

LB/DON/98/07

(85)

DECLARATION

**Modeling and Control of a Surface Vessel for  
"ITS for the Sea" Applications**

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

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

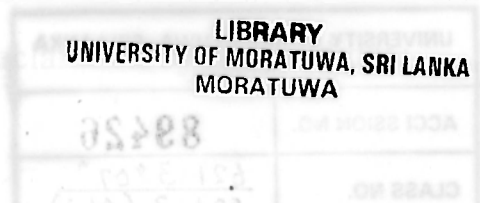
A dissertation submitted to the  
Department of Electrical Engineering, University of Moratuwa  
in partial fulfilment of the requirements for the  
degree of Master of Science

K. J. C. Kumara

07<sup>th</sup> of September, 2007

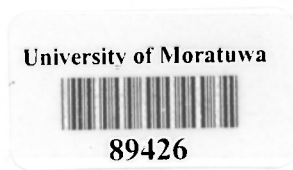
by

**KUDABADU JAYAWICKRAMA CHAMINDA KUMARA**



621.3 '07'  
621.3(043)

**Supervised by: Dr. Sisil Kumarawadu**



89426

**Department of Electrical Engineering  
University of Moratuwa, Sri Lanka**

**September 2007**

**89426**

# DECLARATION

The work submitted in this dissertation 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.



K.J.C. Kumara

07<sup>th</sup> of September, 2007

I endorse the declaration by the candidate.

***UOM Verified Signature***

Research Supervisor

Dr. Sisil Kumarawadu

Senior Lecturer in Electrical Engineering

*BSc Eng(Moratuwa), MEng(Saga), PhD(Saga)*

# CONTENTS

Declaration	i
Abstract	iv
Acknowledgement	v
List of Figures	vi
List of Tables	vii
<b>1. Introduction</b>	<b>1</b>
1.1 Background	1
1.2 Motivation	2
1.3 Goals of present work	3
<b>2. Design Features of the Surface Vessel</b>	<b>4</b>
2.1 Hulls	4
2.2 Strut	4
2.3 Submerged body (Gertler pontoon)	5
2.4 Propellers	5
<b>3. Kinematics Analysis</b>	<b>6</b>
3.1 Coordinate frames	6
3.2 Kinematics	7
3.3 Equation of motion	7
<b>4. Detail Dynamics Analysis</b>	<b>9</b>
4.1 Analysis of Hydrodynamics damping forces and moments	9
4.2 Damping forces on hulls	11
4.3 Strut damping forces	12
4.4 Gertler pontoon damping forces	13
4.5 Thrust and propulsion	13
4.6 Propeller-hull interaction	15
4.7 Unsteady forces	15
4.8 Added mass coefficients	16
<b>5. Application of a Computed Torque-like Controller</b>	<b>17</b>
5.1. State Space Representation	17
5.2. CTC-like Controller	17
5.3. Desired trajectory	18

5.4.	Simulation Results	19
<b>6.</b>	<b>Model Based Speed Control</b>	<b>20</b>
6.1	Speed control problem	20
6.2	Dynamic equations	21
6.3	Stable speed control	23
6.4	Calculating real control inputs	25
6.5	Simulation Results	25
6.6	Conclusion	28
<b>7.</b>	<b>NN Adaptive Controller Design</b>	<b>29</b>
7.1	Nonlinear control problem	29
7.2	Formulation of Dynamic equations	29
7.3	Control approach	30
7.4	Radial Basis Function neural networks	31
7.5	Updating of connecting weights	32
7.6	Measuring and estimating the Motion variables	34
7.7	Simulation Results	35
7.8	Conclusion	38
<b>8.</b>	<b>Shape Adaptive RBF NNs Controller Design</b>	<b>39</b>
8.1	The NN model	39
8.2	Weights update for Guaranteed tracking performance	40
8.3	Longitudinal and Lateral neural subnets	43
8.4	Conclusion	43
<b>9.</b>	<b>Conclusions and Future Works</b>	<b>44</b>
9.1	Conclusions	44
9.2	Recommendations for Future Researches	45
	<b>References</b>	<b>46</b>
	<b>Appendix A</b> Assumptions	<b>49</b>
	<b>Appendix B</b> Matlab programs	<b>50</b>

## Abstract

In the emerging field of intelligent transportation systems (ITS), “*ITS for the sea*” refers to the area of maritime traffic. Automated vehicle control systems are a key technology for ITS. An autonomous surface vessel (ASV) can be defined as a vehicle controlling its own steering and speed for Navigation, dynamic positioning, motion stabilization and obstacle detection and avoidance.

The scope of the research is defined by two main objectives viz. developing complete mathematical model of a surface vessel by analyzing hydrodynamic forces and main other effects arising when manoeuvring in the ocean, and design online-learning adaptive controller for path tracking and speed control using real control inputs; propeller thrust and steering angle. The vessel moves in a hydrodynamic environment where many uncertainties, non-linear and non-predictive behaviours always appear. The ocean vehicle is modelled mathematically using first principles and derivations wherever possible.

In this work, the problem of control with guaranteed sway and yaw stability for automated surface vessel operation is addressed with special emphasis on speed control. A control scheme to solve this problem without simplifying the dynamics is proposed and extensively studied using formative mathematical analyses and simulations.

The main academic motivation of this research was to study and synthesis the power of artificial intelligence techniques in controlling of non-linear dynamical systems with online-learning and adaptive capabilities. A model-based neural network adaptive controller is developed blending a self adaptive neural network module and a classical Proportional plus Derivative (PD)-like control to obtain optimum control performance by complementing each other. The adaptive neural module counteracts for inherent model discrepancies, strong nonlinearities and coupling effects.



# ACKNOWLEDGEMENTS

I would like to thank...

DR. SISIL KUMARAWADU

For the outstanding job he did as my Research Supervisor. For his academic brilliance, dedication, patience, and understanding.

DR. D.H.S. MAITHREEPALA AND DR. NALIN WICKRAMARACHCHI

For the effort they put into reading and correcting my thesis as members of the final evaluation panel.

PROFESSOR. RANJITH PERERA AND DR.LANKA UDAWATTA

For the necessary guidance and invaluable advices during progress evaluations

MR. AMARANATH PREMASIRI

Granting me a valuable text book and sending many research papers

ADIMINTRATION OF UNIVERSITY OF RUHUNA

For funding me to read a M.Sc. degree

MY FAMILY

For their continual support, and for keeping me relatively sane and stable.

MY WIFE

For spoiling me with breakfast in the morning, free laundry services and an open ear even in the middle of the night.

EVERYONE AT DEPARTMENT OF MECHANICAL & MANUFACTURING  
ENGINEERING, UNIVERSITY OF RUHUNA AND DEPARTMENT OF  
ELECTRICAL ENGINEERING, UNIVERSITY OF MORATUWA

For supporting me in various ways

## List of Figures

Figure	.Page
2.1 3D view of preliminary design of the ASV	4
3.1 Coordinate frames	6
4.1 Sketch of a propeller and its shaft	14
5.1 Tracking of a circular trajectory	19
5.2 Velocity diagrams	19
6.1 ASV with directions of interest for speed control	20
6.2 FBD of the surface vessel	21
6.3 Simulation results: Velocities	26
6.4 Simulation results: Net Thrust & Steering Angle	27
7.1 Architecture of the RBF neural network	31
7.2 Desired Octomorphic path	35
7.3 Tracking of a octomorphic trajectory	36
7.4 Position errors in $X_e$ - direction	36
7.5 Position errors in $Y_e$ - direction	37
7.6 Online adaptive process of Weights in X subnet	37
7.7 Online adaptive process of Weights in Y subnet	38

# List of Tables

# Chapter

Table	Page
2.1 Body dimensions of the ASV	5
2.2 Fluid properties	5
4.1 Form factor	10

Main tasks of an ASV include vehicle control (navigation, heading keeping, state following, 2D spatial positioning, motion stabilization, wave management), threat detection, target avoidance, Human-machine interface (HMI) development, communication, data navigation etc. and vehicle supervision by target following and boundary restricted systems are usually used for actuator controls of the ASV.

## 1.1 Background

Research and development of classical controllers for any dynamical system are usually based on the availability of a mathematical model, which provides close and accurate description of dynamics of the real system.

Many research publications are available on mathematical modeling, control and navigation of communication systems for underwater vehicles [1]-[3], but only a limited number has been reported for surface vessels, especially for autonomous navigation [4]-[6] with engine propulsion. A stabilization model for a hovercraft has been developed [7] to exchange stabilization algorithms. This problem is simply solved for a hovercraft on a flat surface vessel as it does not contain many of the dynamic characteristics of a ship. In [8,9] also, similar algorithms were used to stabilize a hovercraft on a flat surface, but those rather publications do not discuss the dynamics of waves or perturbation.

Most of the publications have addressed the following topics and issues when developing systems for surface vessels: (i) models and some of them are only partially realistic [1]-[3];

- Angular speed and angular accelerations for yaw and which powered the motion and control the vessel by contributing to the control moment (thrust)
- Unsteady forces induced on the accelerations  $\ddot{y}$  and where all the relations developed to find resistance of the vessel's hull
- Validity of assumption that the resistance is independent of the Reynolds number ( $R_n$ ), but it is not always true, especially in some cases.