CHAPTER 1

INTRODUCTION

This chapter provides an overview and introduction for Advanced Vehicle Control Systems (AVCS). The course of the entire research work investigates the AVCS features of an Intelligent Transportation System (ITS). Algorithms for sensing the lane in real time, lateral control algorithms to steer the vehicle autonomously to follow the lane and longitudinal control algorithms for accelerating / decelerating the vehicles autonomously, vehicle communication for implementing cooperative vehicle systems and vehicle platooning are developed. These algorithms are simulated and implemented in the prototype autonomous vehicles to test the performance in real time. From the test results it is observed that the proposed algorithms work well in simulation environment as well as in real time environment thus implementing the major features of AVCS in prototype vehicles.

1.1 INTRODUCTION

Autonomous vehicle navigation has been a dream for mankind for a long time. The past decade has seen path breaking developments in the field of automation and it will not be too long before the roads are full of autopiloted vehicles. An autonomous vehicle is fundamentally defined as a passenger vehicle that drives by itself. Most prototypes that have been built so far performed automatic steering that were based on sensing the painted lines in the road or magnetic monorails embedded in the road. Today’s researchers are using sensors and advanced software together with other custom made
hardware in order to assemble autonomous vehicle. Although the prototypes seem to be very successful, a fully autonomous vehicle that is reliable enough to be on the streets has not been commercialized yet. This is mostly because of the difficulties involved in controlling a vehicle in the unpredictable traffic conditions of urban areas. The proposed work focuses on the design and development of auto piloted vehicle and to implement AVCS features. Algorithms for sensing the lane in real time are developed. Lateral control algorithms for making the vehicle to follow the lane and longitudinal control algorithms for maintaining the optimum speed are developed. Vehicle communication is established for implementing intersection collision avoidance which forms cooperative vehicle systems. Vehicle platooning concepts are implemented with four vehicles in platoon. All the developed algorithms are simulated and these algorithms are implemented in the prototype autonomous vehicle and the performance of these algorithms are tested in real time and from the test results it is observed that the proposed algorithms works well in simulation environment as well as in real time environment. Hence these proposed algorithms enable auto-piloted vehicles to take passengers to their destinations without any human driver intervention.

1.2 LITERATURE SURVEY

The idea of automated driving dates back more than 50 years, when GM presented a vision of “driverless” vehicles moved under automated control at the 1939 world’s Fairs in New York. In 1950s, research by industrial organizations conceptualized automated vehicles controlled by mechanical systems and radio controls. After the first appearance of computers in 1960s, researches began to consider potential uses of computers to provide lateral and longitudinal control and traffic management. The fully automated highway concept was initially examined by GM with sponsorship from U.S. Department of Transportation (DOT) during the late 1970s.
Advances in computing technologies, microelectronics, and sensors in the 1980s provoked commercial interest in technologies that enhances driver capability and perception.

The first known worthy attempt to build an autonomous vehicle was in 1977. The project research was carried out by Tsukuba Mechanical Engineering Laboratory in Japan. The car functioned by following white street markers and was able to reach speeds of up to 20 mph on a dedicated test course. DARPA Challenge, during the 1990s, the basic capability for car automation systems was demonstrated in Europe, Japan and the United States respectively by the PROMETHEUS program, AHSRA (Advanced Cruise-Assist Highway System Research Association) and Automated Highway System (AHS) program.

In December, 1991, the Inter-modal Surface Transportation Efficiency Act (ISTEA) enhances partially automated perception. In 1991 ISTEA efforts were focused on prototype development and testing of fully automated vehicles and highways. In 1994 U.S National Automated Highway System Consortium (NAHSC) was comprised of nine major categories. Again in 1994, the NAHSC was created to take over the work of building the first working Automated Highway Systems. High occupancy vehicle lanes are chosen on California for the demonstration, which took place in August of 1997. Another most serious and advanced projects about automatic highways is the project AHS in U.S. A demonstration took place in 1997 in San Diego and a platoon of 8 cars were made to run 10km without any human action guided only by magnetic plots fixed on road. A project by Institute of Transportation Studies –Berkeley and CalTrans (California department of transportation), leading to interesting results, was the Partners for Advanced Transportation Technology (PATH) project which concerns automated buses.
An important milestone in the history of autonomous vehicles was Automated Highway System revolutionary demonstration made in 1997 that included more than 20 fully automated cars. This event stands as gaining the most media coverage of any Intelligent Transportation System activity in US until the 2005. The European projects were completely based on vehicle intelligence, while the Japanese developed systems that were highly vehicle-highway cooperative. The U.S. projects made use of both techniques in their autonomous vehicle systems. The PATH project conducted in California mainly focuses on research issues in traffic operations, transportation safety and modal applications (Lino et al 2001). Japan is aiming to achieve a 15% reduction in motor vehicle accidents. The Japanese Smart way concept is planned for full implementation by 2015 and Korea has targeted 2020 for achievement of vehicle highway automation.

Recently autonomous vehicles such as Google’s self driving cars have been developed and Google announced that the technology is only three to five years away from being road worthy. The Volvo S60 is currently being developed will be commercialized by 2014 will allow drivers to select an autonomous mode that will keep pace with the cars ahead of the driver up to 31mph, follow the bends in the road, and avoid obstacles without any human input. The next generation Audi A8 is poised to have an autonomous mode for high traffic driving in 2016. National Highway Traffic Safety Administration (NHTSA) has begun a study into how best to regulate autonomous cars. Currently only Nevada and California have laws on the books regarding self-driving cars and those are simply allow them for testing purposes. After few years of research NHTSA will announce guidelines for the software and obstacle detection systems that are central to autonomous vehicles.
1.3 NEED FOR CURRENT STUDY

Transportation systems are an indispensable part of human activities. Estimation shows that an average of 40% of the population spends at least one hour on the road each day (Junping et al 2011). People have become more dependent on transportation systems in recent years; transportation systems themselves face not only several opportunities but also several challenges as well. First, congestion has become an increasingly important issue worldwide as the number of vehicles on the road increases. Congestion can lead to an increase in fuel consumption, air pollution, and difficulties in implementing plans for public transportation (Shawe et al 2006). It can also increase the risk of heart attack as indicated by medical report (Peters et al 2004). Second, accident risks increase with the expansion of transportation systems, particularly in several developing countries. According to China’s ministry of Public Safety, 6,67,507 traffic accidents were reported in 2003, resulting in 1,04,372 fatalities, 4,94,174 injured people which resulted in direct economic cost of 3.37 billion US dollars in 2003. In China, traffic accidents cause on average one injury every minute and one death every 5 minutes (Zheng et al 2004). Almost three fourths of all traffic accidents can be attributed to human error (Malta et al 2009). There is a need to reduce traffic accidents and to detect accidents once they have occurred to minimize their impact. Third, land resources are often limited in several countries. It is, thus, difficult to build new infrastructure such as highways and freeways. The competitiveness of a country, its economic strength and productivity heavily depend on the performance of its transportation systems.

Intelligent Transportation System has attracted increasing attention in recent years due to their great potential in meeting this need. There are many areas of ITS that are undergoing rigorous research, such as the reduction in vehicle accidents, realization of automatic driving, relief of
traffic congestion and improvement of environment (Hung et al 2012). The overview of main issues, technological challenges, developments, and achievements of ITSs can be found in (Crainic et al 2009). From the discussion it is seen that ITS will greatly reduce the number of accidents thereby increase the safety of human lives.

1.4 INTELLIGENT TRANSPORTATION SYSTEM

Intelligent Transportation Systems are those utilizing synergetic technologies and systems engineering concepts to develop and improve transportation systems of all kinds. To this end, new technologies and computers have been applied to freeway, traffic and transit systems. ITS applies the cutting edge technology to achieve efficient, reliable, safer and more comfortable highways, inland waterways, airports, ports and linkages among all these means of transport (Figueiredo et al 2001). In technology perspective six major categories of ITS are reviewed, which is shown in Figure 1.1.

![Figure 1.1 Intelligent Transportation System Hierarchies](image)

The six major categories are Advanced Traffic Management System (ATMS), Advanced Traveler Information System (ATIS), Advanced

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Public Transportation System (APTS), Fleet Management and Control System (FMCS), Advanced Rural Transportation System (ARTS) and Advanced Vehicle Control System (AVCS).

ATMS is used to improve traffic service quality and to reduce traffic delays. ATIS is used to supply real-time traffic information to travelers. APTS which make use of electronic technologies to improve the operation and efficiency of high-occupation transports, such as buses and trains. FMCS uses different ITS technologies to increase the safety and efficiency of commercial vehicles and fleets. ARTS is used to solve problem arising in rural zones (steep grades, blind corners, curves, scarce navigational signs, mix of users, lack of alternative routes). AVCS technologies include such areas as smart cruise controls (that can automatically maintain vehicle spacing), collision avoidance systems, vehicle platooning, and other systems that could enhance safety and permit closer spacing of vehicles for increased roadway capacity. Ultimately, in a more futuristic goal, AVCS might enable auto-piloted vehicles to take passengers to their destinations without human driver intervention. The proposed work mainly focuses on the analysis and implementation of AVCS features in prototype vehicles.

1.5 ADVANCED VEHICLE CONTROL SYSTEM

The Advanced Vehicle Control System Committee of the Intelligent Vehicle Highway Society of America has identified research and development activities necessary to improve the performance of the surface transportation system. AVCS represent the application of sensors, computers, and electromechanical actuators to provide drivers with warnings of hazards, assistance in controlling their vehicles, or fully automated control of vehicle motions. The main purposes of these systems are to increase safety, to decrease congestions on roads and highways, and to improve road systems
productivity. AVCS also includes advanced cruise control, automated steering control for lane keeping and autonomous behaviour, including automated stopping and lane changes in reaction to other vehicles.

1.5.1 AVCS Evolution

The Mobility 2000 working group on AVCS has divided AVCS into three evolutionary stages. The first stage of AVCS systems (AVCS I) are the driver assistance systems, which do not necessarily take control of the vehicle away from the driver. In the second stage of AVCS evolution (AVCS II), control of the vehicle can be transferred by the driver to the automatic system on certain special limited access facilities such as High Occupancy Vehicle (HOV) lanes. The third stage of AVCS evolution (AVCS III) extends control of the vehicle operations to the interstate and urban freeway network, using lanes that are continued to be used by conventional, manually controlled vehicles.

1.5.2 Benefits of AVCS

AVCS is the only Intelligent Vehicle Highway Systems function that has the potential to make quantum leaps in the productivity, capacity, speed and safety of road transportation. Current estimates indicate that the ATMS and Advanced Driver Information Systems functions can produce improvements of no more than 10% to 20% in recurrent congestion and a little more than that in non-recurrent congestion (Steven 1993). The AVCS technologies have the potential to increase the capacity of a bridge or freeway by several hundred percent. By taking the driving function over from the driver, these technologies can also eliminate the driver error caused accidents.
1.5.3 AVCS Space Utilization Advantage

A typical automobile, when parked in a garage, occupies about 100 square feet of space. Adding overhead in the form of areas to open the doors and walk around the car brings the total to perhaps 175 square feet. Yet this same automobile, when operated on the highway at 70 miles per hour requires over 5000 square feet of space. Each traveller, from the time he gets on the highway until he gets off requires an average highway space exceeding one-eighth of an acre that "dynamically" moves with him as he travels in order to operate at 70 mph. As the density of vehicles increases, traffic tends to slow down until eventually bumper-to-bumper conditions are reached. Traffic engineers consider that one lane of an optimum highway can carry a maximum of about 2000 cars per hour at 25 – 35mph. Capacity varies with speed from about 750 cars per hour at 5 mph to about 1000 cars per hour at 70 mph. One major factor for such large space requirement is driver reaction time. Human drivers have reaction time between 0.25–2.0s, which necessitates an inter-vehicle spacing of around 30m or more at 60mph. Average reaction time for human drivers is probably on the order of two seconds. An automated system could have dramatically reduced reaction time and headway.

Another factor is the precision of human drivers. While cars are about 6 feet wide, highway lanes are 12 feet wide. An automated system could be more precise and therefore require less lateral space. An automated system could have much faster reaction time and also other characteristics which would dramatically reduce space requirements. In addition to the space advantage it is reasonable to believe that automated guidance systems could safely operate at top speeds substantially higher than the 70 mph.
1.5.4 AVCS Safety Advantage

Automobile accidents are now the leading cause of death in certain segments of the population. In 2010, road crashes killed at least 1.3 million people worldwide and injured 50 million (Fred 2012). To the extent that we could replace safety related driver functions with technology, an automated system could eventually be very substantially safer than the existing system in that we could bring technology to bear directly on a problem that is now virtually completely driver controlled. Vehicle automation could therefore easily be the greatest public health advance of the twenty-first century.

The central theme of AVCS is to improve the throughput and safety of highway traffic by using automatic control with its precision and fast reaction to replace human drivers. Driving in traffic jam conditions is one of the most challenging topics of large city traffic management. The data on Madrid (Spain) indicate that its almost one million workers every day waste more than 30 minutes at rush hours because of traffic jams. The estimated annual cost is more than 800 million euro. This problem is being tackled by both the automotive industry and transport research groups with the goal of reducing these figures. With respect to the automotive sector, particular effort has been put into developing automatic vehicle speed control. The main aim of these controllers is to improve the safety of the car’s occupants by relieving the human driver of tedious tasks so as to make driving easier, as well as making traffic flow more efficient (Milanes et al 2012). The efficient solution to all these problems is to turn towards the AVCS.
1.6 OBJECTIVES OF THE THESIS

The course of the entire research work investigates the AVCS features of an ITS. There are five major objectives in this proposed work. The first is to model a prototype autonomous vehicle and to simulate the performance of the model. Design a prototype autonomous vehicle and its hardware modules to test the performance of the developed algorithms in real time. The second is to design a vision system module to track the lane in front of the autonomous vehicle and make the vision independent of light intensity variations and other uncertainties. The third is the development of lane detection algorithms, position estimation algorithms and lateral control algorithms and to test the performance of the developed algorithms by simulation analysis. The fourth objective is to develop longitudinal control algorithms which include vehicle communication and vehicle platooning. The performance of the developed algorithms is to be tested by simulation analysis. The fifth objective is to integrate the lane detection algorithms, position estimation algorithms, lateral control algorithms and longitudinal control algorithms and to evaluate the performance of each algorithm in the developed prototype vehicle in real time. The prototype automated vehicle with proposed algorithms is allowed to travel in the test bed track, to analyze the results in real time, which should prove the better performance of the proposed algorithms in proposed vehicles. Finally to prove the track sensing algorithms, lateral control algorithms and longitudinal control algorithms works together in real time environment and makes the auto piloted vehicle to complete the test bed track in short duration of time. These algorithms need to be implemented in multiple prototype vehicles and to show the best performance of the proposed algorithms in multiple vehicles too which should prove the proposed algorithms are vehicle independent. All these objectives fulfill the analysis, simulation and implementation of major features of the AVCS.
1.7 ORGANISATION OF THE THESIS

The thesis consists of totally seven chapters discussing AVCS features in ITS environment. Proposed small scale autonomous vehicles, its specifications and vehicle modeling are discussed in chapter 2. Proposed sensing strategies and performance analysis in chapter 3, proposed lateral control algorithms and simulation analysis in chapter 4, proposed longitudinal control algorithms and its performance analysis, vehicle communication techniques, vehicle platooning techniques in chapter 5, performance analysis of all the proposed algorithms in small scale vehicles in real time environment is discussed in chapter 6 and finally conclusions and future scope of the work is being discussed in chapter 7.

Chapter 1 introduces the history about automated vehicles, need for current study, ITS, AVCS, AVCS evaluation, benefits of AVCS, AVCS space utilization advantage, AVCS safety advantage, objective of the thesis and organization of the thesis.

Chapter 2 discusses about the small scale electric vehicle prototypes used for real time implementation of proposed algorithms. Vehicle prototype consists of vision system, vehicle steer module, vehicle drive module, microcontroller module and battery module. The block diagram and the specifications of the all the modules of the prototype vehicles are discussed. Two test bed tracks are used for performance analysis of the prototype vehicles. The nature of the test bed track and its specifications are discussed. Vision system consists of IR based sensing and Linear Sensor Array based sensing. The circuit schematics of IR sensor array based sensing mechanism and linear sensor array based sensing mechanism and its interfacing techniques are discussed. Obstacle sensor and wireless sensor module and its interfacing methods are discussed. Servomotor specifications and interfacing, DC motor specifications and its interfacing circuit with its
drive mechanism are discussed. Encoder module interfacing and current feedback module interfacing for speed measurements are discussed. DC motor and servo motor modeling and overall vehicle system model is discussed at the end of this chapter.

Chapter 3 discusses about the various sensing strategies. Road modeling, road marking extraction, post processing, position tracking and vehicle modeling are being analyzed. Objectives in road sensing, environmental variations and sensing modalities and the common assumptions about the road surface are being discussed. IR based sensing algorithms and linear sensor array based sensing algorithms which includes camera calibration, threshold setting and removing slanting ray uncertainties are discussed. The test results of the sensing strategies are discussed at the end of this chapter.

Chapter 4 discusses lateral control organization of the vehicle. The work progress in lateral control of an autonomous vehicle is being surveyed. Proposed lateral control algorithms used in prototype vehicle-1 and its simulation results are analyzed. The control algorithms used in prototype vehicles which include Kalman filter is discussed and the performance of the Kalman filter in lateral control is simulated for various test cases. Finally the consolidated performance of the proposed two layer control architecture for the lateral control of the vehicle is discussed. The method of lane detection, position identification and anomaly detection of the proposed algorithms are analyzed. Finally the minimum and maximum iterations required to change and settle by the proposed algorithm is analyzed. The control algorithm to control the steer of the vehicle is discussed at the end of the chapter.

Chapter 5 discusses the longitudinal control of the vehicle. The work progress in longitudinal control of the autonomous vehicle is being surveyed, which includes the survey of vehicle communication projects
worldwide. Five methods of vehicle longitudinal control systems with respect to vehicle communication are discussed. Survey of vehicle platooning is being done. The proposed longitudinal control which includes adaptive speed control algorithm, adaptive acceleration control algorithm and obstacle detection and collision avoidance algorithm are discussed. Adaptive speed control algorithm using encoders for prototype vehicle-1 is discussed and simulated. Adaptive speed control algorithm using current feedback for prototype vehicle-2 is discussed along with speed boost performance. Steer error based speed control, adaptive acceleration control algorithm, are discussed. Vehicle communication and vehicle platooning techniques implemented in the vehicles which are discussed at the end of the chapter.

Chapter 6 discusses the overall vehicle system structure and the block diagram of the proposed vehicle model. Simulation results and inference of various algorithms are plotted and tabulated. The performance of the proposed lateral control algorithms in prototype vehicle-1 and in prototype vehicle-2 are analyzed and the compared with the tracking accuracy of various algorithms. Proposed lateral control algorithms is compared with Ismail’s method, Gengyun’s method, Oscar’s method, Julio E. Normey’s method and Jose E. Naranjo’s method and comparison result shows the better performance of the proposed algorithms.

Performance analysis of the proposed longitudinal control algorithms in prototype vehicles-1 and 2 are analyzed. The speed accuracy and tracking accuracy of the three algorithms in prototype-1 is analyzed and plotted. The overall performance of the proposed sensing algorithms, lateral control algorithms and longitudinal control algorithms are tested in real time in multiple vehicles and its tracking accuracy and speed accuracy is tabulated. Concluding remarks and scope for future extension of the proposed work are discussed in Chapter 7.