ANGLE OF ARRIVAL ESTIMATION SYSTEM FOR RADIATION PATTERN RECONFIGURABLE ANTENNA WITH MODIFIED GAUSSIAN MEMBERSHIP FUNCTION

by

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Specially dedicated to my beloved parents, wife, daughter, brothers, sisters and friends

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LIST OF ABBREVIATIONS

AES	AOA estimation system
AOA	Angle of Arrival
AUT	Antenna Under Test
BIOS	Basic Input Output System
COG	Center of Gravity
CPU	Central processing unit
CST	Computer Simulation Technology
DISTRO	Linux Distribution
DOA	Direction of Arrival
Dsig-MF	Double Sigmoidal MF
DUT	Device Under Test
ESPRIT	Estimation of Signal Parameters using Rotational In-variance Techniques
FIS	Fuzzy Inferences system
FL	Fuzzy Logic
Gauss-MF	Gaussian Membership function
GPIB	General Purpose Interface Bus
GPIO	General Purpose Input Output
HDMI	High-definition multimedia interface
IOT	Internet of Thing
ISM	Industrial, Scientific and Medical
LAN	Local Area Network
LED	Light Emitting Diode
LinSSID	Linux Service Set Identifier
LOS	Line of Sight
LMS	Least Mean Square
MF	Membership Function
MOM	Mean of Maximum
MUSIC	Multiple Signal Classification
NIC	Network Interface Card
NOOBS	New Out of Box Software
OS	Operating System

Pattern-MF	Radiation Pattern Membership function
PC	Personal Computer
PIC	Programmable Intelligent Computer
PIDB	PIC Development Board
Psig-MF	Product of 2 Sigmoidal Functions
RADAR	Radio Detection and Ranging
RAM	Random Access Memory
RF	Radio Frequency
RFID	Radio Frequency Identification
RLS	Recursive Least Squares
RLSA	Radial Line Slot Antenna
RPR	Radiation Pattern Reconfigurable
Rx	Receiver
SBC	Single Board Computer
SciKit	SciPy Toolkit
SciPy	Scientific Computing Tools for Python
SD	Secure Digital
SPI	Serial Peripheral Interface
SSD	Solid-State Drives
Sk-Fuzzy	SciKit-Fuzzy
SOC	System on Chip
TDOA	Time Difference of Arrival
Tramp-MF	Trapezoidal Membership function
Tri-MF	Triangular Membership function
TSB	Touch Stone Block
Tx	Transmitter
UART	Universal Asynchronous Receiver Transmitter
UMS	USB Mass Storage
USB	Universal Serial Bus
Wi-Fi	Wireless Fidelity
WSN	Wireless Sensor Network

LIST OF SYMBOLS

S_{11}	Reflection Coefficient
I	Current
R	Resistance
V	Voltage
m	Meter
mm	Millimeter
dB	Decibel
dBi	Decibel Isotropic
f	Frequency
ε_r	Dielectric Constant
t	Times
s	Seconds
θ	Theta
δ	Electrical Loss Tangent
μ	Magnetic Permeability
Ω	Ohm
a_{mode}	Amplitude of Pattern-MF
c	Center of Gauss-MF
GHz	Giga Hertz
MHz	Mega Hertz

Anggaran Sudut Ketibaan bagi Antenna Kebolehupayaan Kawalan Corak Radiasi dengan Fungsi Keahlian Gaussian yang Diubahsuai

ABSTRAK

Disertasi ini memberi tumpuan untuk membangunkan sistem anggaran sudut ketibaan *(AES)* melalui aras kekuatan isyarat yang diterima *(RSSI)*. *AES* yang dicadangkan dibangunkan pada sebuah komputer papan tunggal *(SBC)* menggunakan sumber terbuka sistem operasi *(OS)* berasaskan *GNU Linux*. Sistem anggaran *AOA* yang baik mampu untuk meliputi sudut angaran 360° dengan titik anggaran yang lebih banyak. Walaubagaimanapun, prototaip sistem anggaran *AOA* sebelum ini mengalami kelemahan utama untuk meliputi capaian sudut anggaran 360° kerana batasan corak radiasi antenna. Oleh itu, antena kebolehupayaan kawalan radiasi *(RPR)* yang beroperasi pada frekuensi 2.45 GHz mampu untuk meliputi sudut anggaran *AOA* yang lebih luas diperkenalkan. Walau bagaimanapun, antena *RPR* pada prototaip *AES* mengalami kekurangan titik anggaran *AOA*. Oleh itu, tesis ini memperkenalkan Sistem Inferensi Kabur *(FIS)* untuk membantu dalam membuat keputusan dan meningkatkan bilangan titik anggaran *AOA*. Sistem Inferensi Kabur untuk sistem anggaran sudut ketibaan *(FIS-AES)* adalah usaha pertama dalam merealisasikan kelebihan *FIS* bersama kebolehan tiga set antena *RPR* tanpa sebarang sokongan algoritma pintar untuk meliputi sudut anggaran 360°. Algoritma *FIS-AES* dibangunkan oleh pengaturcaraan *Python 2.7* yang disokong oleh *SciKit*. *FIS-AES* yang dicadangkan berjaya meningkatkan bilangan titik anggaran dari Sembilan titik anggaran kepada 18 titik anggaran. Empat jenis fungsi keahlian *(MF)* diuji untuk mendapatkan tindak balas antara *fuzzifier* dan *defuzzfier* algoritma *FIS-AES*. Satu *MF* terbaru diperkenalkan berdasarkan lengkung *Gaussian-MF* dikenali sebagai *Pattern-MF*. Tindakbalas antara *fuzzifier* dan *defuzzfier* algoritma FIS-AES yang dicadangkan *Pattern-MF* dianggarkan sekitar ~80% hingga ~85%, merupakan yang tertinggi dibandingkan dengan *MF* sedia ada di dalam *SciKit*. Tambahan pula, adaptasi *FIS* berjaya mewujudkan lebih banyak titik anggaran *AOA*, oleh itu ia membantu *FIS-AES* yang dicadangkan mampu memperbaiki ralat mutlak anggaran *AOA* dan ralat punca kuadrat sama rata *(RMSE)* iaitu masing-masing ± 5° dan kurang daripada 10. Penyiasatan prestasi *SBC* penting untuk mengesahkan bahawa *SBC* berwibawa bertindak sebagai platform utama *AES*. Prestasi *SBC* dinilai dari segi penggunaan pusat pemprosesan unit (*CPU)* dan penggunaan memori. Dalam karya ini, *Raspberry-Pi* telah berjaya menyelesaikan semua tugasan dengan purata penggunan *CPU* dan purata penggunaan memori masing-masing kurang daripada 10% dan kurang daripada 31% untuk pengukuran S_{11} serta masing-masing kurang daripada 10% dan kurang daripada 37% untuk pengukuran ralat mutlak anggaran *AOA*. Dengan semua keupayaan yang ditunjukkan dan dibincangkan, *FIS-AES* mempunyai potensi besar sebagai salah satu pilihan terbaik bagi merealisasikan untuk aplikasi seperti sistem penyetempatan dan interaksi komputer.

Angle of Arrival Estimation System for Radiation Pattern Reconfigurable Antenna with Modified Gaussian Membership Function

ABSTRACT

This dissertation focuses on developing angle of arrival (AOA) estimation system (AES) through incoming received signal strength indication (RSSI). Proposed AES is developing on a single board computer (SBC) using an open source GNU Linux operating system (OS). The good AOA estimation systems must able to covered 360° with many estimation points. However, previous AOA estimation systems prototype suffers from a major drawback to achieve 360° angle covered due to limitation of antenna radiation pattern. Therefore, radiation pattern reconfigurable (RPR) antenna operates at 2.45 GHz that capable to cover the wide AOA estimation angle is introduced. Nevertheless, the RPR antenna on AES prototype provides lack of estimation points. Thus, this thesis infuses Fuzzy Inference System (FIS) to further improve decision making and increase the number of AOA estimation points. The FIS-AES is the first effort in realizing the advantages of FIS with only three sets of RPR antenna abilities without any intelligent algorithm support to cover 360° angle estimation. The FIS-AES algorithm is develop by Python 2.7 programming supported by SciKit library. The proposed Fuzzy Inference System of AOA estimation system (FIS-AES) successfully increases number of estimation from nine to 18 estimation points. Four types of membership function (MF) are trained to obtain response between fuzzifier and defuzzfier of FIS-AES algorithm. A novel MF based Gaussian-MF curve named as the Pattern-MF is introduced. The response between fuzzifier and defuzzfier of FIS-AES algorithm of proposed Pattern-MF approximately ~80% to ~85%, which is the highest compared than existed MF in SciKit library. Moreover, adopted the FIS offers more AOA estimation points, thus it helps FIS-AES capable to improve the absolute error of AOA estimation and root mean square error (RMSE) is ±5° and less than 10 respectively. The investigation of SBC performance is important to verify that SBC competent to act as the main platform of AES. The SBC performance is verified in terms of CPU and memory utilization. In this work, the Raspberry-Pi has successfully completed all tasking with average CPU and average memory utilization less than 10% and less than 31% respectively for S_{11} measurement and less than 10% and less than 37% respectively for AES measurement. With all capabilities demonstrated and discussed, the FIS-AES have great potential as one of the best options for realizing applications such as localization system man computer interaction.

CHAPTER 1 : INTRODUCTION

1.1 Overview

Over the past decade, Angle of Arrival (AOA) estimation or direction finding gains a lot of intention among the researchers. Historically, the direction finding technique has been found in the field of wireless sensor networks (WSN), radar, and electronic surveillance applications (De S. Muswieck, Russi, & Heckler, 2013). In recent days, direction finding for WSN has to satisfy various applications such as patient condition monitoring and localization system. Awareness of the physical location of each node is required by WSN applications.

AOA estimation is a process that determines the direction of arrival of a received signal by processing the signal impinging on an antenna array. Estimating the AOA is a crucial step in many military and civilian applications, particularly related to security. Applications of estimating the AOA include beam forming, tracking (Liao, Zhang, & Chan, 2010), localization and physical layer secrecy (A. Badawy, Khattab, Trinchero, ElFouly, & Mohamed, 2017; a Badawy et al., 2015)

Many different approaches can be applied to the localization estimation system, such as the time of the signal (acoustic or RF) arrival (TOA), the angle of arrival (AOA), and time difference of arrival (TDOA). The work carried out in this study focus the AOA estimation through received signal strength indication (RSSI) information. AOA is defined as the angle between the propagation direction of an incident wave and some reference direction. Traditionally, AOA estimation could be performed with phased antenna arrays, mechanically steerable antenna, or multiple antennas (Jiang, Lin, Lin, & Huang, 2013; Zhou, Zhang, & Mo, 2011). Phased antenna arrays usually track the angle using the amplitude and phase angle (Huang & Guo, 2011; Huang, Guo, & Bunton, 2009; Noordin, Arslan, Flynn, Erdogan, & El-Rayis, 2013; Sanudin et al., 2011). In such system, the AOA can be estimated using a complex digital signal processor and a signal processing algorithm such as least mean square (LMS), Recursive Least Squares (RLS) and Multiple Signal Classification MUSIC (Bazzi et al., 2016; Elhag, Osman, Yassin, & Ahmed, 2013; Zhang, Chew, & Wong, 2011). However, in the less complicated systems as proposed in recent works by (Ahmed, Member, Islam, & Member, 2015) only the incoming RSSI is used to estimate the AOA. In other words, the complex information of the signal and the phase angle are not required, which eventually reduces the overall complexity of the AOA detection system.

1.2 Problem Statement

Motivation of developing the AOA estimation system (AES) is to provide reliability of AES with low absolute error of AOA estimation. Various approaches have been proposed previously to AOA estimation through RSSI. An AOA estimation through RSSI could be performed with phased antenna arrays, mechanically steerable antenna, or multiple antennas (Jiang et al., 2013; Zhou et al., 2011). However, different antenna approaches is required for commercial Wi-Fi module to sniff the incoming RSSI.

Thus, thorough investigations have been carried out in this report by reviewing the existing AOA estimation system. Existing works from (Hood & Barooah, 2011; M

Malajner, Cucej, & Gleich, 2012; Park, Park, Park, Lee, & An, 2010) proposed AOA estimation through RSSI that has an ability to estimate 360° direction deploying a stepper motor. In order to the reduce power consumption of overall system and overall complexity of the AOA detection system, deploying stepper motor is not suitable especially for embedded system design.

On the other hand, there are other methods proposed for AOA estimation without the use of stepper motor. The work by (Jamlos, Rahman, Kamarudin, Saad, Shamsudin, et al., 2010; Kamarudin, Nechayev, & Hall, 2009) gave an impression that the AOA estimation can be achieved using a single reconfigurable antenna with just four desired angle directions. However, it can only cover four AOA estimation points. In other related work, the AOA is estimated almost 360° coverage without the use of stepper motor but with 12 antennas and RF modules are need to be used (M Malajner, Gleich, & Planinšič, 2015b). Overall, it could be noticed that the AOA estimation using RSSI but without the use of stepper motor either suffer from poor estimation where the estimation points are less; or with increased design complexity in terms of number of antennas and Wi-Fi modules used. Therefore, the motivation of this research to propose an AOA estimation system (AES) using RSSI that improves the number AOA estimation points and reduces the design complexity using the RPR antenna with Fuzzy Inferences system (FIS).

To the best of our knowledge, none of the previous AOA estimation system approach has combined embedded system design with the RPR antenna to estimate AOA by incoming RSSI value. Overall, to develop an AOA estimation system with Fuzzy Inferences System (FIS) hampered by the following problems:

a) The challenging factor of provide adequate AOA estimation points of AOA estimation system. This is due to fact that the implemented single reconfigurable antenna for AOA estimation has this limitation, where it only covers four AOA estimation (Jamlos, Rahman, Kamarudin, Saad, Abdul Aziz, et al., 2010).

b) The advantages of Fuzzy Inferences System (FIS) with RPR system is unexplored (Bala Krishna, Parvathi, & Latha, 2013; Bandyopadhyay, Mistri, Chattopadhyay, & Maji, 2013; Pujara, Modi, Pisharody, & Mehta, 2014; Tayel, Ismail, & Ramadan, 2006). The decision making for AOA estimation is done without any intelligent support.

c) Existing fuzzy membership function (MF) has some weakness to perform as input to FIS (Anzar & Azeem, 2004; Haeundae-gu, Function, & Algorithm, 1999; Lotfi & Tsoi, 1994; Tay & Lim, 2011). Specifically, this could be more impactful if needed to support the unexplored radiation pattern reconfigurable (RPR) antenna with FIS.

1.3 Research Objectives

The main goal of this research is to develop technical and operational embedded system that could be applied for Angle of Arrival (AOA) Estimation System (AES) to enhance the reliability of the AES through incoming RSSI value. Expectation from this research outcome is to realize that embedded system has potential to apply for various applications such as localization system.