Steering Control System Design and Analysis for an Unmanned Autonomous Mobile Robot

A thesis submitted to the

Division of Graduate Studies and Research

of the University of Cincinnati

in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

In the Department of Mechanical, Industrial and Nuclear Engineering

Of the College of Engineering

1998 by Kalyan Chakravarthi Kolli

B.S., (Mechanical Engineering), Regional Engineering College, Warangal, India., 1995

Thesis Advisor and Committee Chair: Dr. Ernest L. Hall

Abstract

Mobile robots are becoming increasingly significant in industrial, commercial and scientific applications. The rate at which science and industry are developing has opened the door for the use of robots in many fields. There is extensive research being carried out on autonomous mobile robots. Many solutions to problems, including path planning and obstacle avoidance, have been proposed and tested. The purpose of this paper is to describe the design of a steering mechanism for an autonomous mobile robot.

The specific challenge of designing an intelligent controller for an automated guided vehicle (AGV) is in determining what information is needed, how to measure it and how to use this information in a manner that will satisfy the performance specifications of the machine. The steering mechanism replaces a manually turned rack
and pinion arrangement with a crank mechanism driven by a linear actuator that in turn is powered by a brushless DC motor. The system was modeled, analyzed, and redesigned to meet the requirements. A 486 computer through a 3-axis motion controller supervises the steering control. The steering motor is a brushless DC motor powered by three phase signals. It is run in current loop mode. The steering control system is supervised by a personal computer through a multi-axis motion controller.

The kinematic model of the steering system is analyzed and a control model is presented.

A complete and proper integration of the steering control module is ensured and the various system modules are tested for their individual performance.

The proposed model is a novel control system design for an integrated fuzzy logic controlled three-wheeled automated guided vehicle. The design development, system mathematical model and simulation can be extended to other control systems designs, but the specific nature of control, involving the multiple data input and the efficient management of the data, is still an open issue in the ongoing research of mobile robots. Considerable importance has been given to data fusion and the capability of the steering mechanism to respond in the most efficient manner to the various system modules on board BEARCAT 1.

After extensive laboratory testing of individual subsystems an oval outdoor test track was constructed to simulate the contest track with double lines, 4 inches wide spaced 10 feet apart with dashed segments and obstacles. The steering mechanism worked satisfactorily. Implementing the PID controller variables as obtained from the SIMULINK model gave a stable response with almost zero overshoot. The vision system was able to successfully track straight lines, curves, negotiate sharp turns as well as switch control between cameras when the line on either side disappeared. The sonar system reliably detected obstacles between 6 inches and 8 feet within an accuracy of 1 inch. This system was found to be extremely reliable and effective. The mobile robot showed excellent response when the source code was executed. The mobile robot traversed the maximum distance avoiding several obstacles on course and followed the lines for 325 feet, the greatest distance in 5 years of ongoing research on the robot and earned a 8th place in the International Annual ground robotics competition.

Acknowledgments

This research culminated from the motivation given by my advisor Dr. Ernest L. Hall for taking part in the Annual ground robotics competition held in Oakland, MI, June 1997. The work done on the autonomous robot in turn took
the shape into the present form of thesis. Words of gratitude cannot express the encouragement given by my advisor both academically and personally. He has guided me throughout my graduate studies here at the University of Cincinnati, and got me interested in the world of robotics.

Special thanks are due to the committee members, Dr. Richard L. Shell and, Dr. Ash Genaidy for their review of the thesis, and for their ideas and suggestions for improving the robot.

I acknowledge the students of the Center of the Robotics Research for their valuable suggestions and critiques. I would like to also thank my Advisor Dr. Ernest Hall for giving me an excellent opportunity and encouragement to teach the undergraduate course in control system in the summer of 1997 which was a great source or self-confidence and learning for me personally.

Finally I would like to take this opportunity to thank my mother, my father, my sister and ever-loving grandparents for their continuous support and encouragement. My sincere thanks are due to all the friends here at the University and elsewhere.

Contents

Abstracts................................................................. iii

Acknowledgements.................................................... vi

List of figures?.......................................................... ix

1. Introduction..............................................................?1

   1. Motivation?.......................................................?1

   2. Context?............................................................?2

      1. Problem Statement?.........................................?5

   3. Specific goals of the research................................?6
4. Contribution to the research?..........................?7
5. Contribution of the work?...............................?7

2. Literature review?...........................................?9
   1. Introduction?.............................................?9
   2. Linear and Non-linear controller design for robust automatic
      Steering?................................................?12
   3. Parallel linkage steering for an automated guided vehicle ......?14
   4. Modeling and control of an automated vehicle?...........?17

3. An Introduction to control system theory?......................?20
   1. Introduction?.............................................?20
   2. The basic control system?................................?21
      1. The control problem?.................................?21
      2. Description of the input and output?.................?22
   3. Feedback and feedforward control?.......................?24
   4. Linear control systems?................................?28
   5. Control of Non-linear systems?..........................?29
   6. The design process?....................................?31

4. Digital control systems, the PID and the Galil DMC1000 controller? ...?38
   1. Digital control systems?.................................?40
   2. PID controller?............................................?44
      4.2.1 Proportional Band?..................................?45
         2. Integral?..............................................?45
1. Introduction?

2. The AUVS contest and the Bearcat design?

   1. Introduction?
   2. The competition?
   3. The robot structural design?
   4. System design and development?
   5. Vision guidance system?
   6. Obstacle avoidance system?
   7. Speed control?

6. Steering Mechanism Kinematics and the Proposed control model?

   1. Rack and pinion kinematics?
   2. Steering Control System Model?
   3. Modeling the Motor and the Amplifier?
   4. System compensation objective?
7. Simulation and results..............................................80
   1. Introduction.................................................80
   2. Simulation on SIMULINK.................................80
   3. Computer control of the steering module...............85
   4. Results of testing.........................................85
       1. Vision guidance system...............................86
       2. Obstacle Avoidance System.........................86
       3. Steering control system............................87
       4. Safety and Emergency Stop Braking System.......87

8. Conclusions and recommendations..........................88

References.......................................................89

Appendix A?Step response for the Uncompensated system?..96

Appendix B?Step response for the Compensated system?...?97

Appendix C?WSDK software manual tuning step response?..98

Appendix D?Galil DMC -1000 Motion controller Assembly code?...99

Appendix E?C++ Source code for the Steering control?? 100

Appendix F?Matlab code for the calculation of digital gains? 108
List of Figures

1. Lane following feedback structure (Ozguner, Et al. [3])................................. 11
2. Single track model for car-steering (Ackerman, et al [4])............................ 13
3. Nonlinear control structure model block diagram (Ackerman, et al [4])...... 14
4. Design of experimental automated guided vehicle (Sung, Et al [5])......... 15
5. Block diagram of steering control system (Sung, Et al [5]).................... 17
6. Model-reference control system block diagram with input scaling (Will and Zak [6])................................................................. 18
7. Closed-loop system performance with model-reference tracking controller (Will and Zak [6])................................................................. 19
8. Simplified description of a control system (Nise, Norman [29])............... 21
9. Input output for the elevator system (Nise, Norman [29]).................... 23
10. An antenna azimuth position control system (Nise, Norman [29])........ 31
11. Functional Block Diagram of a position control system (Nise, Norman [29]) ............................. 32
12. An example of a 3-bit quantized signal (Santina, Stubberud, Hostetter [36]).. 40
13. A control system (Santina, Stubberud, Hostetter [36]).......................... 41
14. A digital control system controlling a continuous-time plant (Santina, Stubberud, Hostetter [36])................................................................. 42
15. A Time Response plot showing controller action? (Graphic courtesy of ExperTune Inc. Loop Simulator) .......................................................... 46

16. Controller frequency response plot? (Graphic courtesy of ExperTune Inc. Loop Simulator) .......................................................... 48

17. X and Y coordinates for the measured and computed vision calibration points .............................................................. 59


19. Obstacle avoidance strategy? ............................................................... 62

20. Overall traction control system? .......................................................... 64

21. Crank mechanism? ........................................................................... 66

22. Relative velocities? ........................................................................... 68

23. Simulink model of the uncompensated system? ............................... 81

24. Simulink model of the compensated system? ................................. 82