Pedestrian Traffic Monitoring Using Wi-Fi Technology

A Thesis

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by

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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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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 "Pedestrain 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.

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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
$loci(t)$	*Location of* location of group *i at time t*
m	Median value of the corresponding normal distribution
$mpath_j(t)$	*Multi-path fading gain of* group *j at time t*
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
$\mathrm{S}_{\mu \mathrm{i}}$	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 nth 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