

Pedestrian Traffic Monitoring Using Wi-Fi Technology

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CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged with the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

TO MY DEAR PARENTS

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I wish to express my utmost gratitude to my supervisor, Assoc. Prof. Dr Kumbesan Sandrasegaran for providing this opportunity, advice, patience and encouragement. I would never finish my research work without his guidance.

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ABSTRACT

The study of pedestrian traffic has been investigated by many organizations such as governments, city councils and businesses. The knowledge of pedestrian traffic behaviour can be useful for planning better services for citizens. To perform the surveys for obtaining this knowledge, a number of methods were developed for pedestrian monitoring, such as, hand counting, video camera counting and infrared counting. However each of these methods has its application limitations such as excessive human interaction, narrow observable region, limited applicable conditions and false detection. With the development of Wi-Fi Positioning System, the Wi-Fi technology has been introduced into pedestrian traffic monitoring.

The Wi-Fi enabled smartphone which is carried by most of the pedestrian periodically transmits Wi-Fi packets non-intrusively. A number of essential information describing pedestrian traffic behaviours can be extracted from the Wi-Fi packets according to the unique MAC address of each device and received signal strength. This thesis described a mobile tracking system for tracking smartphones, based on these extracted information. This system uses sniffing stations which integrate with Wi-Fi devices, 3G devices, processors and sensors to capture the Wi-Fi packets and transmits data to remote server for storage.

In order to evaluate the system performance and optimize the system efficiency, a series of tests and experiments were designed by considering the three aspects: hardware configuration, channel hopping methods, and pedestrian behaviours. Based on the results of tests and experiments, the optimized system configuration has been determined to ensure a good ability of packets capturing.

Given the nature of outdoor environment condition, the received signal strength measurements are highly inconsistent and are subject to change depending on the devices, human and environment factors. It is a challenge that using received signal strength to localize a smartphone. To address this issue, an EEMD based localization method is proposed in this thesis. Based on the field test result, the EEMD based

localization method can smooth out captured data of the received signal strength and improve the localization accuracy.

In the intersection of a street, the pedestrian can move either in north-south direction or east-west direction, in different speeds and carry various brands of smartphones. The deployment of mobile tracking in such a complex environment becomes an interesting topic. A simulation platform is developed in this thesis and the simulation platform consists of a number of models for describing the street environment under different conditions. Moreover, the intersection of a street is divided into central area and boundary area. Deployment scenarios were simulated to determine the best representable deployment scenario. Based on the simulation results, the sniffing station deployed at the central area has better system performance in terms of the capability of capturing the packet (number of captured packet). In addition, sniffing stations should be well placed to ensure the relative distance between each other is fallen into the classification determined by the expecting localization accuracy.

RELATED PUBLICATIONS

Majority of the contributions included in this thesis appear in peer reviewed journal and conference papers. They are outlined as following:

Journal Articles

Z. Xu, K. Sandrasegaran, B. Hu, and C.-C. Lin, "A Study of WLAN RSSI Based Distance Measurement Using EEMD" accepted by *International Journal of Advanced Research in Computer Science and Software Engineering (IJARCSSE)*, 2013

Z. Xu, K. Sandrasegaran, X. Kong, X. Zhu, J. Zhao, B. Hu and C-C. Lin "Pedestrian Monitoring System Using Wi-Fi Technology and RSSI Based Localization" accepted by *International Journal of Wireless & Mobile Networks (IJWMN)*, 2013

C.-C. Lin, K. Sandrasegaran, X. Zhu, and **Z. Xu**, "Limited Comp Handover Algorithm for LTE-Advanced," *Journal of Engineering*, vol. 2013, p. 9, 2013.

Conference Papers

C.-C. Lin, K. Sandrasegaran, X. Zhu, and **Z. Xu**, "Performance evaluation of capacity based CoMP handover algorithm for LTE-Advanced," in *Wireless Personal Multimedia Communications (WPMC)*, 2012 15th International Symposium on, 2012, pp. 236-240.

C.-C. Lin, K. Sandrasegaran, X. Zhu, and **Z. Xu**, "On the performance of capacity integrated CoMP handover algorithm in LTE-Advanced," in *Communications (APCC)*, 2012 18th Asia-Pacific Conference on, 2012, pp. 871-876.

TABLE OF CONTENTS

Abstract	v
Related Publications	vii
Journal Articles	vii
Conference Papers	vii
List of Acronyms	xvi
List of Symbols	xviii
Chapter 1 Introduction	1
1.1 Existing Pedestrian Monitoring Method	2
1.1.1 Survey: hand counting method	2
1.1.2 Video camera counting method	3
1.1.3 Thermal imaging counter	4
1.1.4 Infrared counter	5
1.2 Mobile Phone Localization	6
1.2.1 GPS based localization	7
1.2.2 Cellular network based localization	8
1.2.3 Wi-Fi based localization	8
1.3 Motivation and Objective	11
1.4 Research Methodology	12
1.5 Thesis Organization	12
Chapter 2 Background	14
2.1 Overview of IEEE 802.11 protocol	14
2.2 Positioning technologies in WPS	17
2.2.1 Time of arrival	18
2.2.2 Time difference of arrival	19

2.2.3	Round trip time of flight	20
2.2.4	Angle of arrival	21
2.2.5	Received signal strength	22
2.2.6	Fingerprinting.....	24
2.3	Pedestrian traffic monitor by using WPS	29
Chapter 3	System Implementation.....	31
3.1	System Structure.....	31
3.2	Sniffing Station.....	32
3.2.1	Components selection	32
3.2.2	The architecture of sniffing station	34
3.3	Sniffing Mechanism	35
3.3.1	Sniffing data format	36
3.3.2	Passive sniffing	37
3.3.3	Active sniffing.....	39
3.4	Sniffing Data Transmitting.....	40
3.5	Conclusion.....	41
Chapter 4	System Performance and Optimization.....	42
4.1	Detection Feasibility Study	43
4.2	System Performance Test and Optimizing.....	45
4.2.1	Test design	45
4.2.2	Test bed	46
4.2.3	Effect of using multiple Wi-Fi adapters.....	47
4.2.4	Sniffing Range Test.....	48
4.2.5	Effect of antennas position separation	49
4.2.6	Hopping Time and Scanning Time Selection	49
4.2.7	Selection of scanning channels	52
4.2.8	Hopping Algorithms Comparison	53

4.2.9	Packets sending rate	55
4.2.10	Pedestrian walking speed and distance	57
4.3	Conclusion.....	58
Chapter 5	Localization.....	60
5.1	Received Signal Strength Indicator	60
5.2	RSSI processing method	61
5.2.1	Statistical mean value model (SMVM).....	62
5.2.2	Gauss model	62
5.3	Principle of EMD and EEMD.....	62
5.3.1	RSSI processing by using EEMD	64
5.4	EEMD Method Comparison and Analysis	65
5.4.1	Experiment test bed.....	66
5.4.2	Reference point RSSI determination.....	66
5.4.3	The movement reproduction	67
5.4.4	EEMD method error analysis.....	68
5.5	EEMD Based Localization	70
5.5.1	Experiment test bed.....	71
5.5.2	Parameters determination.....	71
5.5.3	Localization test and result analysis.....	75
5.6	Conclusion.....	78
Chapter 6	Simulation	79
6.1	Simulation Model	80
6.1.1	Mobility model.....	80
6.1.2	Packet generation model	83
6.1.3	Radio propagation model	85
6.1.4	Channel hopping model	88
6.2	The Simulation Result and Analysis	90

6.2.1	Simulation environment.....	90
6.2.2	Single Station Simulation.....	92
6.2.3	Simulation result and analysis.....	93
6.2.4	Multiple Station Simulation.....	95
6.3	Conclusion.....	98
Chapter 7	Conclusion and Future Research.....	99
7.1	Summary of Thesis Contributions.....	99
7.1.1	Providing Optimized Solution for Pedestrian Counting	99
7.1.2	Providing a Localization Method for Outdoor Environment Condition.	100
7.2	Future Research.....	100
References	102

LIST OF FIGURES

Figure 1.1: Hand counter.....	2
Figure 1.2: The pedestrian traffic survey sites [2]	3
Figure 1.3: The camera tracking [4].....	4
Figure 1.4: The comparison between camera view and thermal view [5]	5
Figure 1.5: The infrared counter	5
Figure 1.6: The laser sensor	6
Figure 1.7: The GPS system and triangulation	7
Figure 1.8: The cellular network based localization	8
Figure 1.9: IEEE802.11 family timeline	9
Figure 1.10: WLAN architecture [10].....	9
Figure 1.11: Wi-Fi positioning system	10
Figure 2.1: ISO network model and IEEE802.11 protocol [14]	14
Figure 2.2: Channels for IEEE802.11b/g [15]	15
Figure 2.3: The Channel hopping for AP discover	15
Figure 2.4: The frame format [10]	16
Figure 2.5: The probe request frame	17
Figure 2.6: The WPS positioning technologies	18
Figure 2.7: Time of arrival.....	19
Figure 2.8: Time difference of arrival.....	20
Figure 2.9: The round trip time of flight.....	21
Figure 2.10: Angle of Arrival.....	21
Figure 2.11: Free Space Path Loss.....	22
Figure 2.12: A Typical Rayleigh Fading at 900MHz [23].....	24
Figure 2.13: RSS Mapping.....	25
Figure 2.14: Two Phases for Fingerprinting Positioning [27]	26
Figure 2.15: The localization using KNN methods when k=3 [35].....	28
Figure 2.16: The sensor deployment [43]	29
Figure 2.17: The pedestrian traffic throughput [43].....	30

Figure 3.1: Wi-Fi Positioning System Structure	31
Figure 3.2: The equipment selection criteria.....	33
Figure 3.3: Holes Planning.....	34
Figure 3.4: Sniffing Station.....	35
Figure 3.5: The sniffing program flow chart.....	35
Figure 3.6: The sniffing data format	36
Figure 3.7: The hopping time and scanning time.....	38
Figure 3.8: The probe request processing	39
Figure 3.9: The active sniffing	40
Figure 3.10: The data transmitting	41
Figure 4.1: The installed sniffing stations (Left: Map of the monitoring location region. Right: installed sniffing stations)	42
Figure 4.2: The captured packets distribution on Friday 7 th of June.....	43
Figure 4.3: The comparison between passive and active sniffing	44
Figure 4.4: Number of captured packets of using multiple adapters	47
Figure 4.5: The result of antenna position separation effect test	49
Figure 4.6: Scanning Time VS. Hopping Time	50
Figure 4.7: Fixed output amount testing result	51
Figure 4.8: The result of channel selection	53
Figure 4.9: The channel hopping method	54
Figure 4.10: The hopping method comparison result	54
Figure 4.11:2012 Australia Smartphone Markets Share [7]	56
Figure 4.12: The Distance Effect Test Result	58
Figure 5.1: A typical RSSI reading.....	60
Figure 5.2: The RSSI processing using EEMD method	65
Figure 5.3: The view of Jones Street (Google Map) and CRIN	66
Figure 5.4: The experiment results processed by EEMD, GM and SMVM	68
Figure 5.5: The RSSI values for outdoor and indoor environment with step size of 0.5m	69
Figure 5.6: The error for outdoor and indoor environment.....	69
Figure 5.7: Experiment A result.....	72
Figure 5.8: RSSI vs Log(d) in Experiment A	73
Figure 5.9: Experiment B result	74

Figure 5.10: RSSI vs Log(d) in Experiment B.....	74
Figure 5.11: Localization experiment set up.....	75
Figure 5.12: Experiment result.....	76
Figure 5.13: Normalized localization result.....	77
Figure 5.14: Localization error	77
Figure 6.1: The mobile tracking system model.....	79
Figure 6.2: The simulated street crossing	80
Figure 6.3: The group vector.....	82
Figure 6.4: The mobility model algorithm.....	83
Figure 6.5: Standby mode and active mode selection.....	84
Figure 6.6: The packets generation model algorithm.....	85
Figure 6.7: The structure of multi-path gain simulator [59]	86
Figure 6.8: The radio propagation model algorithm	88
Figure 6.9: The hopping queue model algorithm.....	89
Figure 6.10: The channel determination model algorithm.....	90
Figure 6.11: The simulation results.....	91
Figure 6.12: The pedestrian and sniffing stations distribution of the first scenario.....	93
Figure 6.13: The single station simulation scenario algorithm	94
Figure 6.14: The result of first simulation scenario	95
Figure 6.15: The second simulation scenario.....	95
Figure 6.16: The simulation result of multiple station simulation scenario.....	96
Figure 6.17: The localization error at different distance.....	96
Figure 6.18: The suggested sniffing stations deployment.....	97

LIST OF TABLES

Table 2.1: The WLAN frames	16
Table 2.2: Interpretation of Address in MAC Frame [10]	17
Table 2.3: The approaches for likelihood function	27
Table 2.4: The possible weighting for WKNN	29
Table 3.1: The selected equipment.....	33
Table 4.1: The smartphone responses	44
Table 4.2: The list of tests	45
Table 4.3: The tests' locations	46
Table 4.4: The sniffing station configures	47
Table 4.5: The test equipment specifications and measured sniffing boundaries.....	48
Table 4.6: Parameter selection for fixed test duration	51
Table 4.7: The hopping queue.....	55
Table 4.8: The probe request generation rate.....	56
Table 4.9: The classification of pedestrian walking speed	57
Table 4.10: Walking speed effect test result	57
Table 5.1: The experiment equipment	66
Table 5.2: The one meter reference RSSI	67
Table 5.3: The correlation between real movement and processed result	68
Table 5.4: The Result of Error Analysis	70
Table 5.5: Upper: the sniffing stations configure. Lower: the view of test location.....	71
Table 6.1: The pedestrian walking speed [55]	81
Table 6.2: The mobile tracking system simulation parameters of single station simulation scenario.....	92
Table 6.3: The localization error category	97

List of Acronyms

3G	Third Generation
AoA	Angle of Arrival
AP	Access Point
BSS	Basic Service Set
CBD	Central Business District
CH	Channel
CTS	Clear-to-Send
DA	Destination Address
EEMD	Ensemble Empirical Mode Decomposition
EMD	Empirical Mode Decomposition
ESS	Extended Service Set
FHSS	Frequency Hopping Spread Spectrum
FIFO	First In First Out
GM	Gauss Model
GPS	Global Positioning System
HOL	Hop On Last
IMFs	Intrinsic Mode Functions
IR	Infrared
ISO/OSI	International Standard Organization's Open System Interconnect
KNN	K-Nearest Neighbour
LoS	Line of Sight

MAC	Media Access Control
MPs	Measuring Points
NNSS	Nearest Neighbour in Signal Space
PDF	Probability Density Function
PHY	Physical
PRN	Pseudo Random Noise
RA	Receiver Address
RPs	Reference Points
RR	Round Robin
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
RToF	Round-trip Time of Flight
RTS	Ready-to-Send
SA	Source Address
SMVM	Statistical Mean Value Model
SSID	Service Set Identifier
TA	Transmitter Address
TDoA	Time Difference of Arrival
ToA	Time of Arrival
ToF	Time of Flight
UTS	University of Technology, Sydney
WKNN	K-Nearest Neighbour
WLAN	Wireless Local Area Network
WPS	Wi-Fi Positioning System

List of Symbols

$\zeta(t)$	Frequency flat Rayleigh fading at time t
$2\sigma^2$	The predicted mean power of multi-path signal
A_{dBm}	Received signal power of 1m distance between devices
w_i	Weight of direction affect from each selected nearest RPs
A	Amplitude of added white noise
A	The peak amplitude of dominant signal
A_{iso}	The effective area of antenna
c	The speed of light
$c_{i,n}$	Doppler coefficient, respectively.
d_0	reference distance
dir_i	Moving direction of group i
\mathcal{E}_e	Standard deviation of error
\mathcal{E}_n	Standard deviation of added noise
\mathcal{E}_o	Standard deviation of original signal
f	The frequency of radio signal
f_i	Packet sending frequency for one unique MAC address
$f_{i,n}$	Discrete Doppler frequency
f_{max}	The maximum Doppler frequency
G	The antenna gain
K	Number of considered neighbour node
$loci(t)$	<i>Location of location of group i at time t</i>
m	Median value of the corresponding normal distribution
$mpath_j(t)$	<i>Multi-path fading gain of group j at time t</i>
n	Path loss exponent

N	The number of ensemble
N_c	Number of hopped channels in one scanning time period
N_i	Number of sinusoids of the i^{th}
N_{MAC}	Total number of MAC
N_p	Total number of captured packets
$p(x)$	The prior probability location of x
$p(y x)$	likelihood function which gives the probability of y in the location x
PL	Path-loss
$position_{i,j}$	location of group member j in group i
Pr	The received power
Pt	The transmitted power
r	The amplitude of the envelope of the received signal
r_n	The residue of EMD method
s	The signal propagation speed
S_n	EMD decomposes a signal
$S_{\mu i}$	Jakes power spectral density function
T	Total sniffing time
t_1	The signal sent time
t_2	The time of the signal arriving at the receiver
vec_j	Group vector is used to determine the position for each group member
v_i	Moving velocity of group i
X	Gaussian distributed random variable with 0 mean value
A	Standard deviation ratio between added noise and original signal
$\Theta_{i,n}$	Uniformly distributed random
λ	The wavelength of radio signal
μ_n	Uncorrelated filtered white Gaussian noise with zero mean of of the n th sinusoid

$\xi_i(t)$	Shadow fading gain of user i at time t
σ	standard deviation of the corresponding normal distribution
d	The distance between these devices