Development of a Novel Zero-Turn-Radius Autonomous Vehicle

by

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Abstract

This thesis describes the development of a new zero-turn-radius (ZTR) differentially driven robotic vehicle hereinafter referred to as NEVEL. The primary objective of this work was to develop a device that could be used as a test-bed for continued autonomous vehicle research at Virginia Tech while meeting the entry requirements of the Annual International Unmanned Ground Robotics Competition. In developing NEVEL, consideration was given to the vehicle's mechanical and electrical design, sensing and computing systems, and navigation strategy. Each of these areas was addressed individually, but always within the context of optimal integration to produce the best overall vehicle system. A constraint that directed much of the design process was the desire to integrate industrially available and proven components rather than creating custom designed systems. This thesis also includes a review of the relevant literature as it pertains to both subsystem and overall vehicle design.

NEVEL, the vehicle that was created from this research effort, is novel in several respects. It is one of the few true embodiments of a fully functioning, three-wheel, differential drive autonomous vehicle. Several previous studies

have developed this concept for indoor applications, but none has resulted in a working test-bed that can be applied to an unstructured, outdoor environment. NEVEL also appears to be one of the few autonomous vehicle systems to fully incorporate a commercially available laser range finder. These features alone would make NEVEL a useful platform for continued research. In addition, however, by using common, off-the-shelf components and a personal computer platform for all computation and control, NEVEL has been created to facilitate testing of new navigation and control strategies. As testimony to the success of this design, NEVEL was recognized at the Sixth Annual International Unmanned Ground Robotics Competition as the best overall design.

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I would like to thank the 1997-1998 Virginia Tech Autonomous Vehicle Team for their contributions and hard work. I would like to single out the NEVEL team for their assistance, without which NEVEL might not have been completed. Thanks also to all the corporate sponsors whose donations made NEVEL's fabrication possible. Thanks also to Alex, Matt, T.J., Mike, and Randy for their suggestions and companionship in the office.

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Chapter 1
Introduction

1.1 Definition of an Autonomous Robotic Vehicle

What exactly is an autonomous robotic vehicle? Webster's Second College Edition New World Dictionary defines the words in this expression as follows. The term *autonomous* means "having self-government; functioning independently without control by others." One definition of the word *robot* is "any mechanical device operated automatically to perform in a seemingly human way." Finally, a *vehicle* is defined as "any device or contrivance capable of carrying or conveying persons or objects." Thus, we may generally conclude that an autonomous robotic vehicle is a "device capable of movement based on independent, human-like decisions." This definition infers other human characteristics necessary for decision making such as perception and reasoning.

Recent literature supports this concept of an autonomous robotic vehicle. Angeles (1997) presents the general concept of robotic devices as dynamic mechanical systems with the possibility of intelligence. Intelligence is described as the ability of the system to perceive, reason, make decisions, and act based on a high order goal. A high order goal, such as "map a planet's terrain", requires a much more complex system than do lower order goals, such as "move from point A to point B". According to Angeles (1997), an intelligent robotic system uses sophisticated sensory systems to perceive an unstructured environment and then make decisions that mimic living systems. Meystel (1991) states that "autonomy" is defined by a system's "ability to independently make intelligent decisions as the situation changes." Meystel is careful to point out that there are varying levels of autonomy. A robot generally controlled by a human operator may be able to plan, control, and execute certain operations without human intervention. It is the concept of “intelligence” that separates autonomous robotic systems from the teleoperated and programmable robots commonplace in today’s industrial settings. This thesis will focus on the development of a completely autonomous robotic vehicle.

1.2 Motivation

The vehicle presented in this thesis was directly motivated by a design project at Virginia Tech. The project culminates with participation in the Annual Unmanned Ground Vehicle Competition sponsored by the Association for Unmanned Vehicle Systems International (AUVSI). However, the possible uses of autonomous vehicles are obviously much broader. Smart highway systems draw upon autonomous vehicle research to make cars safer with the addition of driver assistance systems (Hennessey et al., 1995; Ganci et al., 1995). Robotic vehicles are being used for interplanetary exploration. Great distances cause communication lags that limit real-time teleoperation. Thus, vehicles that can perform obstacle avoidance and specimen collection autonomously are highly beneficial (Schilling and Jungius, 1995; Hayati et al., 1997). Military applications include reconnaissance and perimeter security (Meystel, 1991). As the world of production becomes increasingly competitive, the need for robotic systems capable of real-time decision making increases. Autonomous robotic vehicles and their underlying concepts can be applied to almost any situation where there is concern for human safety, or where speed, or tedium is an issue.

1.3 Technical Challenges

The technical challenges involved in the design and implementation of an autonomous robotic vehicle follow directly from Angeles’s (1997) definition of intelligence. The most obvious challenge is to design a system capable of performing the necessary *action*. A robot could be required to retreive stock in a warehouse, perform security functions, or in this case, autonomously negotiate an outdoor obstacle course. Different applications may require different types of mobile platforms or manipulators. Regardless of the application, the design must consider issues of environment, durability, reliability, complexity, size, and cost.

Once a proper platform is designed, the robot must be given the ability to *perceive* the world around it. This requires the selection and fusion of a variety of sensing instruments. The designer must decide what level of perception is necessary to accomplish a given task. The perception of a highway lane boundary, for example, could be accomplished using several different types of sensors. The designer must consider the importance of resolution, accuracy, reliability, and cost to the application. Consideration must also be given to the ability to combine multiple sensors and how this will affect the robot's ability to *reason* and *make decisions*.

A robot's ability to *reason* and *make decisions* focuses on the systems computing resources and algorithms. Ultimately, a robot is only as "intelligent" as the computer algorithms programmed by its creators. The robot's algorithms must be capable of collecting and modifying sensor data to *perceive* the world. The assembled sensor data must then be interpreted according to the robot's task or goal and used to generate some type of *decision*. Typically this decision involves some action carried out by the physical robotic system. The complexity of these algorithms is again dependent upon the robot's application.

The greatest technical challenge is integrating the perception, reasoning, decision making, and action segments of the overall design. Sensor selection must be done concurrently with *perception* and *decision making* algorithms to ensure a robust and efficient system. The designer must also make sure that computer resources are capable of controlling the mechanical systems so that the *action* is properly carried out. The wisest approach is to simultaneously consider all the subsystems and their interaction. All of these technical challenges and possible solutions will be addressed in the following chapters.

1.4 Thesis Outline

This thesis describes the development of an autonomous robotic vehicle to compete in the Sixth Annual Unmanned Ground Vehicle Competition held at

Oakland University. The concepts presented, however, apply to the development of autonomous systems in general. Chapter 2 presents a survey of different types of robotic vehicles, sensors and sensor fusion, and navigation strategies. This covers the perception, reasoning, decision making, and action stages of the system. Chapter 3 will outline the design goals and constraints. Specific attention will be given to the requirements set forth by the Annual Unmanned Ground Competition. The experience gained by Virginia Tech's Autonomous Vehicle Team, or AVT, during the past three years is also used to impose further design goals. Chapters 4 and 5 will present the proposed and detailed designs. The design and fabrication of the base vehicle, onboard sensors, and navigation strategy will be discussed in detail. Finally, Chapter 6 will present the results obtained during vehicle testing and at competition.