

**ANALYSING AND IMPROVING PATH PLANNING BASED ON LAGRANGE  
POLYNOMIAL AND DESIGNING METHOD FOR DYNAMIC OBSTACLE  
AVOIDANCE OF AN AUTONOMOUS GUIDED VEHICLE**

By

Aryaputra Teguh Purnama  
11110014

A thesis submitted to the Faculty of

ENGINEERING AND INFORMATION TECHNOLOGY

in partial fulfillment of the requirements  
for the  
BACHELOR'S DEGREE  
in

MECHATRONICS



SWISS GERMAN UNIVERSITY  
EduTown BSD City  
Tangerang 15339  
Indonesia

Revision after the Thesis Defense on July 16<sup>th</sup> 2014

### STATEMENT BY THE AUTHOR

I hereby declare that this submission is my own work and to the best of my knowledge, it contains no material previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any other degree or diploma at any educational institution, except where due acknowledgment is made in the thesis.

Aryaputra Teguh Purnama

Student

Date

Approved by:

Dr. Ir. Prianggada Indra Tanaya, MME

Thesis Advisor

Date

SWISS GERMAN UNIVERSITY

Dipl. Ing. Maralo Sinaga

Thesis Co-Advisor

Date

Dr. Ir. Gembong Baskoro, M.Sc

Dean

Date

Aryaputra Teguh Purnama

## ABSTRACT

### ANALYSING AND IMPROVING PATH PLANNING BASED ON LAGRANGE POLYNOMIAL AND DESIGNING METHOD FOR DYNAMIC OBSTACLE AVOIDANCE OF AN AUTONOMOUS GUIDED VEHICLE

By

Aryaputra Teguh Purnama

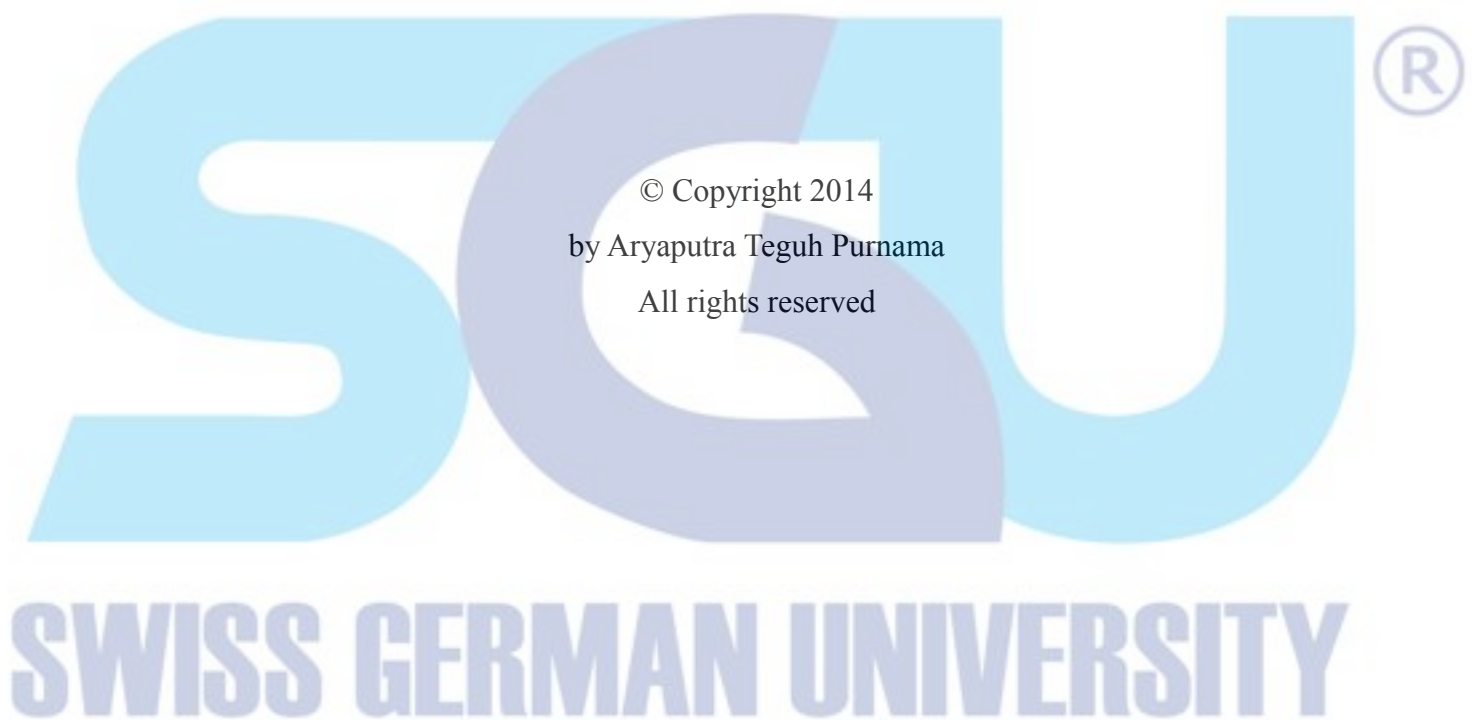
Dr. Ir. Prianggada Indra Tanaya, MME, Advisor

Dipl. Ing. Maralo Sinaga, Co-Advisor

SWISS GERMAN UNIVERSITY

The purpose of this thesis work is to analyse and improve the path planning based on Lagrange Polynomial and design a method for obstacle avoidance. The path planning is used on Automated Guided Vehicle which has been developed in SGU. The Lagrange Polynomial which that will be used are 2<sup>nd</sup> order and 3<sup>rd</sup> order. The form and the shape of the path will be tested and analysed to make an efficient path planning. The experiment will focus on the shape and execution of the path. The testing will be done using V-REP simulation which is also capable to simulate the scenario of obstacle avoidance. The result of the simulation will later be implemented in the AGV. The result of the experiment will be used as a base for improvement for path planning in the AGV.

*Keywords: path planning, Lagrange polynomial, obstacle avoidance, simulation*



## **DEDICATION**

I dedicate this work for my family, teachers and all my friends



## ACKNOWLEDGEMENTS

The author wishes to thank all people who have helped in the making of this work.

I wish to thank my family who supports me every time and during this four year of studying.

I would like to give my thanks to Dr. Ir. Prianggada Indra Tanaya, my thesis advisor, who encouraged me and guided me during this work.

I would like to thank Dipl.-Ing. Maralo Sinaga, my thesis co-advisor, who advised me and gave me support for this work.

I would also like to thank Davine and Saras Safitri who have accompanied me during the making of this work. Thank you all for your time and great help.

Special thanks to Michael Keveen Siahaan, who give me support and information about V-REP. And many thanks to fellow Mechatronics students batch 2010. Thank you all for your help.

SWISS GERMAN UNIVERSITY

## TABLE OF CONTENTS

STATEMENT BY THE AUTHOR.....	2
ABSTRACT.....	3
DEDICATION.....	5
ACKNOWLEDGEMENTS.....	6
TABLE OF CONTENTS.....	7
LIST OF FIGURES.....	12
LIST OF TABLES.....	13
CHAPTER 1 – INTRODUCTION.....	14
1.1 Background.....	14
1.2 Thesis Purpose .....	15
1.3 Significance of Thesis .....	15
1.4 Thesis Scope .....	16
1.5 Thesis Limitations .....	16
1.6 Thesis Organization .....	17
CHAPTER 2 – LITERATURE REVIEW.....	18
2.1 Introduction.....	18
2.2 Robot Path Planning based on Lagrange Polynomial.....	18
2.3 Prediction of Human's Movement for Collision Avoidance of Mobile Robot [4]	20
2.4 On-line Real-time Path Planning of Mobile Robots in Dynamic Uncertain Environment [5].....	22
2.5 Review of Existing Researches and Projects.....	24
2.5.1 Development of Path Planning Based On Lagrange Polynomial Method For Dynamic Obstacle Avoidance of Takeover and Crossroad Maneuver Using Kinect™ Sensor of a Mobile Robot [1].....	24
2.5.2 Development of Trajectory Planner Based on Lagrange Polynomial and B- Spline Equations For an Autonomous Human Follower Transporter Robot [2].....	28

2.5.3 Designing a Framework for Analyzing Mobile Robot Behavior Using V-Rep Simulator [6].....	33
2.6 Concluding Remarks.....	35
CHAPTER 3 – METHODOLOGY .....	38
3.1 General Overview .....	39
3.2 Breakdown Structure of the Robot Platform .....	40
3.2.1 Mechanical Parts .....	40
3.2.2 Electrical Parts .....	40
3.3 Planning Methodology.....	41
3.3.1 Static Object Distance Measurement Methodology with Kinect™.....	42
3.3.2 Dynamic Object Distance Measurement Methodology with Kinect™.....	44
3.3.3 Lagrange Path Planning Method .....	44
3.3.4 Kinematics of Differential Steering .....	50
3.3.5 Kinematic Approach for Lagrange Polynomial Implementation.....	60
3.3.6 Path Planning Process for Static Obstacle Overtaking .....	65
3.3.7 Path Planning Process for Dynamic Obstacle Avoidance.....	67
3.4 Software Tools.....	74
3.4.1 Linux Ubuntu 12.10 .....	74
3.4.2 Qt SDK .....	74
3.4.3 Virtual Robot Experimentation Platform (V-REP) .....	74
CHAPTER 4 – RESULTS AND DISCUSSIONS.....	75
4.1 Experiment Layout in V-REP.....	75
4.2 Lagrange Polynomial Path Execution Analysis in V-REP.....	77
4.3 Static Obstacle Overtaking Test in V-REP .....	88
4.4 Dynamic Obstacle Avoidance Test in V-REP.....	91
4.5 Graphical User Interface (GUI).....	95
4.6 Movement and Pivot Test.....	98
4.7 Circular Path Test.....	103
4.8 Lagrange Polynomial 2 <sup>nd</sup> Order Path Execution Test.....	105
4.9 Concluding Remarks.....	108
CHAPTER 5 – CONCLUSIONS AND RECOMMENDATIONS.....	109
5.1 Conclusions.....	109



5.2 Recommendations and Future Development.....	109
GLOSSARY.....	110
REFERENCES.....	111
APPENDICES.....	113
APPENDIX A – Mechanical Design of Red AGV.....	113
APPENDIX B – Electrical and Datasheet.....	114
B.1 – Electrical Wiring Diagram.....	114
B.2 – Arduino Mega 2560.....	115
B.3 – Hanyoung Rotary Encoder.....	123
B.4 – Motherboard Asrock z77 Extreme 3.....	125
B.5 – Intel Core i-3 3210 LGA1155.....	131
B.6 – EMS 30A H-Bridge.....	135
B.7 – Permanent Magnet DC Motor DKM 60W.....	140
APPENDIX C – Program Code.....	142
C.1 – mainwindow.h.....	142
C.2 – mainwindow.cpp.....	144
C.3 – path_planning.h.....	166
C.4 – path_planning.cpp.....	167
C.5 – arduino_code.ino.....	174
C.6 – Lagrange Polynomial Path Testing in V-REP.....	186
C.7 – Position Testing in V-REP.....	190
C.8 – Obstacle Avoidance Testing in V-REP.....	192
CURRICULUM VITAE.....	198

## LIST OF FIGURES

Figure 2.1: Basic Velocity of Movement of Human [4].....	21
Figure 2.2: Position of the Obstacle: (a) - (c) Case 1, (d) - (e) Case 2, (f) Case 3 [5].	23
Figure 2.3: Fully Assembled Mobile Robot [1].....	24
Figure 2.4: System Design of Mobile Robot [1].....	25
Figure 2.5: Path Planning for Take over Maneuver Flow Chart [1].....	27
Figure 2.6: Path Planning for Crossroad Maneuver Flow Chart [1].....	28
Figure 2.7: Human Follower Transporter Robot [2].....	29
Figure 2.8: The Overview of the Electrical design of the robot [2].....	29
Figure 2.9: Procedure of following the movement of human. (a) The movement of human. (b) The movement of transporter robot. [2].....	30
Figure 2.10: The Planner Module Process Block Diagram of Human Follower Transporter Robot [2].....	31
Figure 2.11: Flowchart of Human Following Process of the Robot Using 2nd Order Lagrange Interpolating Polynomial [2].....	32
Figure 2.12: Mechanical Design of AGV in V-REP Simulation [6].....	33
Figure 2.13: Layout Design of AGV in V-REP Simulation [6].....	34
Figure 2.14: Configuration 1 (left) , configuration 2 (middle), configuration 3 (right) [6].....	35
Figure 3.1: Autonomous Mobile Robot by Yohanes [7].....	38
Figure 3.2: Configuration of Pulley.....	40
Figure 3.3: Arduino Mega 2560 Pins Connection.....	41
Figure 3.4: Breakdown Structure of the AGV.....	42
Figure 3.5: Comparison of Lagrange Polynomial.....	45
Figure 3.6: Comparison of the Use of Lagrange Polynomial.....	46
Figure 3.7: The relationship of $\dot{x} - \dot{y}$ with $v_{res} - \theta$ .....	47
Figure 3.8: Free Body Diagram for Body of AGV.....	51
Figure 3.9: Free Body Diagram for Wheel A of AGV.....	52
Figure 3.10: Free Body Diagram for Wheel B of AGV.....	53
Figure 3.11: Free Body Diagram for Wheel C of AGV.....	54

Figure 3.12: Kinematics of AGV.....	58
Figure 3.13: Configuration for Turning of AGV.....	59
Figure 3.14: Coordinate System for AGV.....	61
Figure 3.15: CW Turn for AGV.....	62
Figure 3.16: CCW Turn for AGV.....	64
Figure 3.17: Static Obstacle Overtaking.....	66
Figure 3.18: Calculating Gap.....	66
Figure 3.19: Dynamic Forward Obstacle Overtake Start.....	67
Figure 3.20: Dynamic Forward Obstacle Overtake Finish.....	68
Figure 3.21: Dynamic Backward Obstacle Overtake.....	69
Figure 3.22: Dynamic Sideway Obstacle.....	70
Figure 3.23: Flowchart of Initial Condition.....	71
Figure 3.24: Flowchart of Dynamic Obstacle x Direction.....	72
Figure 3.25: Flowchart of Dynamic Obstacle y Direction.....	73
Figure 4.1: Model of AGV in V-REP.....	75
Figure 4.2: GUI for Simulation of AGV in V-REP.....	76
Figure 4.3: Graph for Showing the Path of the AGV.....	77
Figure 4.4: Calculation Result of 2 <sup>nd</sup> Lagrange Polynomial for First Set of Setpoints.....	78
Figure 4.5: Simulation Result of 2 <sup>nd</sup> Lagrange Polynomial for First Set of Setpoints.....	79
Figure 4.6: Comparison of Result of 2 <sup>nd</sup> Lagrange Polynomial.....	82
Figure 4.7: Calculation Result of 3 <sup>rd</sup> Lagrange Polynomial for First Set of Setpoints.....	83
Figure 4.8: Simulation Result of 3 <sup>rd</sup> Lagrange Polynomial for First Set of Setpoints.....	84
Figure 4.9: Comparison of Result of 3 <sup>rd</sup> Lagrange Polynomial.....	87
Figure 4.10: Simulation Result of Overtaking Maneuver.....	88
Figure 4.11: Graph Showing Variation of Error final – test with Distance Travelled.....	91
Figure 4.12: Result of Backward Obstacle Avoidance with Green AGV as Obstacle.....	92
Figure 4.13: Result of Forward Obstacle Overtake with Green AGV as Obstacle.....	94
Figure 4.14: Serial GUI.....	96
Figure 4.15: Path Planning GUI.....	97
Figure 4.16: Result of Move 200 mm.....	98
Figure 4.17: Result of Move 200 Calculation.....	99
Figure 4.18: Graph Showing Variation of Movement Error with Command Sent.....	100

---

Figure 4.19: Result of Pivot 20 degree.....	101
Figure 4.20: Result of Pivot 20 degree Calculation.....	102
Figure 4.21: Graph Showing Variation of Pivot Error with Command Sent.....	103
Figure 4.22: Test for Circular Path.....	104
Figure 4.23: Test for Lagrange Polynomial 2 <sup>nd</sup> Order Path Execution.....	106
Figure 4.24: Difference in Result for Lagrange Polynomial 2 <sup>nd</sup> Order Path Execution .....	107
Figure 4.25: Worm Gear Drive [10].....	108



## LIST OF TABLES

Table 2.1: Result of Straight Movement Simulation [6].....	34
Table 2.2: Result of Aversive Behavior Simulation [6].....	35
Table 3.1: History of the Works related to this AGV in SGU.....	39
Table 4.1: Result of the Test for 2 <sup>nd</sup> Order Lagrange Polynomial Path Execution for First Set of Setpoints (0,0), (X/2, 2Y/3), (X,Y).....	80
Table 4.2: Result of the Test for 2 <sup>nd</sup> Order Lagrange Polynomial Path Execution for Second Set of Setpoints (0,0), (X/2, 3Y/4), (X,Y).....	82
Table 4.3: Result of the Test for 3 <sup>rd</sup> Order Lagrange Polynomial Path Execution for First Set of Setpoints (0,0), (X/4,Y/3),(3X/4,2Y/3), (X,Y).....	85
Table 4.4: Result of the Test for 3 <sup>rd</sup> Order Lagrange Polynomial Path Execution for Second Set of Setpoints (0,0), (X/4,3Y/8),(3X/4,5Y/8), (X,Y).....	86
Table 4.5: Result of the Test for Static Obstacle Overtaking Maneuver.....	89
Table 4.6: Result of the Error for Static Obstacle Overtaking Maneuver.....	90
Table 4.7: Result of Backward Obstacle Avoidance Test.....	93
Table 4.8: Result of Forward Obstacle Overtake Test.....	95
Table 4.9: Result of the Straight Movement Test.....	99
Table 4.10: Result of the Pivot Test.....	102
Table 4.11: Result of the Turning Test.....	105