DEVELOPMENT OF AN AUTONOMOUS RADIATION MAPPING SYSTEM

BY

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ABSTRACT

Nuclear power plant accident is a growing problem in the area that has been affected by the natural disaster. The research outlines a number of methods which can be sued to control and vacuum the dust of the related disaster and measure the levels of radiation in the disaster area. This is believed to help enhance the response of the emergency systems. In particular, this work has developed a mobile robot platform with radiation detection capabilities that has been tested for radiation environment suitability. The importance of this work lies in building a radiation mapping system of indoor environment by using an efficient detection Geiger Muller sensor. In order to achieve this objective, the physical environments were equipped with stationary landmarks and Gamma ray that had been tested for simultaneous localization and mapping algorithm. Such testing has been conducted with the help of following such processes as perception, trajectory and localization with the use of Extended Kalman filter. Thus, building the Map is essential for this task to create a representation of the environment while the robot is moving in and measuring the levels of the radiation. The data related to the robot trajectory has been collected by the encoder measurement and incorporated into Kalman filter in order to obtain good result with less noise. The trajectory of the robot shows that, the starting point in this experiment is the same as the ending point which indicates the closing loop associated with the use of SLAM algorithm. The map proposed by this work is incremental and requires no prior exploration of the environment. The use of the Geiger sensor indicates that, the levels of radiation change with change of the radiation existence in the environments. If the levels of radiation are low the map would show high intensity of darkness. Correspondingly, if the levels of radiation are high the map would show high intensity of redness. Finally, the robot has traveled in square area of two dimension (x,y) 540m x 250 cm and successfully results have been obtained, thus, radiation map obtained is very satisfactory, as well the map of the radiation system can be determined even with the use of low quality components. The simultaneous localization and mapping approach has been proven to be efficacy and reliable.

ملخص البحث

حوادث محطات الطاقة النووية هي مشكلة متنامية في المناطق التي تضررت جراء الحوادث الطبيعية. ويعرض هذاالبحث عددا من الطرق التي يمكن استخدامها للتحكم و شفط الغبار الناتج من الكوارث الطبيعية، و قياس مستويات الإشعاع في مناطق الكوارث. ويعتقد أن هذا البحث يساعد علي تطويرالاستجابة لانظمة الطوارئ. على وجه الخصوص، هذا العمل تم فيه تطوير منصة للروبوت المحمول مع القدراة للكشف عن الإشعاعات التي تم اختبارها لملائمة البيئة. أهمية هذا العمل تكمن في بناء نظم رسم الخرائط الإشعاعية بالنسبة لبيئة داخلية باستخدام حساس الجاقار مولر. ومن أجل تحقيق هذا الهدف، تم تجهيز بيئة معينه مع معالم ثابتة وأشعة غاما التي تم اختبارها عن طريق خوارزمية التمركز ورسم الخرائط بالتزامن. وقد أجريت هذه الاختبارات بمساعدة طرق علمية مثل الإدراك، تتبع المسار والتثبيت مع استخدام مصفي كالمان. اذا، بناء الخريطة ضروري جدا في هذا البحث مما يساعد علي صنع بيئة اثناء حركة الروبوت وقياس مستويات الإشعاع. البيانات المتعلقة بتتبع مسار الروبوت تم جمعها عن طريق قياس الانكودر ودمجها مع مصفي الكالمان من أجل الحصول على نتيجة جيدة مع نسبة قليلة من الاخطاء. مسار الروبوت يبين أن نقطة الانطلاق في هذه التجربة هي نفس نقطة النهاية مما يدل على الحلقة المغلقة المرتبطة باستخدام خوارزمية التمركز ورسم الخرائط بالتزامن. الخريطة التي اقترحها هذا العمل تدريجية ولا تتطلب أي استكشاف مسبق للبيئة. ومن خلال استخدام حساس قياس الاشعاعات الجاقار مولر اتضح بانه، كلما كان لون الخريطة احمر دليل علي كثافة مقياس الاشعاع والعكس اذا كانت الخريطة داكنه دليل علي قلة الاشعاع في ذاك المحيط. وهكذا، فإن التجارب اثبتت فعالية وموثوقية الخوارزمية مما سهل من عملية رسم الخرائط وتحديد موقع الروبوت بالتزامن. وأخيرا، تحرك الروبوت في مساحة محورية (س،ص) في مساحة (540،250)سم علي التوالي مما ساهم في الحصول على النتائج المطلوبة، ونتيجة لذلك، فان خرائط الإشعاع التي تم الحصول عليها مقبولة للغاية، حتى مع استخدام ادوات ذات جودة منخفضة. وقد برهن ان استخدام خوارزمة التمركز ورسم الخرائط بالتزامن له فعالية وكفاة عالية.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a research paper for the degree of Master of Science in Mechatronics Engineering.

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Shawgi Younis Ahmed Mounis

Signature……………………………….   Date ……………........……….

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Affirmed by Shawgi Younis Ahmed Mounis

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Signature Date

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In the Name of Allah, the Most Gracious, the Most Merciful.

This thesis is the result of my work as a research assistant and master student at the intelligent Systems Lab of Mechatronic engineering (IIUM).

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LIST OF ABBREVIATIONS

SLAM	Simultaneous Localization and Mapping
KL	Kalman Filter
EKL	Extended Kalman Filter
ETP	Economic Transformation Programme
MCL	Markov Decision Process
WMR	Wheeled Mobile Robot
UV	Unmanned Vehicle
GPS	Global Positioning System
CAD	Computer Aided Design software
LLNL	Lawrence Livermore National Laboratory
LANL	Los Alamos National Laboratory
ORNL	Oak Ridge National Laboratory

LIST OF SYMBOLS

T	Torque
ω	Angular velocity
v	Average speed
θ	Angular Rate
L	Index length between the two wheel
r	Wheel Radius
α	Alpha particles
β	Beta particles
γ	Gamma rays
SEE	Single-event effects
TID	Total Ionizing Dose

CHAPTER ONE
INTRODUCTION

1.1 OVERVIEW

Nuclear radiation or ionizing radiation is extremely dangerous as they can cause changes in human cell DNA which leads to radiation sickness. Recent Fukushima-Daiichi accident which occurred on 11 March 2011 has attracted the attention of the world on the safety issues of nuclear and radiation technology. One of the most important issues that arose includes the involvement of the unmanned systems or robots as a means of emergency response in nuclear and radiation related accident. In Malaysia, nuclear and radiation issue is not a new issue. One example is the Bukit Merah rare earth mining incident which has left continuing environmental and health concerns. Recently, nuclear and radiation related issue arises again with the setting up of Lynas Rare Earth Processing Plant in Kuantan and the plan of setting up nuclear power plants through the Malaysia Economics Transformation Programme. It is no doubt that nuclear technology could bring a huge economic gain for Malaysia or to any other countries if they have used with the standard of the protection issue. However, it is very important for Malaysia to be fully prepared in nuclear and radiation emergency response (Shinji, K., Mineo, F. 2012).

The main problem with the Fukushima Plant incident response is the direct involvement of human in radiation environment. The ability to autonomously perform radiation surveillance without the need of human operator would greatly enhance the emergency response. Unfortunately, the high restriction (by national and international laws), high cost and danger of nuclear and radiation technology had prevented extensive research to be done in this field. Hence, in this research, we propose to design and develop a mobile robot based autonomous radiation mapping system that could be used in nuclear and radiation emergency response. This research is conducted together Malaysia Nuclear Agency in order to overcome the high restriction and cost of the nuclear technology and to ensure safety while doing this research. Recently, when the Fukushima Daiichi accident occurred which is a result of a big earthquake and tsunami, that occurred on 2011 has attracted the attention of the world on the safety issue of nuclear and radiation technology. One of the most important issue that raises include the involvement of the unmanned systems or robots as a means of emergency response in nuclear and radiation related accident. Eventhough Japanese nuclear disaster response robots that was developed since 1999, they failed to work as planned during the Fukushima Plant incident. As a consequence, unmanned constructive heavy machines and robots from the US and Sweden have to be imported (Shinji, K.*et al.* 2012). They were extensively used in the reconnaissance work and cleaning up of rubble of power plant. Special type of robot called Quince and JAEA-3 were deployed for reconnaissance inside of the plant. From the report of Fukushima Plant emergency response, for reconnaissance work, robots were utilized to perform radiation mapping and video footage capturing of the plant area (Tatsujiro, S. 2011). Figure 1 shows a footage obtained from a robot.

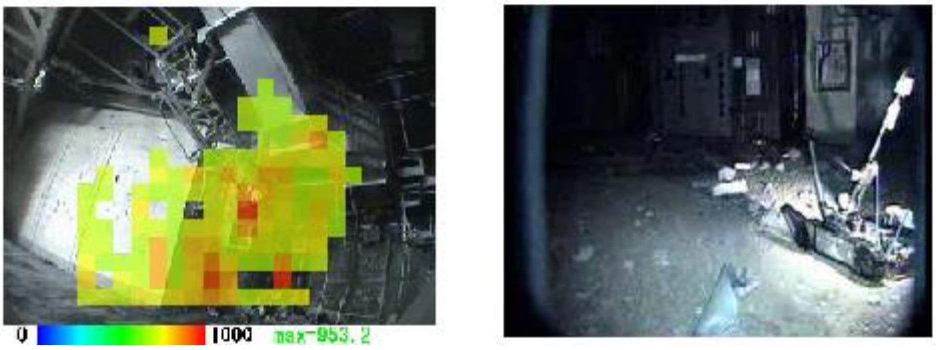

Figure 1. 1 Fukushima-Daiichi radiation level measurement and surveillance footage from robots (Tatsujiro, S. 2011).

It is no doubt that nuclear technology could bring a huge tremendous economic gains for Malaysia. However, it is very important for Malaysia to be fully prepared in nuclear and radiation emergency response which includes having a good unmanned systems or robotics emergency response technology. Radiation mapping is similar to any other robotic exploration and mapping applications. The goal of radiation mapping is to map the spatial distribution of a physical quantity over a given area. Similar to the traditional robot exploration which often based on grid, which devides the area of interest into a discrete number of cells, radiation mapping can also be done in the same way as mapping the distribution of physical quantities over a region such as radiation using robots can be done by maneuvering a robot using a predefined path that sweeps the entire area. Several methods have been reported in robotics literature for the sweeping of known spaces such as the Boustrophedon Cellular decomposition and distance transform method which define different startegy for area sweeping. Figure 1.2 shows the Boustrophedon path generated for a rectangular area sweeping.

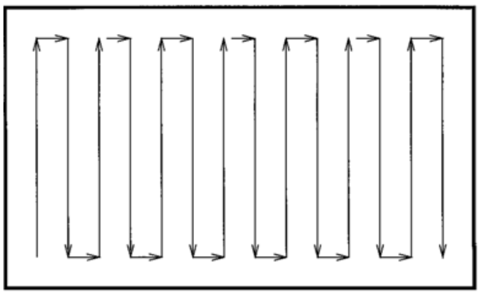

Figure 1. 2 Boustrophedon path (Choset, H. 2000).

There are many types of ionizing radiation sensors available nowadays such as the ionization chamber, proportional counter, geiger counter, scintillation detectors and solid state based radiation sensors. However, the scintillation detectors was reported to be the most commonly used sensors in mapping application due to its high sensitivity and accuracy. When a gamma ray intersects with a scintillator, such as the Sodium Iodide scintillator, a photoelectric interaction occurred, where a photoelectron absorbs the energy of the gamma ray and emits a visible-light. The visible light can then be converted into voltage level for measurement. The measurement of the radiation sensor normally depends on the intensity and distance of the radiation source and exhibits the inverse-square relationship. It can can be expressed as:

$$\lambda_k = \frac{I}{(x_k - x_0)^2 + (y_k - y_0)^2 + (z_k - z_0)^2} + \lambda_b \tag{1.1}$$

Where I is the intensity of the source, (x_k, y_k, z_k) is the position of detector k, (x_0, y_0, z_0) is the position of the source, and λ_b is the background intensity at the measurement point. A radiation mapping could be generated by sampling the radiation detector reading, λ_k , in uniform spatial samples.

1.2 PROBLEM STATEMENT

Nuclear and radiation can be used as a source of energy which are very important for the economic. Unfortunately, they are extremely dangerous due of their bad consequence of catastrophe related to nuclear as they can cause serious consequence such as radiation sickness. In the Fukushima power plant catastrophe, the main issue faced by the disaster response and management team was that the devices used to measure the radiation level have to vacuum the dust containing radiation particles and they are controlled fully by human operators. Hence, a lot of complaints rose by the operators who have to go through extensive work load and exposure to radiation particles. There is not enough communications infrastructure that would allow the operators to do their work from a safer location. However, emergency response is a critical part of preparedness for chemical, biological, radiological, and nuclear incidents at nuclear power plants and therefore must be improvised.

The ability to autonomously perform radiation surveillance without the need of human operator would greatly enhance the emergency response and can be improved through collaborative use of new robotic capabilities. Robotic based response capabilities include casualty identification and mapping of radiation levels, interior walls, major landmarks, obstacles and localization. Radiation mapping for example, could be performed using mobile robots that are equipped with radiation detectors traversing on land where radiation will be existing. With this system, operator exposure to radiation, workload and stress can be reduced.

1.3 RESEARCH OBJECTIVES

The aim of this project is to develop radiation system. This study embarks on the following objectives:

a) To design and develop mobile robot and incorporate with the radiation detection system.
b) To develop exploration and radiation field mapping behaviors.
c) To evaluate the performances of the system.

1.4 RESEARCH METHODOLOGY

In order to achieve the objectives of the research, the procedures of the implemented methodology are described briefly below.

a) Literature review:

   Detail review on the existing radiation mapping related technology will be conducted and catalogued.

b) Data collection:

   Data collection of the mobile robot platform equipped with radiation sensor. CAD design, Components selection and assembly of the mobile robot will be done. The robot will then be tested and evaluated functionaly.

c) Platform of the robot:

   Development and implementation of autonomous radiation mapping algorithm on mobile robot platform. Algorithm for autonomous radiation mapping will be developed and tested through software programming and simulations (Matlab). Then the algorithm will be implemented on the mobile robot platform for functionality testing.

d) Incorporate the system:

   Integration of mobile robot platform with sensors and actuators using microcontroller.

e) Evaluation of the system:

   Evaluation of the autonomous radiation mapping system. Performance evaluation in the actual radiation environment will be conducted.

f) prototype of the system:

   Design and development of a prototype of the mobile robot platform.

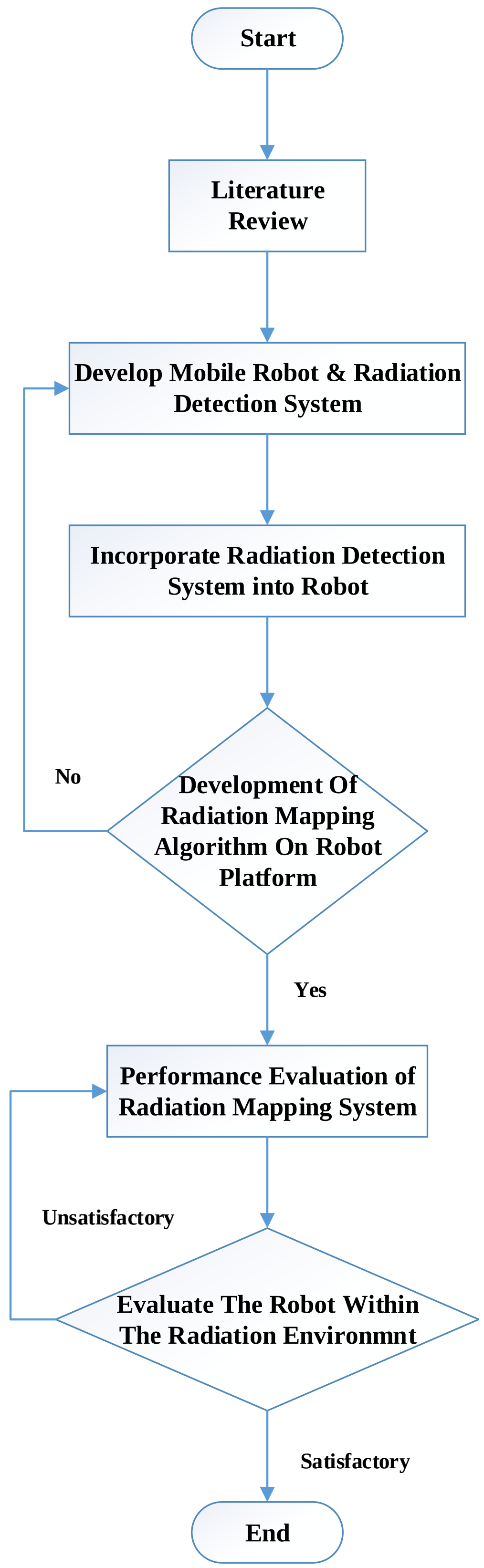

Figure 1. 3 Research Flow Chart