PULSE REPETITION INTERVAL CLASSIFICATION BASED ON DECIMATED WALSH-HADAMARD TRANSFORM FOR ELECTRONIC INTELLIGENCE

KAMARUDDIN ABDUL GHANI

Thesis submitted to the Centre for Graduate Studies (CGS), Universiti Pertahanan Nasional Malaysia, in Fulfilment of the Requirement for the Degree Doctor of Philosophy (Electrical and Electronic Engineering)

ABSTRACT

Pulse Repetition Interval (PRI) classification is conducted in Electronic Intelligence (ELINT) to identify radar system based on the intercepted signal. By classifying the PRI according to their types, ELINT analysis can recognize the functional of radar system. However, in PRI classification, missing and spurious pulses can cause misclassification in PRI types which can lead to wrong identification of radar signal. Typical or common PRI types like constant, jittered and staggered are among the misclassified. Therefore, new method of PRI classification is developed based on decimated Walsh-Hadamard transform (DWHT). Decimation process reduces the sample to limit aliasing signal and noise which contribute to the misclassification. Template for constant, jittered and staggered PRI is developed based on the power spectrum of WHT. Simulated signal to represent transmitted radar signal is used to test the developed method as it would be seen in the ELINT receiver. Gaussian noise is added to simulate noise and clutter. The DWHT template is used as classifier to classify the PRI types accordingly. For comparison with an established method, PRI classification based on statistical histogram is developed. Comparison between DHWT and histogram method shows DWHT has 9% to 30% higher accuracy than histogram depending on the PRI types. DWHT can deliver more than 86% accuracy in PRI classification even with the presence of missing and spurious pulses.

ABSTRAK

Pengecaman jeda ulangan denyutan (PRI) dilaksanakan dalam Perisikan Elektronik (RIKLEK) untuk mengenalpasti jenis radar tertentu hasil dari isyarat radar yang dipintas. Dengan pengecaman ini, analisis RIKLEK dapat dilakukan untuk mengetahui fungsi radar berkenaan. Namun begitu, dalam proses ini kesilapan pengecaman boleh berlaku akibat oleh faktor kehilangan denyutan dan kehadiran denyutan palsu. Jenis PRI yang biasa mengalami kesalahan pengecaman adalah dari jenis tetap, bergetar dan berselang. Oleh itu, satu cara pengecaman jenis PRI yang baru perlu dibangunkan menggunakan *Decimated Walsh-Hadamard transform* (DWHT). Proses pengurangan data dilakukan dalam transformasi ini untuk mengurangkan isyarat bayangan dan isyarat palsu yang menjadi punca kesilapan dalam pengecaman jenis PRI. Templat untuk PRI jenis tetap, bergetar dan berselang dibangunkan berlandaskan spektrum kuasa WHT. Simulasi isyarat bagi mewakili isyarat radar sebenar digunakan untuk menguji kaedah yang dibangunkan ini sepertimana ianya berlaku dalam alat penerima RIKLEK. Hingar jenis Gaussian ditambah untuk menggambarkan hingar dan pantulan dalam keadaan sebenar. Templat DHWT digunakan sebagai alat pengkelasan jenis PRI. Sebagai perbandingan, pengkelasan menggunakan cara histogram iaitu satu cara yang terkenal turut dibangunkan. Perbandingan dari segi ketepatan dalam pengecaman dibuat ke atas DWHT dan histogram. Hasilnya, DWHT mempunyai ketepatan dalam pengecaman 9% hingga 30% lebih tepat dari histogram bergantung kepada jenis PRI. DWHT boleh mencapai ketepatan melebihi 85% walaupun dengan adanya denyutan palsu mahupun kehilangan denyutan.

ACKNOWLEDGMENTS

Alhamdulillah, for the completion of this thesis.

Foremost, I wish to thank my advisors, Prof. Dr. Kaharudin Dimyati and Assoc. Prof. Dr Ahmad Zuri Sha'ameri for their guidance, supervision and patience. I also wish to acknowledge my sincere appreciation for many stimulating technical discussions and lessons on the thesis subject held with Dr Ahmad Zuri both at UPNM and UTM. The travelling has been worthwhile.

Special appreciation is extended to Dr Carlos A. Davila (Georgia Institute of Technology) and Dr Clive M. Alabaster (Cranfield University) for the many helpful discussions while attending short courses on EW.

I am indebted to my wife Noor Liza for providing me love and encouraging me to aspire to complete the doctorate degree. To my children, Sharina Azelin, Sharul Azely, Shahira Adlina and Shahir Adlan, I would like to thank them for their patience and understanding for sacrificing some quality family time in my sojourn of obtaining my PhD.

APPROVAL

I certify that an Examination Committee has met on 11 Jan 2016 to conduct the final examination of **Kamaruddin Abdul Ghani** on his degree thesis entitled **Pulse Repetition Interval Classification Based on Decimated Walsh-Hadamard Transform for Electronic Intelligence**. The committee recommends that the student be awarded the Doctor of Philosophy (Electrical and Electronic Engineering).

Members of the Examination Committee were as follows,

Mohamad Ghani bin Mohamad Madersah
Lt Kol (Retired) Professor Ir
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Chairman)

Siti Nooraya Mohd Tawil, PhD
Assoc. Prof.
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Internal Examiner)

Mahamod bin Ismail, PhD
Professor
Faculty of Engineering and Built Environment
Universiti Kebangsaan Malaysia
(External Examiner)

Raja Syamsul Azmir Raja Abdullah, PhD
Assoc. Prof.
Faculty of Engineering
Universiti Putra Malaysia
(External Examiner)

APPROVAL

This thesis was submitted to the Senate of Universiti Pertahanan Nasional Malaysia and has been accepted as fulfilment of the requirements for the degree of **Doctor of Philosophy (Electrical and Electronic Engineering)**. The members of the Supervisory Committee were as follows,

Kaharudin Dimyati, PhD
Professor Ir
Faculty of Engineering
Universiti Malaya
(Chairman)

Ahmad Zuri Sha'ameri, PhD
Assoc. Prof.
Faculty of Electrical Engineering
Universiti Teknologi Malaysia
(Member)

UNIVERSITI PERTAHANAN NASIONAL MALAYSIA

DECLARATION OF THESIS

Author's full name	:	KAMARUDDIN ABDUL GHANI
Date of birth	:	1 Jan 1964
Title	:	Pulse Repetition Interval Classification Based on Decimated Walsh-Hadamard Transform for Electronic Intelligence
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LIST OF ABBREVIATIONS

AOA	-	Angle of Arrival
ARP	-	Antenna Rotation Period
ADC	-	Analog to digital converter
CDIF	-	Cumulative Difference
dB	-	Decibel
dBc	-	decibel per carrier
DC	-	Direct Current
DF	-	Direction Finder
DWHT	-	Decimated Walsh-Hadamard Transform
D&S	-	Dwell and Sliding
EA	-	Electronic Attack
ECCM	-	Electronic Counter Counter Measures
ECM	-	Electronic Counter Measures
ELINT	-	Electronic Intelligence
EOB	-	Electronic Order of Battle
EP	-	Electronic Protection
ES	-	Electronic Support
ESM	-	Electronic Support Measures
EW	-	Electronic Warfare
FFT	-	Fast Fourier Transform
FWHT	-	Fast Walsh-Hadamard Transform
IFF	-	Identification Friend or Foe
MTI	-	Moving Target Indicator
OFMD	-	Orthogonal Frequency Multiplexing Division
PA	-	Pulse Amplitude
PDF	-	Probability Density Function
PDW	-	Pulse Descriptor Word
PGRI	-	Pulse Group Repetition Interval
PN	-	Pseudorandom Noise
PRF	-	Pulse Repetition Frequency
PRI	-	Pulse Repetition Interval
PW	-	Pulse Width
RF	-	Radio Frequency
RFI	-	Radio Frequency Interference
SDIF	-	Sequential Difference
SNR	-	Signal-to-noise ratio
TDOA	-	Time Difference of Arrival
TOA	-	Time of Arrival
TTP	-	TOA to PRI
UPNM	-	Universiti Pertahanan Nasional Malaysia
WCDMA	-	Wideband Direct Sequence Code Division Multiple Access
WHT	-	Walsh-Hadamard Transform

LIST OF SYMBOLS

P_{CC}	-	Probability for correct classification
P_{D}	-	Probability of detection
P_{FA}	-	Probability of false alarm
P_{MD}	-	Probability of missed detection
P_{MP}	-	Probability of missing pulse
P_{SP}	-	Probability of spurious pulse

CHAPTER 1

INTRODUCTION

1.1 General Overview

In Electronic Intelligence (ELINT) operations, radar signal is searched, located, intercepted, analysed, and then the signal is identified. The purposed of ELINT is to establish and continuously update database normally known as Threat Library. The processed signals gathered by ELINT is analysed for their finger-printings and the characteristics of the radar system. The processed radar pulse train signals are sorted based on their pulse repetition interval (PRI) where the PRI types are identified. The analysed data from ELINT is fusion with other sources of intelligence to update the Threat Library.

Every radar has different PRI types depending on the characteristics and the functional of the radar. By knowing the PRI type, the functional of the radar can be predicted. Three most common PRI classifications are considered in this research and they are constant, jittered, and staggered. Since, every radar has a unique interval of sequences and PRI types, identification of radar emitters can be made possible with PRI classification.

In a dense environment, signals at ELINT receiver are corrupted with missing and spurious pulses due to noise and clutter. Radar misfire and multipath phenomenon also contribute to spurious pulses. Missing and spurious pulses contribute to error in PRI classification. This research is focused on PRI classification using Walsh-

Hadamard Transform (WHT). The transformed PRI is decimated to remove aliasing and spurious pulses. The decimated WHT (DWHT) template is developed with each PRI type has a unique identity to represent their PRI types. The probabilities of occurrence for missing and spurious pulses are modelled statistically to predict the distribution for missing and spurious pulses as part of the performance validation for the developed model. The performance of the developed method is compared to one of the most widely used method in PRI classification. The novelty value of this work is a new method of PRI classification based on DWHT for ELINT analysis with better accuracy.

1.2 Problem Statement

One of the main issues faced in PRI analysis is error in the classification of PRI types. Misclassification of PRI type reflects the inaccuracy in ELINT analysis. Clutter and noise can introduce some errors in the received pulse train. Besides clutter and noise, radar misfire and multipath effect can cause missing and spurious pulses in radar signal. This problem is more obvious in magnetron radars than other radar transmitters [1]. This may make no noticeable difference in the performance of a radar system. However, a few missing pulses in a burst, subjected to ELINT analysis can cause confusion. Confusion in PRI classification leads to wrong identification of radar system. Davies and Hollands [2] have reported that missing and spurious pulses may cause chains of incorrect parameter measurements of PRI. Guo Hua et. al [3] and Mahdavi [4] have reported that PRI recognition error are due to missing and spurious pulses. Incorrect PRI determination leads to inaccuracy in radar signal identification [5].

Missing pulses are resulted from Radio Frequency Interference (RFI) blanking, ambiguous range returns when no filter pulses are used, or eclipsing [6]. Loss in the transmission path and limitation of the receiver leads to a large number of missing pulses inevitably, which can be as much as 25% of the emitted pulses [7].

In RF amplifiers, the value of spurious signals is measured with respect to the intended amplified signal [8]. For example, if the RF carrier is a single frequency with a magnitude of 70 dBm, and a spurious signal is found measuring 40 dBm, that spur would be measured as -30 dBc (dB below the carrier). The lower the spur is from the carrier, the greater the performance. Ikaheimonen [9] has conducted measurement on spurious pulses from weather radar in the C-band and the largest radar spurious transmission level requirements (harmonic and non harmonic) are −100 dBc. The studies also found out that the higher the radar output power is, the higher is the risk of the generation of spurious emissions. Sanders [10] has conducted spurious measurement from maritime surface search radar in X-band and found out that radar unwanted emission levels are found to vary between 12 and 20 log bandwidth, depending upon frequency. Therefore, there is a need to have a new method of PRI classification that is robust to spurious and missing pulses in order to have ELINT analysis with higher accuracy.

1.3 Research Objectives

The research described in this thesis is concerned with classifying PRI classification types. The PRI types is used in ELINT analysis to identify radar emitters based on their signal characteristics. A summary of research objectives is as follows:

i. To develop a new method of PRI classification based on decimated Walsh-Hadamard transform (DWHT) using a template for constant, jittered and staggered signals.
ii. To compare the performance and accuracy of the developed method with an established PRI classification method taking into account the effects of missing and spurious pulses.

1.4 Scope and Limitations of Research

This research is used simulated radar pulse train signal based on ELINT data to represent the real signal. For this research, the scope and limitations are as follows:

a. The work is focused on the three most common PRI and they are constant, jittered, and staggered since these PRI are commonly detected in this region.
b. The measurements of actual intervals for each PRIs are not included in this research.
c. Since the work does not involve measurement of intervals in the PRI, the percentage jitter will not be included. All random jittered and wobulated signals will be considered as jittered PRI.
d. It is assumed that the pulse train generated in this research simulates the video signal at the ELINT receiver system.

1.5 Research Methodology

The research is done with the following methodology as shown diagrammatically in Figure 1.1:

a. Review on the PRI analysis methods.

b. Mathematical modelling of radar pulse train to represent the PRI for constant, jittered and staggered signals. Staggered signal includes 2, 3 and 4-level staggered.

c. Develop a decimated Walsh-Hadamard Transform (DWHT) template.

d. Statistical modelling for the prediction of the occurrences of missing and spurious pulses.

e. Model for signal received at ELINT receiver with Additive White Gaussian Noise (AWGN).

f. Probability for correct classification (P_{cc}) of PRI classification.

g. Performance comparison between the developed method and established PRI classification method.

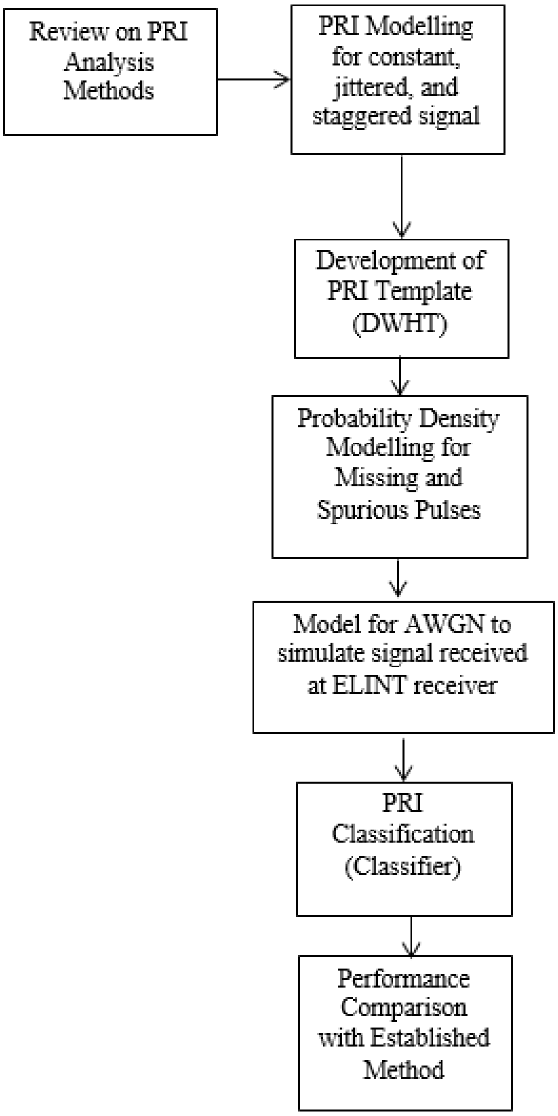

Figure 1.1: Block diagram of the methodology.

1.6 Contributions of the Research

The contributions of the research can be summarized as follows:

(a) A novel PRI classification technique based on decimated Walsh-Hadamard Transform (DWHT).

(b) A new unique DWHT template of PRI classification have been developed for constant, jittered, 2-level staggered, 3-level staggered, and 4-level staggered signals.

(c) A new PRI classification method that has better accuracy than histogram based method.

1.7 Organization of the Thesis

The thesis is organized as follows. Chapter 1 provides an introduction to this research. This chapter covers the research problems and introduces the novel techniques which are presented in the following chapters. A summary of the original contributions is also provided.

Chapter 2 provides a brief review of ELINT and PRI analyses as well as the conventional approaches to PRI classification methods. Methods such as histogram based, Kalman filter, neural networks, symbolization, and transformation techniques to accurately classify PRI types are discussed. In the conventional approach review, basic algorithm concepts are described and the main implementation issues that limit the processing performance are discussed. Description of the probability distribution of missing and spurious pulses is presented and Walsh-Hadamard function is discussed is this chapter.

Chapter 3 introduces the novel PRI classification method using DWHT where the development of DWHT template is discussed. The modelling of PRI sequence and a classifier system for the classification of PRI types is presented. Chapter 3 also shows the model for missing and spurious pulses for validation of the developed method as well as the performance metrics for correct classification of PRI. The performance for developed method is compared with an established PRI classification method.

Chapter 4 presents the theoretical and simulated results for the modelling of probability density function for missing and spurious pulses. Validation of theoretical probability distribution of missing and spurious pulses is revealed. Discussion on the performance comparison between DWHT and an established method is also presented. The accuracy of the developed method is presented and discussed in this chapter.

Chapter 5 concludes the thesis along with discussion and some future works. Some suggestions in improving the reliability of the method are made since it still has scope for improvement.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides a brief review of ELINT and PRI analyses as well as the conventional approaches to PRI classification recognition methods. In the conventional approach review, basic algorithm concepts are described and the main implementation issues that limit the processing performance are discussed. Description of the probability of missing and spurious pulses is presented and Walsh-Hadamard function is also discussed

2.2 Introduction to Electronic Warfare

Electronic Warfare (EW) is the art and science of preserving the use of the electromagnetic spectrum for friendly use while denying its use to the enemy [11]. EW can be divided into three components: Electronic Support Measures (ESM), Electronic Countermeasures (ECM), and Electronic Counter-Countermeasures (ECCM). Current NATO EW definitions are: Electronic Support (ES), Electronic Attack (EA), and Electronic Protection (EP) [12]. The detailed explanation of the EW divisions is shown in Figure 2.1.

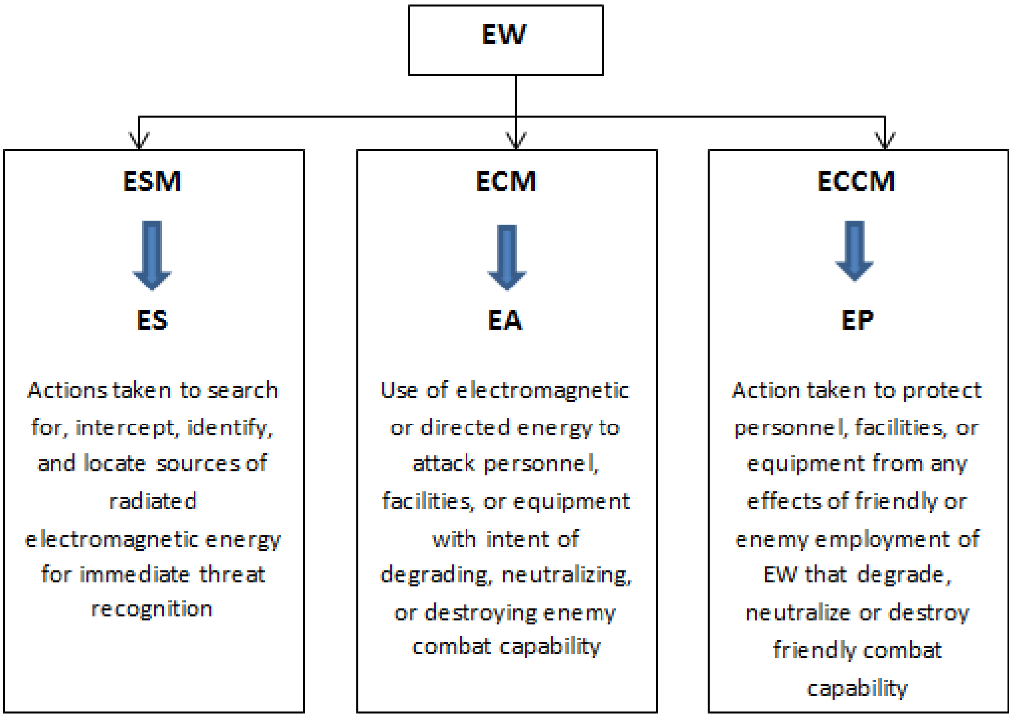

Figure 2.1: Electronic Warfare divisions [12].

Differentiated from ESM is Signal Intelligence (SIGINT) which comprises of Communication Intelligence (COMINT) and Electronic Intelligence (ELINT) [11]. These fields involve the receiving of enemy transmissions where COMINT receives communication signal for the purpose of extracting intelligence while ELINT focuses on non-communication signals such as radar, transponder and laser. SIGINT is strategic in nature where operations are conducted continuously or from time to time without urgency in gathering or processing data. On the other hand, tactical system, ESM or ES intercepts enemy signals (either communication or non-communication) and then immediately react on the signals or the weapons associated with those signals.