



OBSTACLE AVOIDANCE FOR UNMANNED SURFACE VEHICLES: SIMULATIONS AND EXPERIMENTS

A thesis submitted to the
Department of Electrical Engineering, University of Moratuwa
in partial fulfillment of the requirements for the
Degree of Master of Philosophy

by
RANDOBAGEGEETHJAYENDRA

Supervised by: Dr. Sisil Kumarawadu

Department of Electrical Engineering
University of Moratuwa, Sri Lanka

2009

93025



Abstract

Sri Lanka ports authority and many other organizations are increasingly interested in the use of Unmanned Surface Vehicles (USV) for harbor security and surveillance applications. USVs can be used to collect information, samples and perform experiments inside a harbor or outside by. Navigating through ships and other objects.

This research study is focused on finding algorithms for obstacle avoidance (OA) of USVs. The initial paradigm that is used to establish the solution was the OA of Unmanned Ground Vehicles (UGV). The algorithms developed for UGV were implemented practically with the limitations of hardware. Then, effort is taken to apply those algorithms to the surface vehicles with some modifications.

In this study, a novel OA algorithm is proposed for static obstacles based on the Morphin algorithm. This proposed algorithm and the previous algorithm which is developed based on ground vehicles are compared with the potential field method.

Static OA without dynamic OA is not helpful for unmanned vehicles on sea. A lot of researches have been carried out to avoid dynamic objects, but have failed to find an optimum solution although comparatively good approaches have been presented. Intelligent techniques have been rarely applied for dynamic obstacle avoidance. In this research, the effectiveness of applying intelligent or mathematical techniques for path prediction of dynamic obstacles is discussed with simulations to pick the best for a given situation. Then a novel projected dynamic obstacle area method is presented to avoid dynamic obstacles effectively. Comparative results are presented at the end to prove the strength "of the novel dynamic obstacle area method.

DECLARATION

The work submitted in this thesis is the result of my own investigation, except where otherwise stated.

It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

UOM Verified Signature

R.G. Jayendra

(Candidate)

23rd March 2009



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations

I endorse the declaration by the candidate. www.lib.mrt.ac.lk

UOM Verified Signature

Dr. Sisil Kumarawadu

(Supervisor)

CONTENTS

Chapter	Title	Page
	Abstract	v
	Acknowledgement	vi
	List of Figures	vii
	List of Tables	xii
	List of Acronyms	xiii
1	Introduction	1
1.1	Applications of Unmanned Surface Vehicles	1
1.2	Obstacle Avoidance of Unmanned Ground Vehicles	1
1.3	Applying ground vehicle technologies for surface vehicles	3
1.4	Potential field method for path planning	4
1.5	Morphin algorithm for path planning	5
1.6	Defining safety distance for path planning	6
1.7	Dynamic obstacle avoidance	6
1.8	Sensor considerations	7
1.8.1	Radar Contacts	8
2	Obstacle Avoidance of Unmanned Ground Vehicles	9
2.1	Sensor selection for prototypes	9
2.2	Development of prototypes	10
2.2.1	Digital Controller Selection	10
2.2.2	Digital Compass Module Selection	12
2.2.3	Digital Encoder and Encoder Wheel	14
2.2.4	Servo Motors	15
2.2.5	Ultra-Sonic Range Sensors	15
2.2.6	Inter Vehicular Communication scheme	17
2.2.7	ER400RS Receiver	18
2.2.8	ER400TX Transmitter	19
2.2.9	Serial Interface Circuit Design	20
2.2.10	Integrating Sensors to the Controller	22
2.2.11	Interfacing Software for Prototypes	24
2.3	Experimenting with prototypes	24
2.3.1	Position Tracking Algorithm	25
2.3.2	Peripheral Obstacle Avoidance	26
2.3.3	Collision Avoidance	26
2.3.4	Position Tracking without the Digital Compass	26
2.3.5	Fuzzy Based Controlling	30
2.3.6	Collision Condition Function	31
2.3.7	Relative Distance Function	32
2.3.8	Master Slave Switching	32
2.3.9	Controlling Function	33
2.4	Results	35
2.5	Summary	36

3	Design of Navigational Controller for USV	37
3.1	Implementing the controller	37
3.2	Mathematical model for USV	40
3.3	Results from the navigational controller	42
3.4	Summary	45
4	Static Obstacle Avoidance of USV	46
4.1	Utilizing Ground Vehicle Technologies for Surface Vehicles	46
4.1.1	Design of OA controller	46
4.1.1.1	Input Functions	46
4.1.1.2	Output Functions	52
4.1.2	Algorithms for simulation of the controller	55
4.1.3	Simulation Results from the Controller	57
4.1.4	Summary	59
4.2	Novel Algorithm for OA	60
4.2.1	Methodology of the Novel Algorithm	60
4.2.2	Developed Algorithms Utilized for Simulations	65
5	Dynamic Obstacle Avoidance of USV	67
5.1	Introduction to Novel Dynamic Obstacle Avoidance Method	67
5.2	Area Prediction of Dynamic Obstacles	69
5.3	Path Prediction of Dynamic Obstacles	71
5.3.1	Polynomial Approximation Method for Path Prediction	73
5.3.2	Generalized Regression Neural Network for Path Prediction	73
6	Simulation Results	74
6.1	Simulation Results by Applying UGV theories for USV	74
6.2	Simulation Results from the Novel Algorithm	75
6.3	Simulation Results from Potential Field Method	80
6.4	Comparison of Obstacle avoidance methods	82
6.5	Simulation Results Dynamic Obstacle Avoidance	84
6.5.1	Simulation Results for path prediction of Dynamic Obstacles	86
6.5.1.1	Polynomial approximation method for path prediction	86
6.5.1.1.1	Simulations without sensor noise	86
6.5.1.1.2	Simulations with sensor noise	89
6.5.1.2	RBNN method for path prediction	95
6.5.1.2.1	Simulations without sensor noise	95
6.5.1.2.2	Simulations with sensor noise	97
6.5.1.3	Summary of Simulation Results for path prediction	99
6.5.2	Simulation Results for Obstacle area prediction of Dynamic Obstacles	100
6.5.2.1	Simulation Results from Velocity obstacle method	100
6.5.2.2	Simulation Results from the novel method	104
6.5.2.3	Comparison Results	109

7	Conclusion and Recommendations	113
	References	115
Appendix A	OOPic Basic Program for Vehicular Prototypes	119
Appendix B	MatLab Program of Fuzzy PD Navigational Controller with the Dynamic model	129
Appendix C	MatLab Program for Applying UGV algorithms to USV	135
Appendix D	MatLab Program for Novel Algorithm to Avoid Static Obstacles	139
Appendix E	MatLab Program for Applying Polynomial Approximation to Path Prediction	143
Appendix F	MatLab Program for Applying GRNN to Path Prediction	145
Appendix G	MatLab Program to Compare Velocity Obstacle Method with Novel Method for Area Prediction of Dynamic Obstacles	149



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Acknowledgement

Many thanks are due first to my supervisor, Dr. Sisil Kumarawadu, for his great insights, perspectives and guidance throughout the entire duration of the study.

Author extends his sincere gratitude to Dr. J.P. Karunadasa, Head of the Department of Electrical Engineering, for providing him the Research Assistantship and excellent assistance during the study period. Many thanks and appreciations are due to Professor H.Y.R. Perera, Commissioner General of Public Utilities Commission of Sri Lanka as well.

Sincere thanks are also due to the officers in Post Graduate Office of the Faculty of Engineering, University of Moratuwa for helping in various ways to clarify the things related to academic works in time with excellent cooperation and guidance. Thanks are also due to the staff of the Department of Electrical Engineering for the support extended during the study period. Also, I wish to gratefully acknowledge the assistance extended by Mr. Ravipriya Ranatunga, Mr. Samitha Ransara, Mr. Sanjeewa Priyadharshana, Mr. Gamini Jayasighe, Mr. Lackshan Piyasighe, Mr. Kolitha Dharmapriya, Mr. J. Baek, Mr. Harshana Somapriya, Mr. Nadun Chamikara and my brother Chanuka Jayendra.

Many thanks are also due to many individuals, friends and colleagues who have not been mentioned here by name in making this educational process as success.

Lastly, the author expresses his deep appreciation towards his family for their encouragement and support. This work is dedicated to his beloved mother and late father.

List of Figures

No.	Description	Page
1.1	Safety Distance for Obstacles	6
2.1	Basic Block Diagram of the system	10
2.2	OOPic R Micro Controller Board	12
2.3	Digital Compass Module	13
2.4	The Way of Mounting the Compass to the Prototype	13
2.5	Connection Arrangement of the Encoder	14
2.6	The way of mounting the Encoder to the Prototype	14
2.7	HS-422 Servo Motor	15
2.8	Beam Pattern of the SRF235 'Pencil beam' Ultra-sonic Sensor	16
2.9	SRF235 Pencil Beam Ultra-sonic Sonar Sensor	16
2.10	LPRS ER400 Radio Modules	17
2.11	Evaluation Software	17
2.12	Communication Channel Dedication	18
2.13	Receiver	19
2.14	Transmitter	20
2.15	Serial Interface Circuit	21
2.16	The Way of Mounting Transceiver Module	22
2.17	Proposed Prototype (Plan)	23
2.18	The Proposed Prototype (Side view)	23
2.19	Implemented Prototype	24
2.20	Position Tracking with Compass	25
2.21	Executed Program in OOPic	28
2.22	Position Tracking without Compass	29
2.23	Position Tracking without Compass (block diagram)	30
2.24	Fuzzy Based Controlling	31
2.25	Collision Condition Function after Training	34
2.26	Relative Distance Function after Training	34
2.27	Master-Slave Switching Function after Training	35
2.28	Screenshot of the Developed GUI	36
3.1	Boat with Fuzzy Based Navigational Controller	37
3.2	Fuzzy Based Navigational Controller	38

3.3	Error Input Membership Function of the Fuzzy based Navigational Controller	38
3.4	Rate of Change Error Input Membership Function of the Fuzzy based Navigational Controller	39
3.5	Rate of Change Error Input Membership Function of the Fuzzy-based Navigational Controller	39
3.6	Output Surface of the Fuzzy based Navigational Controller	40
3.7	Picture of the Actual Boat Model	41
3.8	Path Tracking of a Sinusoidal Trajectory with PD Controller	42
3.9	Path Tracking of a Sinusoidal Trajectory with Fuzzy Controller	43
3.10	Error in Lateral Direction of a Sinusoidal Trajectory with Fuzzy Controller	43
3.11	Error in Longitudinal Direction of a Sinusoidal Trajectory with Fuzzy Controller	44
3.12	Path Tracking of a Straight Trajectory with Fuzzy Controller	44
4.1	Calculating Collision Direction	47
4.2	Calculating Collision Direction	48
4.3	Boats Path Near Obstacle without Obstacle Avoidance Controller	49
4.4	β Changes Near Obstacle	49
4.5	Names of Collision Direction Input Membership Function	50
4.6	Collision Direction Input Membership Function to the Obstacle Avoidance Controller	50
4.7	Relative Distance Input Membership Function to the Obstacle Avoidance Controller	51
4.8	X Direction Velocity Output Surface of the Obstacle Avoidance Controller	53
4.9	Y Direction Velocity Output Surface of the Obstacle Avoidance Controller	54
4.10	Algorithm of the Obstacle Avoidance Controller	55
4.11	Simulation Setup of the Obstacle Avoidance Controller	56
4.12	Path Starting Near Root of the Coordinate System	57
4.13	Path Starting Near Root of the Coordinate System	57
4.14	Path Starting near the Left Corner of the Coordinate System	58
4.15	Path Finishing Near Root	58
4.16	Path Starting Near Obstacle	59
4.17	Obstacle in the Grid	60
4.18	Obstacle Matrix with Obstacle	61
4.19	Possible Paths of the USV	61

4.20	Possible Paths of the USV on the Obstacle Matrix	62
4.21	Obstacle Coordinate Conversion	63
4.22	Path Value Calculation	64
4.23	Simplified Flow Chart of the Novel Algorithm	66
5.1	Two Dynamic Obstacles with Projected Obstacle Areas	67
5.2	Two Dynamic Obstacles with their Reduced Projected Obstacle Areas	68
5.3	Path Planning Between three Dynamic Obstacles	68
5.4	Effective Time Prediction of Dynamic Obstacles	69
5.5	Area Calculations for Dynamic Obstacle	70
5.6	Simulation result of an Actual and Predicted path in 3D space	71
6.1	Obstacle Avoidance Using UGV Algorithms (Safety distance = 50m)	74
6.2	Obstacle Avoidance Using UGV Algorithms (Safety distance = 60m)	75
6.3	Possible Paths Matrix of the USV	76
6.4	Obstacle on the Obstacle Matrix A	76
6.5	Obstacle on the Obstacle Matrix B	77
6.6	Obstacle on the Obstacle Matrix C	77
6.7	Obstacle on the Obstacle Matrix D	77
6.8	Obstacle Avoidance using Naval Algorithm (Safety distance = 40m)	78
6.9	Obstacle Avoidance using Naval Algorithm (Safety distance = 60m)	79
6.10	Contour Map of Potential Field with 3 obstacles	80
6.11	3D Surface of Potential Field with 3 obstacles	81
6.12	Obstacle Avoidance Using PFM	81
6.13	Comparison of Safety Distances	82
6.14	Comparison of Distances Towards two Obstacles	83
6.15	Dynamic Obstacle Avoidance with Time Values	84
6.16	Dynamic Obstacle Avoidance with 3 Obstacles	85
6.17	Longitudinal Coordinates of Actual Path	86
6.18	Lateral Coordinates of Actual Path	86
6.19	Actual Path and Predicted Paths of the Obstacle for Different Degrees	87
6.20	Longitudinal Error of Predicted Paths for Different Degrees of Polynomials	88
6.21	Lateral Error of Predicted Paths for Different Degrees of Polynomials	88
6.22	Longitudinal Coordinates of Actual Path with Noise (noise=5m)	89
6.23	Lateral Coordinates of Actual Path with Noise (noise=5m)	89
6.24	Actual Path of the Obstacle with Noise (noise=5m)	90
6.25	Actual and Predicted Path of the Obstacle (Degree = 6, noise = 1m)	91

6.26	Actual and Predicted Path of the Obstacle (Degree = 5, noise = 1m)	92
6.27	Actual and Predicted Path of the Obstacle (Degree = 4, noise = 1m)	93
6.28	Actual and Predicted Path of the Obstacle (Degree = 4, noise = 5m)	94
6.29	Actual Path and Predicted Paths of the Obstacle for Different Spreads	95
6.30	Longitudinal Error of Predicted Paths for Different Spreads	96
6.31	Lateral Error of Predicted Paths for Different Spreads	96
6.32	Actual Path and Predicted Paths of the Obstacle for Different Noise Values	97
6.33	Longitudinal Error of Predicted Paths for Different Noise Values	98
6.34	Lateral Error of Predicted Paths for Different Noise Values	99
6.35	Longitudinal Velocity of the Obstacle	100
6.36	Lateral Velocity of the Obstacle	101
6.37	Upper and Lower Boundaries of Predicted Obstacles Area ,Longitudinal Direction	101
6.38	Upper and Lower Boundaries of Predicted Obstacles Area ,Lateral Direction	102
6.39	Error towards Longitudinal Direction	103
6.40	Error towards Lateral Direction	103
6.41	Upper and Lower Boundaries of Predicted Obstacles Area towards Longitudinal Direction (S = 0.5)	104
6.42	Upper and Lower Boundaries of Predicted Obstacles Area Towards Lateral Direction (S = 0.5)	105
6.43	Error Towards Longitudinal Direction (S = 0.5)	105
6.44	Error Towards Lateral Direction (S = 0.5)	106
6.45	Upper and Lower Boundaries of Predicted Obstacles Area Towards Longitudinal Direction for Different Sea Condition Values	106
6.46	Upper and Lower Boundaries of Predicted Obstacles Area towards Lateral Direction for Different Sea Condition Values	107
6.47	Width of Predicted Obstacles Area Towards Longitudinal Direction For Different Sea Condition Values	107
6.48	Error towards Longitudinal Direction for Different Sea Condition Values	108
6.49	Error towards Lateral Direction for different Sea condition values	108
6.50	Upper and Lower Boundaries of Predicted Obstacles Area towards Longitudinal Direction from Conventional and Novel Methods	109
6.51	Upper and Lower Boundaries of Predicted Obstacles Area towards Lateral Direction from Conventional and Novel Methods	110
6.52	Error Towards Longitudinal Direction for Conventional and Novel Methods	110

6.53	Error towards Lateral Direction for Conventional and Novel Methods	111
6.54	Width of Predicted Obstacle Area towards Longitudinal direction from Conventional and Novel Methods	111
6.55	Predicted Distance reduction from Novel Method	112



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

List of Tables

No.	Description	Page
2.1	RF Channel Setting Commands	20
2.2	Centers of Gaussian Membership Functions	31
3.1	Rule Table for Fuzzy PD Controller -	40



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

ACRONYMS

USV	-	Unmanned Surface Vehicles
UGV	-	Unmanned Ground Vehicles
DAMN	-	Distributed Architecture for Mobile Navigation
GPS	-	Global Position System
INU	-	Inertial Navigation Unit
PFM	-	Potential field method
VOM	-	Velocity Obstacle method
DNC	-	Digital Nautical Chart
GRNN	-	Generalized Regression Neural Network



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk