MULTI-FLOOR INDOOR LOCATION ESTIMATION SYSTEM BASED ON WIRELESS LOCAL AREA NETWORK

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To my beloved parents and brothers.

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ABSTRACT

The proliferation of high speed wireless technologies and mobile computing infrastructures has fostered a rapid development in location based services. The key to the success of location based services is the estimation of user's location. Indoor location estimation system using various wireless technologies such as infrared and ultrasound are available. However, these systems require specialized infrastructures and incur high costs. This study focuses on design and development of a software-based multi-floor indoor location estimation system using Wireless Local Area Network (WLAN). Location fingerprinting technique is employed to estimate Mobile Terminal's (MT) location. WLAN Received Signal Strength (RSS) measured by MT is used as location fingerprint. Before location estimation, database of location fingerprint is constructed by collecting histograms of RSS at predefined reference locations. During location estimation, current histogram of RSS at unknown location will be compared to the database. The most probable match is selected and returned as estimated location based on Bayesian filtering algorithm. Estimated location is reported as physical location and symbolic location. Before developing the system, study on characteristics of RSS is conducted to help the design, development and implementation of the proposed system. The proposed system is then designed and developed using Java programming language. The performance of the proposed system is evaluated in a two-floor building using off-the-shelf WLAN access points and client device. Finally, various factors which affect the performance of the proposed system are investigated. From the evaluations in the two-floor building, the proposed system achieved best accuracy of 4.56 meters during stationary tests and 4.54 meters during mobile tests with 90% precision. The best percentage of correct floor estimation is 100% for both tests.

ABSTRAK

Perkembangan pesat teknologi wayarles berkelajuan tinggi dan infrastruktur komputer bergerak telah menggalakkan pembangunan cepat dalam perkhidmatan berdasarkan lokasi. Kunci kejayaan perkhidmatan berdasarkan lokasi ialah penganggaran lokasi pengguna. Sistem penganggaran lokasi dalam bangunan yang menggunakan pelbagai jenis teknologi wayarles seperti inframerah dan ultrabunyi boleh didapati. Namun, sistem-sistem ini memerlukan infrastruktur khas dan mendatangkan kos yang tinggi. Kajian ini memfokus pada rekabentuk dan pembangunan perisian sistem penganggaran lokasi dalam bangunan bertingkat dengan menggunakan Rangkaian Kawasan Setempat Wayarles (WLAN). Teknik pencap-jarian lokasi diguna untuk menganggarkan lokasi Terminal Bergerak (MT). Kekuatan Isyarat Diterima (RSS) WLAN yang diukur oleh MT digunakan sebagai cap jari lokasi. Sebelum penganggaran lokasi, pangkalan data untuk cap jari lokasi dibina dengan mengumpulkan histogram RSS di kawasan rujukan yang ditakrifkan awal. Semasa penganggaran lokasi, histogram RSS semasa di lokasi yang tidak diketahui dibanding dengan pangkalan data. Padanan yang paling hampir dipilih dan dikembalikan sebagai lokasi anggaran berasaskan algoritma penapisan Bayesian. Lokasi anggaran dilaporkan sebagai lokasi fizikal dan lokasi simbol. Sebelum membangunkan sistem ini, kajian atas ciri-ciri RSS dijalankan untuk membantu rekabentuk, pembangunan dan perlaksanaan sistem yang dicadangkan. Sistem yang dicadangkan kemudiannya direkabentuk dan dibangunkan dengan menggunakan bahasa pengaturcaraan Java. Perlaksanaan sistem yang dicadangkan dinilai dalam bangunan dua tingkat dengan menggunakan titik capaian dan alat pelanggan WLAN. Akhirnya, pelbagai faktor yang menpengaruhi perlaksanaan sistem yang dicadangkan telah disiasat. Daripada penilaian dalam bangunan dua tingkat, sistem yang dicadangkan mencapai kejituan terbaik 4.56 meter semasa ujian pegun dan 4.54 meter semasa ujian bergerak dengan kepersisan 90%. Peratusan terbaik penganggaran tingkat yang betul adalah 100% untuk kedua-dua ujian.

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a	-	Angle
A	-	Set of access points installed in indoor area
$Bel(\bullet)$	-	Current belief / Corrected belief
$Bel^{-}(\bullet)$	-	Predicted belief
b	-	Number of topological nodes, $\mathcal{V}$
c	-	Number of edges in topological map, $\mathcal{E}$
d	-	Direction
D	-	Euclidean distance in signal space
$\mathcal{E}$	-	Set of edges in topological map
e	-	Edge in topological map
$\mathcal{F}$	-	Fingerprint information (RSS Values)
f	-	Floor number
$\mathcal{G}$	-	Graph
i	-	Arbitrary index
j	-	Arbitrary index
l	-	Calibration node
$\mathcal{L}$	-	Location Information
L	-	Set of calibration nodes
$meanRSS$	-	Mean received signal strength
M	-	Set of single RSS measurement
N_a	-	Number of access points installed in indoor area
N_b	-	Number of access points detected at a given calibration node
N_c	-	Number of calibration nodes
N_m	-	Number of RSS samples in histogram

N_p	-	Number of different RSS values in histogram
N_s	-	Number of state
O	-	Location sensor observation / Observed RSS value
r	-	Radius
RSS	-	Value of received signal strength
$\tilde{S}$	-	State space
S	-	State
s_t	-	State at time t
t	-	Time
$\mathcal{V}$	-	Set of topological nodes in topological map
v	-	Topological node
x	-	x-axis coordinate
y	-	y-axis coordinate
z	-	z-axis coordinate
%	-	Percentage
α	-	Normalizing constant
θ	-	Orientation (Forward or backward)

LIST OF ABBREVIATIONS

2D	-	Two-Dimensional
3D	-	Three-Dimensional
a.m.	-	Ante Meridiem
AOA	-	Angle of Arrival
AP	-	Access Point
API	-	Application Programming Interface
BER	-	Bit Error Rate
BSS	-	Basic Service Set
cdf	-	Cumulative Distribution Function
dB	-	Decibel
dBm	-	mili-Decibel
DOA	-	Direction of Arrival
DSSS	-	Direct Sequence Spread Spectrum
ESS	-	Extended Service Set
FHSS	-	Frequency Hopping Spread Spectrum
GHz	-	GigaHertz
GPS	-	Global Positioning System
GUI	-	Graphical User Interface
HP	-	Hewlett-Packard
IBSS	-	Independent Basic Service Set
IEEE	-	Institute of Electrical and Electronics Engineers
ISM	-	Industrial, Scientific and Medical
kHz	-	KiloHertz
k-NNSS	-	k- Nearest Neighbor in Signal Space
LANDMARC	-	Location Identification based on Dynamic Active RFID
LBS	-	Location Based Services
LES	-	Location Estimation System

LOS	-	Line of Sight
MAC	-	Medium Access Control
Mbps	-	Mega bits per second
MILES	-	Multi-floor Indoor Location Estimation System
MiniPCI	-	Mini Peripheral Component Interconnect
MT	-	Mobile Terminal
NNSS	-	Nearest Neighbor in Signal Space
NLOS	-	No Line of Sight
OFDM	-	Orthogonal Frequency Division Multiplexing
OS	-	Operating System
PAL	-	Precision Asset Location
PC	-	Personal Computer
PCMCIA	-	Personal Computer Memory Card International Association
PDA	-	Personal Digital Assistant
PHY	-	Physical
p.m.	-	Post Meridiem
POA	-	Phase of Arrival
RF	-	Radio Frequency
RFID	-	Radio Frequency Identification
RL	-	Reference Location
RSS	-	Received Signal Strength
RSSI	-	Received Signal Strength Indicator
SNR	-	Signal to Noise Ratio
SSID	-	Service Set Identifier
TDOA	-	Time Difference of Arrival
TOA	-	Time of Arrival
UNII	-	Unlicensed National Information Infrastructure
USB	-	Universal Serial Bus
UTM	-	Universiti Teknologi Malaysia
UWB	-	Ultra-wideband
WCC	-	Wireless Communication Centre
WLAN	-	Wireless Local Area Network

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CHAPTER 1

INTRODUCTION

1.1 Background

The rapid development of mobile computing technology and high speed wireless communication systems has fostered tremendous growth in location based services (LBS). Through LBS, various applications and services are delivered to the user based on their current physical location. Indoor environments present opportunities for a rich set of LBS such as navigational tools for humans and robots, interactive virtual games, resource discovery and asset tracking.

The key to the success of LBS is the estimation of user’s location. Location estimation is a process of estimating physical location of a mobile terminal (MT) with respect to a set of reference locations within a predefined space. This research focuses on design and development of multi-floor indoor location estimation system (MILES) using wireless local area network (WLAN). This system is proposed to determine the MT’s location in a multi-floor indoor environment.

Currently, there are many location estimation systems (LES) available. Global Positioning System (GPS) is the most common and universally used LES for outdoor area. Unfortunately, GPS is not suitable for indoor applications due to the absence of line of sight (LOS) from the MT to the GPS satellites [1].

Various alternatives are proposed to provide indoor location estimation. Some researches use specialized hardware for indoor location estimation. These hardware are designed specifically and solely for location estimation purpose only. Ultrasonic, infrared, optical and radio frequency (RF) are major technologies used for this type of system. Although these systems able to estimate indoor location accurately, they are usually expensive in terms of investment and maintenance costs.

In order to overcome the disadvantages mentioned above, indoor LES can be developed using existing infrastructures. WLAN, Bluetooth and cellular network are major infrastructures used for this type of systems. These infrastructures are usually developed for other purposes such as data networking and communication. By developing a software layer on top of these infrastructures, a lower cost LES can be achieved. In this study, the proposed MILES is built on top of off-the-shelf WLAN infrastructure.

1.2 WLAN-Based Multi-Floor Indoor Location Estimation System

WLAN is widely deployed in various indoor areas such as homes, offices, schools and museums. Besides using the WLAN infrastructure for wireless data networking, the RF signals transmitted or received by WLAN devices can be used to estimate the MT's location. Because signal strength measurement is part of the standard operating mode of WLAN devices, no other hardware infrastructure is required. WLAN-based LES can be developed using proximity sensing, triangulation or location fingerprinting technique.

Location fingerprinting technique is the most popular solution for WLAN-based indoor location estimation [2]. The basic idea behind location fingerprinting is that RF signal has different characteristics in different indoor locations. Location dependent RF signal elements such as WLAN received signal strength (RSS), signal to noise ratio (SNR) or bit error rate (BER) are used as the "fingerprint" of a particular location.

Location fingerprinting usually works in two phases [3]. First, in off-line phase, the LES is calibrated by collecting location fingerprints at finite pre-determined reference locations (RL) within the targeted multi-floor indoor area and stored in a database called radio map. Second, location is estimated in on-line phase. The current observed location fingerprint is measured and the LES will determine the best match between the on-line observations and the off-line fingerprints in the radio map. The RL with the closest match is then reported as the estimated MT's location. This matching can be done according to deterministic or probabilistic algorithms.

In this study, the proposed system is developed using location fingerprinting technique. WLAN RSS is used as the location fingerprint. Probabilistic algorithm is adopted to estimate the MT's location.

1.3 Problem Statement

Currently, conventional GPS system does not work well in indoor area. Indoor LES based on specialized hardware usually require high investment and maintenance costs. Therefore, an economic LES is needed.

WLAN-based indoor LES is one of the economic alternatives. Many solutions are proposed for this type of system in previous researches and their performances are very encouraging [4, 5, 6, 7]. However, most of the proposed systems are only tested for single-floor indoor location estimation [4, 5, 6, 7]. In reality, an indoor LES is usually used in a multi-floor environment.

In this study, location fingerprinting uses the WLAN RSS to estimate indoor location. The RF propagation channel in indoor environment is complex due to multi-path fading phenomenon. Therefore, a basic understanding of the indoor WLAN RSS characteristics is crucial before the design, development and deployment of the proposed system.

In addition, performance of WLAN-based location fingerprinting system is affected by various factors such as number of WLAN access points (AP) installed. A basic understanding on these factors will help to achieve and improve the targeted LES performance level.

1.4 Objectives

The following objectives are determined in order to solve the problems mentioned above.

(i) To study the characteristics of WLAN RSS in indoor environment through measurement for WLAN-based indoor location estimation application.
(ii) To design and develop a WLAN-based indoor location estimation system for multi-floor environment using RSS location fingerprinting technique.
(iii) To evaluate the performance of the proposed WLAN-based multi-floor indoor location estimation system.
(iv) To study factors which affect the performance of the proposed WLAN-based multi-floor indoor location estimation system.

1.5 Research Scope

In this study, a software-based MILES is designed and developed. The proposed system is implemented and evaluated over the off-the-shelf IEEE 802.11g WLAN infrastructures deployed in Wireless Communication Centre (WCC), Universiti Teknologi Malaysia (UTM).

The study is divided into four major phases. In the first phase, literatures on current indoor location estimation technologies and previous researches in the field are reviewed. Strengths and weaknesses of available systems are compared.

In the second phase, measurements are conducted to study the characteristics of WLAN RSS in multi-floor indoor environment. The goal of the measurement is to understand the characteristics of WLAN RSS for indoor location estimation application. Results obtained here are used to design and develop the proposed system.

Based on the literature review and results from the RSS characteristics study, the MILES is designed and developed. In this third phase, location fingerprinting technique using WLAN RSS is proposed. Java programming language is used to develop the proposed system.

In the final phase, the performance of the proposed MILES is evaluated via real-time stationary and mobile multi-floor indoor location estimation experiments. This is followed by a series of experiments on effects of four factors on the performance of the proposed system. The factors investigated are number of WLAN APs installed, number of topological nodes, number of RSS samples collected per location fingerprint and off-line phase sampling interval.

1.6 Contributions

Contributions of this study are listed below:

(i) A test-bed for WLAN-based multi-floor indoor location estimation is built at WCC, UTM. This test-bed can be used as a general platform for future researches related to WLAN-based indoor location estimation and WLAN technology.

(ii) Characteristics of WLAN RSS as location fingerprints are identified through measurements. The results obtained can be used in future for design, development and deployment of LES based on WLAN RSS.

(iii) An economical software-based MILES using off-the-shelf WLAN infrastructures is proposed and developed. The prototype can be further developed into commercial product.

(iv) Practicality and reliability of MILES using off-the-shelf WLAN infrastructures is validated via real-time experiments.

(v) Various factors affecting the performance of WLAN-based MILES is identified. Results obtained will help to achieve and improve targeted performance of a given MILES in real-time implementation.

1.7 Thesis Organization

The thesis consists of eight chapters. Chapter 1 introduces the background of this study. In addition, the problem statement, research objectives, research scope, research contributions and thesis organization are included.

Chapter 2 contains the literature reviews on general indoor LES technology. Basic architecture of LES, location estimation technique, classification and properties of LES are reviewed. Previous studies on LES using various technologies are also reviewed. Advantages and disadvantages of these systems are identified.

Chapter 3 presents the overview on WLAN-based indoor LES. WLAN technology is reviewed. A detailed description on WLAN-based indoor LES, location fingerprinting technique and previous related studies are given. Strengths and weaknesses of available systems are compared.

Chapter 4 discusses the methodology of the study. Approach taken to achieve the research objectives is presented here. The test-bed, hardware and software components used in the study are also listed.

Chapter 5 presents the study on WLAN RSS characteristics. Measurements are conducted to study the characteristics of WLAN RSS for location fingerprinting application.

Chapter 6 presents the design, development and implementation of the proposed WLAN-based MILES.

Chapter 7 contains the real-time evaluation results of the proposed system. Type of experiments, experimental setups and results are analyzed and discussed. In addition, real-time experimental results on various factors affecting the performance of the proposed system are presented and discussed.

Finally, Chapter 8 concludes the thesis with conclusion and gives directions for future works.