



**UNIVERSITI PUTRA MALAYSIA**

**TOPOLOGICAL MAPPING AND QUALITATIVE LOCALIZATION  
BASED ON K-ADJACENT UNION CLUSTERING ALGORITHM**

**BABAK KARASFI**

**ITMA 2012 12**

**TOPOLOGICAL MAPPING AND QUALITATIVE LOCALIZATION BASED  
ON K-ADJACENT UNION CLUSTERING ALGORITHM**



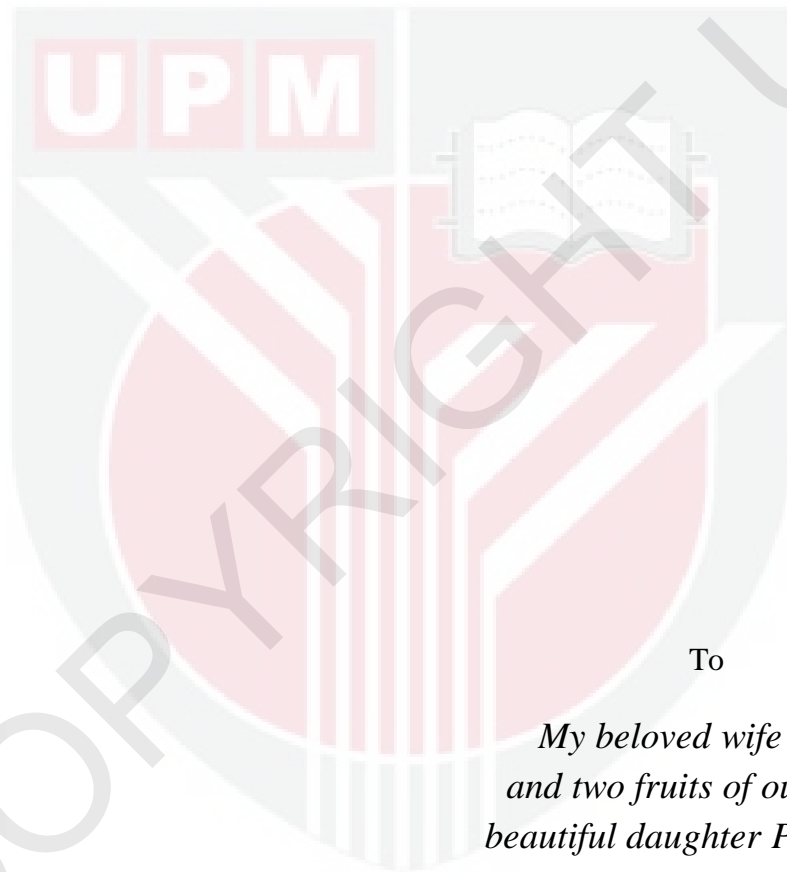
By

**BABAK KARASFI**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra  
Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of  
Philosophy.**

**October 2012**

## DEDICATION



To

*My beloved wife Afsaneh  
and two fruits of our lives my  
beautiful daughter Parmida and  
my sweet son Bardia*

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of doctor of philosophy

**TOPOLOGICAL MAPPING AND QUALITATIVE LOCALIZATION  
BASED ON K-ADJACENT UNION CLUSTERING ALGORITHM**

By

**BABAK KARASFI**

October 2012

**Chairman: Associate Professor Tang Sai Hong, PhD**

**Faculty: Institute of Advanced Technology**

In robotic applications, localization and mapping as parts of the navigation system are fundamental competence for mobile autonomous systems. The position of the mobile robot is known as qualitative localization inside a topological map, where the place recognition is an essential problem to overcome. Previously, supervised place recognition approaches have been used to solve global localization in offline mode. The aim of this thesis is to develop a mobile robot topological mapping and qualitative localization method based on unsupervised and fully appearance-based place recognition approach. In this research, two different methods are designed and implemented to answer the aim of this thesis. These methods focus on perspective or omnidirectional image similarity based on local features or the

combination of global and local features which are identified as speed-up robust feature (SURF) and hue saturation intensity (HIS) color histogram. Moreover, proposed methods are spatial and sequential based place clustering methods (unsupervised learning) which are try to find the representative image that is more similar to the current adjacent robots query image. Therefore, the topological map graph of the place clusters can be created and qualitative localization can be performed over the topological map graph.

According to the experimental results, the average of recognition precision for the first offline proposed method is 95% and in a different illumination condition is 86%. Moreover this performance in the kidnapped robot experiment is more than 90%. The average of online place recognition percentage for the second online, incremental and expandable proposed method is 93.56% and in different illumination conditions is 86.06%. In addition, the average performance of the topological mapping and qualitative localization results, obtained from expanded-environment experiments is 91.71%. Considering all results, the proposed topological mapping and qualitative localization methods are robust, accurate, cost effective, portable, low power consumption, low weight, easy to install without any camera calibration and can be applied on various mobile robot platforms.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PEMETAAN TOPOLOGI DAN PENYETEMPATAN KUALITATIF  
BERDASARKAN ALGORITMA PENGELOMPOKAN KESATUAN  
K-BERSEBELAHAN**

Oleh

**BABAK KARASFI**

October 2013

**Pengerusi: Profesor Madya Tang Sai Hong, PhD**

**Fakulti: Institut Teknologi Maju**

Dalam aplikasi robotik, penyetempatan dan pemetaan sebagai sebahagian daripada sistem navigasi adalah kecekapan asas bagi sistem mudah alih autonomi. Kedudukan robot mudah alih dikenali sebagai penyetempatan kualitatif di dalam peta topologi di mana pengiktirafan tempat adalah satu masalah yang penting untuk diatasi. Sebelum ini, pendekatan pengiktirafan tempat diselia telah digunakan untuk menyelesaikan penyetempatan global dalam mod luar talian. Tujuan tesis ini adalah untuk membangunkan satu kaedah pemetaan topologi robot mudah alih dan penyetempatan kualitatif berdasarkan pendekatan tanpa pengawasan dan pengiktirafan tempat yang berasaskan penampilan sepenuhnya. Oleh itu, dua kaedah yang berbeza direka dan dilaksanakan untuk menjawab matlamat tesis ini. Kaedah-kaedah ini

memberi tumpuan kepada perspektif atau persamaan imej berbilang-haluan berdasarkan ciri tempatan atau kombinasi ciri-ciri global dan tempatan yang dikenal pasti sebagai cirri peningkatan kelajuan teguh (SURF) dan keamatan warna tepu (HIS) histogram warna. Selain itu, kaedah yang dicadangkan adalah ruang dan berurutan kaedah berasaskan kelompok tempat (pembelajaran tanpa pengawasan) yang cuba untuk mencari imej wakil yang lebih serupa dengan robot semasa pertanyaan imej bersebelahan. Oleh itu, graf peta topologi kelompok tempat boleh dicipta dan penyetempatan kualitatif boleh dilakukan di graf peta topologi.

Menurut keputusan eksperimen, purata ketepatan pengiktirafan bagi kaedah pertama offline dicadangkan ialah 95%; dalam keadaan pencahayaan yang berbeza adalah 86% dan dalam eksperimen robot diculik adalah lebih daripada 90%. Purata peratusan pengiktirafan tempat dalam talian untuk kaedah kedua yang dicadangkan dalam talian, peningkatan dan diperkembangkan adalah 93.56% dan dalam keadaan pencahayaan yang berbeza adalah 86.06%. Di samping itu, prestasi purata pemetaan topologi dan keputusan penyetempatan kualitatif, yang diperolehi dari eksperimen diperluaskan-persekitaran adalah 91.71%. Memandangkan semua keputusan, cadangan pemetaan topologi dan kaedah penyetempatan kualitatif adalah teguh, tepat, kos efektif, mudah alih, penggunaan kuasa yang rendah, berat badan yang rendah, mudah untuk memasang tanpa

penentuan sebarang kamera dan boleh digunakan pada pelbagai platform robot mudah alih.





## ACKNOWLEDGEMENTS

The journey of completing and finalizing this thesis has been challenging and exciting. My warm gratitude goes to the people who inspired me and helped in many ways. Foremost, I would like to express my sincere gratitude to my supervisor Associate Prof. Dr. Tang Sai Hong for the continuous support of my Ph.D study and research, for his patience, motivation, enthusiasm, immense knowledge and for the invaluable freedom I had in my research. His guidance helped me throughout the research and writing of this thesis. Besides my supervisor, I am deeply grateful to my co-supervisors Associate Prof. Dr. Abd Rahman Ramli and Dr. Khairulmizam Samsudin for their advices, valuable technical discussions and constructive criticisms.

The long, hard process of completing a thesis would have been completely impossible without the support of many friends and colleagues at Institute of Advanced Technology and Qazvin Azad University. I would also like to thank to my brother Behruz Karasfi for his help, support and friendship. Last but not the least; I am grateful to my wife Afsaneh, my daughter Parmida and my little son Bardia for their love and valuable support.

**Babak Karasfi**

## APPROVAL

I certify that a Thesis Examination Committee has met on 23 Oct 2012 to conduct the final examination of Babak Karasfi on his thesis entitled "**TOPOLOGICAL MAPPING AND QUALITATIVE LOCALIZATION BASED ON K-ADJACENT UNION CLUSTERING ALGORITHM**" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy (PhD.).

Members of the Thesis Examination Committee were as follows:

**Dr. Mohd Nizar b Hamidon, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Dr. Ishak bin Aris, PhD**

Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Member)

**Dr. Mohammad Hamiruce Marhaban, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Member)

**Dr. Kar-Ann Toh, PhD**

Professor  
School of Electrical and Electronic Engineering  
Yonsei University  
Korea / Singapore  
(External Member)

---

**SEOW HENG FONG, PhD**

Professor and Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 21 March 2013

This thesis was submitted to the senate of Uiversiti Putra Malaysia and has been accepted as fulfillment of the requirement of the degree of Doctor of Philosophy.

The members of the supervisory committee were as follows:

**Dr.Tang Sai Hong, PhD**  
Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Dr.Abdul Rahman b. Ramli**  
Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

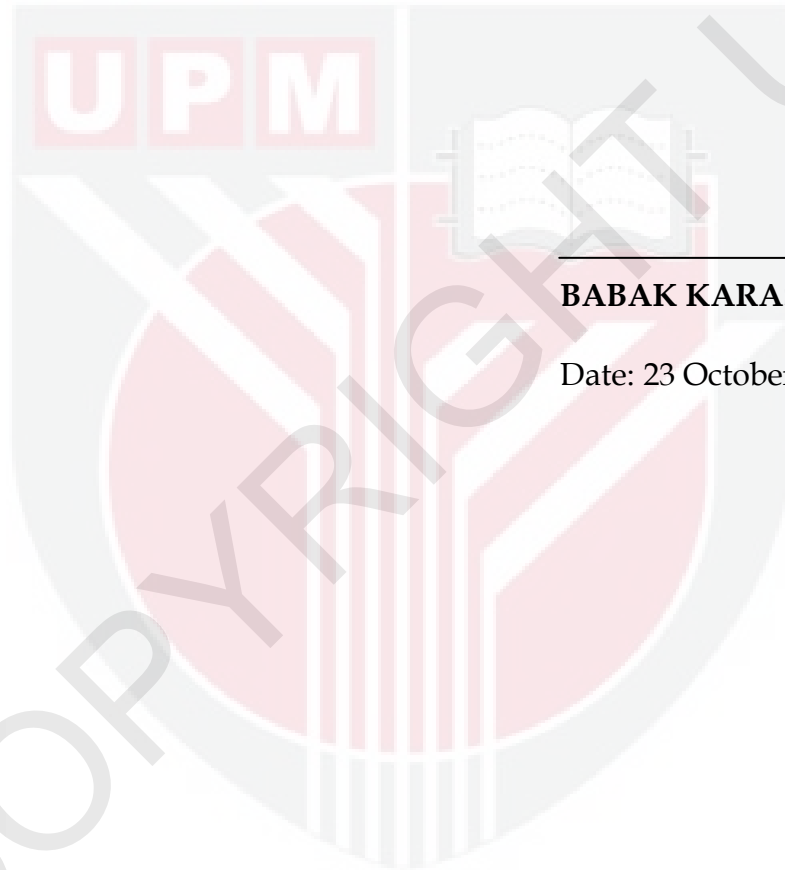
**Dr.Khairulmizam b. Samsudin**  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

---

**BYJANG BIN KIM HUAT, PhD**  
Professor and Dean  
School of Graduate Studies  
University Putra Malaysia  
Date:

## DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.



---

**BABAK KARASFI**

Date: 23 October 2012



## TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENTS	viii
APPROVAL	x
DECLARATION	xi
TABLE OF CONTENTS	xii
LIST OF TABLES	xv
LIST OF FIGURES	xvi
LIST OF ABBREVIATION	xviii
<b>CHAPTER</b>	
<b>1 INTRODUCTION</b>	<b>1</b>
1.1 Background of the Study	1
1.2 Problem Statement	6
1.3 Objectives of the thesis	9
1.4 Scope of the study	10
1.5 Thesis Contributions	12
1.6 Thesis outlines	13
<b>2 LITERATURE REVIEW</b>	<b>15</b>
2.1 Mobile Robot	15
2.2 Concept of Mobile Robot Navigation	17
2.3 Robot's Environments and Sensor Categories	21
2.3.1 Sensor Categories	21
2.3.2 Global versus Local Mapping and Localization	23
2.3.3 Qualitative versus Quantitative Mapping and localization	25
2.4 Map Representations	27
2.4.1 Metric Maps	28
2.4.2 Topological Maps	29
2.5 Image Features	31
2.5.1 Local Features	32
2.5.2 Global Features	36
2.6 Appearance-based Mapping and Localization Methods	41
2.6.1 Object-Based Place Recognition	42
2.6.2 Scene-Based Place Recognition	44
2.7 Summary	49

<b>3</b>	<b>METHODOLOGY</b>	<b>51</b>
3.1	Introduction	52
3.2	SURF Vs. SIFT Local features	57
3.3	Topological Mapping and Qualitative Localization Based on K-Adjacent-Union Place Clustering Algorithm	59
3.3.1	Scene change detection	59
3.3.2	Union of local Features	61
3.3.3	Sequence adjacent characteristic of robot places	63
3.3.4	The K-Adjacent-Union Place Clustering Algorithm	64
3.3.5	Mobile Robot Qualitative Localization based on K-adjacent-union Place Clusters (Topological-Map)	66
3.4	Topological Mapping and Qualitative Localization Based on Online Incremental and expandable Place Clustering method	70
3.4.1	Key-Images Selection Method	71
3.4.2	Distance Measurement Based on Global and Local Features	76
3.4.3	Clusters Permanence Rate	82
3.4.4	Cluster Kernels Update Procedure	83
3.4.5	Online Incremental and expandable Place Clustering Method Based on Combination of Global and Local Image Features	85
3.5	Validation of Proposed Methods	90
<b>4</b>	<b>EXPERIMENTAL RESULTS AND DISCUSSION</b>	<b>93</b>
4.1	Introduction	93
4.2	Experimental Results on The k-adjacent-union place clustering algorithm	94
4.2.1	Experimental Setup	95
4.2.2	Place Clustering Performance	98
4.2.3	Place Recognition Performance	102
4.2.4	Performance Analyses on Illumination Changes	103
4.2.5	Performance Analyses on Various Trajectories	106
4.2.6	Cluster-Kernels Feature Size Analyses	108
4.2.7	Performance on Robot Kidnapped Problem	110
4.3	Experimental Results of the Online Incremental and Expandable Place Clustering Method	112
4.3.1	Experimental Setup	112
4.3.2	Place Recognition Precision Performance	115
4.3.3	Place Recognition Time Consumption Performance	116
4.3.4	Performance Analyses on Memory Usage	119
4.3.5	Mapping and Qualitative Localization Performance	121
4.3.6	Performance Analyses on Illumination Changes	126
4.3.7	Performance Analyses on Expanded Environments	128
<b>5</b>	<b>CONCLUSION AND FUTURE WORKS</b>	<b>133</b>

5.1	Conclusions	133
5.2	Suggestion and Future Works	139
	<b>APPENDIX A:</b>	141
	<b>APPENDIX B:</b>	161
	<b>REFERENCES</b>	167
	<b>LIST OF PUBLICATIONS</b>	178



© COPYRIGHT UPM