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SEARCH ALGORITHMS FOR PATH PLANNING PROBLEMS IN MULTIPLEWIRELESS SENSOR NETWORK ENVIRONMENT

HONG SIAW SWIN

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SEARCH ALGORITHMS FOR PATH PLANNING PROBLEMS IN MULTIPLE WIRELESS SENSOR NETWORK ENVIRONMENT

By

HONG SIAW SWIN

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SEARCH ALGORITHMS FOR PATH PLANNING PROBLEMS IN HARSH WIRELESS SENSOR NETWORK ENVIRONMENT

By

HONG SIAW SWIN

July 2017

Chairman : Shamala Subramaniam, PhD
Faculty: Computer Science and Information Technology

This dissertation presents three heuristic search algorithms which all of them descended from the origin Dijkstra's algorithm that solve multiple different problems arise from path planning in WSN environment. The three addressed problems are 1) long initial computation delay in dynamic environment, 2) slow reaction towards rapid change of goal points and massive number of node depending on single source of computational power, and 3) tradeoffs between optimality and computational effort to achieve optimality in TSP path planning problem. Literatures are reviewed, restructured in chronological form, and discussed. Open issues of reviewed algorithms had been briefed in this dissertation. In order to solve the addressed problem, this dissertation proposed three algorithms which are Enhanced D*, Natural Behaviour Navigation (NBN), and Frothing Waypoint Navigation (FWN). Each algorithm solves its respective problem with Enhanced D* solving long initial delay in dynamic environment, NBN solves harsh conditions with limited computational power, and FWN optimized the result of TSP path planning problem with minimal computational effort. Experiments have been done for each algorithm by comparing with other suitable algorithms. Multiple performance metrics have been defined and discussed for all experiments. The metrics included but not limited to the few following: Average Path Length, Initial Delay, Computational Time, Cell Visit, and so on. Finally, conclusion is drawn from the results of all experiments at the end of the dissertation and future works are proposed along.

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

ALGORITMA CARIAN UNTUK MASALAH PERANCANGAN PERJALANAN DALAM PERSEKITARAN *WIRELESS SENSOR NETWORK* YANG PENUH KEPAYAHAN

Oleh

HONG SIAW SWIN

Julai 2017

Pengerusi: Shamala Subramaniam, PhD
Fakulti: Sains Komputer dan Teknologi Maklumat

Disertasi ini membentangkan tiga algoritma carian heuristik yang kesemua adalah asal dari keturunan algoritma Dijkstra. Ketiga-tiga algoritma ini adalah bertujuan untuk menyelesaikan pelbagai masalah yang berbeza timbul dari perancangan perjalanan dalam persekitaran WSN. Tiga masalah yang ditangani adalah 1) penggunaan masa yang panjang semasa permulaan pengiraan dalam persekitaran yang dinamik, 2) tindak balas yang perlahan terhadap situasi penukaran titik matlamat yang amat pantas serta jumlah besar nod yang bergantung kepada sumber kuasa pengiraan tunggal, dan akhirnya 3) keseimbangan antara optimaliti dan keusahaan pengiraan untuk mendapatkan keputusan yang optimum dalam masalah perancangan perjalanan *TSP*. Literatur telah dikaji semula, disusun semula dalam bentuk kronologi, dan dibincangkan. Isu terbuka algoritma-algoritma telah dikaji dan diberikan penerangan dalam disertasi ini. Untuk menangani masalah yang ditunjukkan, ketiga-tiga algoritma yang dicadangkan dalam disertasi ini adalah *Enhanced D*, Natural Behaviour Navigation (NBN),* dan *Frothing Waypoint Navigation (FWN)*. Setiap algoritma menyelesaikan masalah masing-masing dengan *Enhanced D** menangani masalah penggunaan masa yang panjang dalam pengiraan untuk persekitaran dinamik, *NBN* menyelesaikan keadaan amat payah dengan kuasa penggiraan yang terhad, dan akhirnya masalah perancangan laluan *TSP* telah diselesaikan oleh *FWN* dengan usaha pengiraan yang amat minimum. Eksperimen telah dilakukan bagi setiap algoritma dengan membandingkan dengan algoritma lain yang sesuai. Pelbagai metrik prestasi telah ditetapkan dan dibincangkan untuk semua eksperimen. Metrik-metrik yang ditentukan adalah termasuk tetapi bukan terhadap seperti yang berikut: Purata Panjang Perjalanan, Kelewatan Pengiraan apabila Permulaan, Masa Pengiraan, Lawatan Sel, dan sebagainya. Akhirnya, kesimpulan telah disediakan pada bahagian terakhir disertasi ini dengan menggunakan keputusan-keputusan yang terdapat dalam eksperimen-eksperimen yang telah dibuat. Selain itu, keupayaan penambahan masa depan telah pun dibincangkan dan dinyatakan.

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I certify that a Thesis Examination Committee has met on 19 July 2017 to conduct the final examination of Hong Siaw Swin on his thesis entitled "Search Algorithms for Path Planning Problems in Harsh Wireless Sensor Network Environment" 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.

Members of the Thesis Examination Committee were as follows:

Masrah Azrifah binti Azmi Murad, PhD
Associate Professor
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Chairman)

Rohaya binti Latip, PhD
Associate Professor
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Internal Examiner)

Azizol bin Hj Abdullah, PhD
Senior Lecturer
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Internal Examiner)

Bala Srinivasan, PhD
Professor
Monash University Clayton Campus
Australia
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 30 November 2017

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Shamala Subramaniam, PhD
Professor
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Chairman)

Zuriati Ahmad Zukarnain, PhD
Associate Professor
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Member)

Nor Asila Wati Abdul Hamid, PhD
Senior Lecturer
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Member)

____

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

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LIST OF ABBREVIATIONS

ACK	Acknowledgement
CPA	Cooperative Path finding Algorithm
DES	Discrete Event Simulation
FWN	Frothing Waypoint Navigation
GA	Genetic Algorithm
GNA	Genetic Navigation Algorithm
GPS	Global Positioning System
IDE	Integrated Development Environment
IoT	Internet of things
LPA*	Lifelong Pathplanning A*
MSVS	Microsoft Visual Studio
NBN	Natural Behaviour Navigation
PSO	Particle Swarm Optimization
RTS	Request-to-send
SA	Simulated Annealing
TSP	Travelling Salesmen Problem
VD	Visual Domain
WSN	Wireless Sensor Network
ACK	Acknowledgement
CPA	Cooperative Path finding Algorithm
DES	Discrete Event Simulation

CHAPTER 1

INTRODUCTION

In our current Information Age, connecting each device in order to obtain first hand information has become a routine for every individual. Due to such needs, Internet that from the past that had been connecting people has emerged into connecting devices more than people in the year 2008 (Steven E Collier, 2015). Such scenario has already been foresaw by a British visionary back in year 1999 who then introduced a term called "Internet of things" (IoT) (Wood, 2015). IoT is defined as the network that connecting physical objects instead of people. The physical objects include devices, buildings, vehicles, and any possible items through embedding sensors, software, and networking connectivity to enable the data exchange in between (International Telecommunication Union, 2015). The applications of IoT are smart grid, smart homes, smart water networks, intelligent transportation, and so on. These applications are established via distributed sensor network which is also addressed as Wireless Sensor Network (WSN) (Li Li, 2011; Ahmad El Kouche, 2012; Mehaseb Ahmed Mehaseb, 2013). WSN is a network region which consists of multiple nodes that connect to each other using ad-hoc mechanism for surrounding monitoring purpose. Currently WSN is vastly implemented in real-time applications. Applications include temperature monitoring (Ricardo Badia-Melis, 2014), construction site monitoring (Sun-Chan Bae, 2013), slope disaster prediction and monitoring (Che-I Wu, 2014), vehicular traffic control (Juan Pedro Muñoz-Gea, 2013).

Despite WSN's enormous growth of applications, it still has constraints which are mainly due to the limited resources in its processing, storage, as well as life energy (Uthman Baroudi, 2014). Thus, these justifying the constant focus of several areas worthy of research. These research areas include routing (Shazana MdZin, 2014), nodes deployment (Fan Tiegang, 2014; Uthman Baroudi, 2014), scheduling (Tarek Sheltami, 2013), localization (Jaehun Lee, 2013), energy management (Elhadi M. Shakshuki, 2014), and path planning (Juan Pedro Muñoz-Gea, 2013).

1.1 Research Issues

The limitation of resources in WSN causes the routing protocols to be unable to be mapped to the general network routing protocols (Shazana MdZin, 2014). The manner of operation, frequently change of networking topology, inconsistent route establishment, and interference between communications. Properties of WSN created severe challenges for routing algorithm to be developed (Shazana MdZin, 2014). There are several literatures specific for ad-hoc network protocols but none of them can be applied to WSN due to its limitation of resources (Yih-Chun andPerrig, 2004; Huetal, 2005; Boukercheetal, 2011). These constraints have made WSN routing to become a specific research area up until now. There is a substantial survey publication on this research area by Shazana which compares various routing strategies in WSN. This survey concludes that only a few routing protocols has fully achieved the security needs. Thus, it provides critical analysis as well as open issues on most noteworthy protocols in order to stimulate researchers to further improve them (Shazana MdZin, 2014).

In each WSN, there is at least one base-station which has high capacity in all aspect of resources. All other nodes in WSN will transmit their gathered information back to the base-station either directly or via other nodes through multiple hops (Elhadi M. Shakshuki, 2013). Therefore, the transmissions among all nodes would be uneven. Uneven transmissions would cause the WSN imbalance life energy and finally a WSN unable to function even though most of the nodes are still alive (Fan Tiegang, 2014). In order to balance the load, the deployment of the nodes cannot be uniform. Thus, nodes deployment has become another important research area in WSN (Fan Tiegang, 2014). The recent research in this area by Fan is by using an energy allocation theorem and an integer programming model to minimize the cost per unit area (Fan Tiegang, 2014).

The transmission in WSN is very massive, and most of the transmissions are not universal target. There are many transmissions are not desired to the receivers has become wasted when the receivers have used their life energy to sense from the sender. In order to solve this problem, the sensor nodes are to schedule by turning on and off to prevent unnecessary transmissions wastage (Tarek Sheltami, 2013). Therefore, scheduling the nodes in WSN for activeness has become a worthy research area. There is a recent research in WSN scheduling using cooperative Rank Based Sleep Scheduling protocol to solve the problem by Tarek (Tarek Sheltami, 2013).

WSN is usually deployed in a huge number of nodes with very minimum number of location known nodes. The locations known nodes are called as anchor node. All those non-anchor nodes will have their location unknown. The simplest way to get the location of these nodes would be using GPS. However, GPS implementation is costly and highly consumes the life energy of the nodes. And yet the location of each node is representing one of the most important information in almost all WSN application (Jaehun Lee, 2013). Therefore, to know the location of these nodes would require certain algorithms by referencing those anchor nodes. And this method and research area is called as localization. Localization further divided into two categories which are range-based and range-free algorithms. There is a recent research of range-free localization by using kernelized approach in WSN proposed by Jaehun to solve localization problem in cheaper sensors which does not have the range-measurement feature (Jaehun Lee, 2013).

As the life energy is one of the limited resources in WSN, preserving the life energy of the entire network is one of the most important factors to prolong the WSN operation period (Fan Tiegang, 2014). However, it is hard to avoid life energy wastage on the deployment of WSN. The life energy wastage includes frequency channel competing among nodes, network self-forming among nodes, data transmissions collisions resulting retransmissions, and excessive redundant transmissions (Elhadi M. Shakshuki, 2013). Therefore, energy management becomes a very important research area in WSN. There is a recent research in this area by using Software Agent approach in energy management (Elhadi M. Shakshuki, 2013).

The deployment of WSN nodes is hard to control in precise. Therefore, due to this, it is hard to pre-program the topology and routing table for the network. In dynamic environment, it is even harder to predict the changes that would affect the deployed WSN. In order to overcome this issue, mobile sink is introduced. Mobile sink is a data collector node which could traverse physically. Thus, it is able to visit logically networking isolated nodes to collect the sensed data (Majid I. Khan, 2013). However, the deployed nodes including the mobile sink are no longer in control either locally or remotely. Thus, the mobile sinks have to discover their own path in order to visit those self-organized WSN nodes (Tzung-Shi Chen, 2013). As the environment is usually unknown or even dynamic, dynamic path planning algorithm is required for the mobility nodes to navigate (Juan Pedro Muñoz-Gea, 2013). Therefore, WSN path planning has become a recent research area after the introduction of mobile sink.

1.2 Path Planning in WSN

As stated in previous section, path planning in WSN is introduced after the implementation of mobile sink. However, mobility in WSN is not only used on the mobile sink, it can be used in solving various other tasks. One of the examples would be mobile anchor-based localization (Chia-Ho Ou, 2013). Therefore, this dissertation has categorized the path planning into two sections which are WSN logical path planning and WSN physical path planning. The need of separating two sections of path planning is because the objectives of them are completely different hence producing very distinct results. Their performance metrics comparisons are contradictory as well. WSN logical path planning would be involving the movement pattern to achieve certain objectives such as visiting all nodes, within range of transmissions, and so on (Chia-Ho Ou, 2013; Tzung-Shi Chen, 2013; Yung-Liang Lai, 2009; Kap-Ho Seo, 2012). While WSN physical path planning would be involving avoiding obstacles, selecting the lowest path cost by measuring the physical terrain of the surrounding (Juan Pedro Muñoz-Gea, 2013). One of the examples of implementing physical path planning algorithm in its mobility WSN in the recent research is a vehicular traffic control application by Juan. The physical path planning algorithm he used is Dijkstra's algorithm (Juan Pedro Muñoz-Gea, 2013; E. W. Dijkstra, 1959). The research of this dissertation is focus on the physical path planning in WSN. The motivation of selecting this research area is due to the lack of research focusing the different requirement between general path planning and WSN path planning in terms of physical movement. Although the physical movement of mobility nodes in WSN is similar with other mobility applied applications, but the harsh environment of WSN has made its physical path planning having different requirement compared to other mobility applications.

1.3 Problem Statement

There are several scenarios of environment where WSN usually deployed are being observed**.** First scenario, an environment where sensors deployed needs to be updated dynamically due to environmental change but in a very minor scale, path from start to destination needs to be pre-planned, changes in environment expected would not alter the entire planned path. Second scenario, an environment which changes extremely rapid, each time the changes could alter all pre-planned path, more than one more sensors. Third scenario, the environment is static, but mobile sensor needs to move to more than one destination without any weighted path information. Therefore, The problems identified in this dissertation based on scenarios are as follows:

- In first scenario, the solution would need a path planning algorithm with path repair mechanism while maintaining most of the information from the pre-planned path. However, such existing path planning algorithms have long initial delay.

- In second scenario, the existing path planning algorithms would waste its computational resources by calculating the whole path which will be altered during the middle of the node's journey. This would result in overall longer time taken as well as higher energy consumption.

- In third scenario, current way of solving the problem will be by viewing multiple destinations problem as travelling salesman problem (TSP) and discovering weight of path as path planning problem separately. There is no known problem that describes the third scenario as one combined problem. Thus, this dissertation has addressed it as multiple goal point problem. The isolation of these two problems has resulted in the computational delay greatly increases as the number of destination increased.

1.4 Research Objectives

- To modify an existing algorithm in order to reduce its long initial delay while maintaining its suitability in the first scenario stated in section 1.3.

- To develop an algorithm that would solve dynamic path planning partially and massive amount of node at one time. This allows adaptation to frequently change of environment. This solution is to solve the problem stated in the second scenario of section 1.3.

- To develop an algorithm that view TSP and path planning problem as one combined problem, and then solve them conjunctively in that algorithm. The solution would highly reduce wastage of computation resources and greatly speed up the computational time. Therefore, it allows high number of destination with an almost constant of low delay which this situation is stated in the third scenario of section 1.3.

1.5 Dissertation Organization

In Chapter 2, a detail review of the algorithms has been done. After that, a list of related path planning literature will be reviewed and each will be summarized with their advantages and disadvantages. A taxonomy that discusses all the reviewed literature will be given and explained. Further, there will be an open issue section that discussed the advantages and disadvantages observation of each reviewed literature.

In Chapter 3, an introduction related to the current trend of methodology in this research area will be given. And then a selected base algorithm will be selected and explained followed by a detailed explanation of the created simulation model for all the experiments in this dissertation. Experiment to verify the created simulation model will be performed and explained. After that, the performance metrics being selected in the verification experiment will be discussed. And finally, the results and outcome of the verification experiment will be shown and discussed.

In Chapter 4, there will be an introduction of the proposed algorithm (Enhanced D*) and the comparing existing algorithm followed by the motivation of Enhanced D* algorithm. After that, detailed explanation of Enhanced D* will be given. And then the performance metrics and experiment design will be stated and explained for all the experiments to verify Enhanced D*. Multiple experiments are performed and objectives of each experiment will be explained. Results will be discussed for all experiments outcome. Finally, there will be a summary for this whole chapter.

In Chapter 5, there will be an introduction of the proposed algorithm (Natural Behavior Navigation – NBN) and the comparing existing algorithm followed by the motivation of NBN algorithm. After that, detailed explanation of NBN will be given. And then the performance metrics and experiment design will be stated and explained for all the experiments to verify NBN. Multiple experiments are performed and objectives of each experiment will be explained. Results will be discussed for all experiments outcome. Finally, there will be a summary for this whole chapter.

In Chapter 6, there will be an introduction of the proposed algorithm (Frothing Waypoint Navigation – FWN) and the comparing existing algorithm followed by the motivation of FWN algorithm. After that, detailed explanation of FWN will be given. And then the performance metrics and experiment design will be stated and explained for all the experiments to verify FWN. Multiple experiments are performed and objectives of each experiment will be explained. Results will be discussed for all experiments outcome. Finally, there will be a summary for this whole chapter.

In Chapter 7, which is also the final chapter of this dissertation, there will be two detail sections which are conclusion for the whole dissertation and the possible future work for all three proposed algorithms.

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