

ELECTROMAGNETIC INVERSE SCATTERING FROM BURIED
CYLINDER USING SUPPORT VECTOR REGRESSION

by

Ayman Sherif Ismail Negm

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE

in

ELECTRONICS AND COMMUNICATIONS ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT

2015

ELECTROMAGNETIC INVERSE SCATTERING FROM BURIED
CYLINDER USING SUPPORT VECTOR REGRESSION

by

Ayman Sherif Ismail Negm

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE

in

ELECTRONICS AND COMMUNICATIONS ENGINEERING

Under the Supervision of

Prof. Ragia Ismail Badr

Dr. Islam Abdelsattar Eshrah

.....

.....

Professor

Associate Professor

Electronics and Communications Department

Electronics and Communications Department

Faculty of Engineering, Cairo University

Faculty of Engineering, Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

GIZA, EGYPT

2015

ELECTROMAGNETIC INVERSE SCATTERING FROM BURIED CYLINDER USING SUPPORT VECTOR REGRESSION

by
Ayman Sherif Ismail Negm
A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
ELECTRONICS AND COMMUNICATIONS ENGINEERING

Approved by the
Examining Committee

Prof. Ragia Ismail Badr, Thesis Main Advisor

Dr. Islam Abdelsattar Eshrah, Thesis Advisor

Prof. Dr. Amir Soryal Attiya, Internal Examiner

Prof. Dr. Said El-Sayed El-Khamy, External Examiner, Faculty of Engineering,
Alexandria University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2015

Engineer's Name: Ayman Sherif Ismail Negm

Date of Birth: 18/6/1988

Nationality: Egyptian

Phone: 01009244866

Email Address: ayman.negm@eng.cu.edu.eg

Registration Date: 1/10/2011

Awarding Date:

Degree: Master of Science

Department: Electronics and Communications Engineering

Supervisors: Prof. Dr. Ragia Ismail Badr

Associate Prof. Dr. Islam Abdelsattar Eshrah

Examiners: Prof. Dr. Ragia Ismail Badr (Thesis Main Advisor)

Associate Prof. Dr. Islam Abdelsattar Eshrah (Thesis Advisor)

Prof. Dr. Amir Soryal (Internal Examiner)

Prof. Dr. Said El-Sayed El-Khamy (External Examiner, Faculty of Engineering, Alexandria University)



Thesis Title: “Electromagnetic Inverse Scattering from Buried Cylinder using Support Vector Regression”

Keywords: inverse scattering – buried cylinder – signal flow graph - Prony model - support vector regression

Summary:

In this thesis, Support Vector Regression technique is used to solve the inverse scattering problem of a circular cylinder buried in a dielectric half-space. A fast and accurate technique based on T-matrix and Signal-Flow Graph is employed to solve the forward scattering problem. The solution of the forward problem is then used to generate dataset for training the Support Vector Machine (SVM). Feature extraction based on Prony modeling of reflection coefficient data is performed to simplify the training process. Selection of SVM parameters is performed using a hybrid optimization algorithm whose objective is to minimize the cross validation error over the training data. After the training process is complete, the SVM can be used to estimate the buried cylinder parameters in real-time. Different cases are studied and the results show good performance of the employed approach.

Acknowledgment

All praise is to almighty **ALLAH** who guided me, aided me and gave me strength to complete this thesis. I would like to express my sincere gratitude to my advisors, **Prof. Dr. Ragia Ismail Badr** and **Dr. Islam Abdelsattar Eshrah** for their guidance, kind patience and continuous support during my postgraduate years of study. I dedicate a special feeling of devotion to **Prof. Dr. Essam Hashish** for his kind guidance inspiration and encouragement. I would like to appreciate the help offered by the Electronics and Communications department staff, Faculty of Engineering, Cairo University. I would also like to thank my friends and colleagues for their true help and support throughout my postgraduate study. Finally I would like to thank my family for helping me survive all the stress during my study and not letting me give up.

Table of Contents

Acknowledgment	i
List of Tables	vii
List of Figures	xi
List of Symbols	ix
List of Abbreviations	xiii
Abstract	xv
1 Introduction	1
1.1 Motivation	1
1.2 Relation between Inverse Problem and Machine Learning	2
1.3 Localization and Characterization Problems	2
1.4 Thesis Outline	2
2 Literature Review	5
2.1 Mathematical Formulation	5
2.2 Solution to the Inverse Scattering problem	7
2.2.1 Numerical Inversion of Integral Equations	7
2.2.2 Linearization	7
2.2.3 Iterative Approach	7
2.2.3.1 Gradient-based Scheme	8
2.2.3.2 Evolutionary Algorithms	9
2.2.4 Inspection Approach	10
2.2.5 Supervised Machine Learning Approach	11
2.2.5.1 Neural Network (NN)	11
2.2.5.2 Support Vector Machines (SVM)	15
3 Forward Scattering Problem	21
3.1 Problem Formulation	21

3.2	Signal-Flow Graph (SFG) Approach	23
3.3	Series Truncation	24
3.4	Series Truncation for Wider Range	27
3.4.1	PEC Cylinder in Lossless Half-Space	27
3.4.2	PEC Cylinder buried in Dispersive Half-Space	27
3.4.3	Dielectric Cylinder in Lossless Half-Space	28
3.4.4	Dielectric Cylinder in Dispersive Half-Space:	30
3.5	Efficiency of the Proposed Approach	30
3.6	Conclusion	31
4	Feature Extraction based on Parametric Modeling of Forward Problem Data	37
4.1	Introduction	37
4.2	Damped Exponential Model	38
4.2.1	Singular Value Decomposition (SVD)	39
4.2.2	Extraction of Prony Model Parameters	39
4.3	The Significance of Extracted Poles	40
4.4	Application of Prony Model to the Buried Cylinder problem	40
4.5	Main Features extracted from Prony model	41
4.6	Handling Issues related to Prony Model	45
4.6.1	Variant Model Order	45
4.6.2	Cylinder Buried in unknown Half-Space	45
4.7	Conclusion	45
5	Optimized Support Vector Regression	47
5.1	Structural Risk Minimization and Empirical Risk Minimization	47
5.2	Training Phase	48
5.2.1	Mathematical Formulation of the SVR model	48
5.2.2	Mapping of Input Vectors for Non-Linear Regression	50
5.2.3	Optimization Algorithm	51
5.2.4	User-defined parameters of SVR	52
5.2.4.1	Kernel function	52
5.2.4.2	The ratio of support vectors (ν)	53
5.2.4.3	The trade-off constant (C)	53
5.2.5	Optimized Selection of SVR Hyperparameters	54
5.2.5.1	Artificial Bee Colony (ABC) Algorithm	54
5.2.5.2	Simplex Algorithm	55
5.2.5.3	Optimization Approach	56
5.2.6	Calculation of Bias Term b	56
5.3	Testing Phase	57
5.4	Conclusion	58

6	Results and Discussion	59
6.1	Software Tools for SVR implementation	60
6.2	Data Preprocessing and Postprocessing	61
6.2.1	Removal of Irrelevant data	61
6.2.2	Normalization	61
6.2.3	Denormalization	61
6.3	Objective Function and Accuracy Measure	61
6.4	PEC cylinder buried in Dielectric Half-space	62
6.5	Dielectric Cylinder Buried in Dispersive Dielectric Half-space	64
6.5.1	Reconstruction of Radius and Permittivity for a given Depth	64
6.5.2	Reconstruction of Radius, Depth and Permittivity	65
6.5.3	Robustness of Estimation	70
6.6	Dielectric cylinder buried in an Unknown Half-Space	70
6.7	Conclusion	71
7	Conclusion and Future Work	73
7.1	Summary of the work	73
7.2	Future Work	74
	List of Publications	75
	References	77

List of Tables

2.1	Comparison between SVM and NN	15
2.2	Advantages and Disadvantages of Different Techniques	19
3.1	Ranges involved in T-matrix calculations	26
3.2	Ranges of variables for Truncation Order calculation	27
3.3	Ranges of variables for Truncation Order calculation for dielectric case	29
3.4	Different simulation cases for buried PEC cylinder	31
3.5	Different simulation cases for buried Dielectrc cylinder	32
6.1	Ranges of Parameters	62
6.2	Error in reconstruction of radius and depth of buried PEC cylinder	62
6.3	Error in reconstruction of radius and depth of buried PEC cylinder	63
6.4	Ranges of Parameters	64
6.5	Ranges of Parameters	65
6.6	Erros in Reconstruction of Radius	65
6.7	Errors in Reconstruction of Relative Permittivity	65
6.8	Error in Reconstruction of Radius using Direct data	68
6.9	Error in Reconstruction of Radius using Prony Features	68
6.10	Error in Reconstruction of Buried Cylinder parameters using NN and SVM approaches	69
6.11	Average Estimation Error under the effect of noise using threshold-based fitting	70
6.12	Average Estimation Error under the effect of noise using 3 poles fitting	70
6.13	Reconstruction Accuracy for Unknown Lossless Half-Space ($\epsilon_r = 3$)(3 phase+3 singular values)	71
6.14	Reconstruction Accuracy for Unknown Lossless Half-Space ($\epsilon_r = 4$)(3 phases+3 singular values)	71
6.15	Reconstruction Accuracy for Unknown Lossless Half-Space ($\epsilon_r = 14$)(2 phases+2 singular values)	71