THE AUTOMATED HIGHWAY SYSTEM - DRIVERLESS TECHNOLOGY

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Abstract: An automated highway system (AHS) or Smart Road is a proposed intelligent transportation system technology designed to provide for driverless cars on specific rights-of-way. It is most often touted as a means of traffic relief, as it would drastically reduce following distances and headway, thus allowing more cars to occupy a given stretch of road. It is a vehicle and road based system that can drive vehicle automatically. This is done using sensors that serve as the vehicle's eyes, determining lane position and the speed and location of other vehicles. The concept of an Automated Highway has been around for a long time. But it has not been until recently that the technology has become available to build automated highways and vehicles. The AHS program is a broad international effort "to provide the basis for, and transition to, the next major performance upgrade of the vehicle/highway system through the use of automated vehicle control technology". The first vehicle in market with adaptive cruise control was introduced in 1997.

Keywords: *intelligent transportation system, smart highways, automated vehicles, driverless technology, platoon, hybrid systems, features, applications.*

1. INTRODUCTION

1.1. General Analysis

WORKING

In one scheme, the roadway has magnetized stainless-steel spikes, driven one meter apart from its center. The car senses the spikes to measure its speed and locate the center of the lane. Furthermore, the spikes can have either magnetic north or magnetic south facing up. The roadway thus provides small amounts of digital data describing interchanges, recommended speeds, etc.

The cars have power steering and automatic speed controls, which are controlled by a computer.

The cars organize themselves into platoons of eight to twenty-five cars. The platoons drive themselves a meter apart, so that air resistance is minimized. The distance between platoons is the conventional braking distance. If anything goes wrong, the maximum number of harmed cars should be one platoon.

1.2 Technology behind AHS

The automated highway system is defined as "a lane or set of lanes where specially equipped cars, trucks and buses could travel together under computer control." It is one aspect of intelligent transportation systems (ITS), which apply electronics, computers and control technology mainly developed for aviation, space program and defense to the improvement of highways, vehicles and public transportation.

Automated highway systems combine magnetic sensors, computers, digital radio, forward-looking sensors, video cameras, and display technologies. Various combinations of these technologies are being applied in different pilot tests.

Magnetic sensors: Magnetic sensors could be imbedded along the highway lanes. Magnetometers under the car's bumpers would sense the magnets and automatically keep the cars in the center of the lane.

Networked Computers: The system would not rely on a central computer to direct the movement of all vehicles. Rather, networks of small computers would be installed in vehicles and along the sides of roadways to coordinate the flow of traffic.

Digital radio: Digital radio equipment in each car would allow the computer on board to communicate with other vehicles in the vicinity and with supervisory computers monitoring the roadway.

Forward looking sensors: Using radar or an infrared laser, these sensors would detect dangerous obstacles and other vehicles ahead.

Video cameras: Linked to computers that process images rapidly, video cameras could detect dangerous obstacles and other vehicles ahead. They could also be used along with or instead of magnets to track lane boundaries.

Visual Displays: Mounted on the dashboard or projected onto the windshield, it would give the driver information about the operation of the vehicle.

A large-scale demonstration of such ICTs was held in Japan in 1996. A similar project run by the European Commission involves commercial vehicles. In the United States, several pilot tests of automated highway systems are underway, including a large scale Congressionally-mandated demonstration run by the National Automated Highway System Consortium in August 1997. This four-day demonstration, held in San Diego, involved the installation of digital communications equipment at the roadside and magnets down the center of both lanes. Other demonstration projects are in various phases throughout the country, including a $12 million Federal Highway Commission test in Nevada and a $17.3 million project in Virginia. In addition, over a dozen U.S. research universities gave major intelligent-vehicle research programs.

1.3 Policy behind AHS

The Intermodal Surface Transportation Efficiency Act (ISTEA) passed by Congress in 1991 has been a driving force behind the recent developments in automated highway systems. ISTEA aims to improve the safety and efficiency of the existing transportation system. Marked by an unprecedented cooperation between the public and private sectors, the act launched an initiative to research, develop, test, and evaluate advanced electronic systems. The act had invested almost $5 billion of public money in transportation research and development in the past 20 years. Features of ISTEA include a comprehensive program of basic and applied research on enabling technologies, over 70 operational tests of technologies and services, a long-term prototype development effort for an automated highway system, deployment planning studies in over 75 metropolitan areas, and eleven model deployment projects.

1.4 Evolution of AHS

Evolution of the AHS system will continue with lane departure warning. It will be the first system to control lateral movement of vehicles. The lane holding feature will consequently be added to the adaptive cruise control, shortly after the lane departure warning feature. Interesting thing is; automatic lane holding will provide a "hands off/feet off" driving situation where the driver is still responsible for all command decisions in the vehicle and must be aware at all times of his surroundings. If the infrastructure knows the location of each vehicle, possesses the information about its current path, and is communicating with the vehicle, then the lateral control can be coordinated from the infrastructure. Further advances in technology will force the driver to “lose” his control of the vehicle. In order to gain any additional benefit of safety and efficiency, the driver must be removed as the primary source of command and control. Of course, this change requires that the automated system perform better than a good driver. This step will be the natural consequence of the previous progress. Obviously, not all vehicles will be equipped with this technology right away. Automated and manually driven vehicles have to coexist for some time.

A vehicle that can “predict” the actions of neighboring vehicles is an important step for safer highway transportation. Locating the position of all the vehicles in close proximity to the automated vehicle with high accuracy is essential. This can be accomplished through multi-sensor systems for adjacent vehicles and possibly inter-vehicle communications to give an idea of what to expect beyond adjacent vehicles. Alternatively, the “roadside control” may have knowledge of the positions of the vehicles relative to fixed reference points. This knowledge is obtained by either vehicle based or roadside based detection, and/or by communicating with the vehicle. This technology requires extreme accuracy in vehicle location at all times. If the system is infrastructure-based, the infrastructure needs to know the locations of the non-automated vehicles, for safe and efficient implementation. The minimum update rate of information must be larger than 100 times per second with accuracy less than 10 cm for the desired level of safety. Automated vehicle control (AVC) systems are expected to boost the capacity by 50% even for mixed vehicle traffic. Once the system has knowledge of the surrounding environment to all extents, it can make decisions on merging and passing in addition to the headway control and lane keeping performed under driver control. Full system optimization and higher efficiencies can then be obtained as the percentage of automated vehicles on the road increases.

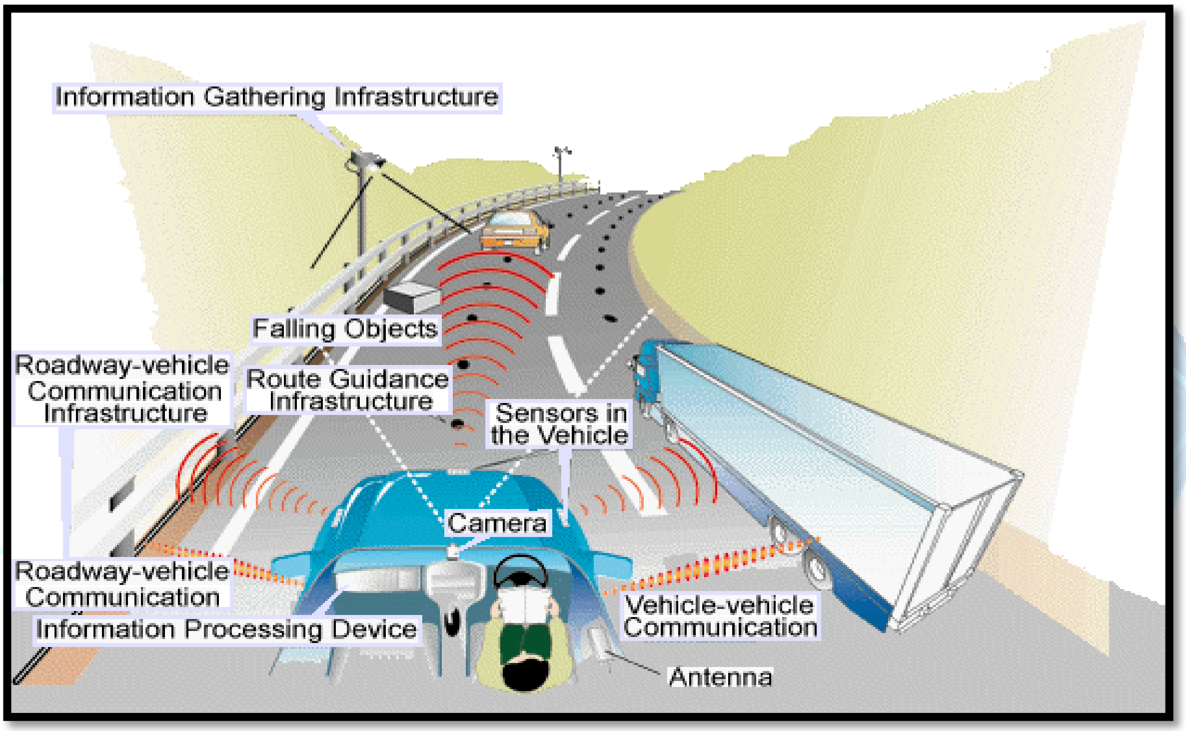

Figure 1: Automated highway system with AHS vehicle

1.5 Goals of AHS

1. Enhancement of surface transportation efficiency.
2. Achievement of national transportation safety goals.
3. Protection and enhancement of the natural environment and communities affected by surface transportation.
4. Accommodation of the needs of all users of surface transportation systems.
5. Improvement of the Nation’s ability to respond to emergencies and natural disasters.

AHS is designed to cover the following characteristics:-

1. **Affordability:** The AHS must be affordable and cost-effective to users and operators.

2. **User Desirability:** The AHS must be practical, desirable, and user-friendly.

3. **Consistency with Surrounding Non-AHS Roadways:** AHS operation must integrate with adjacent connecting non-automated traffic operations, and be consistent with the continued efficient operation of those roadways.

4. **Dual-Mode Vehicle Instrumentation:** Only vehicles instrumented for and operating under full automated control will operate on AHS roadways. AHS-instrumented vehicles will be able to operate on regular (non-instrumented) roadways, and use some of the AHS instrumentation for safer operation including collision avoidance. A design goal is that it be possible to retrofit future vehicle models with AHS instrumentation.

5. **Reliable, Modular System Technology:** The AHS must be highly reliable and modular to accommodate continuing advances in technology.

6. **Evolvability:** The AHS will not be a standalone system; it will evolve from and integrate with today's vehicle-highway system, and other transportation services; the driver's role will evolve as AHS evolves.

7. **Support for Various Vehicle Types:** The AHS will support all normal vehicle types, including cars, buses, and trucks, although not necessarily intermixed.

8. **Freeway Type of Roadway:** In general, an AHS roadway is expected to have freeway characteristics.

9. **Intermodality:** AHS must reflect the intermodal nature of our surface transportation system; consideration must be given to ensure convenient transfer between modes such as private vehicles and public transportation.

1.6 Vision of AHS

An efficient surface transportation system is essential for people. Vitality of the Nation's commercial growth, international competitiveness, national security, quality of life, social fabric, lifestyle, and even its world status all depend on transportation mobility; that is, easy access to reliable, and dependable, affordable, extensive transportation. There is a strong demand for quality ground transportation in world. Vehicle highway transportation, the core of which is the Interstate Highway System, is a major element of today's world transportation system.

Even if there is major growth in heavy rail traffic, the automated highway system is expected to play a major role in meeting the Nation's surface transportation demand in the 21st century.

1.7 Today's Problems in Vehicle-Highway System

The vehicle-highway system must continue to be improved for the foreseeable future.

The system must be able to address a number of problem areas; many of today's transportation problems will continue to grow with the increasing demand unless steps are taken to resolve them. Here are some of the vital problems that highway users face:-

Safety - Although traffic fatalities continue to decrease, there are still approximately 40,000 lives lost annually on any country's roads and highways, and there are over 17,00,000 serious disabling injuries. The annual cost to the Nation in dollars is estimated at over $137 billion.

Congestion - Traffic volume has increased between 38-54 percent for each of the last three decades. Since capacity has not kept pace, 70 percent of all urban interstate peak-hour traffic is congested, and this figure is predicted to grow to 80 percent by the upcoming years. It is projected that congestion will worsen by 300 to 400 percent over the next 15 years unless significant changes are made. Today, congestion costs the Nation an estimated $100 billion in lost productivity annually. It also increases driver frustration and discomfort as congestion worsens and travel times become less predictable. Moreover, shipping costs rise as delivery times become less reliable.

Air Quality - As population mounts, traffic volume and congestion will worsen, and clean air requirements will become more stringent. The key emissions produced by individual vehicles have decreased between 70 percent (oxides of nitrogen) and 100 percent (lead) since 1990. Nevertheless, the vehicle-highway system is still one of the largest contributors to air pollution in urban areas, as a result of increases in VMT, vehicles idling in congestion, and the driving habits of the vehicle operators. The Nation's concern is reflected in the Clean Air Act (CAA) and amendments, which have established emission guidelines that must be considered in transportation planning.

Trip Quality - Trip quality for many Indian drivers and passengers continues to erode. The reasons for this erosion include safety concerns, driver frustration and discomfort as congestion increases, and lack of predictable trip times. Also, some drivers, including the elderly, are intimidated or frightened by freeway travel.

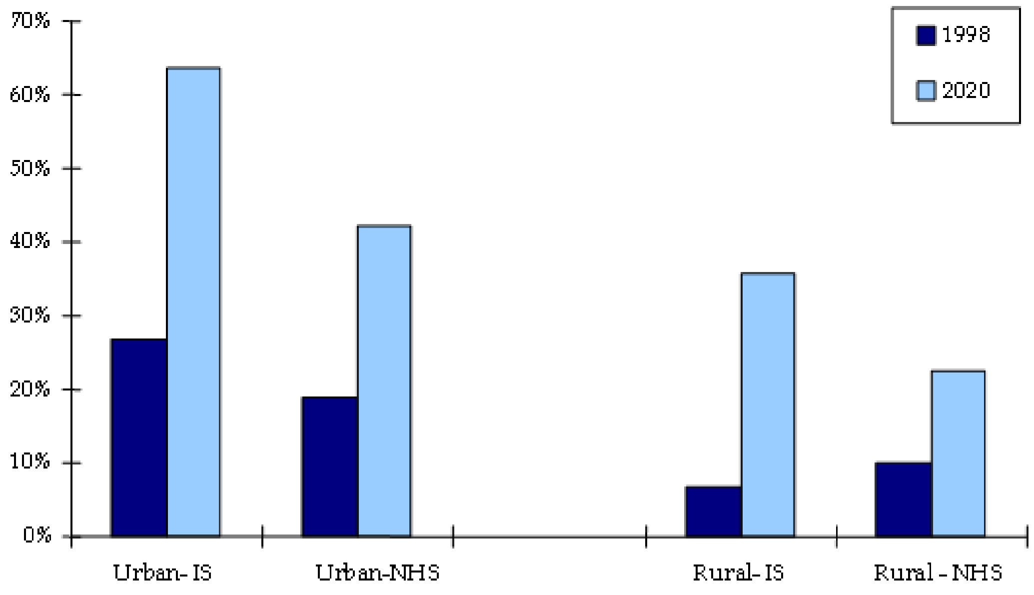

Figure 2: Traffic congestion forecast

2.0 VEHICLE CONTROL

Vehicle control is probably the most important part of the advanced AHS applications. Implementation of AHS necessitates automatically controlled vehicles as mentioned previously. Achieving the optimal solution to congestion and safety problems requires extensive research in system modeling, lateral (steering) controls and longitudinal (speed and headway) controls. In a fully automated highway system, these control systems will rely on vehicle-to-vehicle communication, as information on velocity and acceleration of other vehicles will be utilized in individual vehicle controllers. The same information and much more (*e.g.*, desired speed and lane) may also be received via vehicle-to-roadside communications. Here, we will briefly discuss the research on lateral, longitudinal and combined lateral and longitudinal control of vehicles.

2.1 Lateral Control

Hessburg and Tomizuka designed a fuzzy rule-based controller for lateral guidance of a vehicle. This system is based on human-type reasoning. Advantages of such a controller include flexibility in the choices of input/outputs, and on-line/off-line training capability. Their focus was achieving good tracking for a variety of roadway curves over a range of longitudinal vehicle speeds. Simulations to demonstrate its performance under parameter variations and external disturbances gave satisfactory results.

It concentrates the intelligence in the vehicle, using the visual sensing approach described. In this model, no infrastructure modification is needed, but considerable cost and complexity is added to each individual vehicle. With the current rate of technology improvement, this system may become feasible for production purposes. During the last five years, the research on lateral vehicle control and lane changing maneuvers was extensive.

Besides the theoretical modeling for lateral control of vehicles, there are a few important experimental accomplishments: the use of magnetic markers, and the use of visual information for lateral position handling. The first method was designed by the PATH Program and employs magnetic markers imbedded into the road to detect the lateral displacement from the center of the lane. Current tests with a vehicle equipped with magnetic sensors on its front bumper are reported to be successful. The second application for lateral control uses visual data and on-board computing resources to obtain the steering command, and is designed by another NASHC participant. In order to locate the road ahead, the “rapidly adapting lateral position handler” (RALPH) uses a template-based matching technique to find parallel image features such as lane markings or tire and oil markings. During the experiment called “No Hands across America,” the test bed vehicle equipped with the RALPH system drove 98% of the 2850 mile journey autonomously. An average speed of 63mph in conditions that included bright sunlight, dusk, rain and nighttime, and a maximum stretch of 69- miles autonomous driving are reported. A third application for lateral control consists of a vision-based system with neural network learning from a driver. Performance levels comparable to the human driver were reported well.

2.2 Longitudinal Control

Longitudinal control is an important aspect of the future AHS. One of the major concepts in this area is platooning, which is a formation of traveling vehicles that maintain close spacing at highway speeds. The concept requires inter-vehicle communication links to provide velocity and possibly acceleration information from the lead vehicle to each of the following vehicles, as well as the velocity and acceleration of the preceding vehicle in the platoon. Sheikholeslam and Desoer showed that inter-vehicle communications increases the stability of the platoon formation in the case of identical vehicle platoons.

In the case of a platoon of non-identical vehicles, the situation is more complex. Frank, Liu, and Liang explicitly considered the case of non-identical vehicles. The control scheme presented combines three nested control loops for speed regulation, spacing control, and speed synchronization. They also concluded that:

(a) The platoon size must be limited to approximately 15 vehicles.

(b) Nonlinearities significantly affect the response characteristic of the platoon.

(c) Emergency situations need further investigation before proper sensor specifications can be set.

It has also been shown that communicating the lead vehicle’s information to other vehicles is not a requirement if we can tolerate degradation in the performance. This degradation is said to be not catastrophic. Recent research on longitudinal control includes vehicle follower control design for heavy-duty vehicles, adaptive control of a nonlinear platoon model, automatic braking systems and their effects on capacity, advanced control techniques, and adaptive traction control.

Experimental results of longitudinal vehicle control include a platoon of four vehicles traveling at 55mph with a headway distances under 50 cm. Again, lead vehicle’s information is transmitted to following vehicles in order to achieve string stability.

2.3 Combined Lateral and Longitudinal Control

Although much of the research up to date has focused primarily on either lateral or longitudinal control, an overall automated driving system combining both lateral and longitudinal control is vital for future automated highway systems.

System models which incorporate longitudinal and lateral dynamics are very rare. Kachroo and Tomizuka studied combined longitudinal and lateral control to investigate the resulting behavior of the coupled system. It is shown that longitudinal controllers that directly control the wheel slip are inherently more stable, especially during lateral maneuvers on very slippery road conditions. Spooner and Passino also developed sliding mode controllers for longitudinal and lateral control. Their fault tolerant algorithms were found to be stable for a variety of faults such as braking, power train, and steering systems. Sideris considered combined control using partial state-measurements of longitudinal and lateral deviations, longitudinal velocity and yaw rate. The research on combined control of vehicles is moving toward more realistic systems. New control approaches for more platoon operations in more complex situations such as entry and exit maneuvers are being studied.

The PATH program investigates the use of machine vision for guiding lane change maneuvers. The vision system is modularly interfaced with the existing magnetic sensor system for lateral position measurements, and with active range sensors. Ozguner also described a vehicle-roadway system in which the control of vehicle movement is based on instrumentation located both in the vehicle and the roadway. A radar based system is used for both cruise control, and for providing position information in lateral maneuvers.

Combined lateral and longitudinal control experiments are yet to be designed and implemented.

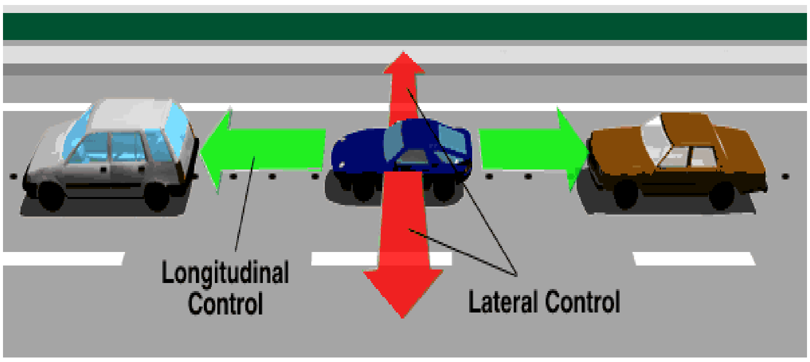

Figure 3: Vehicle control

CONCLUSIONS

1. Without the advantage of increased efficiency through platooning, the only advantage of using automation in mixed traffic is improved safety.
2. Although safety is an important improvement, it may not be enough to justify investment.
3. The cost/benefit ratio may be too low for government and consumers to make an investment, especially since the value of added safety is difficult to measure.
4. However, mixed traffic intelligent vehicles may be an important first step in the use of AHS that will lead to the building of more and more dedicated lanes.
5. Vehicles should be able to run in either scenario, but perhaps would have some functions limited while driving in mixed traffic.

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