UNIVERSITI PUTRA MALAYSIA

OFF-THE-SHELF INDOOR LOCALIZATION SYSTEM USING RADIO FREQUENCY FOR WIRELESS LOCAL AREA NETWORK

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FK 2019 34

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

August 2018

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August 2018

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The indoor localization system becomes a substantial issue in recent research, especially in terms of the accuracy. Location based services have been used in many mobile applications as well as wireless sensor networks. High accuracy and fast convergence are very important issues for a good localization system. However, the type of obtained received signal strength (RSS) data is very important in order to get high accuracy. Recently, several of indoor localization techniques that are based on signals of wireless local area network (WLAN) become a substantial issue in recent research.

In this research, a fingerprinting-based location algorithm is applied in indoor environments using WLAN. The location fingerprinting algorithm consists of two phases: offline phase and online phase. In the offline phase the reference points (RPs) are collected at certain places in the experimental testbed. The measurement campaign is conducted by using developed Wi-Fi scanner software. During the offline phase an extensive study is performed on the RSS properties for indoor environment such as duration effects, RSS stationary, RSS dependency and a user's presence. In the online phase, the proposed model infers the unknown locations based on the RPs available in the radio map.

The user location is inferred based on three dimensional (3-D) Bayesian graphical model using the OpenBUGS program. The inference of user location in the environment is investigated and compared to the actual location. Besides, the numbers of iterations are examined in order to show its effectiveness on the proposed model. It shows that the model is converged at a level of 100000 iterations. Thus, the best choice of number of iterations for the proposed model is 100000 since there is no improvement if the number of iterations increases. Finally, the proposed Bayesian graphical model based on fingerprinting location algorithm is compared with Madigan model. The proposed Bayesian graphical model and Madigan model achieved an average accuracy of 2.9 and

3.8 meters for 50 RPs, respectively. Besides, the proposed model is off-the-shelf which does not require any additional hardware to integrate to the proposed model.

The proposed system is enhanced further by using offline clustering (OC) algorithm to reduce the data size of radio map and improve the system's accuracy. In the first stage, the OC tries to reduce the number RPs in the radio map by grouping sets of RPs that are close to each other into one cluster. In the second stage, one or more cluster joins together based on the distance of signal space between adjacent clusters. The proposed OC algorithm slightly reduced the localization error to 2.4 meters, while it significantly reduced the data size of radio map by 68%.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

SISTEM PENYETEMPATAN DALAMAN MENGGUNAKAN FREKUENSI RADIO UNTUK RANGKAIAN WAYARLES KAWASAN SETEMPAT

Oleh

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Sistem penyetempatan dalaman menjadi satu isu besar dalam penyelidikan baru-baru ini, terutama daripada segi ketepatan. Perkhidmatan berasaskan lokasi telah digunakan di dalam banyak aplikasi mudah alih dan juga rangkaian sensor tanpa wayar. Ketepatan yang tinggi dan penumpuan pantas adalah isu-isu yang sangat penting untuk sistem penyetempatan yang baik. Walau bagaimanapun, jenis data yang diperolehi pada kekuatan isyarat diterima (RSS) adalah sangat penting untuk mendapatkan ketepatan yang tinggi. Baru-baru ini, beberapa teknik penyetempatan tertutup yang berdasarkan isyarat rangkaian tanpa wayar kawasan setempat (WLAN) menjadi isu besar dalam penyelidikan baru-baru ini.

Dalam kajian ini, pertama, algoritma lokasi berasaskan pencapjarian telah digunakan di dalam persekitaran dalaman menggunakan WLAN. Algoritma lokasi pencapjarian terdiri daripada dua fasa: fasa luar talian dan fasa dalam talian. Dalam fasa luar talian titik rujukan dikumpulkan di tempat-tempat tertentu di tapak ujian eksperimen. Kempen pengukuran telah dijalankan dengan menggunakan perisian pengimbas Wi-Fi yang dibangunkan. Semasa fasa luar talian kajian mendalam telah dilakukan ke atas sifat RSS bagi persekitaran dalaman seperti kesan jangka masa, RSS pegun, RSS pergantungan dan kehadiran pengguna.

Lokasi pengguna tersebut disimpulkan berdasarkan model grafik Bayesian tiga dimensi (3-D) menggunakan program OpenBUGS. Kesimpulan mengenai lokasi pengguna di dalam persekitaran disiasat dan dibandingkan dengan lokasi sebenar. Selain itu, bilangan lelaran telah diperiksa untuk menunjukkan keberkesanannya terhadap model yang dicadangkan. Ia menunjukkan bahawa model itu menumpu pada paras 100,000 lelaran. Oleh itu, pilihan terbaik bilangan lelaran untuk model yang dicadangkan adalah 100,000 kerana tiada lagi peningkatan jika bilangan lelaran meningkat. Akhir sekali, model grafik Bayesian yang dicadangkan berdasarkan algoritma lokasi pencapjarian telah

dibandingkan dengan model Madigan. Model grafik Bayesian yang dicadangkan dan model Madigan telah mencapai ketepatan purata 2.9 dan 3.8 meter masing-masing untuk 50 titik rujukan (RP). Selain itu, model yang dicadangkan itu adalah tersedia yang tidak memerlukan apa-apa perkakasan tambahan untuk diintegrasikan dengan model yang dicadangkan.

Prestasi model yang dicadangkan telah dipertingkatkan dengan menggunakan algoritma *Offline Clustering* (OC) untuk mengurangkan saiz data peta radio serta meningkatkan ketepatan sistem tersebut. Pada peringkat pertama, OC cuba mengurangkan jumlah *RP* di dalam peta radio dengan mengelompokkan set RP yang berdekatan satu sama lain ke dalam satu kelompok. Dalam peringkat kedua, satu atau lebih kluster bergabung bersama berdasarkan jarak ruang isyarat antara kluster yang bersebelahan. Algoritma *OC* yang dicadangkan menunjukkan sedikit kesilapan penyetempatan dalam lingkungan 2.4 meter, sementara ia mengurangkan saiz data peta radio secara ketara sebanyak 68%.

ACKNOWLEDGEMENT

Firstly, I would like to thank God for his love and the success of completing this thesis. I would also like to express my deepest gratitude to my supervisor Dr. Fazirulhisyam Hashim and my supervisory committee member Assoc. Prof. Dr. Mohd. Fadlee with their guidance and moral support throughout my master's research. Secondly, all of my dearest friends and beloved family, I thank you for being supportive and helpful.

I would also express my profound gratitude to my wife for her helping, encouragement and patience during my study. Also, my deepest thank to my lovely son for giving me the inspiration to do well in my study. In addition, my special thanks to my parents, siblings and relatives for their continued love, support and encouragement. They always cheer me up and make my life much easier.

Last but not least, I would like to express my grateful appreciation to everybody, who has directly and indirectly involved in completing this research. Thank you.

I certify that a Thesis Examination Committee has met on (date of viva voce) to conduct the final examination of Abdulraqeb Shaif Ahmed Alhammadi on his thesis entitled **"Indoor Localization System Using Radio Frequency for Wireless Local Area Network "** 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 (insert the name of relevant degree).

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LIST OF ABBREVIATIONS

AOA	Angle of Arrival
AP	Access Point
BTS	Base Transceiver Stations
BUGS	Bayesian inference Using Gibbs Sampler
CDF	Cumulative distribution function
CF	Constriction Factor
DOA	Direction of Arrival
IR	Infrared Radiation
FAF	Floor Attenuation Factor.
FM	Frequency Modulation
GSM	Global System for Mobile
GPS	Global Positioning System
KNN	K Nearest Neighbour
LDIW	Linearly Decreasing Inertia Weight
LOS	Line Of-Sight
MAC	Medium Access Control
MC	Monte Carlo
MCMC	Markov Chain Monte Carlo
NLOS	Non-Line Of-Sight
NN	Nearest Neighbour
NNSS	Nearest Neighbor in Signal Space
OC	Offline Clustering
PAN	Personal Area Network
PC	Principal Component
PDA	Personal Digital Assistant
RF	Radio Frequency
RFID	Radio Frequency Identification
RP	Reference Point
RSS	Received Signal Strength
SSID	Service Set Identifier
UWB	Ultra-WideBand
WLAN	Wireless Local Area Network

CHAPTER 1

INTRODUCTION

1.1 Background

Localization system is one of the most important issues nowadays. It could be used in outdoor or indoor environment. However, the location accuracy in indoor environment should be higher due to narrower space compare to outdoor environment. The most popular localization system in an outdoor environment is global positioning system (GPS). It is a satellite-based navigation system and it requires line of sight communication.

The indoor positioning system is famously used in the indoor environments to localize and determine the location of people, materials, and equipment. In addition, it is useful for several industrial applications such as the construction industry, health industry, and logistic industry [1]. Many indoor localization technologies have been developed and have different localization performance, such as localization based on Bluetooth, ultra-wideband [2, 3], radio frequency identification (RFID) [4], and received signal strength (RSS) [5]. However, these technologies are still suffering from poor accuracy and high complexity. Currently, wireless local area network (WLAN) has become widely used in indoor areas. Moreover, the mobile devices based on WLAN have an advantage to obtain the signal information for each access points (APs) in the particular area. The signal information such as channel number, RSS and MAC address are utilized to design sophisticated localization systems. Most of the indoor localization systems depend on RSS due to its high impact factor in indoor environments.

There are various techniques used in the indoor localization systems. The two most common techniques are lateration [6] and fingerprinting [7]. These two techniques are main RSS based indoor localization [3], [1]. Lateration technique is a geometry-based method that estimates the relative location of target by calculating the distance between reference points (RPs) and APs. However, this method requires at least three RPs in order to obtain the target location.

The fingerprinting technique is one of the most popular techniques that is using RSS-based localization and has become an interesting research topic in the indoor localization system in recent years. It is based on RSS that consists of two phases: offline phase and online phase. In the offline phase, creating a radio map that contains of the RSS measurements associate with APs coordinates. In the online phase, the mobile device collects samples of current RSS and then compare them with the stored data in the radio map to determine and localize the current location of the user [5, 6]. The performance of this technique depends on the number of the RPs in the particular area, which means increasing in the number of the RPs results to increase the accuracy of estimated location. In addition, the system accuracy changes according to the methodology of simulation or

experimental based system. In other word, the difference types of collecting RSS data are significantly affecting the system accuracy.

1.2 Problem Statement

Despite there are many indoor localization systems are introduced with different techniques, they are still suffering from poor accuracy and high complexity [8-10]. Therefore, this research work focuses on two main issues which leads to improve the accuracy and complexity of the system. These issues are described as follows: Firstly, Investigation the characteristics of the RSS in indoor environment is an important aspect for developing localization system. The RSS in such indoor environments is suffering from multipath phenomena which leads to predict un accurate value. Secondly, most of the existing models are investigated for two-dimensional environment, thus, there is a lack of models or approaches that consider three-dimensional (3-D) environment [9], [10]. In additional, a huge number of -RPs are used in order to improve the system's accuracy, which results of high computational cost. This research proposes a Bayesian graphical model for three-dimensional environment to improve the system's accuracy. Finally, the size of radio map is one of the issues that needs to be addressed in which effect the localization accuracy. Thus, clustering algorithm needs to be developed to reduce the size of radio map with low localization error.

1.3 Objectives

The main aim of this research is to develop a Bayesian graphical model based on fingerprinting technique which able to infer the user location in the indoor environment with a good accuracy and low complexity. In order to achieve this aim, the following objectives are set for this thesis:

1. To investigate the effects of RSS in indoor environments.
2. To design 3D Bayesian model for localization system in indoor environment.
3. To develop offline clustering (OC) algorithm to reduce the radio map size for indoor localization system.

1.4 Scope and Limitations

This thesis focuses on off-the-shelf 3D indoor localization system based on the WLAN. The important issues that should be considered in developing indoor localization system are accuracy and complexity. In this research work, the measurement campaign was conducted with one user along the corridor in a single floor environment at the Faculty of Engineering. The reading of RSS obtained from four APs that are deployed at four different places in the testbed using a Wi-Fi scanner software. Fingerprinting technique is implemented to predict the user location based on the proposed Bayesian graphical model. It consists of two phases: offline phase and online phase. Offline phase presents the data collection, analysis and RSS properties investigation. In the online phase, the system predicts the user location according to the proposed model and collected data.The methodology of this research is divided into three stages. The first stage is an intensive study of the properties of RSS in indoor environments. This study investigates the effect

of multipath on the RSS and the number of RSS samples. Moreover, performs a set of experiments on the RSS properties such as RSS stationary and RSS location dependency. The second stage consists of two phases: offline phase and online phase. In the offline phase, developing Wi-Fi scanner software to be used for data collection and building the radio map. In the online phase, proposing a Bayesian graphical model to be used for estimation of the user's location.

1.5 Thesis Layout

The rest of this thesis is organized as follows:
Chapter 2 presents a comprehensive literature review on localization techniques and the algorithms that were used to determine the user location, background on the Bayes theorem, Bayesian graphical model, and some existing indoor localization systems.

Chapter 3 presents the methodology of the system which describes in three sections. Firstly, the investigation of the RSS properties is discussed. Secondly, this section is divided into three subsections, (i) developing the Wi-Fi scanner software for collecting data collection in offline phase is described. (ii) the proposed indoor localization system based on Bayesian graphical model is presented. (iii) the procedures of using Doodle and OpenBUGS program based on the Gibbs sampling is explained. Thirdly, this section presented a clustering algorithm to minimize the size of radio map.

Chapter 4 presents the experiments results and discussion in three sections. First, the results show the effect of RSS properties in indoor environments. Second, the results of the proposed Bayesian graphical model are compared with Madigan model are described. Lastly, the results of the proposed clustering algorithm are presented. The results of the system's accuracy are compared with previous works.

Chapter 5 concludes this thesis and it consists of two sections. First, presents the general analysis of the proposed indoor localization system for indoor environments. Second, provides some suggestions and ideas for future work.

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LIST OF PUBLICATIONS

International Journals:

[1] Abdulraqeb Alhammadi, Fazirulhisyam Hashim and Mohd. Fadlee A. Rasid "A 3D Pattern-Recognition Localization System Based on Bayesian Graphical Model" International journal of distributed sensor network (under review)

[2] Abdulraqeb Alhammadi, Fazirulhisyam Hashim " Analysis of effect RSS indoor environment using Bayesian network" Lecturer Notes in Computer Science (LNCO), Pages, 200-211, Springer, Cham, 2017.

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International Conferences:

[1] A. Alhammadi, Fazirulhisyam, M. Fadlee and S. Alraih "Robust 3D Indoor Positioning System Based on Radio Map Using Bayesian Network" IEEE 5th World Forum on Internet of Things (WF-IoT) , 15-18 April 2019 – Limerick, Ireland

[2] A. Alhammadi, Fazirulhisyam, M. Fadlee and S. Alraih. "Analysis of effect RSS indoor environment using Bayesian network" 17th International Conference on Computational Science and Applications (ICCSA 2017) Trieste, Italy 3 - 6, 2017.

[3] A. Alhammadi, Fazirulhisyam, M. Fadlee and S. Alraih. "A new indoor localization system using Bayesian graphical model" IEEE international Conference on Wireless Communications, Signal Processing and Networking (WiSPNET), Chennai-603110, India, from March 22 to 24, 2017.

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