University of Technology, Sydney
Faculty of Engineering & IT

LOCALISATION OF WIRELESS SENSOR NETWORK WITH MOBILE BEACON BY DYNAMIC PATH

By
Songsheng Li

Major: Computer and Communication
Supervisor: Dr. Xiaoying Kong
Co-supervisor: Prof. David Lowe

Submitted in partial fulfilment of the requirements for the degree of
Doctor of Philosophy

22 April 2013

STATEMENT OF ORIGINALITY

I, Songsheng Li, declare that I am the author of this document and that I have not used fragments of text from other sources without proper acknowledgment, and that theories, results and designs of others that I have incorporated into my report have been appropriately referenced and all sources of assistance have been acknowledged.

Signature:

Date: 22 April 2013

ABSTRACT

Small size and low-cost sensors are practicable because of evolution of the semiconductor field, which is led by increasing miniaturisation. They are still limited in processor capacity, memory size and energy resources; however, ubiquitous wireless is added to extend their communication capacity. Wireless sensor networks (WSN) are formed by large numbers of such sensors and can be used to monitor a field of interest in military and civilian areas.

The resulting data are only meaningful when combined with geographical position information of the sensors. Both the Global Positioning System (GPS) and the Global System for Mobile Communication (GSM) are hungry for energy and expensive, and are not suitable to be used extensively in every sensor. But localisation is essential in WSN, which should be implemented with help of some beacons that are equipped with GPS or GSM.

A mobile beacon (MB) is the replacement of many static beacons; it is movable and flexible and can be powerful so that some heavy computational mathematical methods (such as probability and graph theory) could be applied in an algorithm of localisation.

The walking path of a MB will determine the rate of coverage and accuracy of localisation. The static path is planned before action and is suitable for regular terrain; whereas, the dynamic path is decided in real-time action depending on the demand of unknown sensors, and is more efficient than the static path.

Concentrating on the algorithm of dynamic path to reach a better result in terms of accuracy, coverage, and trajectory of localisation in WSN, a framework of dynamic path of mobile beacon (DPMB) is proposed first, and then reinforcement learning (RL) is fit to the DPMB as the inner controller to improve the performance. Finally, direction is employed to assist the MB to find a better next position instead of distance in the DPMB. Simulations demonstrate that the performance is improved gradually.

ACKNOWLEDGEMENTS

I wish to express my gratitude to my supervisors Dr. Xiaoying Kong and Prof. David Lowe for their suggestions, logical way of thinking, encouragement and generous support. I would be lost without their guidance.

I would like to extend my appreciation to the administrative officers of the FEIT and UGS for their friendly support.

Finally, I wish to express my deepest gratitude to my family for helping me get through the difficult times. Without their encouragement, it would have been impossible for me to complete this research work.

CONTENTS

STATEMENT OF ORIGINALITY ..... **II**

ABSTRACT ..... **III**

ACKNOWLEDGEMENTS ..... **IV**

CONTENTS ..... **V**

LIST OF FIGURES ..... **VIII**

LIST OF TABLES ..... **XI**

LIST OF ABBREVIATIONS ..... **XII**

CHAPTER 1 ..... **1**

INTRODUCTION **1**

1.1. Topic overview 1

1.2. Motivation and Objectives 3

1.2.1. Motivation 3

1.2.2. Objectives 3

1.2.3. Research methodology 5

1.3. Thesis Overview 5

1.4. Related Publications 7

CHAPTER 2 ..... **9**

LITERATURE REVIEW: **9**

LOCALISATION OF WIRELESS SENSOR NETWORK **9**

2.1. Wireless Sensor Networks 9

2.2. Elements of Localisation 11

2.2.1. Beacon 13

2.2.2. Mobile Beacon 13

2.2.3. Distance Estimation 14

2.2.4. Position Computation 18

2.3. Algorithm of Localisation 21

2.3.1. Centralised Localisation 23

2.3.2. Range-based Localisation 24

2.3.3. Range-free Localisation 28

2.4. Localisation with a Mobile Beacon 31

2.4.1. Geometry 32

2.4.2. Perpendicular Bisector 35

2.4.3. Probability 38

2.4.4. Particle Filter 41
2.4.5. Static Path Planning 44
2.4.6. Dynamic Path Planning 46
2.4.7. Graph Theory 48
2.5. Summary 51
CHAPTER 3 52
FRAMEWORK FOR DYNAMIC PATH OF MOBILE BEACON 52
3.1. Introduction 52
3.2. Dynamic Path of Mobile Beacon in Localisation of WSN 53
3.2.1. Basic Concepts 53
3.2.2. Algorithm 55
3.3. Simulation 74
3.3.1. Setup for Simulation 74
3.3.2. Sample of Simulation 74
3.3.3. Settled Rate 75
3.3.4. Total Steps 79
3.3.5. Settled and Steps 80
3.4. Summary 82
CHAPTER 4 84
REINFORCEMENT LEARNING 84
4.1. Introduction 84
4.2. Reinforcement Learning in Localisation of WSN 85
4.2.1. Markov Decision Process 85
4.2.2. Reinforcement Learning 85
4.2.3. Reinforcement Learning and Dynamic Path of Mobile Beacon 90
4.3. Simulation 103
4.3.1. Sample of Simulation 103
4.3.2. Details of implementation 105
4.3.3. DPMB vs. RL 106
4.4. Summary 110
CHAPTER 5 112
VECTOR COSINE SIMILARITY 112
5.1. Introduction 112
5.2. Autonomous Mobile Beacon in Localisation of WSN 113
5.2.1. Assumption and Definition 113
5.2.2. Next Position on Group VCS 119
5.2.3. Position of Core Members 127

5.3. Simulation 129
5.3.1. R_m and Density 130
5.3.2. Starting Point 132
5.3.3. VCS vs. DPMB 133
5.4. Summary 136
CHAPTER 6 137
COMPARISON OF ALGORITHMS 137
6.1. Method 137
6.2. Results 139
6.3. Comparison with static path algorithms 140
CHAPTER 7 143
CONTRIBUTIONS AND FURTHER RESEARCH 143
7.1. Contributions 143
7.2. Limitations 144
7.3. Future research 145
REFERENCES 147

LIST OF FIGURES

Figure 1-1: Evolution to dynamic path of mobile beacon 2
Figure 1-2: Standard research flow 6
Figure 2-1: V_u and V_b in polar coordinate 14
Figure 2-2: TDoA 16
Figure 2-3: Position estimation with messages 18
Figure 2-4: Position computation using simultaneous equations of trilateration 18
Figure 2-5: The ideal and realistic result of trilateration 19
Figure 2-6: Multilateration 19
Figure 2-7: Bounding boxes 20
Figure 2-8: Triangulation 21
Figure 2-9: PinPoint ToA 24
Figure 2-10: Implementation of AoA 25
Figure 2-11: DV-distance in APS 27
Figure 2-12: Euclidean in APS 27
Figure 2-13: From beacon table to combined table 30
Figure 2-14: SCAN in APIT aggregation 31
Figure 2-15: ADO and moving pattern 33
Figure 2-16: RSS 34
Figure 2-17: Coordinate estimation 34
Figure 2-18: RSS moving pattern 35
Figure 2-19: Beacon point selection 36
Figure 2-20: Position of unknown sensor 37
Figure 2-21: RSSI as function of distance 38
Figure 2-22: PDF as function of distance when RSSI=77 38
Figure 2-23: Evolution of position estimation 40
Figure 2-24: Four static paths 45
Figure 2-25: Reference movement 47
Figure 2-26: Candidate area for two references 47
Figure 2-27: Candidate area for only one reference 48
Figure 2-28: Trajectory for BRF 50
Figure 2-29: Trajectory for BTG 50
Figure 3-1: Six next positions 54
Figure 3-2: Work flow 60
Figure 3-3: First triple positions 61
Figure 3-4: Unique position 66
Figure 3-5: No new target 70
Figure 3-6: Choice of next position 72

Figure 3-7: Simulation of DPMB 75
Figure 3-8: Distribution of settled $R_m = 8$ 76
Figure 3-9: Distribution of settled $R_m = 10$ 77
Figure 3-10: Distribution of settled $R_m = 12$ 77
Figure 3-11: Distribution of steps $R_m = 8$ 78
Figure 3-12: Distribution of steps $R_m = 10$ 78
Figure 3-13: Distribution of steps $R_m = 12$ 79
Figure 3-14: Coverage and distance $R_m = 8$ 80
Figure 3-15: Coverage and distance $R_m = 10$ 81
Figure 3-16: Coverage and distance $R_m = 12$ 81
Figure 3-17: Collective results for coverage and distance for Rm=8, 10 and 12 82
Figure 4-1: Reinforcement learning 86
Figure 4-2: States and actions in DPMB 90
Figure 4-3: Flow of RL 94
Figure 4-4: Samples of UN and SN 97
Figure 4-5: Problem of heard = 2 101
Figure 4-6: Problem of heard = 1 101
Figure 4-7: Bridge sensor 102
Figure 4-8: One simulation result of RL 104
Figure 4-9: Exploration heard = 2 105
Figure 4-10: Decision from DPMB 106
Figure 4-11: Decision from RL 106
Figure 4-12: 100 simulation results 107
Figure 4-13: 3D distribution of DPMB 108
Figure 4-14: 3D distribution of RL 108
Figure 4-15: Comparison of settled number 109
Figure 4-16: Comparison of steps 110
Figure 5-1: Six next positions and area 114
Figure 5-2: Relative position 114
Figure 5-3: Definition of group 117
Figure 5-4: Sub-steps in the method 118
Figure 5-5: Explanation of data mining 120
Figure 5-6: Actual distribution for Figure 5-3 122
Figure 5-7: Possible area of heard = 2 128
Figure 5-8: Total comparison of VCS from the corner 131
Figure 5-9: Total comparison of VCS from the centre 132
Figure 5-10: VCS vs. DPMB for R_m=10 134
Figure 5-11: CVS for R_m=10 135

Figure 5-12: DPMB for R_m=10 135
Figure 6-1: DPMB vs. RL vs. VCS 140
Figure 6-2: Steps for different algorithms 142

LIST OF TABLES

Table 2-1: Comparison of two particle algorithms 43
Table 2-2: Performance of the four static paths 45
Table 3-1: Message 55
Table 3-2: MBP 58
Table 3-3: Neighbour (NB) 58
Table 3-4: Heard 59
Table 3-5: Weight 69
Table 3-6: P and T matrix 72
Table 4-1: RL and DPMB 92
Table 4-2: Receiver (R) 96
Table 4-3: Average steps and settled number 109
Table 5-1: Receivers (R) in VCS 119
Table 5-2: Starting from the corner 130
Table 5-3: Starting from the centre 131
Table 5-4: VCS vs. DPMB in R_m=10 133
Table 6-1: Comparison of three algorithms 137
Table 6-2: Results of three algorithms in R_m=10 139

LIST OF ABBREVIATIONS

ADO	Arrival and Departure Overlap
AoA	Angle of Arrival
AoS	Area number of the Sensor
APIT	Approximate Point in Triangulation Test
APS	Ad Hoc Positioning System
BTG	Backtracking Greedy
BRF	Breadth-First
CoM	Count of Message
DPMB	Dynamic Path of Mobile Beacon
DV	Distance Vector
GPS	Global Positioning System
GSM	Global System for Mobile Communication
GSW	Group Similarity Weight
LMB	Localisation with a Mobile Beacon
MB	Mobile Beacon
MBAL	Mobile Beacon-Assisted Localisation
MBP	Mobile Beacon Position
MDS	Multidimensional Scaling
MLE	Maximum Likelihood Estimation
QoN	Quantity of Neighbours
PDF	Probability Distribution Function
RF	Radio Frequency
RL	Reinforcement Learning
RSS	Radio Signal Strength
RSSI	Received Signal Strength Indicator
SDP	Semidefinite Programming
SMC	Sequential Monte Carlo
ToA	Time of Arrival
TDoA	Time Different of Arrival
VCS	Vector Cosine Similarity
WSN	Wireless Sensor Networks