemeriksaan Menumpu (FIS). Tidak seperti kaedah pemetaan lain, hierarki SOM mempertimbangkan ralat penyetempatan semasa penyekutuan maklumat normal dengan kedudukan robot. FIS adalah pemantauan dengan resolusi pelbagai, berfungsi dengan meningkatkan kekerapan pengukuran bergantung kepada pengesanan anomali. Dalam tesis ini, dua model dipertimbangkan; model resolusi injak (FS) dan model resolusi linear (FL). Hierarki SOM telah disahkan menggunakan simulasi dan eksperimentasi untuk pemeriksaan persekitaran dalam keadaan biasa dan novel. Kadar positif palsu diukur untuk menentukan prestasi peta tersebut. Hasilnya menunjukkan bahawa hierarki SOM mampu memetakan keadaan normal dengan baik. Hasil pemeriksaan menunjukkan kadar positif palsu berlaku serendah 0.1 pada kepekaan sistem yang tertinggi 0.9 sama ada dalam keadaan normal atau novel. Prestasi FIS telah diselidik dengan melaksanakan ia untuk memeriksa objek novel dengan saiz yang berbeza. Keputusan menunjukkan bahawa FS dan FL menambah bilangan pengesanan positif benar sehingga 80% berbanding dengan kaedah pemantauan resolusi tetap, mengurangkan ralat penganggaran kedudukan sebanyak 8.8% dan 10.9% untuk FS dan FL, dan mengekalkan pengesanan positif palsu pada kadar serendah 0.1.

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LIST OF ABBREVIATIONS

ARIA	-	Advanced Robotics Interface for Applications
BMU	-	Best Matching Unit
FIS	-	Focusing Inspection Strategy
FL	-	FIS with Linear Resolution
FN	-	False Negative
FP	-	False Positive
FRM	-	Flexible Region Map
FS	-	FIS with Step Resolution
GMM	-	Gaussian Mixture Model
ROC	-	Receiver Operating Characteristics
SCT	-	Spherical Coordinate Transform
SOM	-	Self Organizing Map
SONARNL	-	Sonar-based Advanced Robotics Navigation and Localization
TN	-	True Negative
TP	-	True Positive

LIST OF PUBLICATIONS

1. M.N.A.H. Sha'abani and Miskon, M. F., 2011. "**The Effect of Anomaly Detection Accuracy in Varying the Angular Resolution of Sonar Using Repetitive Observation Strategy**", *in Proceedings of the IEEE Symposium on Industrial Electronics and Applications (ISIEA)*, Langkawi, Malaysia, 25-28 Sept, IEEE Publisher, pp. 669-674.

2. M.N.A.H. Sha'abani, M.F. Miskon and M. H. Taib. 2011. "**A Focusing Inspection Strategy for Recognizing the Presents of an Anomalous**" in *Malaysian Technical Universities International Conference on Engineering and Technology (MUiCET)*, Batu Pahat, Malaysia, 13-15 Nov.

3. M.N.A.H. Sha'abani, M.F. Miskon and H. Sakidin. 2013. "**Hierarchical Self Organizing Map for Novelty Detection using Mobile Robot with Robust Sensor**", in *5th International Conference of Mechatronics (ICOM'13)*, Kuala Lumpur, Malaysia, IOP Publishing: IOP Conference Series: Materials Science and Engineering, 012018.

4. M.N.A.H. Sha'abani, M.F. Miskon, H. Sakidin and M.H. Taib. 2014. "**A Focusing Inspection Strategy for Mobile Novelty Detection**", in *Australian Journal of Basic and Applied Sciences (AJBAS)*, 8(7), pp. 168-184.

CHAPTER 1

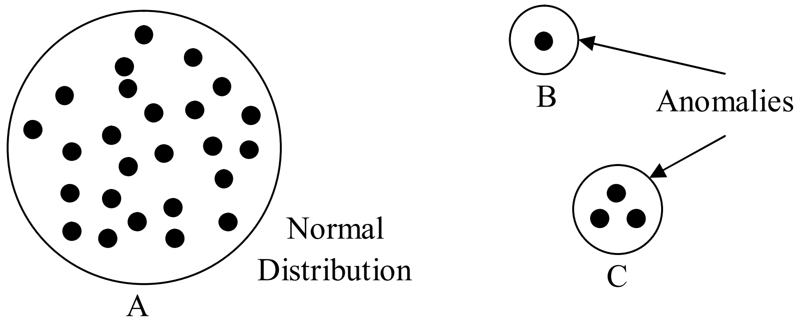
INTRODUCTION

1.1 Introduction

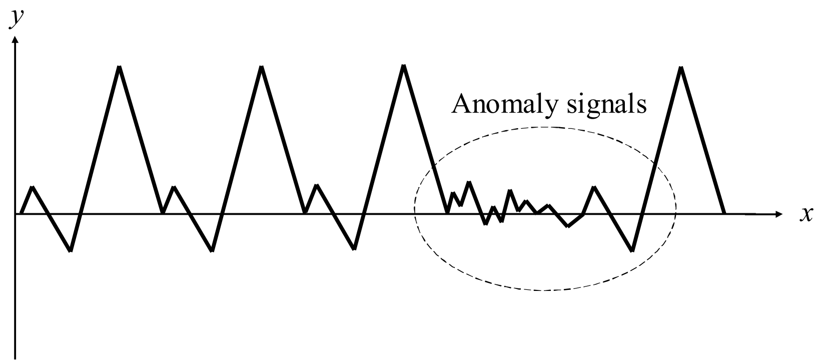
Novelty detection is a perception of recognizing changes in an environment based on previous experience knowledge (Markou and Singh, 2003a, Markou and Singh, 2003b). It is an important inherent ability of animals for their survival. By detecting a novelty or unexpected perception, animals can use it as their first approach in hunting preys or avoiding predators. In animal science, the study of animal nervous systems that influences their natural behaviour is neuroethology (Hoyle and Graham, 1984). A popular research in this field, done by Jörg-Peter Ewert *et. al.* was on the natural behaviour of a toad in prey-predator situation. They found that a toad responses to a specific cues such as shape, colour, size and movement of the stimulus. Similar concept is used in novelty detection.

There are several types of data engaged in novelty detection such as data point, pattern of signals and observation data. Figure 1.1 depicted some examples of novelty pattern in several types of data. A novelty is usually identified after several processes of raw data. In this thesis, a novelty is referred as a group of anomaly points.

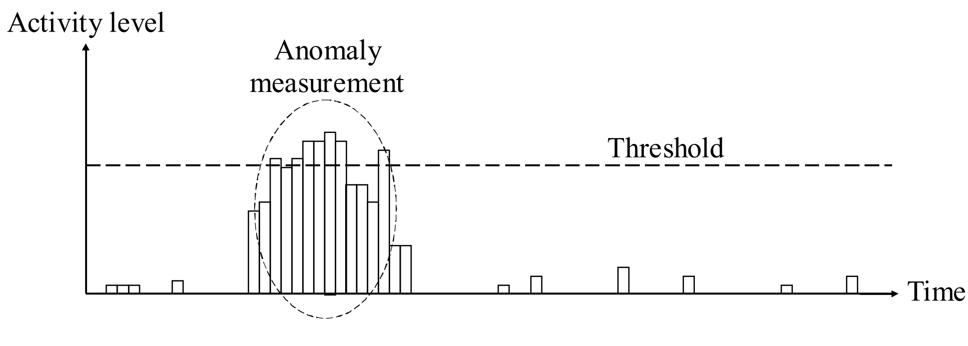
For the past decade, there have been various fields that benefited from novelty detection such as aeronautics (Brotherton and Johnson, 2001, Hayton *et. al.*, 2001), medical (Tarassenko *et. al.*, 1995), robotics (Marsland *et. al.*, 2000b, Marsland *et. al.*, 2005, Neto and Nehmzow, 2005a, Miskon, 2009, Sofman *et. al.*, 2009), computer engineering (Manikopoulos and Papavassiliou, 2002, Abouabdalla *et. al.*, 2009) and even forensic (Ratle *et. al.*, 2007). By learning the normal state rather than learning all possible abnormalities, novelty detection has become practical for surveillance and inspection applications.



(a) Point data.



(b) Signal data.



(c) Observation data.

Figure 1.1: Several examples of novel pattern in different type of data

In surveillance system, the most important thing is the ability of a system to accurately determine the presence of a novelty with a low or zero occurrence of false alarm. It is an advantage if the system can estimate the position of novelty source; hence an immediate action for further analysis can be done. To realize this task, a mobile novelty detection system is required. For this reason, this research is focused on the development of a surveillance system by implementing a mobile robot as a platform of novelty detection.

Recently, novelty detection has become popular in mobile robot's field, especially for surveillance and inspection purposes (Nehmzow and H.V.Neto, 2004, Marsland *et. al.*, 2005, Miskon and R.Russell, 2008, Di Paola *et. al.*, 2010, Neto, 2011). Training a robot to learn a normal state and highlighting changes in an environment is an attractive idea. However, it is not a trivial task to be achieved due to some of the technical challenges. As it is a machine learning process, there is no guarantee that the robot could learn every possible problem (Marsland, 2001).

The key idea of mobile robot novelty detection is to achieve an autonomous mobile robot that can stay alert of any changes in the environment. The ultimate goal is to utilize a mobile robot capable of performing novelty detection with a high true positive detection while at the same time minimizing false positive detection. By using an inexpensive and high noise sensor, the method proposed is expected to be adaptable for other types of sensors.

In this research, an Amigobot mobile robot attached with an array of eight sonar sensors was used. The robot is tasked to learn an indoor environment (i.e. corridor) and do an inspection to detect changes. The research described in this thesis is motivated by many potential surveillance activities that may benefit from a mobile novelty detection system. The motivation of this research will be presented in the next section.

1.2 Motivation

There are many advantages of using a mobile robot for novelty detection. The most important thing is an appropriate action can be taken immediately. For example, a robot attached with sonar sensors can be used to preliminary identify an abnormal object. An immediately action such increasing sampling rate and going close to the object can increase the reliability of the detection. Once the presence of an abnormal object is confirmed, further investigation using other available sensors can be taken. This can avoid the risk of human from becoming a victim of an explosion if the suspected object is a bomb.

Furthermore, performing novelty detection in mobility platform overcomes the limitation of a static sensor such sonar sensor. The sensor can be transported to any edge of covered environment. This will lower the cost of system installation since a single sensor can cover most of the inspection environment rather than installing many sensors in each part of the environment (Miskon, 2009).

Another advantage is that a robot is capable of performing its tasks repeatedly with a constant accuracy and performance (Craig, 2004). In this case, human can easily get tired or become bored. This is an extremely important characteristic of the inspection system to get an acceptable result. In order to achieve this, the system should be capable of distinguishing the perceptions received at a specific location whether it is deviating from its normal state or not. In the next section, the discussion of constraints and problems involved are discussed.

1.3 Problem Statement

The main problem of a novelty detection system is the occurrences of false alarm, especially false positive detection. It happens when the system has wrongly identified a normal measurement as an abnormal one. This makes a mobile robot perform unnecessary action, hence wasting robot energy and inspection time. There are two processes that potentially contribute to the occurrence of false positive detection, which are mapping and monitoring process.

In order to perform novelty detection in an environment, a robot requires a map that stores the normal state of the environment. To take advantage of a mobile platform, the learned normal data should be associated with the robot pose. This is to ensure that it can determine the position of the novel object. However, due to localization error, the association of data with its respective robot pose can be misclassified if the process is carried out directly. Besides that, even if the localization is accurate, the measurement error can also reduce the accuracy of the map built. These problems disrupt the quality of the map and the performance of detection during inspection.

Since the mapping built might not always be accurate, there are possibilities on occurrences of false positive detection in inspection. Although this happens occasionally, it is hard to determine whether the detection is a false or actually a true positive. Thus, a novelty is identified by grouping the anomaly points found. However, an inspection with a fixed distance interval for each measurement can cause the robot to overlook a novel object. This is especially true when the object exists between reading intervals. Furthermore, sonar sensor has a limitation on its firing angle which can cause a low number of true positive detection and in addition, might be rejected by a novelty filter, hence falsely detecting the novelty presence. However, solving this problem by continuous measurement or with the highest capability of sensor operation can cause excessive data to be processed. It will be disadvantages to a high dimensional sensor for such vision.

In order to solve the problems, this thesis proposes two solutions. The first concerns the effect of localization and sonar measurement errors on the quality of map building. A new mapping technique based on perception based map and hierarchical neural network is proposed. The method works by adopting both localization and measurement error into robot learning. The robot should be train by allow it to run several times in a normal state of an environment so that it can adopt both normal data and the errors. By this method, it is hypothesized that the robot will recognize the errors as normal during inspection, thus will reduce the occurrences of false alarm.

The second solution involved sensor measurement errors and monitoring strategies. A multi-resolution monitoring technique is proposed. It is a technique of changing the detection rate per area based on detected anomaly points. The idea is to increase the frequency of measurement only when a suspicious measurement is detected. Combined with clustering and filtering technique, high number of data in a single cluster will identify as a novelty, whereas low number of data will be rejected. For example, if novelty is present, the robot will keep it measurement in high rate so that more data is collected, thus high number of data can be grouped together. However, when the suspicious measurement is a false positive, the detection rate per area will back to low in the next measurement since the occurrence of false positive is very rare. This will leaving the false positive detection as a single cluster and can be rejected. Through method, it is hypothesized that this will increase the true positive detection and the accuracy of position estimation of a novelty.

1.4 Objectives

The general aim of this research is to utilize a mobile robot in detecting novelty with a low false positive detection, high true positive detection and improve the accuracy of inspection. To be more specific, the objectives of this research are:

i. To develop a mapping strategy that minimizing the occurrences of false alarm.
ii. To develop a monitoring strategy that can increase the number of true positive detection and increase the accuracy of novelty positioning estimation.
iii. To validate both methods via simulation and experimentation based on Receiver Operating Characteristics (ROC) curve analysis.

1.5 Scope of Works

The research focuses on implementing and utilizing a mobile robot for novelty detection purposes. The scope of work includes:

i. Tools that be used is Amigobot mobile robot with an array of sonar sensors.
ii. The environment target is an indoor corridor.
iii. The novel object is static and no obstacle is considered along the robot route.
iv. The validation process is through simulation and experimentation.