



**UNIVERSITI
MALAYSIA
PERLIS**

**THE MOBILE ROBOT SYSTEM FOR MAPPING
AND LOCALISATION UTILISING SINGLE
LASER RANGE FINDER IN STATIC
ENVIRONMENTS**

by

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TABLE OF CONTENTS

	PAGES
THESIS DECLARATION	i
ACKNOWLEDGEMENT	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	vii
LIST OF FIGURES	x
LIST OF ABBREVIATIONS	xiii
LIST OF SYMBOLS	xv
ABSTRAK	xvi
ABSTRACT	xvii
CHAPTER 1 INTRODUCTION	
1.1 Introduction	1
1.2 Problem Statements	3
1.3 Research Objectives	7
1.4 Research Scopes	8
1.5 Methodology	9
1.6 Thesis Outlines	10
CHAPTER 2 LITERATURE REVIEW	
2.1 Introduction	11
2.2 Indoor Mobile Robot with Mapping and Localisation Algorithm	12
2.3 Single Sensor in Mobile Robot Mapping and Localisation	15
2.4 Mapping Strategy	19
2.4.1 Segmentation and Local Map Building	20

2.4.2	Filtering	22
2.4.3	Validation Testing	25
2.5	Localisation Algorithm using Classification Tool	28
2.5.1	Scan Matching	28
2.5.2	Probabilistic Method	32
2.5.3	Kalman filter and Extended Kalman Filter (EKF)	33
2.5.4	Classifier for Localisation and Positioning Recognition	35
2.5.5	Distance Parameters	36
2.6	Summary	39
CHAPTER 3 MOBILE ROBOT SENSING MODALITY AUGMENTATION & THE LOCALISATION ALGORITHM DEVELOPMENT		
3.1	Introduction	40
3.2	Augmentation of the Mobile Robot System	45
3.2.1	Basic Part Upgrades	45
3.2.2	Laser Range Finder for the Mobile Robot	49
3.2.3	User Interface for the Mobile Robot	50
3.3	Mobile Robot Navigation System	51
3.3.1	Navigation for Building the Reference Map	52
3.3.2	Navigation for the Real Implementation	54
3.4	Strategy to Build Reference Maps	64
3.4.1	Preparation of the Scanning Environment	65
3.4.2	Environment Segmentation and Scanning Nodes	66
3.4.3	Scanning and Data Collection of the Environment	72
3.4.4	Data Consistency	74
3.5	Filtering	76
3.5.1	Raw Filter	76

3.5.2	Moving Average Smooth Filter	77
3.5.3	Filtering Results	78
3.6	Local Map and Global Map Building for the Reference Map	82
3.6.1	Local Map Building	83
3.6.2	Global Map Building	83
3.7	Selection of a Classification Tool	84
3.7.1	Non-Linear Data and High Accuracy	85
3.7.2	Distance-based Classifier	88
3.7.3	Capability to Update the Reference Map into the Database	89
3.8	k -parameter Determination	91
3.8.1	k -parameter Results	92
3.9	Scan Matching and KNN Classification Model	94
3.9.1	Results Based on the Reference Samples	99
3.9.2	Results Based on Non-Reference Samples	103
3.9.3	Classification Results Summary	106
3.9.4	Rotation and Translation	107
3.10	Localisation Algorithm Development	111
3.10.1	KNN Database Development	112
3.10.2	Input Sample Preparation	115
3.10.3	Scan Matching	119
3.10.4	KNN Classification	121
3.10.5	Position Estimation	122
3.10.6	Testing and Results	126
3.11	Reference Map Update	128
3.12	Summary	129

CHAPTER 4 RESULTS AND DISCUSSIONS

4.1	Introduction	131
4.2	Path Tracking and Localisation Estimation Test	133
4.2.1	Path Tracking without Shortest Path Estimation Algorithm	133
4.2.2	Path Tracking with Shortest Path Estimation Algorithm	137
4.3	Test with Obstacle Introduced in the Path (A)	142
4.4	Test with Obstacle Introduced in the Path (B)	145
4.5	Summary	147

CHAPTER 5 CONCLUSION AND THESIS CONTRIBUTIONS

5.1	Introduction	149
5.2	Summary of Finding	150
5.3	Research Contribution	153
5.4	Recommendation	154

REFERENCES	155
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APPENDIX 3A	162
--------------------	-----

APPENDIX 3B	163
--------------------	-----

APPENDIX 3C	173
--------------------	-----

APPENDIX 3D	179
--------------------	-----

APPENDIX 3E	185
--------------------	-----

APPENDIX 4A	186
--------------------	-----

LIST OF PUBLICATION	189
----------------------------	-----

LIST OF AWARD	189
----------------------	-----

LIST OF TABLES

NO.	PAGE
Table 2.1: Laser range finder and its cost in Malaysia market as per 2015 price (Cytron, 2015)	19
Table 3.1: The comparison between the existing and upgraded mobile robot	48
Table 3.2: RP Lidar scanning measurement results	49
Table 3.3: Arrangement of scanning results and the obstacle detection results	60
Table 3.4: Example for the flow of scanning results, the obstacle detection results and the obstacle avoidance	63
Table 3.5: The position of the scanning points for environment with 10 segments	67
Table 3.6: MANOVA results	69
Table 3.7: Standard deviation results (σ) based on 20 times of scanning for segment 1 to segment 10	75
Table 3.8: Normality test result for local map 1 to local map 10 data	85
Table 3.9: Confusion matrix of the KNN classification based on 10 local maps and 10 new testing samples	88
Table 3.10: ANN parameters	90
Table 3.11: Time consume to update the new data into the database for KNN and ANN	90
Table 3.12: Distance parameters to be tested on the justification work for the scan matching algorithm	96
Table 3.13: Decision making variables to be tested on the justification work for the scan matching algorithm	96
Table 3.14: Classification accuracy results of the distance parameters based on the lowest summation for 100 samples that are obtained from the reference scanning points	101

Table 3.15: Classification accuracy results of the distance parameters based on the distance range to the real position for 100 samples that are obtained from the reference scanning points	101
Table 3.16: Classification results of the distance parameters based on similarity angle data for 100 samples that are obtained from the reference data	102
Table 3.17: Fusion result using three decision making variables	102
Table 3.18: Justification of the scan matching KNN model random location based on the lowest summation of Euclidean, Mahalanobis and Manhattan	104
Table 3.19: Justification of the scan matching KNN model random location based on the accuracy range of Euclidean, Mahalanobis and Manhattan	104
Table 3.20: Classification accuracy results of the distance parameters based on the highest number of similar angles for 100 samples of the non-reference data	105
Table 3.21: Fusion result using three decision making variables	105
Table 3.22: Summary of the scan matching of KNN models which have 90% of classification accuracy	107
Table 3.23: Scan matching with rotation results with the range accuracy of $\pm 5\text{cm}$	111
Table 3.24: Arrangement of path nodes and its environment scanning data	114
Table 3.25: Arrangement of Euclidean distance, eucm , n , for the data processing	120
Table 3.26: Location estimation situation on x axis issues and solutions	124
Table 3.27: Mobile robot localisation results	127
Table 3.28: Consistency results of the mobile robot localisation	128
Table 4.1: The test performed for localisation and path tracking.	132
Table 4.2: Localisation results based on five times trials	135
Table 4.3: Mobile robot testing with shortest path estimation algorithm results	140

Table 4.4: Mobile robot navigation and localisation result for the implementation (A)	143
Table 4.5: Mobile robot navigation and localisation result for the implementation (B)	146

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LIST OF FIGURES

NO	PAGE
Figure 1.1: General methodologies	9
Figure 2.1: Example of the mobile robot (a) UGV - Indoor wheeled robot (Clearpath,2017) (b) UAV - Quad rotor (Tetracam, 2017) (c) AUV submarine robot (Geomar, 2017) (d) Polar robot (Maria-José V., 2013)	12
Figure 2.2: Example of map representations (a) occupancy grid (Howard, A., 2006), (b) feature map (Humphries, M., 2013) and (c) topological map (Sujan, V.A., 2006)	14
Figure 2.3: Dendrogram example	21
Figure 2.4: Example of raw data (red line) and data filtered by smooth – moving average method	24
Figure 2.5: Example of median filter in laser range finder data set	25
Figure 2.6: Point-to-point scan matching	29
Figure 2.7: Example of rotation process	31
Figure 2.8: Example of the transformation process	32
Figure 3.1: Mobile robot augmentation works	41
Figure 3.2: Reference maps building	42
Figure 3.3: Selection of KNN and its parameters	43
Figure 3.4: Construction of the localisation algorithm	44
Figure 3.5: The 3D mobile robot design with the RP Lidar	47
Figure 3.6: The existing mobile robot and the upgraded mobile robot	47
Figure 3.7: SDK for data collection	51
Figure 3.8: Flow of the navigation for the reference map building	53
Figure 3.9: Mobile robot navigation strategy	55

Figure 3.10:	Path nodes in the studied environment (a) in the real environment (b) the full description of the path nodes	57
Figure 3.11:	Shortest path algorithm	58
Figure 3.12:	Object detection by laser range finder	60
Figure 3.13:	Description of obstacle sides for the obstacle avoidance	61
Figure 3.14:	Block diagram of the strategy to build reference map	65
Figure 3.15:	The studied environment. (a) View from the back, and (b) View from the front.	66
Figure 3.16:	The scanning nodes of the environment division for 10 segments	68
Figure 3.17:	2 segment result	70
Figure 3.18:	4 segments result	70
Figure 3.19:	10 segments result	71
Figure 3.20:	16 segments result	71
Figure 3.21:	32 segments result	72
Figure 3.22:	(a) Floor plan of the research laboratory (b) Scanning result of the research laboratory	73
Figure 3.23:	Raw filter's flow	77
Figure 3.24:	Moving average of smooth filter program	78
Figure 3.25:	Local maps with raw data and filtered data	82
Figure 3.26:	The completed construction of the global map for the research laboratory (a) Global map with raw data, and (b) Global map with filtered data	84
Figure 3.27:	LDA classification result with the local maps sample	87
Figure 3.28:	k -parameter determination result	92
Figure 3.29:	Local maps discriminate using PCA	93
Figure 3.30:	Scan matching KNN model for the sample classification	98

Figure 3.31:	Rotation and transformation process in the scan matching based on Euclidean distance	108
Figure 3.32:	Scan matching and rotation results for the testing input and the reference local map	110
Figure 3.33:	Localisation flow block diagram	112
Figure 3.34:	Flow of input preparation	115
Figure 3.35:	KNN classification process	121
Figure 3.36:	Situation of the mobile robot in the environment	123
Figure 3.37:	The rule-based for the mobile robot coordinate, yr	125
Figure 3.38:	Process of reference map update	129
Figure 4.1:	Mobile robot system movement results without shortest path estimation algorithm	136
Figure 4.2:	Selection path for the test	138
Figure 4.3:	Mobile robot testing with the shortest path estimation algorithm result	141
Figure 4.4:	Static environment implementation (A) result	144
Figure 4.5:	Static environment implementation (B) result	147

LIST OF ABBREVIATIONS

1NN	1 Nearest Neighbour
2D	2-Dimensions
3D	3-Dimensions
AI	Artificial Intelligent
ANN	Artificial Neural Network
AUV	Autonomous Underwater Vehicle
CDF	Cumulative Distribution Function
DCV	Direct Current Voltage
DP	Dynamic-Programming
DSP	Digital Signal Processing
EDF	Empirical Distribution Function
EKF	Extended Kalman Filter
GA	Genetic Algorithm
GPS	Global Positioning System
GUI	Graphic of User Interface
ICP	Iteration Closest Points
INS	Initial Navigation System
KNN	K Nearest Neighbours
LDA	Linear Discriminant Analysis
LM	Local Map
MANOVA	Multivariate Analysis of Variance
MYR	Malaysian Ringgit
PC	Personal computer
PCA	Principle Component Analysis
RFID	Radio Frequency Identification
RSSI	Received Signal Strength-Indicator
SDK	Software Development Kits
SLAM	Simultaneous Localisation And Mapping
SNR	Signal To Noise Ratio
TOF	Time Of Flight
UAV	Unmanned Aerial Vehicle

UGV	Unmanned Ground Vehicle
USB	Universal Serial Bus
WSN	Wireless Sensor Network

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LIST OF SYMBOLS

D/d	Distance
cm	Centimeter
m	Meter
x	Coordinate at horizontal axis
y	Coordinate at vertical axis
θ	Theta/angle
σ	Standard deviation
$^{\circ}$	Degree

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Sistem Robot Mudah-Alih Untuk Pemetaan dan Penyetempatan Menggunakan Satu Laser Pencari Julat Untuk Digunakan Di Dalam Persekitaran Statik

ABSTRAK

Sistem robot mudah alih dengan keupayaan untuk melaksanakan pemetaan dan penyetempatan mempunyai potensi untuk digunakan dalam pelbagai aplikasi seperti dalam dan di luar bangunan, di kawasan yang diketahui dan tidak diketahui, di luar talian dan dalam masa yang sebenar serta di dalam persekitaran yang statik dan dinamik. Pada masa ini, penggunaan robot mudah alih menggunakan ultrasonik, inframerah, RFID dan lain-lain sebagai penderia untuk pemetaan dan penyetempatan. Walau bagaimanapun, penggunaan penderia-penderia ini mempunyai batasan dan keburukan termasuk memerlukan rujukan untuk penyetempatan, memerlukan pengiraan yang tinggi, pemprosesan data yang perlahan kerana faktor penderia tersebut dan juga keputusan pengukuran penderia yang kurang tepat. Jadi, kajian ini mencadangkan penggunaan satu laser untuk robot mudah alih pemetaan dan penyetempatan bagi persekitaran yang statik. Laser yang digunakan adalah RP Lidar, dan penggunaannya membolehkan robot mudah alih untuk melaksanakan pemetaan dan penyetempatan di tempat yang dikenali, tidak diketahui, serta persekitaran dalaman yang berstruktur. Penggunaan laser secara tunggal ini boleh menolak kaedah penggunaan multi penderia dalam satu system untuk melaksanakan pemetaan dan penyetempatan. Sebuah robot mudah alih kawalan jauh telah diperkukuhkan dengan RP Lidar bagi membolehkan ia berfungsi secara autonomi. Pemetaan dan penyetempatan algoritma telah dibangunkan menggunakan pendekatan imbasan pemadatan dan mengeksploitasi pengimbasan kelajuan tinggi RP Lidar. KNN dan algoritma berasaskan peraturan telah diuji secara simulasi dan dalam persekitaran yang sebenar. Penilaian juga telah dilakukan terhadap sistem ini pada persekitaran dalaman yang berstruktur dan statik. Keputusan ujian menunjukkan bahawa sistem robot mudah alih berjaya memperolehi lokasi dirinya dengan ketepatan yang tinggi, iaitu, 90% dan ke atas. Selain itu, ia mampu untuk mengemudi ke lokasi sasaran dalam persekitaran statik. Pemetaan robot mudah alih dan sistem penyetempatan dengan penggunaan tunggal laser RP Lidar dapat menggantikan pendekatan menggunakan kaedah multi penderia dalam satu system dan ia juga berjaya menjalankan fungsinya dengan ketepatan yang tinggi untuk persekitaran statik.

The Mobile Robot System for Mapping and Localisation Utilising Single Laser Range Finder in Static Environments

ABSTRACT

A mobile robot system with the ability to perform mapping and localisation has the potential to be applied in various applications such as indoors and outdoors, known and unknown, offline and real time as well as static and dynamic environments. At present, implementations for these mobile robots utilise ultrasonic, infrared, RFID and similar sensing modalities. However, such implementations have severe limitations including the need of reference for localisation, high computational requirements, slow processing due to sensing requirements and may also be less accurate. Hence, this thesis proposes the utilisation of single laser range finder for mobile robot mapping and localisation system for static. The laser range finder used is the RP lidar, and its utilisation enables the mobile robot to perform the mapping and localisation in known, unknown, as well as structured indoor environments. The implementation of the laser range finder negates the need of multiple sensing modalities to perform the mapping and localisation. A remote control mobile robot was augmented with a single RP Lidar laser range finder and transformed to enable it to function autonomously. The mapping and localisation algorithm were developed using scan-matching approach and exploits the high-speed scanning of the RP Lidar. KNN and rule-based algorithm were implemented for decision making and the testing was performed both in simulation and as well as real world in real time. The evaluations of the proposed system were performed in static and structured indoor environments. The results of the testing showed that the mobile robot system was able to perform self-location with high accuracy, 90% and above. Also, it was able to navigate to the target location in static dynamic environments. The mobile robot mapping and localisation system with the use of single RP lidar laser range finder was able to replace the multiple sensing modalities approach and it was able to perform with high accuracy for static environments.

CHAPTER 1

INTRODUCTION

1.1 Introduction

During the last few decades, there has been an increase in the implementation of mobile robot systems to assist humans. These applications of mobile robots include operations in hazardous and volatile environments unsuitable for human operators such as underwater pipe investigations. Also, the benefits of using mobile robots have the additional advantage of possible higher accuracy and speed of operation.

The use of mobile robots has also seen successful implementations in various fields, such as home appliances (Roomba, 2016), military (Karthikeyan; Bolton, 2015), exploration (Tack, 2012; Clemens, 2016), search and rescue (Kunjin, 2012), tracking (Abel, 2004; Ivanjko, 2005; Huili, 2011) and positioning (Ghidary, 1999).

In mobile robot system, mapping and localisation can be considered as priority parts. Both are usually incorporated together in order to facilitate the mobile robot to move in a particular environment autonomously. Also, they can be applied to expand capability and function of a mobile robot. For example, in order to move to a target, a mobile robot needs information regarding its position and target position. Therefore, to get position information, an environment information is needed. The environment information can be represented in a map form. Based on the map, a mobile robot is able to locate itself in the environment. Also, it can estimate the path to the target. This

example shows how the mapping and localisation is important to assist a mobile robot to navigate autonomously in an environment.

Many studies have been conducted to develop and design the mapping and localisation algorithms, methods and techniques in order to ensure a mobile robot is able to work accordingly. Most of the algorithms, methods and techniques that have been proposed and developed cannot work in general field, for example, indoor mapping algorithm cannot work for outdoor environment. In other word, most of the developed algorithm only can be applied in specific application and environment.

Recent studies regarding mobile robot for mapping and localisation system can be considered to have advanced with better technology. The applications are as expansive as mentioned above. This phenomenon occurs with the growing sensing modality technology, computerisation and the advent of new electronic devices. Also, it is expected to grow continuously.

The advancement of these technologies allows the mobile robot system to be used in wider research and applications as well as to solve many issue and problems. Even though the new technologies help to solve the mobile robot problems, it is still lacking especially in unstructured mapping, dynamic localisation, and large-scale environment. This thesis approaches issues regarding utilisation of single sensing modality for mapping and localisation and a strategy to build an accurate reference map.

1.2 Problem Statements

Based on previous and recent studies, there are many approaches and methods to set up a mobile robot system for mapping and localisation. As environment and issues to be solved are determined, a mobile robot system can be set up.

Typically, the research work on mapping and localisation system and algorithm development is based on these three subjects:

- i. Mapping based on known pose.
- ii. Localisation based on the reference map.
- iii. Simultaneous localisation and mapping (SLAM)

Each subject carries its own issues and solution methods. Step (i) and step (ii) are related and they are also known as the fundamental technique to create the localisation algorithm. Here, the known pose is defined as the mobile robot scanning position. It is recognised and initialised at the early stage of work. Based on the scanning results at these known pose, the environment map can be constructed and is known as reference map. Finally, the reference map is used to localise the mobile robot position based on its current scanning.

Next, SLAM is describable as a technique where the mobile robot needs to map and localise its position at the same time. Most of the mobile robot system and its algorithm are considered complicated with high computational demands. The main requirement for this system is fast processing in terms of its scanning ability and data processing capacity. The use of this system can provide benefits to many applications, especially in exploration (Clemens, J., 2016).

However, each subject has their own limitations. For mapping based on known pose, there are a few issues:

- i. To acquire accurate environment scanning results.
- ii. To construct precise map (local and global map).
- iii. To construct the global map based on a merger of the local maps.

These issues are highlighted because they may influence the accuracy and inaccuracy of the whole localisation results. The localisation process needs the local and global maps (reference maps) to estimate the mobile robot position. Furthermore, the global map can show the mobile robot position in the whole environment and the local map is used to estimate the mobile robot position based on its current scanning.

Basically, there are no specific or proper methods on building a global and reference map. Previous studies have shown that the methods are dependent on the environment, the application and implementation. For example, the global map development is based on the merging of local maps. The scanning position meanwhile may have several inaccuracies due to the mobile robot movement or the weakness of the sensors' capability. Then, there is also a need for a method to correct the scanning results so that the map is accurate and can be matched to the real environment.

The issue regarding the local map is related to the number and size of the map. This is because there are no previous studies that had proposed a formula on how to get the number of local maps about the size of the environment. The reason is similar to the method of building the reference map, which is dependent on the application and implementation.

The main issue regarding localisation is algorithm. Typically, there are three types of methods to construct the localisation algorithm:

- i. Scan matching method
- ii. Probability method
- iii. Kalman filter

These algorithms are applied to calculate and estimate the mobile robot position based on the sensor scanning results and the reference maps. General issues that are related to the localisation algorithms are described below:

- i. Improve the accuracy of the mobile robot position.
- ii. Optimisation of the sensor scanning results.
- iii. The computational complexity to the simple and fast data processing.
- iv. Ability to apply in various environment and situation.
- v. Dynamic localisation.
- vi. Real time result.

Based on step (i) and (ii), as well as the mapping and localisation issue, it can be concluded that the fundamental technique still has limitations and it can be improved and optimised using appropriate sensors and methods.

Basically, the key point in mapping and localisation system is the utilisation of reference and without reference. The reference can be defined as the surrounding information that is obtained from the information source, and the source is not from the mobile robot system. It can be a beacon, a sensor as well as a priori map. Essentially, if the priori map is used, then the environment is classified as a known environment.

For researchers that utilised beacons such as wireless sensor network (WSN), such as Mansor, H. (2012), the beacon would provide communication signal such as signal-to-noise-ratio (SNR) and received-signal-strength-indicator (RSSI) to its group. Then, based on these signals, each beacon in the group may determine the location of others beacons. Unfortunately, this set up has limited application which only provides the system to work in a specific and known environment. This also happens to the system which utilises a priori map. It is limited to a known environment.

Some researchers avoid using the reference method as described previously. The set up requires the mobile robot to be independent and depend on itself. At this stage, researchers utilise multiple sensors or multi types of sensors to support the mobile robot to make decision in terms of motion, navigation and position estimation of a target as well as itself. Moreover, this system appears smart and very promising in accuracy and reliability. Also, it is able to attain benefits from all the sensors and improve each sensor's limitation. However, it is limited by its high cost and high computational need because of the slow data processing.

Recently, some researchers have introduced the use of single sensor for the mobile robot mapping and localisation system. This is due to the sensing modality technology that have grown and successfully developed high accuracy and reliability. The most common sensors that are used are ultrasonic and laser range finder. However, ultrasonic sensors must be used with multiple ultrasonic in the system. This is due to the disability of single ultrasonic to perform 360° scan of surrounding area, unless, it includes a motor to allow the ultrasonic to be able to rotate and perform scanning. Yet, the scanning process is quite slow due to the signal transmission between the transceiver in the ultrasonic sensor. Hence, the system mostly fails to achieve real time system.

For the laser range finder, it has proven to be most popular among researchers due to the fast sampling processing which is able to get 2000 data per second. Unfortunately, it is very costly, for instance a laser range finder with four meter scanning range is about MYR 8000. Also, the cost increases as the range expands.

Nevertheless, an alternative new laser range finder is available, called RP lidar. It is developed in 2012 by Robopeak from China. The company managed to develop a relatively inexpensive laser range finder that costs only MYR 1900. As an added advantage, the scanning range is up to six meters. Hence, this thesis proposes to work

with the implementation of a single laser range finder, the RP Lidar for mobile robot mapping and localisation system that enables it to work as a real time system in known and unknown, static and dynamic indoor environment.

1.3 Research Objectives

The main objective of this research is to propose for the utilisation of single laser range finder for mobile robot mapping and localisation system that would be able to work in a static environment.

Based on the main objective, several sub-objectives are laid down to support the main objective:

- i. To construct proper steps on building reference map and a global map.
- ii. To develop a localisation algorithm that is based on the single laser range finder scanning data and enable it to work in real time system.
- iii. To implement the mobile robot that would be able to work in static environment with referring to the developed localisation algorithm results.