LOCALIZATION TECHNIQUE BASED ON DUAL-FREQUENCY DOPPLER RANGING ESTIMATION

NOR AWANI BINTI CHE HASSAN

UNIVERSITI TEKNOLOGI MALAYSIA

LOCALIZATION TECHNIQUE BASED ON DUAL-FREQUENCY DOPPLER RANGING ESTIMATION

NOR AWANI BINTI CHE HASSAN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

OCTOBER 2016

To my beloved mother, father, sisters, grandpa, family and friends for their continuous never ending support.

ACKNOWLEDGEMENT

Alhamdulillah, Thank to Allah S.W.T the most merciful, the most gracious and the most compassionate, my utmost gratitude to Him for guidance, strength and knowledge bestowed upon me to complete this thesis. Peace be upon prophet Muhammad S.A.W. family as well as his beloved friends.

I would like to express my sincere gratitude to my supervisor Assoc. Prof. Dr. Sharifah Kamilah Syed Yusof for her invaluable advice, guidance as well as support in the effort to accomplish this work. Her frankness, constructive ideas, great experience and vast knowledge, helped me a lot in the course of my project.

My appreciation also goes to my co-supervisor, Dr. Kamaludin Mohamad Yusof for his cooperation, guidance, assistance as well as criticisms to increase the quality of this work especially in the technical part. His relentless encouragement for me to write up a paper for the conference as the complement of this thesis to complete my masters degree proved to be a great asset and experience.

A special thank to my family and all my friends for their advice, patience and consistence encouragement. My thanks also go to all of my laboratory mates who help me in my research and my social needs. Lastly, my heartfelt appreciation goes to all who have directly or indirectly helped me to make this project a success.

Nor Awani Binti Che Hassan

ABSTRACT

Positioning awareness plays an important role in modern applications such as internet of thing (IoT) and intelligent transportation system (ITS). One of the commonly used positioning techniques is trilateration as it estimates the location of a blind device or node by using the distance from several other devices or anchor nodes. The ranging technique used to obtain distance information is a crucial step to provide high accuracy in location estimation. Dual-frequency Doppler radar (DFDR) ranging technique has been widely used in radars and radio frequency identification (RFID) applications. In radar application, this technique requires a closed-loop communication link to estimate distance and has not been exploited in single radio frequency transmission. In this thesis, a ranging technique not requiring a closed-loop communication link named one-way forward communication link dual-frequency Doppler (DFD) ranging technique is introduced. The performances of the DFD distance estimation were analysed using simulations and experimental measurements. In the DFD experiment, the anchor node transmitted two different frequencies with a certain frequency separation. The blind node captured the received signal, and the phase difference was extracted and unwrapped using offline processing system. The phase difference between the two received signals was used for DFD ranging estimation before being applied to locate the position of the blind node through trilateration method. Software defined radio (SDR) platform using GNU radio and universal software radio peripheral (USRP) was used to develop the localization system. The experimental results showed that DFD ranging technique can deliver up to 84% distance estimation improvement in comparison to conventional receive signal strength (RSS) ranging technique. In conclusion, the proposed DFD ranging technique is a promising positioning solution for future applications such as IoT and ITS.

ABSTRAK

Kesedaran tentang kedudukan memainkan peranan penting dalam aplikasi moden seperti $internet\, of\, thing$ (IoT) dan sistem pengangkutan pintar (ITS). Salah satu teknik penentuan kedudukan yang biasa digunakan ialah penigasegian yang menganggarkan lokasi peranti atau nod sasaran dengan menggunakan jarak dari beberapa peranti atau nod utama. Teknik penentuan jarak yang digunakan untuk mendapatkan maklumat jarak adalah satu langkah penting dalam menentukan kedudukan nod secara tepat. Teknik radar dwi-frekuensi Doppler (DFDR) ini digunapakai secara meluas dalam aplikasi radar dan pengecaman frekuensi radio (RFID). Dalam aplikasi radar, teknik ini memerlukan komunikasi gelung tertutup untuk menentukan jarak dan konsep ini kurang diguna pakai dalam perhubungan frekuensi radio sehala. Dalam tesis ini, teknik penentuan jarak yang tidak memerlukan komunikasi gelung tertutup yang dinamakan sebagai dwi-frekuensi Doppler (DFD) bagi komunikasi satu hala diperkenalkan. Prestasi penentuan lokasi menggunakan teknik penentuan jarak DFD dianalisis berdasarkan simulasi dan eksperimen. Dalam eksperimen DFD, nod utama menghantar dua frekuensi yang berbeza dengan perbezaan antara frekuensi yang tertentu. Nod sasaran menerima isyarat yang dihantar oleh nod utama dan data diekstrak di mana data perbezaan fasa akan diproses menggunakan sistem pemprosesan di luar talian. Perbezaan fasa antara kedua-dua isyarat yang diterima akan digunakan dalam persamaan jarak DFD sebelum digunakan untuk mencari lokasi atau kedudukan nod sasaran dengan menggunakan kaedah penigasegian. Platform radio tentuan perisian (SDR) yang terdiri daripada GNU radio dan persisian radio perisian universal (USRP) digunakan untuk membina sistem penentuan lokasi. Keputusan eksperimen menunjukkan bahawa teknik penentuan jarak DFD mampu memberikan penganggaran jarak dengan peningkatan sebanyak 84% jika dibandingkan dengan teknik kekuatan isyarat terima (RSS). Kesimpulannya, teknik penentuan jarak DFD yang dicadangkan menjanjikan penyelesaian penentuan jarak bagi aplikasi masa hadapan seperti IoT dan ITS.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADC	-	Analogue Digital Converter
AoA	-	Angle of Arrival
CR	-	Cognitive Radio
CRT	-	Chinese Remainder Theorem
DAC	-	Digital Analogue Converter
DFD	-	Dual-Frequency Doppler
DoA	-	Direction of Arrival
ESPRIT	-	Estimation of Signal Parameter via Rotational Invariance
EDSM	-	Enhance Dynamic Spectrum Management
FFT	-	Fast Fourier Transform
FPGA	-	Field Programmable Gate Array
GPS	-	Global Positioning System
GRC	-	GNU Radio Companion
GPSDO	-	GPS Disciplined Oscillators
IoT	-	Internet of Things
ITSs	-	Intelligent Transportation Systems
ISM	-	Industrial, Scientific, Medical
LOS	-	Line of Sight
LSE	-	Least Square Estimator
MLE	-	Maximum Likelihood Estimator
MUSIC	-	Multiple Signal Classification
MIMO	-	Multiple Input Multiple Output
PPS	-	Pulse per Second
PLE	-	Path Loss Exponent
PU	-	Primary User
PDoA	-	Phase Difference of Arrival
RIPS	-	Radio Interferometric Positioning System
RMSE	-	Root Means Squared Error

RSS	-	Received Signal Strength
RF	-	Radio Frequency
RFID	-	Radio Frequency Identification
RTT	-	Round Trip Time
SAR	-	Synthetic Aperture Radar
SU	-	Secondary User
SNR	-	Signal to Noise Ratio
SDR	-	Software Define Radio
ToA	-	Time of Arrival
TDoA	-	Time Difference of Arrival
USRP	-	Universal Software Radio Peripheral

LIST OF SYMBOLS

P_r	-	Power Receive
D	-	Distance
P_t	-	Power Transmit
G_t	-	Gain Transmit
G_r	-	Gain Receive
L	-	Loss that not related to propagation loss
λ	-	wavelength of transmitted signal
P_L	-	Path Loss
n	-	Path Loss Exponent
X	-	Shadowing effect
d_{los}	-	Distance of LOS signal
d_{gr}	-	Distance of the reflected signal
h_t	-	Transmitter antenna height
h_r	-	Receiver antenna height
r	-	Reflection coefficient
V	-	Velocity of the signal
t	-	Time
R_x	-	Receiver (blind node)
T_x	-	Transmitter (anchor node)
f_i	-	Frequency of the i^{th} signal
n_t	-	noise
ϕ_i	-	Phase of the i^{th} signal
Δf_{2-1}	-	Frequency separation/ difference
$\Delta\phi_{2-1}$	-	Phase difference
f_s	-	Frequency Sampling
N	-	FFT size
H_0	-	Target is idle
H_1	-	Target is active

f_c	-	Centre frequency
k	-	positive integer
γ	-	Decision for Energy detection frequency scanning

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

Positioning awareness has a huge potential in wide variety research field that involves the localization, tracking, and identification of humans, object, and vehicle. This location awareness computing is expanding in numerous modern applications, such as personal and public navigation, security, healthcare, entertainment, and military. Today, with an advanced technology known as Internet of Things (IoT), the feasibility of employing the localization via the Internet is on demand. For this reason, tracking ability in real time is often anticipated. Following this, another current development of Intelligent Transportation System (ITS) has been established, which aims to support a wide range of application related to different modes of transportation and traffic management such as navigation, vehicle routing and location based service, hence increases the requirement of robust localization techniques.

There are different ways to get the location of an object, such as by using Global Positioning System (GPS). However, GPS is inefficient in term of cost effective approach and unviable for a specific condition, especially when there is no Line of Sight (LOS) between target or blind node and GPS satellite, also known as an anchor node [1]. Due to this limitation, different ranging technique has been developed over a decade with different approaches such as Receive Signal Strength (RSS) and Time of Arrival (ToA).

The ranging technique is the key essentials in providing high accuracy location estimation. For instance, in trilateration localization concept, the distances information between the anchor nodes and the blind node are required before the location of the blind node can be estimated. From the existing ranging techniques, it has been reported that the phase-based ranging technique is more robust in estimating the distance [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]. The phase differences of the return signal in phase-based ranging technique are exploited to estimate the distance of the target which is commonly applied in radar applications.

The Radio Frequency (RF) approach has been proposed to provide cheaper and robust localization solution compared to infrared or ultrasound approach [13]. Previously, the development of Software Define Radio (SDR) platform builds opportunities for a cost effective ranging estimation resolution. However, in the field of localization, the usage of SDR platform has not been fully investigated on the distance estimation, especially in phase dependent estimation algorithm.

1.2 Problem Statement

As mentioned before, localization plays an important role in the current technology development, such as IoT and ITS. The location information can assist various system functionalities, such as location identification of an event of interest, especially during rescues and disasters mission. One of the examples in rescues and disasters mission is when the structure collapsed due to the earthquake. Providing these high-risk applications, requirements that needed to be fulfilled are cost effective and low complexity system.

Several research on ranging technique developments have been studied to design a robust localization technique, which is considered as the main factor affecting localization accuracies. Phase-based ranging that employs phase difference between two received signals is one of the robust ranging techniques that has been applied in a two-way communication system such as radar and Radio Frequency Identification (RFID) system [9, 10, 14, 15, 16]. Seemingly, the phase-based ranging technique has the potential via one-way forward link communication system. In addition, the SDR platform provision, especially on Universal Software Radio Peripheral (USRP), has not been fully utilized in this localization field.

In this thesis, localization technique is proposed by implementing Dual-Frequency Doppler (DFD) ranging method that exploits the phase difference of the arriving signals to estimate distance information. The research expectation is to provide reliable accuracy in distance and localization estimation.

1.3 Research Objective

The research objective of this thesis are as follows:

1. To propose localization technique using Dual-Frequency Doppler (DFD) ranging estimation method.
2. To implement the proposed localization technique using Universal Software Radio Peripheral (USRP)
3. To evaluate and validate the performance of the proposed system through simulation and experimental work.

1.4 Scope of Work

Several assumptions are considered in the research development process. The experimental setup of the DFD ranging estimation was executed on Universiti Teknologi Malaysia (UTM) main soccer field near P19a building. The dual frequencies that were used during the experiment for transmission are predetermined and the frequencies are within the range of Industrial Scientific Medical (ISM) band, 2.4 GHz till 2.5 GHz. The equipment used for data measurements are USRP platform, GNU Radio system and Matlab for simulation. Two nodes are required for experimental setup, which is known as anchor node and blind node, used as a transmitter and receiver respectively. However, for each anchor node, two USRPs are needed to transmit two frequencies. Therefore, these USRPs are assumed to be synchronized with each other.

The modulation scheme is unnecessary since the anchor node only transmitting tone signals for distance estimation. Hence, this project research focuses on the study of the physical layer and the power transmitted within allowable limits provided by national regulation bodies. Last but not least, the data collection throughout research will be post-processing using Matlab to analyse the performance of distance and location estimation. It is assumed that blind node and anchor node are in the same coverage area and able to communicate with each other.

1.5 Contributions

The significant contribution of this project is the development of the range estimation using DFD ranging technique which evolving from the phase difference of RFID system arrival technique and the conventional ranging technique applied in a radar system. In this project, the proposed technique is suitable for a one-way forward communication link system instead of two-way communication as applied in RFID and Radar. This project also computes the location of the blind nodes based on the ranging estimation data obtained from the experimental work. However, this location of the blind nodes was constructed through simulation using collected database of range estimation.

Based on simulations, the proposed DFD ranging technique shows adequate accuracy in distance estimation under the influence of 15^o variance of White Gaussian Noise with minimum error in distance estimation for 10 Mhz frequency separation is achieved 1.19 meter. The phase unwrapping technique known as Maximum likelihood estimation (MLE), Least Square Estimator (LSE) and Chinese Remainder Theorem (CRT) is proposed to improve distance estimation using DFD ranging technique. Following this, the minimum error in distance estimation through experiment achieved is 0.23 meters while by using Receive Signal Strength (RSS) ranging technique the minimum error achieved is 1.44 meters. In comparison with RSS technique in term of minimum error, DFD can provide better distance estimation with the same experiment configuration up to 84% improvement.

It is also worth mentioning that two conference paper already been published related to this research work such as "Ranging Estimation Using Dual-frequency Doppler Technique " and "Phase Unwrapping Technique for Dual-Frequency Doppler Ranging Estimation ".

1.6 Thesis Organization

Chapter 1 stated the background of the research, problem statement, objective, scope of work and contribution of the research.

Chapter 2 elaborates the fundamental background and relevant literature reviews on propagation studies, localization techniques, ranging techniques that are used as references for phase unwrapping techniques. This chapter also discussed the improvement of DFD ranging technique. Lastly, general information on the platform used in this project is also provided.

Chapter 3 introduces the theory of the proposed ranging technique which is DFD ranging technique. The theory on data extraction technique using Fast Fourier Transform (FFT), phase unwrapping techniques and localization using trilateration technique is also discussed in depth.

Chapter 4 discussed the simulation and experimental implementation by using the related theory explained in Chapter 3 to achieve the research objectives of this project. The method used for this project is extensively explained with additional flowchart presentation.

Chapter 5 presents the result obtain from simulation and experimental work that discussed in Chapter 4. Then this result is further discussed in term of performance accuracy by comparing with other research works that applied the same approach. Then, the reason behind the degradation of the data from experiment compared to simulation data is elaborate. Chapter 5 presents the result obtained from simulation and experimental work that were discussed in Chapter 4. Results interpreted in term of performance accuracy by comparing with existing research works which use a similar approach. The data degradation factor from the comparison of actual and simulation data was elaborated.

Chapter 6 concludes the research findings and also provides the recommendation for future work.

Then, this DFD ranging technique can be implemented on the moving nodes since various applications especially transportation system is always moving.

This proposed technique can be investigated to be implemented in Wireless Sensor Network (WSN) since WSN is in the need of high accuracy localization system especially in disaster and rescue mission. Next, several frequencies separation pair can be used for distance estimation instead of using only two transmitted frequency at a time in this thesis. Beside that, this distance estimation system can be develop to estimate the distance between blind node and anchor node without the need for the post-processing that usually offline. Last but not least, the additional investigation can be carried out where experimental measurement can be perform at different time that have less signal traffic.

REFERENCES

1. Celebi, H. and Arslan, H. Cognitive positioning systems. *Wireless Communications, IEEE Transactions on*, 2007. 6(12): 4475–4483.
2. Li, X., Wang, W., Yang, B. and Yin, Q. Distance estimation based on phase detection with robust Chinese remainder theorem. *Acoustics, Speech and Signal Processing (ICASSP), 2014 IEEE International Conference on 4-9 may,2014. Florence, Italy*. IEEE. 2014. 4204–4208.
3. Zhang, Y., Amin, M. and Ahmad, F. A novel approach for multiple moving target localization using dual-frequency radars and time-frequency distributions. *Signals, Systems and Computers, 2007. ACSSC 2007. Conference Record of the Forty-First Asilomar Conference on, 4-7 Nov. 2007. Pacific Grove, CA*. IEEE. 2007. 1817–1821.
4. Zhou, C. and Griffin, J. D. Accurate phase-based ranging measurements for backscatter RFID tags. *Antennas and Wireless Propagation Letters, IEEE*, 2012. 11: 152–155.
5. Pelka, M., Bollmeyer, C. and Hellbrück, H. Accurate radio distance estimation by phase measurements with multiple frequencies. *2014 International Conference on Indoor Positioning and Indoor Navigation, 27-30 Oct. 2014. Busan*. 2014. 142 – 151.
6. Yang, B., Wang, W., Xia, X. and Yin, Q. Phase detection based range estimation with a dual-band robust Chinese remainder theorem. *Science China Information Sciences*, 2014. 57(2): 1–9.
7. Scherhaufl, M., Pichler, M., Schimback, E., Muller, D. J., Ziroff, A. and Stelzer, A. Indoor localization of passive UHF RFID tags based on phase-of-arrival evaluation. *Microwave Theory and Techniques, IEEE Transactions on*, 2013. 61(12): 4724–4729.
8. Setlur, P., Amin, M. and Ahmad, F. Dual-frequency Doppler radars for indoor range estimation: Cramér–Rao bound analysis. *IET Signal Processing*, 2010. 4(3): 256–271.
9. Povalac, A. and Sebesta, J. Phase difference of arrival distance estimation

for RFID tags in frequency domain. *RFID-Technologies and Applications (RFID-TA), 2011 IEEE International Conference on 15-16 Sept. 2011. Sitges*. IEEE. 2011. 188–193.

10. Zhang, Y., Amin, M. and Ahmad, F. Localization of inanimate moving targets using dual-frequency synthetic aperture radar and time-frequency analysis. *Geoscience and Remote Sensing Symposium, 2008. IGARSS 2008. 7-11 July 2008. Boston, MA*. IEEE. 2008, vol. 2. II–33.

11. Zhang, H., Li, L. and Wu, K. Software-defined six-port radar technique for precision range measurements. *Sensors Journal, IEEE*, 2008. 8(10): 1745–1751.

12. Tan, D. K. P., Lesturgie, M., Sun, H. and Lu, Y. Moving target localization using dual-frequency continuous wave radar for urban sensing applications. *Radar Conference-Surveillance for a Safer World, 2009. RADAR. International, 12-16 Oct. 2009. Bordeaux*. IEEE. 2009. 1–6.

13. Moschitta, A., Macii, D., Trenti, F., Dalpez, S. and Bozzoli, A. Characterization of a geometrical wireless signal propagation model for indoor ranging techniques. *Instrumentation and Measurement Technology Conference (I2MTC), 2012 IEEE International*. IEEE. 2012. 2598–2603.

14. Amin, M., Zemany, P., Setlur, P. and Ahmad, F. Moving target localization for indoor imaging using dual frequency CW radars. *Sensor Array and Multichannel Processing, 2006. Fourth IEEE Workshop on*. IEEE. 2006. 367–371.

15. Yipeng, D., Shun, D. and Guangyou, F. Moving Targets Localization for Dual Frequency Continuous Wave Radar Using Time Domain Analysis. *Intelligent System Design and Engineering Application (ISDEA), 2010 International Conference on 12-14 July 2006. Waltham, MA*. IEEE. 2010, vol. 1. 964–967.

16. Shames, I., Bishop, A. N., Anderson, B. *et al.* Doppler shift target localization. *Aerospace and Electronic Systems, IEEE Transactions on*, 2013. 49(1): 266–276.

17. Wyne, S., Santos, T., Singh, A. P., Tufvesson, F. and Molisch, A. F. Characterisation of a time-variant wireless propagation channel for outdoor short-range sensor networks. *IET communications*, 2010. 4(3): 253–264.

18. Kamarudin, L., Ahmad, R., Ong, B., Malek, F., Zakaria, A. and Arif, M. Review and modeling of vegetation propagation model for wireless sensor networks using omnet++. *Network Applications Protocols and Services*

(NETAPPS), 2010 Second International Conference on 22-23 Sept. 2010. Kedah. IEEE. 2010. 78–83.

19. Sklar(1987), B. DIGITAL COMMUNICATIONS Fundamentals and Applications (2nd ed).

20. Kochlan, M. and Micek, J. Indoor propagation of 2.4 GHz radio signal propagation models and experimental results. *Digital Technologies (DT), 2014 10th International Conference on 9-11 July 2014. Zilina*. IEEE. 2014. 125–129.

21. Hidayab, M., Ali, A. H. and Azmi, K. B. A. Wifi signal propagation at 2.4 GHz. *Microwave Conference, 2009. APMC 2009. Asia Pacific, 7-10 Dec. 2009. Singapore*. IEEE. 2009. 528–531.

22. Ali, A. H., Razak, M. R. A., Hidayab, M., Azman, S. A., Jasmin, M. Z. M. and Zainol, M. A. Investigation of indoor WIFI radio signal propagation. *Industrial Electronics & Applications (ISIEA), 2010 IEEE Symposium on 3-5 Oct. 2010. Penang*. IEEE. 2010. 117–119.

23. Stoyanova, T., Kerasiotis, F., Prayati, A. and Papadopoulos, G. A practical RF propagation model for wireless network sensors. *Sensor Technologies and Applications, 2009. SENSORCOMM'09. Third International Conference on 18-23 June 2009. Athens, Glyfada*. IEEE. 2009. 194–199.

24. Hossain, C. A., Hossain, M. A. and Tarique, M. Effects of shadowing on the performances of mobile ad hoc networks. *Computational Intelligence and Communication Networks (CICN), 2011 International Conference on 7-9 Oct. 2011. Gwalior*. IEEE. 2011. 319–322.

25. Ezzine, R., Al-Fuqaha, A., Braham, R. and Belghith, A. A new generic model for signal propagation in Wi-Fi and WiMAX environments. *Wireless Days, 2008. WD'08. 1st IFIP*. IEEE. 2008. 1–5.

26. Borries, K., Wang, X., Judd, G., Steenkiste, P. and Stancil, D. Experience with a wireless network testbed based on signal propagation emulation. *Wireless Conference (EW), 2010 European, 12-15 April 2010. Lucca*. IEEE. 2010. 833–840.

27. Luu, B. B., Hardy, R. L. and Tran, G. T. A technique for determining radio-signal propagation in an emulated wireless environment. *Military Communications Conference, 2008. MILCOM 2008.16-19 Nov. 2008. San Diego, CA*. IEEE. 2008. 1–5.

28. Sabri, N., Aljunid, S., Ahmad, R., Malek, M. A., Kamaruddin, R. and Salim, M. Wireless sensor network wave propagation in vegetation: Review and

simulation. *Antennas and Propagation Conference (LAPC), 12-13 Nov. 2012. Loughborough*. IEEE. 2012. 1–4.

29. Yang, T., Mino, G., Barolli, L., Durresi, A. and Xhafa, F. Comparison evaluation for mobile and static sensor nodes in wireless sensor networks considering tworayground and shadowing propagation models. *Network-Based Information Systems (NBiS), 2011 14th International Conference on 7-9 Sept. 2011. Tirana*. IEEE. 2011. 186–193.

30. Varzandian, S., Zakeri, H. and Ozgoli, S. Locating WiFi access points in indoor environments using non-monotonic signal propagation model. *Control Conference (ASCC), 2013 9th Asian, 23-26 June 2013. Istanbul*. IEEE. 2013. 1–5.

31. Japertas, S., Orzekauskas, E. and Slanys, R. Research of IEEE 802.11 standard signal propagation features in multi partition indoors. *Digital Information Processing and Communications (ICDIPC), 2012 Second International Conference on 10-12 July 2012. Klaipeda City*. IEEE. 2012. 1–4.

32. Miranda, J., Abrishambaf, R., Gomes, T., Goncalves, P., Cabral, J., Tavares, A. and Monteiro, J. Path loss exponent analysis in Wireless Sensor Networks: Experimental evaluation. *Industrial Informatics (INDIN), 2013 11th IEEE International Conference on 29-31 July 2013. Bochum*. IEEE. 2013. 54–58.

33. Kamaludin Mohamad Yusof, J. W. and Fitz, S. Short range frequency scanning estimation for localisation in cognitive radio environment. *International Conference on Computer Communication Networks, ICCCN 2011 on 31 July 4 August 2011. Maui, Hawaii*. IEEE. 2011. 1–6.

34. Yazdandoost, K. Y. and Kohno, R. The ultra-wideband signal propagation. *Circuits and Systems, 2004. MWSCAS'04. The 2004 47th Midwest Symposium on 25-28 July 2004*. IEEE. 2004, vol. 2. II–645.

35. Oguejiofor, O., Aniedu, A., Ejiofor, H. and Okolibe, A. Trilateration based localization algorithm for wireless sensor network. *Int. J. Sci. Mod. Eng*, 2013. 7.

36. Celebi, H. and Arslan, H. Adaptive positioning systems for cognitive radios. *New Frontiers in Dynamic Spectrum Access Networks, 2007. DySPAN 2007. 2nd IEEE International Symposium on 17-20 April 2007. Dublin*. IEEE. 2007. 78–84.

37. Drawil, N. M., Amar, H. M., Basir, O. *et al.* GPS localization accuracy classification: A context-based approach. *Intelligent Transportation Systems,*

IEEE Transactions on, 2013. 14(1): 262–273.

38. Kos, T., Markezic, I. and Pokrajcic, J. Effects of multipath reception on GPS positioning performance. *Elmar, 2010 Proceedings, 15-17 Sept. 2010. Zadar*. IEEE. 2010. 399–402.

39. Chen, S., Shu, R., Zhang, S. and Zheng, X. Evaluate distance measurement how to influence localization in wireless sensor networks. *Consumer Electronics, Communications and Networks (CECNet), 2012 2nd International Conference on 21-23 April 2012. Yichang*. IEEE. 2012. 323–325.

40. Hassan, N. A. C., Yusof, K. M. and Yusof, S. K. S. Ranging Estimation Using Dual-Frequency Doppler Technique. *IT Convergence and Security (ICITCS), 2015 5th International Conference on 24-27 Aug. 2015. Kuala Lumpur*. IEEE. 2015. 1–5.

41. Suzhe, W. and Yong, L. Node localization algorithm based on RSSI in wireless sensor network. *Signal Processing and Communication Systems (ICSPCS), 2012 6th International Conference on 12-14 Dec. 2012. Gold Coast, QLD*. IEEE. 2012. 1–4.

42. Suo, H., Wan, J., Huang, L. and Zou, C. Issues and challenges of wireless sensor networks localization in emerging applications. *Computer Science and Electronics Engineering (ICCSEE), 2012 International Conference on 23-25 March 2012. Hangzhou*. IEEE. 2012, vol. 3. 447–451.

43. Yusof, K. M., Woods, J. and Fitz, S. Frequency scanning using software defined radio for localised range estimation. *Sensor Technologies and Applications, 2009. SENSORCOMM'09. Third International Conference on 18-23 June 2009. Athens, Glyfada*. IEEE. 2009. 181–186.

44. Shi, W. and Wong, V. W. A two-phase algorithm for locating sensors in irregular areas. *Global Telecommunications Conference (GLOBECOM 2010) 6-10 Dec. 2010. Miami, FL*. IEEE. 2010. 1–6.

45. Radhi, N., Aziz, K., Hamad, S. and Al-Raweshidy, H. Estimate primary user localization using cognitive radio networks. *Innovations in Information Technology (IIT), 2011 International Conference on 25-27 April 2011. Abu Dhabi*. IEEE. 2011. 381–385.

46. Kianoush, S., Vizziello, A. and Gamba, P. A cooperative localization algorithm exploiting a mobile device in cognitive radio networks. *Networks and Communications (EuCNC), 2014 European Conference on 23-26 June 2014. Bologna*. IEEE. 2014. 1–5.

47. Wang, J., Chen, J. and Cabric, D. Cramer-Rao bounds for joint RSS/DoA-based primary-user localization in cognitive radio networks. *Wireless Communications, IEEE Transactions on*, 2013. 12(3): 1363–1375.

48. Gustafsson, F. and Gunnarsson, F. Positioning using time-difference of arrival measurements. *Acoustics, Speech, and Signal Processing, 2003. Proceedings.(ICASSP'03). 2003 IEEE International Conference on 6-10 April 2003*. IEEE. 2003, vol. 6. VI–553.

49. Krishnaveni, V., Kesavamurthy, T. and Aparna, B. Beamforming for Direction-of-Arrival (DOA) Estimation-A Survey. *International Journal of Computer Applications*, 2013. 61(11): 4–11.

50. Kazemi, M., Ardebilipour, M. and Noori, N. A dynamic AOA-RSS positioning algorithm for cognitive radio. *Wireless Communications Networking and Mobile Computing (WiCOM), 2010 6th International Conference on 23-25 Sept. 2010. Chengdu*. IEEE. 2010. 1–5.

51. Ahmed, K., Heidari-Bateni, G. *et al.* Wsn06-3: Improving two-way ranging precision with phase-offset measurements. *Global Telecommunications Conference, 2006. GLOBECOM'06. Nov. 27 2006-Dec. 1 2006. San Francisco, CA*. IEEE. 2006. 1–6.

52. Brchan, J. L., Zhao, L., Wu, J., Williams, R. E. and Pérez, L. C. A real-time RFID localization experiment using propagation models. *RFID (RFID), 2012 IEEE International Conference on 3-5 April 2012. Orlando, FL*. IEEE. 2012. 141–148.

53. Mao, G., Fidan, B. and Anderson, B. D. Wireless sensor network localization techniques. *Computer networks*, 2007. 51(10): 2529–2553.

54. Bandiera, F., Coluccia, A. and Ricci, G. A Cognitive Algorithm for Received Signal Strength Based Localization. *Signal Processing, IEEE Transactions on*, 2015. 63(7): 1726–1736.

55. Mariani, A., Kandeepan, S., Giorgetti, A. and Chiani, M. Cooperative weighted centroid localization for cognitive radio networks. *Communications and Information Technologies (ISCIT), 2012 International Symposium on 2-5 Oct. 2012. Gold Coast, QLD*. IEEE. 2012. 459–464.

56. Dardari, D., Conti, A., Ferner, U., Giorgetti, A. and Win, M. Z. Ranging with ultrawide bandwidth signals in multipath environments. *Proceedings of the IEEE*, 2009. 97(2): 404–426.

57. Dieng, N. A., Chaudet, C., Charbit, M., Toutain, L. and Ben Meriem, T. Experiments on the RSSI as a Range Estimator for Indoor Localization.

New Technologies, Mobility and Security (NTMS), 2012 5th International Conference on 7-10 May 2012. Istanbul. IEEE. 2012. 1–5.

58. Zàruba, G. V., Huber, M., Kamangar, F. A. and Chlamtac, I. Indoor Location Tracking Using RSSI Readings from a Single Wi-Fi Access Point. *Wirel. Netw.*, 2007. 13(2): 221–235. ISSN 1022-0038. doi: 10.1007/s11276-006-5064-1. URL `http://dx.doi.org/10.1007/s11276-006-5064-1`.

59. Akiyama, T., Nakamura, M., Sugimoto, M. and Hashizume, H. Smart phone localization method using dual-carrier acoustic waves. *Indoor Positioning and Indoor Navigation (IPIN), 2013 International Conference on 28-31 Oct. 2013. Montbeliard-Belfort*. IEEE. 2013. 1–9.

60. Ren, M. and Zou, Y. X. A novel multiple sparse source localization using triangular pyramid microphone array. *Signal Processing Letters, IEEE*, 2012. 19(2): 83–86.

61. Maroti, M., Kusy, B., Balogh, G., Volgyesi, P., Molnar, K., Nadas, A., Dora, S. and Ledeczi, A. Radio interferometric positioning. *ACM Third International Conference on Embedded Networked Sensor Systems (SenSys 05), 02 - 04 Nov 2005. San Diego, CA, USA*. 2005. 1–12.

62. Siqueira, P., Ahmed, R., Wirth, J. W. and Bachmann, A. Variable precision two-channel phase, amplitude, and timing measurements for radar interferometry and polarimetry. *Microwave Theory and Techniques, IEEE Transactions on*, 2007. 55(10): 2248–2256.

63. Wang, Y., Shinotsuka, M., Ma, X. and Tao, M. Design an asynchronous radio interferometric positioning system using dual-tone signaling. *Wireless Communications and Networking Conference (WCNC), 7-10 April 2013. Shanghai*. IEEE. 2013. 2294–2298.

64. Patwari, N. and Hero, A. Indirect radio interferometric localization via pairwise distances. *Proceedings of 3rd IEEE Workshop on Embedded Networked Sensors*. Citeseer. 2006. 26–30.

65. Li, X., Zhang, Y. and Amin, M. G. Multifrequency-based range estimation of RFID tags. *RFID, 2009 IEEE International Conference on 27-28 April 2009. Orlando, FL*. IEEE. 2009. 147–154.

66. Li, W., Wang, X., Wang, X. and Moran, B. Distance estimation using wrapped phase measurements in noise. *Signal Processing, IEEE Transactions on*, 2013. 61(7): 1676–1688.

67. McKilliam, R. G., Quinn, B. G., Clarkson, I. V. L., Moran, B. and Vellambi,

B. N. Polynomial phase estimation by phase unwrapping. *arXiv preprint arXiv:1211.0374*, 2012.

68. (1985), R. W. R. The FFT Fundamentals and concepts.

69. Bioucas-Dias, J., Katkovnik, V., Astola, J. and Egiazarian, K. Multi-frequency phase unwrapping from noisy data: adaptive local maximum likelihood approach. In: *Image Analysis*. Springer. 310–320. 2009.

70. Miesen, R., Kirsch, F., Groeschel, P. and Vossiek, M. Phase based multi carrier ranging for UHF RFID. *Wireless Information Technology and Systems (ICWITS), 2012 IEEE International Conference on 11-16 Nov. 2012. Maui, HI*. IEEE. 2012. 1–4.

71. Spagnolini, U. 2-D phase unwrapping and instantaneous frequency estimation. *Geoscience and Remote Sensing, IEEE Transactions on*, 1995. 33(3): 579–589.

72. Sun, W., So, H. and Chen, Y. Estimation of the frequency and phase of a single sinusoid based on the downsampling technique.

73. McKilliam, R. G., Quinn, B. G., Moran, B. *et al.* Frequency estimation by phase unwrapping. *Signal Processing, IEEE Transactions on*, 2010. 58(6): 2953–2963.

74. Zielinski, T. Instantaneous phase shift estimation methods. *Instrumentation and Measurement Technology Conference, 1996. IMTC-96. Conference Proceedings. Quality Measurements: The Indispensable Bridge between Theory and Reality., 04-06 Jun 1996. Brussels*. IEEE. 1996, vol. 1. 162–167.

75. Cao, N., Lee, H. and Jung, H. C. Mathematical Framework for Phase-Triangulation Algorithms in Distributed-Scatterer Interferometry. *Geoscience and Remote Sensing Letters, IEEE*, 2015. 12(9): 1838–1842.

76. Zeng, F., Yu, M., Zou, C. and Gong, J. An Improved Point-in-Triangulation Localization Algorithm Based on Cosine Theorem. *Wireless Communications, Networking and Mobile Computing (WiCOM), 2012 8th International Conference on 21-23 Sept. 2012. Shanghai, China*. IEEE. 2012. 1–4.

77. Mathias, A., Leonardi, M. and Galati, G. An efficient multilateration algorithm. *Digital Communications-Enhanced Surveillance of Aircraft and Vehicles, 3-5 Sept. 2008. Capri*, 2008: 1–6.

78. Zhou, Y., Li, J. and Lamont, L. Multilateration localization in the presence

of anchor location uncertainties. *Global Communications Conference (GLOBECOM), 3-7 Dec. 2012. Anaheim, CA*. IEEE. 2012. 309–314.

79. Alkasi, U., Al Shayokh, M. and Partal, H. P. An experimental comparison study on indoor localization: RF fingerprinting and Multilateration methods. *Electronics, Computer and Computation (ICECCO), 2013 International Conference on 7-9 Nov. 2013. Ankara*. IEEE. 2013. 255–259.

80. Wang, J., Urriza, P., Han, Y. and Čabric, D. Performance analysis of weighted centroid algorithm for primary user localization in cognitive radio networks. *Signals, Systems and Computers (ASILOMAR), 2010 Conference Record of the Forty Fourth Asilomar Conference on 7-10 Nov. 2010. Pacific Grove, CA*. IEEE. 2010. 966–970.

81. Salih, S. H., Suliman, M. and Mohammed, A. A novel spectrum sensing scheduler algorithm for Cognitive Radio Networks. *Computing, Electrical and Electronics Engineering (ICCEEE), 2013 International Conference on 26-28 Aug. 2013. Khartoum*. IEEE. 2013. 350–356.

82. Lee, W.-Y. and Akyildiz, I. F. Optimal spectrum sensing framework for cognitive radio networks. *Wireless Communications, IEEE Transactions on*, 2008. 7(10): 3845–3857.

83. Yücek, T. and Arslan, H. A survey of spectrum sensing algorithms for cognitive radio applications. *Communications Surveys & Tutorials, IEEE*, 2009. 11(1): 116–130.

84. Kale Sandikar, R., Wadhai, V. M. and Helonde, J. B. Efficient spectrum sensing in cognitive Radio using energy detection method with new threshold formulation. *Emerging Research Areas and 2013 International Conference on Microelectronics, Communications and Renewable Energy (AICERA/ICMiCR), 2013 Annual International Conference on 4-6 June 2013. Kanjirapally*. IEEE. 2013. 1–5.

85. Ye, Z., Memik, G. and Grosspietsch, J. Energy detection using estimated noise variance for spectrum sensing in cognitive radio networks. *Wireless Communications and Networking Conference, 2008. WCNC 2008. IEEE*. IEEE. 2008. 711–716.

86. Hu, X., Xie, X.-Z., Song, T. and Lei, W. An algorithm for energy detection based on noise variance estimation under noise uncertainty. *Communication Technology (ICCT), 2012 IEEE 14th International Conference on 9-11 Nov. 2012. Chengdu*. IEEE. 2012. 1345–1349.

87. Uyanik, G. S., Cepheli, O., Kurt, G. K. and Oktug, S. Implementation

and performance evaluation of dynamic spectrum access using software defined radios. *Communications and Networking (BlackSeaCom), 2013 First International Black Sea Conference on 3-5 July 2013. Batumi*. IEEE. 2013. 157–161.

88. Rahman, M. A., Khadka, S., GAHADZA, M., HANIZ, A., KIM, M., TAKADA, J.-i. *et al.* Development of spectrum sensing system with GNU Radio and USRP to detect emergency radios (). *ŁŁ. SR,* , 2009. 109(246): 39–44.

89. Dalai, J. and Patra, S. K. Spectrum sensing for WLAN and WIMAX using Energy Detection Technique. *Emerging Trends in Computing, Communication and Nanotechnology (ICE-CCN), 2013 International Conference on*. IEEE. 2013. 620–624.

90. Lim, C. H. Adaptive energy detection for spectrum sensing in unknown white Gaussian noise. *Communications, IET*, 2012. 6(13): 1884–1889.

91. Sanabria-Russo, L., Barcelo, J., Domingo, A. and Bellalta, B. Spectrum Sensing with USRP-E110. In: *Multiple Access Communications*. Springer. 79–84. 2012.

92. Nasif, A. O. and Mark, B. L. Measurement clustering criteria for localization of multiple transmitters. *Information Sciences and Systems, CISS 2009. 43rd Annual Conference on 18-20 March 2009. Baltimore, MD*. IEEE. 2009. 341–345.

93. Adams, A., Tummala, M., McEachen, J. and Scrofani, J. Source localization and tracking in a Cognitive Radio environment consisting of frequency and spatial mobility. *Signal Processing and Communication Systems (ICSPCS), 2013 7th International Conference on 16-18 Dec. 2013. Carrara, VIC*. IEEE. 2013. 1–6.

94. Thomas, R. R., Zayen, B., Knopp, R. and Maharaj, B. T. Multiband Time-of-Arrival positioning technique for cognitive radio systems. *Personal Indoor and Mobile Radio Communications (PIMRC), 2011 IEEE 22nd International Symposium on 11-14 Sept. 2011. Toronto, ON*. IEEE. 2011. 2315–2319.

95. Kazemi, M., Ardebilipour, M. and Noori, N. Improved weighted RSS positioning algorithm for cognitive radio. *Signal Processing (ICSP), 2010 IEEE 10th International Conference on 24-28 Oct. 2010. Beijing*. IEEE. 2010. 1502–1506.

96. Figueiredo e Silva, P., Daniel, O., Nurmi, J. and Lohan, E.-S. Cyclostationary features of downsampled 802.11 g OFDM signal for

cognitive positioning systems. *Wireless Communications Systems (ISWCS), 2014 11th International Symposium on 26-29 Aug. 2014. Barcelona*. IEEE. 2014. 950–954.

97. Patton, L. K. A GNU Radio Based Software-Defined Radar. 2007: 1–125.

98. Ahmad, F., Amin, M. G. and Zemany, P. D. Dual-frequency radars for target localization in urban sensing. *IEEE transactions on aerospace and electronic systems*, 2009. 45(4): 1598–1609.

99. Liechty, L. C., Reifsnider, E. and Durgin, G. Developing the best 2.4 GHz propagation model from active network measurements. *Vehicular Technology Conference, 2007. 66th VTC-2007 Fall. 30 Sept. 3 Oct. 2007. Baltimore, MD*. IEEE. 2007. 894–896.

100. Reidt, S., Ebinger, P., Kuijper, A. and Wolthusen, S. D. Resource-constrained signal propagation modeling for tactical mobile ad hoc networks. *Network Science Workshop (NSW), 2011 IEEE*. IEEE. 2011. 67–74.

101. Pennock, S. R. and Watson, R. J. Analysis of propagation effects in LANs and WANs by FDTD and ray tracing techniques. *Antennas and Propagation (EuCAP), 2010 Proceedings of the Fourth European Conference on 12-16 April 2010. Barcelona, Spain*. IEEE. 2010. 1–5.

102. Hur, Y., Park, J., Woo, W., Lim, K., Lee, C.-H., Kim, H. and Laskar, J. A wideband analog multi-resolution spectrum sensing (MRSS) technique for cognitive radio (CR) systems. *ISCAS*. 2006.

103. Akyildiz, I. F., Lee, W.-Y., Vuran, M. C. and Mohanty, S. NeXt generation/dynamic spectrum access/cognitive radio wireless networks: a survey. *Computer Networks*, 2006. 50(13): 2127–2159.

104. Tian, Y., Tang, Z. and Yu, Y. Third-Order Channel Propagation Model-Based Indoor Adaptive Localization Algorithm for Wireless Sensor Networks. *Antennas and Wireless Propagation Letters, IEEE*, 2013. 12: 1578–1581.