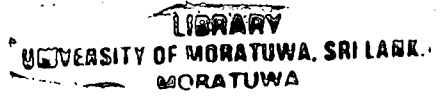


LIBRARY
UNIVERSITY OF MORATUWA, SRI LANKA
MORATUWA

**Integration of Fingerprinting and Trilateration Algorithms
for
Improved Indoor Localization**



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk



LB/DON/70/2012

Integration of Fingerprinting and Trilateration Algorithms for Improved Indoor Localization

This dissertation was submitted to the Department of Electronic & Telecommunication Engineering, University of Moratuwa in partial fulfillment of the requirements for the Degree of M.Sc. in Telecommunications



Supervisor

Prof. Dileeka Dias

Nilushika Shironi Kodippili

June, 2010

University of Moratuwa



102874

621.38⁵ 10¹⁰

621.39(043)

TH

102874

DECLARATION

I certify that this dissertation does not incorporate without acknowledgement any material previously submitted for a degree in any University to the best of my knowledge and believe that it does not contain any material previously published, written or orally communicated by another person or myself except where due reference is made in the text. I also hereby give consent for my dissertation, if accepted, to be made available for photocopying and for inter-library loans, and for the title and summary to be made available to outside organizations.

UOM Verified Signature

Signature of the Candidate

Date: June, 2010



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

To the best of my knowledge, the above particulars are correct.

UOM Verified Signature

Supervisor

ABSTRACT

Integration of Fingerprinting and Trilateration Algorithms for Improved Indoor Localization

Nilushika Shironi Kodippili, Dept. of Electronic and Telecommunication Engineering
Supervisor: Prof. Dileeka Dias

Keywords: Indoor localization, positioning algorithm, positioning accuracy, performance indicators, commercial applications, fingerprinting, trilateration, deployment, radio propagation

Many useful commercial, educational, security and health-care applications of location-awareness related to navigation, tracking and detection of people and objects have been developed through out the history. However the demand for the location information has been limited to outdoor applications until many indoor localization requirements appeared recently with the emergence of ubiquitous computing.

The indoor applications inherently call for higher positioning accuracy than those of outdoor. The existing sophisticated outdoor localization techniques like A-GPS do not perform satisfactorily in indoors due to the poor satellite signal coverage and the signal propagation complexities in indoor environments. On the other hand, though a number of different indoor techniques have been implemented and tested hitherto, none of those techniques have displayed satisfactory overall performance adequate for large scale deployment of commercial applications.

The key performance indicator of positioning techniques is the positioning accuracy, which is quantified in terms of error distance. This research was focused on integrating two existing basic positioning algorithms, fingerprinting and trilateration, with a view to improving the performance with respect to positioning accuracy as well as cost, complexity, response time and implementation aspects etc.

The fingerprinting has been used to identify few locations of known coordinates and signal strengths, closer to the target location. The final position estimation is done by applying the trilateration technique over the range between the selected known locations and the target location. The signal propagation model employed in this technique reproduces the real signal propagation behaviour accurately since it is being applied over a short range and hence the distances calculated using the signal propagation model are fairly accurate. Consequently a better estimation of the location can be derived without getting affected by typical practical problems associated with unpredictable nature inherent to the radio signal propagation.

This research thesis describes the design and implementation of the proposed integrated algorithm in an indoor WLAN environment to evaluate its performance in comparison with the basic techniques it is derived from. The proposed technique estimates the location of an object accurately within 1.1 m in less than a second with manageable training grid size at almost no additional cost. The overall satisfactory performance suitable for generic commercial applications demonstrated by the proposed technique could be a good foundation for ubiquitous deployment of indoor localization applications.

DEDICATION

To all who encouraged me to pursue my higher studies



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

ACKNOWLEDGEMENTS

I am grateful to my close friends Walpola, Sandamalee, Kasuni and Ganesh, those who emphasized that I should pursue my higher studies in parallel to busy office schedules I have been involved with in relation to my job at Sri Lanka Telecom.

I express my gratitude to management of Sri Lanka Telecom who released me on Fridays on study leave to attend to lectures conducted at university of Moratuwa during the first academic year of the MSc degree course.

I thank my colleagues in the MSc batch, Amritha, Anagi, Deviga, Damith and Sameera who shared the knowledge and valuable resources with me during the entire time period of studies.

My heartfelt gratitude is expressed to Prof. Dileeka Dias who has been my favourite teacher since my undergraduate studies though she is unaware of it, for her kindness, support, understanding which put me on the right track from time to time. She has been a great backup throughout all this time for successfully completing the course requirements as well as the research work under her supervision. I am still amazed about her humbleness and humanity. I wonder being such a highly reputed intellectual in the country bound by a tight routine how down to earth she is and how easily she spares her valuable time answering our problems.

I sincerely thank my teachers at university of Moratuwa, specially Dr. Pasqual, Mr. Kithsiri Samarasinghe and Dr. Thilakumara who extended their helping hands whenever needed.

I convey my special thanks to Prof. Mrs. Dayawanse, though she did not directly involve with my post graduate studies, who extended her kind wishes and encouragements from the time she provided a recommendation on me for the enrolment to MSc course to date whenever I met her on the way.

I thank and much appreciate the non-academic staff of the department, who always provided their fullest support in every matter their help was needed in such a cordial

manner which is not a behaviour frequently found in typical government office environment.

Kasun Pathirana who I convey my special thanks to, has been more a brother than a friend who helped me with the development of the software application related to my research work.

I appreciate my good friends Nadira, Bindu, Kosala and Thusitha those who inquired on the progress of my studies and the research work from time to time and encouraged me to complete the MSc degree.

Finally it is with deepest gratitude and love that I remember my parents, the two sisters and younger brother for all their love, dedication and support on my education all over the time without which I would not have been in this position today.



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

TABLE OF CONTENTS

DECLARATION.....	III
ABSTRACT.....	IV
DEDICATION.....	V
ACKNOWLEDGEMENTS.....	VI
TABLE OF CONTENTS.....	VIII
LIST OF FIGURES	XIII
LIST OF TABLES	XV
INTRODUCTION.....	1
1.1 BACKGROUND.....	1
1.2 LITERATURE SURVEY.....	2
1.3 PERFORMANCE INDICATORS.....	5
1.3.1 Accuracy.....	5
1.3.2 Precision.....	6
1.3.3 Cost	6
1.3.4 Ease of deployment.....	7
1.3.5 Complexity.....	7
1.3.6 Response time	7
1.3.7 Efficiency	7
1.3.8 Scalability.....	8
1.3.9 Availability.....	8
1.4 SCOPE OF THE RESEARCH.....	8
1.5 IMPLEMENTATION OF THE PROPOSED ALGORITHM	9
1.6 OUTCOME	12
1.7 ORGANIZATION OF THE THESIS	13
POSITIONING TECHNIQUES AND SYSTEMS.....	14
2.1 INTRODUCTION.....	14
2.2 GLOBAL POSITIONING SYSTEM (GPS).....	14
2.3 WLAN BASED LOCALIZATION TECHNIQUES	14

2.3.1	Cell Identification.....	15
2.3.1.1	Functionality	15
2.3.1.2	Performance	15
2.3.2	Trilateration.....	16
2.3.2.1	Functionality	16
2.3.2.1.1	Signal propagation model	18
2.3.2.2	Performance	19
2.3.3	Fingerprinting.....	20
2.3.3.1	Functionality	20
2.3.3.1.1	KNN algorithm	21
2.3.3.2	Performance	22
2.3.4	Neural Networks	23
2.3.4.1	Functionality	23
2.3.4.2	Performance	24
2.3.5	Robot Localization.....	24
2.3.5.1	Functionality	24
2.3.5.1.1	Global localization	25
2.3.5.1.2	Pose maintenance	26
2.3.5.2	Performance	27
2.4	IMPROVEMENTS TO LOCATION FINGERPRINTING ALGORITHM.....	28
2.4.1	KWNN (K weighted nearest neighbours, $k \geq 2$).....	28
2.4.2	Viterbi-like algorithm for continuous user tracking.....	28
2.4.3	AP based environmental profiling scheme	30
2.4.4	Radio Map Locations Clustering	31
2.4.4.1	Explicit Clustering (Joint Clustering)	31
2.4.4.2	Implicit Clustering (Incremental Triangulation algorithm)	31
2.4.5	Light AP.....	32
2.4.6	Extension to 3D space.....	32
2.4.7	Interpolated Map Grid (IMG)	33
2.4.8	Hybrid method of fingerprinting and trilateration	33
2.5	WLAN BASED LOCATION SUPPORT SYSTEMS.....	34
2.5.1	RADAR.....	35
2.5.2	The Horus System.....	35

2.5.3	3D-iD (Pin-Point) RF Tag System.....	35
2.5.4	The Daedalus project.....	36
2.6	CELLULAR MOBILE NETWORKS BASED LOCATION SUPPORT SYSTEMS	36
2.6.1	Place Lab system.....	37
2.7	INFRARED BASED LOCATION SUPPORT SYSTEMS.....	37
2.7.1	Active Badge.....	37
2.8	ULTRASOUND BASED LOCATION SUPPORT SYSTEMS.....	38
2.8.1	Cricket.....	38
2.8.2	Active Bat.....	39
2.9	OTHER COMMERCIAL SYSTEMS	39
2.9.1	SpotON.....	39
2.9.2	Easy Living	39
2.9.3	Smart Floor	40
2.9.4	Motion Star	40
PROPOSED POSITIONING ALGORITHM.....		41
3.1	OVERVIEW.....	41
3.2	INITIAL APPROXIMATION OF THE LOCATION.....	41
3.3	FRAMEWORK FOR THE FINAL LOCATION ESTIMATION	42
3.4	FINAL ESTIMATION OF LOCATION	44
3.4.1	Event no.1	46
3.4.1.1	Event no. i	47
3.4.1.2	Event no.s ii, iii and v.....	48
3.4.1.3	Event no.s iv, vi and vii.....	49
3.4.1.4	Event no. viii	50
3.4.2	Event no.s 2, 3 and 5	51
3.4.2.1	Event no. i	51
3.4.2.2	Event no. ii and iii.....	52
3.4.2.3	Event no. iv	53
3.4.3	Event no.s 4, 6 and 7	53
3.4.3.1	Event no. i	54
3.4.3.2	Event no. ii	55
3.4.4	Event no.8	55



3.5	OTHER IMPLEMENTED ALGORITHMS.....	57
3.5.1	KNN for $K=1,2,3,4$	57
3.5.2	KWNN for $K=1,2,3,4$	58
SYSTEM ARCHITECTURE.....		59
4.1	HARDWARE AND SOFTWARE MODULES.....	59
4.1.1	Terminal based approach	59
4.1.2	Test bed	59
4.1.3	Application software	60
4.1.3.1	Training phase	60
4.1.3.2	Positioning phase	62
4.1.3.3	Analysis phase.....	63
4.2	METHODOLOGY	64
4.2.1	Training the system with RP coordinates.....	64
4.2.2	Measurement of RSS	66
4.2.3	Database generation	67
4.2.4	Positioning testing.....	70
4.2.5	Testing data analysis	71
EXPERIMENT AND RESULTS ANALYSIS		73
5.1	TEST SCENARIOS	73
5.1.1	Identifying the applicable path loss exponent (n)	73
5.1.2	Identifying the attenuation loss (L_a) of the environment.....	74
5.1.3	Positioning accuracy of the proposed technique compared to other techniques.....	74
5.1.4	Effect of the training grid size.....	74
5.1.5	Effect of number of samples per reference point	75
5.1.6	Effect of the orientation of the mobile terminal.....	75
5.2	TEST RESULTS ANALYSIS.....	75
5.2.1	Identifying the effect of L_a and n.....	75
5.2.2	Comparison of positioning accuracy and precision	76
5.2.3	Effect of grid size	77
5.2.4	Cumulative distribution of positioning error	78
5.2.5	Effect of number of samples per reference point	80

PRACTICAL PROBLEMS	82
6.1 INTRODUCTION	82
6.2 THE EFFECT OF WIRELESS CHANNEL CHARACTERISTICS	82
6.3 THE EFFECT OF DYNAMIC ENVIRONMENTAL CHANGES	83
6.4 DEPLOYMENT AND OPERATIONAL COST	84
6.5 SYSTEM TRAINING.....	84
6.6 ALIASING	85
6.7 EFFECT OF MULTIPLE CHANNELS.....	85
6.8 THE EFFECT OF MULTIPLE FLOORS.....	86
6.9 WIRELESS SECURITY	86
DISCUSSION	87
7.1 GENERIC PERFORMANCE REQUIREMENTS OF LOCALIZATION SYSTEMS.....	87
7.2 PERFORMANCE OF THE PROPOSED ALGORITHM	88
7.2.1 Positioning Accuracy	88
7.2.2 Precision of location estimation.....	88
7.2.3 Size of the training grid.....	89
7.2.4 Number of readings per location.....	89
7.2.5 Number of access points	90
7.2.6 Orientation of the mobile terminal.....	90
7.2.7 Simplicity, response time and cost.....	90
7.2.8 Limitations	91
7.3 GENERAL PRACTICAL ISSUES.....	91
7.3.1 Effect of WLAN characteristics.....	91
7.3.2 Aliasing	91
7.3.3 Temporal changes to signal strength.....	92
7.3.4 Effect of manufacture hardware.....	92
7.4 ENHANCEMENTS	92
7.5 CONCLUSION.....	93
BIBLIOGRAPHICAL REFERENCES	96

LIST OF FIGURES

Fig. 1.2.1. The architecture of RSS based positioning systems.....	4
Fig. 1.2.2. The function of KNN algorithm.....	5
Fig. 1.3.1. Accuracy and precision of positioning.....	6
Fig. 1.4.1. The basic concept of the proposed positioning algorithm.....	9
Fig. 1.5.1. Implementation of the proposed positioning technique.....	11
Fig. 2.3.1. Basic cell identification method.....	15
Fig. 2.3.2. Improved cell identification using TA information.....	16
Fig. 2.3.3. Lateration technique can be improved with AOA information.....	17
Fig. 2.3.4. Trilateration technique.....	17
Fig. 2.3.5. Database correlation in (a) KNN and (b) Probabilistic algorithms.....	21
Fig. 2.3.6 The function of neural networks method.....	24
Fig. 2.3.7. The basic function of robot localization.....	27
Fig. 2.4.1. The function of the Viterbi-like algorithm.....	29
Fig. 2.4.2. AP based environmental profiling.....	30
Fig. 3.3.1. Calculating the distance between the NN and the target position.....	43
Fig. 3.4.1. All possible cases resulting from the orientation and relative radii of the 3 circles... 44	44
Fig. 3.4.2. The layout of the proposed positioning algorithm.....	45
Fig. 3.4.3. Each 2 circles of all the 3 pairs either intersect (fully/partially) or just touch at one point.....	46
Fig. 3.4.4. Each 2 circles of all the 3 pairs either intersect partially or just touch at one point..	47
Fig. 3.4.5. Each 2 circles of 2 pairs either intersect partially or just touch at one point while the 2 circles of other pair intersect fully.....	49
Fig. 3.4.6. Each 2 circles of 2 pairs fully intersect while the 2 circles of the other pair either intersect partially or just touch at one point.....	50
Fig. 3.4.7. Each 2 circles of all 3 pairs fully intersect.....	50
Fig. 3.4.8. Each 2 circles of any 2 pairs either intersect (fully/partially) or just touch at one point while the 2 circles of the other pair are disintegrated.....	51
Fig. 3.4.9. Each 2 circles of the 2 intersecting pairs of circles either intersect partially or just touch at one point.....	52
Fig. 3.4.10. Two circles of one pair either intersect partially or just touch at one point while the 2 circles of the other pair fully intersect.....	52
Fig. 3.4.11. Each 2 circles of both intersecting pairs fully intersect.....	53
Fig. 3.4.12. Two circles of one pair either intersect (fully/partially) or just touch at one point while the circles of the other 2 pairs are disintegrated.....	54

Fig. 3.4.13. Two circles of the intersecting pair either intersect partially or just touch at one point.....	54
Fig. 3.4.14. The 2 circles of the intersecting pair fully intersect.....	55
Fig. 3.4.15. All the 3 circles are disintegrated from each other.....	56
Fig. 3.4.16. Centres of the circles are equally spaced.....	56
Fig. 3.4.17. Two pairs of centres are equally spaced and are closely spaced than the other pair.....	57
Fig. 3.4.18. Only one pair of centres corresponds to the shortest inter-circle distance.....	57
Fig. 4.1.1. Experimental set up.....	60
Fig. 4.1.2. Training the system with RP coordinates.....	61
Fig. 4.1.3. RSS Scan by Network Stumbler at RPs.....	62
Fig. 4.1.4. The Estimated location is indicated on the map.....	63
Fig. 4.1.5. Input the true location against the estimated location.....	64
Fig. 4.2.1. Small training grid used in the experiment.....	65
Fig. 4.2.2. Large training grid derived from the small training grid.....	65
Fig. 4.2.3. RSS scan being exported to a txt file.....	66
Fig. 4.2.4. The system training process.....	67
Fig. 4.2.5. Format of the table of RPs.....	68
Fig. 4.2.6. Format of the table of RSS.....	68
Fig. 4.2.7. Format of the table of positioning analysis data.....	69
Fig. 4.2.8. Format of the table of calculated Euclidean distances.....	69
Fig. 4.2.9. Format of table of calculated distances (R) between selected NNs and estimated position.....	70
Fig. 4.2.10. Tested positions.....	70
Fig. 4.2.11. Positioning Process.....	72
Fig. 5.2.1. Cumulative Distribution Function of error distance for small training grid.....	79
Fig. 5.2.2. Cumulative Distribution Function of error distance for large training grid.....	80
Fig. 5.2.3. The average relative RSS from different APs for varying scan time periods.....	80
Fig. 5.2.4. The average number of records per AP against the scan time period.....	81

LIST OF TABLES

Table 3.4.1. All possible events resulted from the check of intersection between each pair of circles.....	46
Table 3.4.2. Possible events from the check of whether circles intersect fully or partially	47
Table 3.4.3. Possible events from the check of whether the circles intersect fully or partially....	51
Table 3.4.4. Possible events from the check of whether the circles intersect fully or partially....	54
Table 5.2.1. Mean error distance (in m) for varying L_a and n values	76
Table 5.2.2. Error distance variance (in m) for varying L_a and n values	76
Table 5.2.3. Positioning accuracy (in m) obtained with different positioning algorithms	77
Table 5.2.4. Mean and variance of error distance (in m) for different training grid size	78
Table 5.2.5. Improvement of position estimation with reduced grid size.....	78



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk