UNIVERSITI PUTRA MALAYSIA

# SPEED ESTIMATION IN FORWARD SCATTERING RADAR USING STANDARD DEVIATION AND IMPROVED ZERO-CROSSING METHOD

MUTAZ SALAH MOHAMED SADIG

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# Speed Estimation in Forward Scattering Radar Using Standard Deviation and Improved Zero-crossing Method

By

**MUTAZ SALAH MOHAMED SADIG**

**Thesis Submitted to the School of Graduate Studies, University Putra Malaysia, in Fulfillment of the Requirement for the Degree of Master of Science**

**February, 2009**

## DEDICATION

**I dedicate this thesis to my parents. Without their patience, understanding, support, and most of all love, the completion of this work would not have been possible.**

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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**February 2009**

**Chairman: Raja Syamsul Azmir Bin Raja Abdullah, PhD**

**Faculty: Engineering**

Current research on Forward Scattering Radar (FSR) dedicates to the target detection and classification. In the classification technique, the target's speed information is required prior to the classification processes. Unfortunately, the speed is hidden inside the received signal and cannot be extracted directly. This is due to the loss in range resolution in FSR system. This is the main disadvantage of FSR. Thus, this thesis presents a work on speed estimation in FSR. Theory of FSR systems is briefly described together with practical experiments to evaluate the feasibility of such a system in real-life scenarios. The data collected from the practical experimentation and typical ground vehicle is used as the target (e.g. car, lorry). The overall speed estimation system is described. For vehicle speed estimation, two methods are proposed: the first method applies Standard Deviation (STD) theory to the raw radar signal. In the second method, the number of zero-crossing in the received signal is analyzed for speed estimation. On top of that, de-noising pre-processing is introduced to increase the accuracy of speed result. These two methods show a good result in estimating the vehicle speed crossing FSR baseline.

From the analysis, speeds estimation using STD work best for high SNR value. By analyzing 917 experimentally obtained car signatures, the performance of the system is evaluated and the effectiveness of the system is confirmed.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master of Sains

**SPEED ESTIMATION DALAM PENYERAKAN FORWARD RADAR MENGGUNAKAN SISIHAN PIAWAI DAN KAEDAH-KAEDAH IMPROVED ZERO LINTASAN**


Oleh

**MUTAZ SALAH MOHAMED SADIG**


**Februari 2009**


**Chairman: Raja Syamsul Azmir Bin Raja Abdullah, PhD**

**Faculty: Kejuruteraan**


# Abstrak


Kajian terkini ke atas Forward Scattering Radar (FSR) tertumpu kepada teknik klasifikasi dan mengenalpasti sasaran. Maklumat kelajuan sasaran diperlukan dalam teknik pengkelasan. Walaubagaimanapun, maklumat tersebut tersembunyi dalam isyarat penerimaan dan tidak boleh diekstrak secara langsung. Ini disebabkan oleh kehilangan julat resolusi sistem FSR dan ini merupakan kelemahan utama FSR. Tesis ini mengetengahkan kajian ke atas penganggaran kelajuan dalam FSR. Teori sistem FSR diterangkan secara ringkas disusuli dengan eksperimen bagi menilai kebolehan sistem. Data diperolehi daripada eksperimen menggunakan kenderaan bermotor sebagai sasaran (seperti kereta, lori). Sistem penganggaran kelajuan diperihalkan. Dua kaedah dicadangkan bagi menganggarkan kelajuan kenderaan. Kaedah pertama mengaplikasi teori Sisihan Piawai (STD) kepada sasaran radar asal manakala bagi kaedah kedua, bilangan lintasan sifar dalam isyarat penerimaan dianalisis bagi menganggarkan kelajuan. Selain itu, de- noising sebelum pemprosesan

diperkenalkan untuk meningkatkan ketepatan hasil kelajuan. Ini dua kaedah-kaedah menunjukkan satu kebaikan mengakibatkan menganggarkan kelajuan kenderaan lintasan garis tapak FSR. Daripada analisis, mempercepatkan anggaran menggunakan STD bekerja paling baik untuk nilai SNR tinggi. Dengan menganalisa 917 tandatangan-tandatangan kereta yang memperolehi secara eksperimen, prestasi sistem adalah dinilaikan dan keberkesanan sistem penyampaian disahkan.

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Finally I want to express my love and gratitude to my beloved families; especially, my father, my mother, my brothers and my lonely sister Malaz, for their continuous support, understanding and endless love, through the duration of my studies.

**APPROVAL**

I certify that an Examination Committee has met on 27 FEB 2009 to conduct the final examination of Mutaz Salah Mohamed on his Master of Science thesis “Speed Estimation in Forward scattering Radar using Standard Deviation and Improved Zero-crossing methods” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

**Mohammad Hamiruce b. Marhaban, PhD**
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

**Nor Kamariah bt. Noordin, PhD**
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

**Helmi Zulhaidi b. Mohd. Shafri, PhD**
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

**Mohamad Kamal B. A. Rahim, PhD**
Associate Professor
Faculty of Engineering
Universiti Teknologi Malaysia
(External Examiner)

**HASAN AH MOHD GHAZALI, PhD**
Professor /Deputy Dean
School Of Graduate Studies
University Putra Malaysia

Date:

This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science.
The members of the Supervisory Committee are as follows:

**Raja Syamsul Azmir Bin Raja Abdullah, PhD**
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

**Mohd.Fadlee B.A.Rasid, PhD**
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

______________________

**HASANAH MOHD GHAZALI, PhD**
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 14 May 2009

## DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

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**MUTAZ SALAH MOHAMED**

Date:

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# LIST OF ABBREVIATION

| | |
|---|---|
| **ADC** | **A**nalogue to **D**igital **C**onverter |
| **BPF** | **B**and **P**ass **F**ilter |
| **CPF** | **C**omplex **P**rofile **F**unction |
| **CW** | **C**ontinuous **W**ave |
| **DSP** | **D**igital **S**ignal **P**rocessing |
| **EM** | Electro**m**agnetic |
| **FSCS** | **F**orward **S**cattering **Cross** **S**ection |
| **FSR** | **F**orward **S**cattering **R**adar |
| **GMM** | **G**aussian **M**ixture **M**odelling |
| **HPF** | **H**igh **P**ass **F**ilter |
| **IC** | **I**ntegrated **C**hip |
| **IF** | **I**ntermediate **F**requency |
| **ISAR** | **I**nverse **S**ynthetic **A**perture **R**adar |
| **ISM** | **I**ndustrial, **S**cientific and **M**edical |
| **LNA** | **L**ow **N**oise **A**mplifier |
| **LO** | **L**ocal **O**scillator |
| **LPF** | **L**ow **P**ass **F**ilter |
| **RAM** | **R**adar **A**bsorbing **M**aterial |
| **RCS** | **R**adar **C**ross **S**ection |
| **RF** | **R**adio **F**requency |
| **SAR** | **S**ynthetic **A**perture **R**adar |
| **SISAR** | **S**hadow **I**nverse **S**ynthetic **A**perture **R**adar |
| **StD** | **St**andard **D**eviation |
| **SNR** | **S**ignal to **N**oise **R**atio |
| **WE** | **W**alker **E**rror |

# LIST OF SYMBOLS

| | |
|---|---|
| $\beta$ | Bistatic Angle |
| $E_{sum}$ | Total Electrical field |
| $E_s$ | Self Scattering Fields |
| $E_{sh}$ | Shadow Field |
| $P_T$ | Transmitted Power |
| $G_T$ | Transmitter Gain |
| $G_R$ | Receiver Gain |
| $\lambda$ | Wavelength |
| $\sigma_B$ | Target's Bistatic RCS |
| $F_T$ | Constants defined by Willis |
| $F_R$ | Constants defined by Willis |
| $K_b$ | Boltzman's constant |
| $T_o$ | Reference temperature (290K) |
| $F$ | Noise figure |
| $R_T$ | Transmitter to Target Distance |
| $R_R$ | Receiver to Target Distance |
| $d$ | Distance |
| $L_T$ | Transmitter Loss |
| $L_R$ | Receiver Loss |
| $\sigma_F$ | Forward scattering RCS |
| $\alpha_v$ | Receiver Vertical Diffraction Angle of the Target under Observation |
| $\alpha_h$ | Receiver horizontal Diffraction Angle of the Target under Observation |
| $A$ | Area of the Aperture |
| $\sigma_M$ | Monostatic RCS |
| $v$ | Velocity Vector |
| $f_{dbr}$ | Doppler Frequency |
| $\delta$ | Angle between Target Trajectory and Speed Vector |
| $z_a$ | Receiver to imaginary line of Target Trajectory |
| $z_b$ | Transmitter to imaginary line of Target Trajectory |

| | |
|---|---|
| $\psi$ | Angle between imaginary line of Target Trajectory and Transmitter Receiver Distance |
| $\alpha_T$ | Diffraction Angle with respect to Transmitter |
| $\alpha_R$ | Diffraction Angle with respect to Receiver |
| $Z$(t) | Analytical signal |
| $\theta(t)$ | The phase |
| $x(t)$ | Input Signal |
| $\psi\ (t)$ | Wavelet Function |
| $\psi_{a,b}(t)$ | Wavelet Function with Scale *(a)* and Translation *(b)* |
| $a$ | Scale |
| $b$ | Translation |
| $j$ | Level of Decomposition |
| $\psi_{2^j}(t)$ | Dyadic wavelet |
| $f_c$, | Centre Frequency |
| $d$ | Transmitter Receiver Separation Distance |
| $E$ | Electrical Field |
| $\phi$ | Magnetic Field |
| $E_r$ | Electrical Field in $r$ direction (cylindrical coordinates) |
| $E_\theta$ | Electrical Field in $\theta$ direction (cylindrical coordinates) |
| $E_y$ | Electrical Field in y direction (cylindrical coordinates) |
| $l$ | Length of the Target |
| $h$ | High of the Target |
| $c$ | Speed of Light |
| $\theta$ | Transmitter Horizontal Diffraction Angle |
| $f_{Tgt}$ | Target Frequency |
| $f_{dbr}$ | Doppler Frequency |
| $f_{dma}$ | Maximum Doppler Frequency |
| $\hbar_{k,0}$ | Scaling Filter (low pass) |
| $\hbar_{k,1}$ | Wavelet Filter (high pass) |
| $g_{L,0}$ | Reconstruction Filter (Low Pass) |
| $g_{k,1}$ | Reconstruction Filter (high Pass) |
| $A_j$ | Approximation at Level $j$ |
| $D_J$ | Detail at Level $j$ |

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