A REVIEW OF VEHICLE COLLISION AVOIDANCE SYSTEMS

A. Nmngani[1] and M. Akyurt[2]

1: P.O. Box 13925, SCECO(West), Jeddah 21414
2: Mechanical Eng. Dept., King Abdulaziz Univ., P.O. Box 80204, Jeddah 21589

E-mail: namngani@yahoo.com, Akyurt99@yahoo.com

ABSTRACT

In view of the increasing number of traffic accidents in recent years, it is conceded that traffic accidents have assumed the dimensions of a serious social problem. It is indicated that there are three main elements involved in an accident, i.e., the driver, the vehicle and the environment. It is reported that the main cause of accidents has been identified as the driver.

Given the complexity of the issue, it is concluded that, not much can be done to improve the drivers= skills and/or their levels of attentiveness, or to appreciably reduce the levels of stress experienced by drivers. It is considered plausible, however, to provide assistance to the driver in the form of non-human supplemental means, and to complement the driver=s natural capabilities regarding attention capabilities and reflexive response times.

It is reported that many different sensors and systems, from sonar to machine vision, have been installed on ground vehicles and automobiles in experiments that have been conducted for over 40 years. A review of the more promising of these sensors and related devices is presented. A brief summary is also provided of a number of attempts to develop autonomous vehicles, i.e., vehicles that can navigate in traffic without intervention by drivers.

Keywords: *accident, driver, sensor, traffic, vehicle*

الملخص

بالنظر إلى العدد المتزايد لحوادث المرور خلال السنوات الأخيرة، يمكن التسليم بأن هذه الحوادث افترضت أبعاد مشكلة اجتماعية بصورة جدية. وقد تبين بأن هناك ثلاثة عناصر رئيسة تشترك في أي حادثة، وهي: السائق، العربة والبيئـة. وتبين أيضا أن السبب الرئيس من بين هذه الاسباب هو السائق.

بتناول جميع أبعاد وتعقيدات هذه المشكلة، أستنتج أنه لا يمكن تحسين مهارات سائق المركبة إلى حد كبير، و/أو مستواه الوعيي، بالإضافة إلى عدم الاستطاعة في تخفيض مستوى الإجهاد أو الضغط الواقع عليه. بينما وجد في المقابل أنه من الممكن تزويد السائق بنوع من العون أو المساعدة خارجة عن التدخل البشري، وكذلك دعم قدرات السائق فيمـا يتعلـق بمقدرته على الانتباه، وسرعة الاستجابة ورد الفعل.

أظهرت التقارير بأنه قد تم تركيب بعض المحسات (sensors) والأنظمة (systems)، كـأجهزة الموجـات الصـوتية (السونار)، أو أجهزة الإبصار الإليكتروني في بعض السيارات والمركبات لإجراء تجارب وذلك علـى مـدى أربعـين عاما. وقد تم هنا استعراض أهم هذه الأنظمة والأجهزة، كما تم دراسة ما هو واعد منها. وتم عـرض مختصـر عـن المحاولات التي تمت لإنتاج نوع من المركبات المستقلة (المركبات التي تستطيع أو تمتلك المقدرة على القيـادة داخـل الحركة المرورية دون تدخل من السائق).

1. INTRODUCTION

The increasing number of traffic accidents in recent years has assumed the dimensions of a serious social problem, making it imperative to find effective ways of reducing traffic accidents and fatalities. As an initial step in this direction, it is important to identify the elements of the problem through analysis of its mechanism.

Traffic accidents involve different processes according to where the accident occurs and in what situation the collision occurs. Of the three main elements involved in an accident, i.e., the driver, the vehicle and the environment, the main cause of accidents has been identified as the driver [Kuge et al., 1995]. Statistics on accidents seem to demonstrate further that the responsibility of the driver for accidents increases with his age [Ulmer, 1994]. Analysis of the behavior of the driver for each accident pattern is therefore deemed essential.

Recognizing the surrounding environment, the driver of a vehicle ordinarily selects the most rational, effective and reckless driving operation to complete the maneuver in process. This may, at times, involve the choice of a particular route [Hamed and Al-Rousan, 1998; Katamine and Hamarneh, 1998; Robinson, 1998]. Human errors can occur at any stage during this period of information processing. This is especially true if there is a difference between the driver=s subjective judgment of a situation of danger and the actual situation [Hughes, 1999]. An error of judgment may cause the driver to operate the vehicle in an inappropriate way, resulting in a collision. It is therefore important to clarify the characteristics of driver behavior in order to analyze the causes of accidents [Katamine and Hamarneh, 1998].

A common mode of accident occurs when two vehicles are traveling in the same direction, one going behind the other. A rear-end collision is said to take place when the second vehicle rams into the rear end of the vehicle in front of it. It is reported [Kuge et al., 1995] that rear-end collisions typically account for about 25% of all traffic accidents.

One of the most frequent causes of rear-end accidents is the failure of a vehicle to maintain an assured safe distance behind another vehicle to prevent a rear end collision, should the front vehicle suddenly stop or slow down. The assured safe distance required to prevent such a rear-end collision depends on the reaction time of the vehicle driver before the brake pedal is actually depressed, and the braking distance traversed by the vehicle before it comes to a complete stop after the brake pedal has been depressed [Davidian, 1994]. Both of these factors vary according to the driver-vehicle-environment conditions at the time of driving.

In order to prevent collisions, many parameters which are constantly changing during the year or even during a trip, and which may affect the stopping distance of the vehicle, should therefore be taken into account. These parameters include the condition of the driver, such as the driver's reaction time; the condition of the vehicle, such as the vehicle load, the condition of the brake system and the tires as well as the pressure of tires; and environmental conditions, such as road type [Prem et al., 1999], visibility, and skidding conditions [Akcelik et al., 1999 and 1999a; Polus et al., 1998]. A very serious type of accident frequently takes place, especially in hot climates, when the vehicle develops a flat tire at high speed.

Universally established traffic regulations stipulate [Chi, 1992; Shyu, 1992] that, at a speed of 60 km/hr, a car must maintain a distance of six car lengths from the front car, and at a speed of 90 km/hr, a distance of nine car lengths. Admittedly it is difficult for the driver to judge how many car lengths there are between his own car and the car in front. If the distance between the two cars is too short, then when the front car brakes abruptly, the car behind may not be able to stop in time, causing a rear-end accident. Also if the distance between the two cars is too great, then the car following the second car will keep on pressing the horn or flashing the headlights to urge the front car to move faster [Chi, 1992]. Also other cars can intrude at random, thus endangering the safety distance.

Many modern cars are equipped with a third brake light at the rear window to boost the warning signal to the car behind. Some experienced drivers, whenever they sense an approaching danger, also apply the method of slightly depressing the brake pedal to light up the brake lights [Shyu, 1992], turn the head lights on, turn on the flashers, and/or blow the horn, all for the pre-warning of other cars in the vicinity, and especially the rear car.

Because of health conditions, psychological factors, or lack of concentration, drivers often fail to stop in time, causing accidents. Nowadays there are so many cars in cities that there are frequent traffic jams. During a jam, cars move slowly and have to frequently and alternately stop and move, and the drivers have to keep on stepping on the accelerator, changing shifts, or applying the brakes; all this is not only time-consuming but also exhausting. Air pollution may also result (because the speed of acceleration is not easily controlled, combustion of gasoline may not be complete). A collision may easily happen if the drivers are careless. Although many cars are equipped with automatic shifting systems, drivers still have to constantly step on the accelerator and/or the brakes, while concentrating their attention on maintaining a safe driving distance. To the busy and nervous people of our times, this is really very exhausting. On many occasions, the hot climate also plays a role in raising the stress level of the driver.

Given the complexity of the issue, it seems unlikely that much can be done to improve the drivers = skills and/or their levels of attentiveness, or to appreciably reduce the levels of stress experienced by drivers [David, 1989; Theeuwes and Riemersma, 1995]. It is considered plausible, however, to provide assistance to the driver in the form of non-human supplemental means, and to complement the driver=s natural capabilities regarding attention capabilities and reflexive response times. It is believed in this regard, that certain driving and traffic conditions can be better judged and assessed by automatic systems than by the average driver. Also, such systems may be able to react and take appropriate action quicker than the average driver. Furthermore, it may be appropriate to notify other drivers in the vicinity, and perhaps even the police, when it is determined that a nearby vehicle has become a traffic menace. Preventive measures can then be taken by other parties [Chung and Rosalion, 1999].

Very little work has been reported on the ability of humans to perceive and scale the relative motion between vehicles, and to take appropriate control actions in order to avoid a collision. The most direct measure of a drivers' estimate of the risk of a rear-end accident is the perceived time-to-collision *TTC*. This is the time it would take a following vehicle to collide with a leading vehicle if the current relative velocity *Vr* were maintained from the given headway *H*, expressed as [Hoffmann et al., 1994]

$$TCC = H / Vr = \Theta / (d\Theta / dt)$$

where Θ is the visual angle subtended by the lead vehicle at the eye of the driver of the following vehicle, and $d\Theta /dt$ is the rate of change of the subtended visual angle.

It was found [Hoffmann et al., 1994] that the accuracy of estimation of time to collision is dependent on three independent variables, i.e., viewing time, relative velocity, and headway between the vehicles. At low values of *TTC*, which corresponds to the region critical to the occurrence of rear-end crashes, drivers, on average, underestimate the time to collision.

A number of researchers proposed models for predicting vehicle-time head ways [Hamed and Jaber, 1997; Fukuhara, 1994]. Being one of the earlier workers in this field, Fukuhara [1994] presented a relationship for computing a safety distance Rs (in meters) which is calculated as

$$Rs = \frac{Vr\,(2\,Va \bullet Vr)}{2a} + Va\,Td + K$$

where *Vr* (in meters per seconds) is the relative speed of the vehicle (reference vehicle) with respect to the vehicle in front of it, *Va* (in meters per seconds) is the speed of the reference vehicle, *Td* (in seconds) is the driver's response time, *K* (in meters) is the distance between the reference vehicle and the vehicle in front of it when the application of braking to the reference vehicle is completed, and a is the deceleration (m/s^2). This equation represents the condition where the reference vehicle can come to a safe stop with a safety distance *K* spaced away from the vehicle in front when both of the vehicles are decelerated at the same rate a. Figure 1 is a graph of safety distance *Rs* versus vehicle speed *Va*. Note in Fig. 1 that the dashed curve represents the case when the front car is stopped or parked. Figure 2 shows a block diagram of an excessive approach decision apparatus [Fukuhara, 1994].

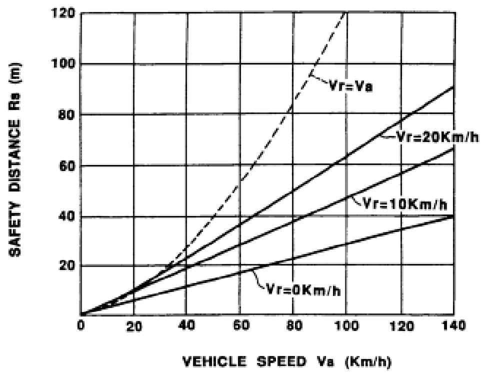

Fig. 1 Variation of safety distance with vehicle.

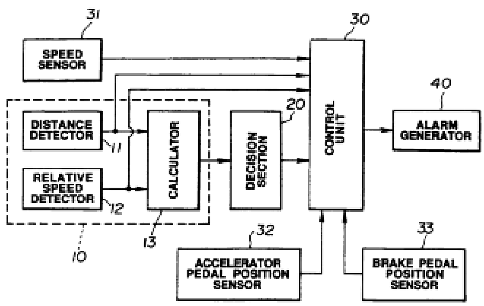

Fig. 2 Block diagram for excessive approach decision kit.

The driver cannot be expected, naturally, to estimate or determine safety distance *Rs* unassisted. Fortunately, the ever-increasing demand for reliability and safety on modern automobiles has led to the application of various advanced technologies, especially microelectronic technologies, albeit experimentally [Li et al., 1994]. Much attention has been given to technologies related to the development of experimental intelligent electronic vehicles [Chi, 1992; Sargent, 1995; Garrett, 1998]. Future generations of cruise control systems may possibly incorporate Doppler sensing and ranging for both lateral and longitudinal controls [Hoffmann et al., 1994]. Already research and development efforts are well underway [Garrett, 1998; Ulmer, 1994a; Sharp, 1998] for autonomous road vehicles. It would be expected that such vehicles would be in a position to effectively prevent or minimize collisions automatically.

Minimizing the number of automobile collisions through automated obstacle detection and vehicle response is vital to these efforts. Simple, reliable and low cost sensors installed in automobiles to warn the driver and / or to provide input to safety systems such as braking or cruise control are the key components for making this technology as common as air bags and seat belts.

In what follows, a summary is presented of recent and current efforts to develop driving aids that assist the driver in sensing, decision making and controlling of his vehicle, all with the ultimate aim of making driving safer.

2. SENSORS

Many different sensors and systems, from sonar to machine vision, have been installed on ground vehicles and automobiles. [Guinand et al. ,1995] and others [Sobottka and Wetzel, 1995; Persad and Shetty, 1994] observed that most of the projects on vehicles with a collision avoidance system use cameras in order to build their environment. With the purpose of providing an alternative, the authors proposed the use of one-dimensional sensors to reduce costs and development times. The results of this application, however, were not satisfactory.

[Ulmer, 1994a] described a system where the traffic situation is acquired from the vehicle by two black-and-white CCD video cameras with different focal lengths. The small focal length was used in the near field for the lane keeping function, while the large one served for obstacle detection in the mid- and far field. They found that there exist difficult requirements related to the dynamics of the intensity, which cannot be satisfied by these standard cameras.

[Sargent, 1995] discussed beam splitting techniques, and introduced low-cost laser sensors that are based on the use of commercially available pulsed high power InGaAs laser diodes. A system using sonar is discussed by Langer and Thorpe [1995]. The general hardware configuration of the system is shown, followed by a description of how the system builds a local grid map of its environment. The information collected in the map can then be used for a variety of applications in vehicle navigation like collision avoidance, feature tracking and parking. An algorithm was implemented that can track a static feature such as a rail, wall or an array of parked cars and use this information to drive the vehicle. Methods for filtering the raw data and generating the steering commands are discussed and the implementation for collision avoidance, parallel parking and its integration with other vehicle systems is described.

Top

An artificial retina sensor is described by Kim et al. [1995]. It consists of a linear (semiconductor) CCD sensor and a dove prism rotating in front of the camera lens. It was found that the system works reliably well when tracking a moving object from a stationary reference point.

The feasibility of using electronically steerable antennas for health monitoring of civil structures and early warning of collapsing bridges to approaching vehicles was presented by the Varadans [Varadan and Varadan, 1995]. The sensors are fabricated with interdigital transducers printed on a piezoelectric polymer or ceramic type film. The authors suggest that these antennas can also be used in automobile collision warning systems.

3. RADARS

Woll [1995] discussed the use of radar technology for collision warning and other vehicular applications. [Grosch ,1995] observed that radars are valuable sensors for all weather operation, and that experiments with automotive radar sensors have been conducted for over 40 years. Radar design difficulties and tradeoffs regarding operating frequencies, frequency bandwidth requirements, transmitted power and the use of existing low cost production components are presented by the author. A commercial production radar system is discussed, and the theory of operation of this radar system is described. A discussion of existing FCC regulations as related to intentional radar radiators and future FCC considerations is provided as well as some insight into international regulatory considerations.

The collusion warning radar is a potentially significant application of radar technology to the automotive market. Thus other researchers [Esteve et al., 1995] proposed using a LIDAR system to detect range, and a RADAR system to measure distance, and a Doppler system to find velocity. Hiscke [1995] observed that radar systems do not function properly in the presence of signals from other radiators. He anticipated that, as the number of radars increases, systems designed without consideration of the interference problem will exhibit poor or degraded performance. He identified the fundamental design parameters useful for maximizing operation in the presence of interference.

Kenue [1995] developed an algorithm for specifying range and azimuth angular coverage of a radar sensor. The algorithm combines geometric and accident data analysis of straight and curved roads with worst-case horizontal curvature. A bounded area for the selected collision warning algorithms (stopping distance and closing rate) is defined for a particular set of vehicle decelerations, initial speeds and delay time. These parameters are then varied by a Monte-Carlo technique. The bounded area is then integrated with the accident data for generating the number of potential accidents per specified sensor range. The sensor's range and the azimuth angular coverage were specified, assuming range gating on curved roads is implemented

Top

A frequency modulated /continuous wave (FM/cw) radar was developed [Grosch et al., 1995] for automotive applications. The objective of this effort was to design a low-cost automotive collision warning radar that could be operated under Part 15 of the U.S. Federal Communications Commission regulations regarding intentional radiators including proximity sensors. The authors described a forward looking homodyne FM/cw 24.125 GHz radar with a digital signal processor (DSP). The data is collected while the FM/cw transceiver is modulated with several linear chirps of differing bandwidths and modulation slopes. The processor uses this data to calculate the range and Doppler velocity of multiple targets for the purpose of finding the safe following distance that should be kept between the host vehicle and targets. The system specifications and the effects of power and bandwidth on radar performance are shown. The ambiguity function of the homodyne transceiver and FFT spectral processor are shown along with the method of resolving these ambiguities for multiple targets. Data are presented showing radar measurements of a conducting sphere and test vehicle.

Li et al. [1994] proposed a technique that they have tested for use in connection with a collision avoidance radar to be used in automobiles. To this end a six-port microwave / millimeter wave digital phase / frequency discriminator is used to measure Doppler frequency shifts. They explained that this arrangement allows the determination of relative speed and the direction of travel of the target vehicle. Ranging is implemented by the measurement of phase difference at two adjacent frequencies.

Grosch [1995] discussed the advantages and disadvantages of applying microwave and millimeter wave radar to obstacle detection and collision avoidance in a roadway environment. The performance differences between avoidance and warning sensors are discussed and a problem set is devised for a typical forward-looking collision warning application. The author noted that various radar system have been applied to this problem that include pulse and continuous wave transceivers. These system types are evaluated as to their suitability as a collision warning sensor. The various possible solutions are reduced to a small number of candidate radar types, and one such radar was chosen for full scale development. A low cost frequency modulated/continuous wave radar system is developed for automotive collision warning. The radar is attached to the sun visor inside the vehicle. It is reported that this radar has been in operation for over four years. The radar monitors the range and range-rate of other vehicles and obstacle and warns the driver when it perceives that a dangerous situation is developing. A system description of measured data is presented that shows how the 24.075 to 24.175 GHz band can be used for an adequate early warning system.

Other researchers [Lowbridge et al., 1991] noted that the frequency spectrum from 30 to 100 Ghz offers distinct advantages for use in collision avoidance. They cited specifically the 94 Ghz frequency, which has been successfully used in short-range anti-armor weapon systems to measure very accurately the distance to the target and the closing velocity. They

Top

discussed the application of the same frequency on a cruise control system for road vehicles. Nicholls [1990] also reviewed the measurement capabilities and limitations of millimeter wave radars for collision avoidance sensors. He suggested that possible applications include precision altimeters, cable avoidance systems for light aircraft and helicopters, terminal landing aids, and collision avoidance systems for motor way and railway use. Examples of relevant radar signatures are shown in his paper, and the problems of false alarms are discussed. This leads to a choice between fully automatic systems and sensors that simply provide improved information to a human operator.

4. OTHER DEVICES AND SYSTEMS

Chi [1992] disclosed an automatic device for controlling the safe driving distance for vehicles. The device includes a microcomputer which, within the range of 0 to 120 km/hr, can adjust the safety distance between the vehicle and the front vehicle according to the speed data transmitted from the speedometer, and can automatically control the speed of the vehicle to maintain a safety distance from the front vehicle so as to avoid collision. When the vehicle is in motion, the microcomputer calculates the safety distance between both vehicles according to the speed of the vehicle, and the actual distance from the front vehicle according to the data from the distance detector. If the distance is too short, it can automatically motivate the brake motor to cause the vehicle to decelerate and the brake lights to turn on; if the distance is too great, it can automatically motivate the acceleration/deceleration motor to cause the vehicle to accelerate so that a safety distance is kept between both vehicles. If the front vehicle stops, then the brake motor and acceleration/deceleration motor will be both motivated to stop the vehicle. If the front vehicle moves forward, the acceleration/deceleration motor will also be motivated, and the vehicle moves forward, keeping a safety distance from the front vehicle, and maintaining a safe speed according to the value set by the speed limit device.

David [1989] patented a proximity sensing and indicating system for use in automobiles. This system detects the differential velocity between the car and the obstacle, and determines the distance separating the car from the obstacle. A signal is generated whenever the combination of differential velocity and separation distance reaches an unsafe level. This signal may be processed so as to emit various types of signals that can be seen, heard and/or be used for taking emergency action. Dessailly [1972] and other researchers [Davidian, 1994; Shyu, 1992; Fukuhara, 1994; Donnaly, 1972; Etoh, 1991, 1987, 1988; Tachibana et al., 1985; Yoshino et al., 1987; Doi et al., 1994] proposed similar systems. Provisions are built-in, in the system of David [1989], to prevent the driver from turning off the system after the emission of a signal has been initiated. The system proposed by Etoh [1988] can ascertain the presence of the preceding vehicle accurately, without mistaking the preceding vehicle for another vehicle moving on a different traffic lane or as a stationary object located at either side of a traffic lane. This is true even when the controlled vehicle and preceding vehicle move on a curved road [Etoh, 1988; Yamada et al., 1994].

Top

The systems of Yoshino et al. [1987] and of Persad and Shetty [1994] control the throttle valve of the engine for speed control. The system of Doi et al. [1994] prevents rear-end collisions by automatic brake control. The system proposed by Shyu [1992] detects the distance from the rear car also. Britt [1994] applied formal methods to a collision avoidance system, improving the assurance of safety in three areas: product review, process and personnel certification, and functional testing. Figure 3 shows the location of sensors and devices on a vehicle [Fukuhara, 1994] equipped with an anti-collision system.

Yasuma et al. [1994] developed a compact, high performance laser radar and an indicator designed for trucks and buses, and an air-blow type laser radar which can be used in snow. This system was installed on a heavy duty truck, and it was tested successfully on the test course, freeways, local roads, and in cold districts.

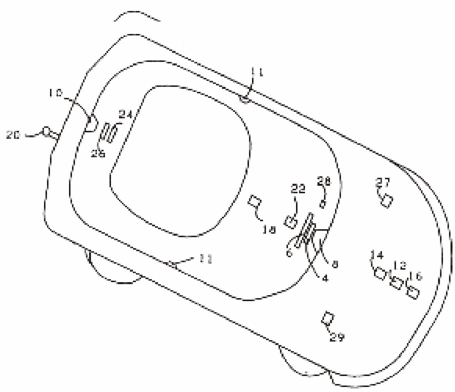

Fig. 3. Location of sensors and devices on a vehicle with an anti-collision system. 4 = microcomputer, 6 = control panel, 8 = frontal space sensor, 10 = rear space sensor, 11 = side sensor, 12 = speed sensor, 14 = daylight sensor, 16 = rain sensor, 18 = vehicle load sensor, 20 = trailer hitch sensor, 22 = reverse gear sensor, 24 = brake light, 26 = brake light actuator, 27 = start-up enable device for engine, 28 = black box to record every alarm, and 29 = automatic brake actuator (Davidian, 1994).

Esteve et al. [1995] reported on the implementation of yet another anti-collision system on a car. The vehicle was provided with two LIDAR systems integrated near the headlights, and a RADAR included in the calender, both used for active detection. Twelve infrared beacons were also set up on the front part of the vehicle for telecommunication exchanges with surrounding vehicles or with infrastructure.Other authors [Wikman et al., 1993] proposed using reflex control for avoiding collisions. Still other researchers [Sinclair et al., 1994] presented a method for doing motion segmentation for autonomous vehicles, and methods for collision prediction and avoidance [Dear and Sherif, 1991].

5. AUTONOMOUS VEHICLES

There have been a number of attempts [Ulmer, 1994;1994a; Langer and Thorpe, 1995; Kim et al., 1995 and Esteve et al., 1995] to develop autonomous vehicles, i.e., vehicles that can navigate in traffic without intervention by drivers. The general aim is to develop something like an autopilot in airplanes, which may be called an auto-driver. Thus Ulmer [1994];Ulmer, 1994a and Esteve et al., 1995 presented, in theory, an autonomous road vehicle which will, in principle, prevent collisions automatically. This safety relevant project is part of the PROMETHEUS program (PROgraM for a European Traffic with Highest Efficiency and Unprecedented Safety). The vehicle demonstrator VITA II (VIsion Technology Application) consists of a passenger car which demonstrates its capabilities of collision avoidance on motor ways. Video cameras installed on the vehicle acquire information about the environment. The hardware consists of two clusters of parallel processors. The application cluster hosts computer vision, planning, decision and control modules to perform driving tasks such as lane keeping with desired speed, reduction of the speed in narrow curves, obeying the restrictions given by traffic signs, following the vehicles in front with adaptive distance control, computer vision based traffic sign recognition, object detection and recognition around the vehicle, and autonomous immediate collision avoidance maneuvers including overtaking. The vehicle cluster provides the basic structure to control the vehicle by computer. Esteve et al. [1995] presented some experimental results regarding the sensors used on this project.

Another ambitious autonomous vehicle project was presented by Langer and Thorpe [1995], who pointed out that detecting unexpected obstacles and avoiding collisions is an important task for any autonomous mobile system. The GANESHA {Grid based Approach for Navigation by Evidence Storage and Histogram Analysis), is a system using sonar that was implemented for the autonomous land vehicle Navlab. The general hardware configuration of the system is shown, followed by a description of how the system builds a local grid map of its environment. The information collected in the map can then be used for a variety of applications in vehicle navigation like collision avoidance, feature tracking and parking. An algorithm was implemented that can track a static feature such as a rail, wall or an array of parked cars and use this information to drive the vehicle. Methods for filtering the raw data and generating the steering commands are discussed, and the implementation for collision avoidance, parallel parking and its integration with other vehicle systems is described.

A fuzzy approach to collision avoidance for automated guided vehicle (AGV) navigation was proposed by Lee and Wang [1994]. Static obstacles with no a priori position information as well as moving obstacles with unknown trajectories are considered in this study. Intuitive and subjective human ideas of collision avoidance are modeled into fuzzy rules. Fuzzy logic is applied in the inference procedure for AGV navigation, such that the AGV is guided from the starting point toward the target without colliding with obstacles. Furthermore, the proposed method can also be used for the navigation of multiple AGVs, where each AGV must avoid other AGVs as well as obstacles in the environment. Simulation results are presented to show the feasibility of the proposed fuzzy approach. Sinclair et al. [1994] presented a method for doing motion segmentation for autonomous vehicles.

6. CONCLUDING REMARKS

There seems to be universal consensus that roads will not get any less congested with the passage of time. It is important, therefore, to give the issue of accident prevention the consideration it deserves, and to take concrete steps in this direction. Providing vehicles with sensors and other anti-collision devices is a step in the right direction. It is further plausible that driving aids of the near future will be able to provide contingency support during an emergency. Thus if the driver falls asleep or becomes unconscious, or when the vehicle experiences a tire puncture at high speed, the auto-driver system will be able to bypass the driver, and immediately take the most appropriate action without panic.

Of the various systems that are currently under consideration, the use of laser sensors seems to possess the most potential for application. The use also of special video cameras can be expected to find early commercial application due to economic feasibility. The utilization of radars and related equipment must be weighed against complications regarding frequencies, band widths, power levels and FCC regulations.

It must be stressed, however, that despite the emergence of all technological aids, the human element remains the most important single factor in road safety. There just is no substitute for drivers with safe driving habits. Road safety rules must be promptly enforced on all offenders, including the traffic police itself. Safe driving habits must be cultivated and nurtured at all phases of human activity.

It may be pointed out that a vital sector that does not seem to be so far receiving sufficient research and development attention is that of traffic supervision. The vital role being played by the air traffic control system and management in the skies does not require any emphasis. It is the authors = contention that supervision and control of road traffic also possesses the potential to become an activity of significant dimensions, in preventing road accidents as well as in the streamlining and easing of traffic.

Top

REFERENCES

1. Akçelik, R., Besley, M., Roper, R., 1999a, "Fundamental Relationships for Traffic Flows at Signalized Intersections," Res. Rept ARR 340, *ARRB Transport Res.* Ltd, Australia.
2. Akçelik, R., Roper, R., Besley, M., 1999, "Fundamental Relationships for Freeway Traffic Flows", Res. Rept ARR 341, *ARRB Transport Res.* Ltd, Australia.
3. Britt, J.J., 1994, "A Case study: applying formal methods to the traffic alert and collision avoidance system (TCAS) II," *Proc. of the 9th Annual Conference on Computer Assurance*, COMPASS'94, Gaithersburgh, MD, USA, IEEE, Piscataway, NJ, USA, 94CH3415-7. pp 39-51.
4. Chi, C. Y., 1992, "Automatic Safety Driving Distance Control Device for a Vehicle," US Patent Number: 5,165,497, date: Nov. 24.
5. Chung, E., Rosalion, N., 1999, "An Incident Detection and Management on Freeways," Res. Rept ARR 327, ARRB Transport Res. Ltd, Australia.
6. David, C.V., 1989, "An Obstacle Proximity Detector for Moving Vehicles and Method for Use Thereof," US Patent Number: 4,833,469, date: May 23.
7. Davidian, D., 1994, "An Anti-collision System for Vehicles," US Patent no: 5,357,438, date: Oct 18.
8. Dear, R.G. and Y.S. Sherif, 1991, "A Z-Basic Algorithm for Collision Avoidance System," *IEEE Trans. on Systems, Man, and Cybernetics*, 21(4), pp 915-921.
9. Dessailly, R., 1972, "Anti-Crash Radio Detector for Automotive Vehicles," US Patent No: 3,689,882, date: Sept. 5.
10. Doi, A., Butsuen, T., NiSbe, T., Takagi, T., Yamamoto, Y., Senl, H., 1994, "Development of a Rear-end Collision Avoidance System with Automatic Brake Control," *JSAE Review,* 15 (4), pp 335-340.
11. Donnaly, R., 1972, "An Anti-crash Radio Detector for Automotive Vehicles," US Patent No: 3,689,882 Sept 5.
12. Esteve, D., Rolland, P.A.; Simonne, J.J.; Vialaret, G., 1995, "Prometheus-prochip status of sensor technology applied to automotive collision avoidance," *Proc. of SPIE - The International Society for Optical Engineering,* v 2470 1995- Society of Photo-Optical Instrumentation Engineers, Bellingham, WA, USA. pp 386-395.
13. Etoh, Y., (Nissan), 1988, "Method and System for Automatically Detecting a Preceding Vehicle," US Patent No: 4,757,450, date: Jul 12.
14. Etoh, Y., (Nissan), 1991, "System and Method for Automatically Controlling Vehicle Speed So as to Trail a Preceding Vehicle," US Patent No: 5, 053, 979, date: Oct 1.
15. Etoh, Y., (Nissan),1987, "System and Method for Automatically Controlling Vehicle Speed," US Patent No: 4,670,845, date: Jun 2.
16. Fukuhara, H. (Nissan), 1994, "Vehicle Collision Alert System," US Patent No: 5 355 118, date: Oct. 11.
17. Garrett, A., 1998, "An Intelligent Transport Systems - Potential Benefits and Immediate Issues," *Road and Transport Research*, 7(2), pp 61-69.

18. Grosch, T., 1995, "Radar sensors for automotive warning and avoidance," *Proc. of SPIE - the Intern Soc for Optical Engineering*, v 2463, 1995, Society of Photo-Optical Instrumentation Engineers, Bellingham, WA, USA, pp 239-247.
19. Grosch, T.O., Klimkiewicz, W., Moosbrugger, P., Carpenter, L.,1995, "24-GHz frequency modulated/continuous wave automotive radar designed for collision warning," *Proc. of SPIE - The International Society for Optical Engineering* v 2344 1995- Society of Photo-Optical Instrumentation Engineers, Bellingham, WA, USA. pp 146-158.
20. Guinand, Y., Valayden, N., Bizouerne, F., Bouaziz, S., Maurin, T., 1995, "Low cost sensors for collision avoidance applications," *Intelligent Vehicles Symposium, Proc*. 1995. IEEE, Piscataway, NJ, USA, 95TH8132. pp 478-482.
21. Hamed, M., Al-Rousan, T., 1998, "The Impact of Perceived Risk on Urban Commuters = Route Choices," *Road and Transport Research*, 7 (4), pp 46-63.
22. Hamed, M., Jaber, S.,1997, "Modelling Vehicle-time Head Ways in Urban Multilane Highways," *Road and Transport Research*, 6 (4), pp 32-44.
23. Hischke, M., 1995, "Collision warning radar interference," *Intelligent Vehicles Symposium, Proc*., 1995. IEEE, Piscataway, NJ, USA, 95TH8132. pp 13-18.
24. Hoffmann, Errol R.; Mortimer, Rudolf G., 1994, "Drivers Estimates Of Time To Collision", *Accident Analysis and Prevention,* 26 (4) Aug.
25. Hughes, R.G., 1999, "Variations In Average Vehicle Speeds And The Likelihood Of Peak Period Crashes," *Road and Transport Research*, 10 (1).
26. Katamine, N.M., Hamarneh, I.M., 1998, "Use Of The Traffic Conflict Technique To Identify Hazardous Intersections," *Road and Transport Research*, 7 (3), pp 17-35.
27. Kenue, S.K., 1995, "Selection of range and azimuth angle parameters for a forward looking collision warning radar sensor," *Intelligent Vehicles Symposium, Proceedings* 1995. IEEE, Piscataway, NJ, USA, 95TH8132. pp 494-499.
28. Kim, Kwang I.; Shin, Cheon W.; Inoguchi, SeiMi, 1995, "Collision avoidance using artificial retina sensor in ALV," *Intelligent Vehicles Symposium, Proc.* 1995. IEEE, Piscataway, NJ, USA, 95TH8132. pp 183-187.
29. Kuge, Nobuyuki; Ueno, Hiroshi; Ichikawa, Hideaki; Ochiai, Kiyoshi, 1995, "Study on the Causes of Rear-end Collision Based on an Analysis of Driver Behavior," *JSAE Review,* 16 (1) Jan, pp 55-60.
30. Langer, D., Thorpe, C., 1995, "Range Sensor Based Outdoor Vehicle Navigation, Collision Avoidance and Parallel Parking," *Autonomous Robots,* 2 (2), pp 147-161.
31. Lee, Pai-Shth; Wang, Ling-Ling, 1994, "Collision Avoidance for Fuzzy Logic Control for Automated Guided Vehicle Navigation," *Journal of Robotic Systems,* 11 (8) Dec, pp 743-760.
32. Li, j., Bosisio, R.G. and Wu, K., 1994, "Collision Avoidance Radar Using Six-Port Phase/Frequency Discriminator (SPFD)," *IEEE MTT-S Digest*, pp. 1553-1556.
33. Lowbridge, P.L., P.M. Brigginshaw and B. Kumar, 1991, "Millimeter wave technology for collision avoidance and cruise control," *Proc. 8th Int Conf on Automotive Electronics*, IEE London, Conf. Publ. No 346, pp 150-154.
34. Nicholls, M.R., 1990, "Millimeter wave collision avoidance Radars," *Proc. IEE Colloquium on Millimeter-Wave Radar*, Digest No 089, pp. 3/1-7, London.

35. Persad, P.; Shetty, D., 1994, "Study in Design for Environment-passive System for Vehicle Rear End Collision Avoidance," Concurrent Product Design, American Society of Mechanical Engineers, Design Engineering Division (Publication) DE v 74 1994. ASME, New York, NY, USA. pp 145-149.
36. Persad, P.; Shetty, D., 1994, "Study in Design for Environment-passive System for Vehicle Rear End Collision Avoidance," Concurrent Product Design American Society of Mechanical Engineers, Design Engineering Division (Publication) DE v 74 1994. ASME, New York, NY, USA. pp 145-149.
37. Polus, A., Craus, J., Livneh, M., Katznelson, S., 1998, "An Analysis of Flow, Safety and Warrants for Paved Shoulders on Two-lane Rural Highways," *Road and Transport Research*, 8 (1),
pp 42-55.
38. Prem, H., Ramsay, E., Fletcher, C., George, R., Gleeson, B., 1999, "An Estimation of Lane Width Requirements for Heavy Vehicles on Straight Paths," Res. Rept ARR 342, ARRB Transport Res. Ltd, Australia.
39. Robinson, D.L., 1998, "Accidents at Roundabouts in New South Wales," *Road and Transport Research*, 7 (1).
40. Sargent, R., 1995, "Miniaturized, multibeam, solid state scanning laser Radar in automobile collision avoidance sensor systems," *Proc. SPIE - The International Society for Optical Engineering*, v 2472 1995. Society of Photo-Optical Instrumentation Engineers, Bellingham, WA, USA. pp 82-92.
41. Sharp, K.G., 1998, "OECD Cooperative International Research into Vehicle-road Interaction - DIVINE project," *Road and Transport Research*, 7 (1).
42. Shyu, J.M., 1992, "Vehicle Anti-collision System," US Patent No: 5,091,726, date: Feb 25.
43. Sinclair, D., B. Boufama and R. Mohr, 1994, "An Independent motion segmentation and collision prediction for road vehicles," *Proc. 1994 IEEE Comp Soc Conf on Computer Vision and Pattern Recognition*, Cat No. 94CH3405-8, pp. 958-961, IEEE Comput. Soc. Press, Los Alamitos, CA, USA.
44. Sobottka, K.; Wetzel, D., 1995, "An Attention control integrated in a system to autonomous driving and collision avoidance under egomotion," *IEE Conf. Publication* n 410 1995- IEE, Stevenage, Engl. pp 796 - 800.
45. Tachibana, A., Yokohama, F., Yokosuka, H.E., Yamaki, K., 1985, "Moving Obstacle Detection System for a Vehicle," US Patent No: 4,543,577, date: Sep. 24.
46. Theeuwes, J., Riemersma, J., 1995, "Daytime Running Lights as a Vehicle Collision Countermeasure - Swedish Evidence Reconsidered," *Accident Analysis and Prevention,* 27 (5) Oct, pp 633-642.
47. Ulmer, B., 1994, "VITA - An Autonomous Road Vehicle (ARV) for Collision Avoidance in Traffic," Mercedes-Benz Research Institute, Stuttgart, OCLC No: 26912130, p.36-41.
48. Ulmer, B., 1994a, "VITA II - active collision avoidance in real traffic," *Intelligent Vehicles Symposium, Proc.* 1994. IEEE, Piscataway, NJ, USA, 94TH8011. pp 1-6.
49. Varadan, V.K.; Varadan, V., 1995, "Smart electronics and sensors for IVHS and automobile collision warning antenna systems," *Proc. of SPIE - The International Society for Optical*

Engineering v 2448 1995. Society of Photo-Optical Instrumentation Engineers, Bellingham, WA, USA. pp 35-40.

50. Wikman, T.S., M.S. Branicky and W.S. Newman, 1993, "Reflexive collision avoidance: a generalized approach," *Proc. IEEE Int Conf on Robotics and Automation*, IEEE Comput. Soc. Press, Los Alamitos, CA, USA, Cat no: 93CH3247-4, pp. 31-36, v 3.
51. Woll, J.D., 1995, "VORAD collision warning Radar," *IEEE National Radar Conference - Proc*. 1995. IEEE, Piscataway, NJ, USA, 95CH3571-0. pp 369-372.
52. Yamada, Y., Tokoro, S., FuJita, Y., 1994, "Development of a 60 GHz Radar for rear-end collision avoidance," *Intelligent Vehicles Symposium, Proc. of the 1994 Intelligent Vehicles Symposium*, Detroit, MI, IEEE, Piscataway, NJ, USA, 94TH8011. pp 207-212.
53. Yasuma, T., Gonmori, A., Matsumori, S., Nishino, J., 1994, "Performance and Functions of a Rear-end Collision Warning System Equipped with a Small-sized Laser Radar," *JSAE Review* 15(4) Oct, pp 341-365.
54. Yoshino, O., Yoshiyuki Kago, N., Hiroyuki Sakakibara, H., Yoshio Shinoda, N., 1987, "Speed Control System for a Motor Vehicle," US Patent No: 4,706,195, Nov. 10.

Top