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PROGRAM ON ADVANCED TECHNOLOGY
FOR THE HIGHWAY

Lateral Guidance Systems Requirements
Definition

Robert E. Parsons
Wei-Bin Zhang

PATH Research Report UCB-ITSPRR-88-1

October 1988

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Program on Advanced Technology for the Highway

Lateral Guidance System Requirements Definition

Robert E. Parsons and Wei-Bin Zhang

UCB-ITS-PRR-88-1

Prepared in cooperation with the State of California, Business and Transportation Agency, Department of Transportation.

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The research reported herein is a part of the Program on Advanced Technology for the Highway, **PATH**, which aims to obtain better productivity from the State's most used urban highway segments. **PATH** centers on opportunities that advanced technologies may contribute to relief of traffic congestion, with related problems of safety, air pollution and parking, and on cleaner energy for transportation.

**Program on Advanced Technology for the Highway-
Lateral Guidance System Requirements Definition**

Robert E. Parsons and Wei-Bin Zhang

1.0 INTRODUCTION

The Institute of Transportation Studies (ITS) is assisting the California Department of Transportation (CALTRANS) to establish and conduct a program of advanced highway technology R&D to obtain better productivity from the States' most used highway segments. The Program on Advanced Technology for the Highway, **PATH**, centers on advanced technology opportunities that may contribute to the relief of traffic congestion, with related problems of air pollution and parking; and on energy for transportation, in particular continued use of petroleum based fuels,

PATH is structured around important but non-dependent technologies of automation, non-contact roadway electrification, and navigation. The **PATH** management plan [1] presents a program philosophy that stresses an evolutionary implementation approach for any new technologies that may be developed or evaluated that can collectively be used to evolve a more automated urban highway system for major California cities. The authors have reflected these **PATH** criterion into a set of lateral guidance system requirements in Section 2 of this work. Program guidelines that bear on choice of specific technologies to be evaluated are discussed under Section 4 and 5 of this report. At this point however, it is only necessary to state that a set of selection criterion specific to **PATH** have been enumerated to guide technology assessments of candidate areas under consideration.

By design, program activities will build upon the technology developed in the Santa Barbara Electric Bus Project [2]. The major R&D effort in the early years of **PATH** will be the refinement of the previously developed electric bus and a thorough test and evaluation of that concept. A test track is currently under design [3] and is to be built at the University's Engineering Field Station later this year.

Another major consideration relating to the selection of research topics or work activities is that whenever possible new technologies in one of the three aforementioned fields will be considered for evaluation in on-going projects in any of the three **PATH** technology areas. For example, the existing prototype electric bus will be enhanced somewhat to improved its expected propulsive efficiency, prior to full scale testing at the Richmond Field Station. The

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University's contract [4] with Systems Control Technology, Inc. (SCT) of Palo Alto, California, the systems engineering firm that developed the technology, contains a provision for centering of the bus power pick up system over the electrified alternating electric roadway elements and thus reduce the lateral dimensions of power pick-up hardware and increase the power transferred.

In fact, based largely on experience gained from field trips to Europe [5] to examine some of the existing lateral guidance concepts being assessed in this work, the SCT contract was structured to contain a two step lateral guidance examination. The initial automatic steering provisions will be met by purchase of off-the-shelf hardware, with necessary modification, if needed, to match the unique characteristics of the prototype bus.

Plans call for later investigation of a second generation system to be installed on the same electric bus by SCT. Even though that second system may be initially deployed on this medium speed electric bus, system selection criteria were based on the overall PATH goals relating to high speed urban passenger/freight freeway transportation.

This research was sponsored to define the requirements of this improved lateral guidance system and to investigate whether such a lateral guidance system can evolve into a multifunction systems inherent in the broader PATE goals implicit in the automation of highways. It is desirable that individual automatic highway system components work well together as a combined system, for example the reference used by a lateral guidance concept may also contribute to longitudinal or speed control systems as well. i.e. to later become a part of longitudinal guidance or vehicle positioning subsystems of an eventual Automatic Highway System.

2.0 SCOPE OF REVIEW

A lateral control system provides the "steering" function of driving an automobile. Lateral guidance systems are necessary on individual automated vehicles. It has to ensure that the vehicle could be moved automatically along a prescribed course, such as staying in the guideway. Lateral guidance systems should possess three subsystems [6]:

- (a) a reference system which can be detected by an on-board sensor and used as a basis for positioning the vehicle along a predetermined path.
- (b) compatible sensors mounted on-board the vehicle; and
- (c) a steering control system which responds to the sensed signal and maintains the desired vehicle direction.

The most common example of automatic guided vehicles is the fixed rail system. It employs steel rails, secured to wooden or concrete ties usually set into a gravel ballast bed, as the reference system. The sensor and control system functions are provided by flanged steel wheels, which steer the rail cars along the desired route. Rail switches can be used to steer cars to other routes.

This well proven rail switching technology did not carry over into automatic vehicle guidance use mainly because of the desire to keep switching times small

and switch maintenance low. Therefore on-board switching concepts have been more common in rubber wheeled vehicle use.

Other mechanical reference systems have been developed and deployed to steer busses [7], rapid rail, Group Rapid Transit (GRT) [8] and Personal Rapid Transit (PRT) [9] vehicles. Some use a mechanical-hydraulic steering system, which operates on a concrete guideway. Rubber-tired vehicles follow the guideway sidewall and steer the vehicle through linkages to a control which responds to the relative position between the vehicle and the sidewall [10]. Mechanical-hydraulic guidance systems have been designed for difference concepts, e.g. open or closed guideway, single or dual steered axle vehicles, and this approach has been used by moat PRT or GRT systems.

However, since it is the implicit goal of the PATE program to address ways to provide more flow on the urban freeways, none of the mechanical systems are considered suitable for this application.

A review of non-mechanical system work in this field was made and several classes of lateral sensing and control systems were analyzed in depth. Much effort has been directed at wire following type systems, as reported by Olson [6]. The German Ministry of Research and Technology sponsored extensive lateral guidance development work and guided bus systems were implemented in Essen and Furth, Germany and Adelaide, Australia. Other innovative approaches, including the use of optical, magnetic, radar and video sensors, have also been studied or developed to implement lateral steering control systems for application in situation where mechanical reference systems may not be practical,

The following sections present a summary of the review of these non-mechanical based systems, which can further be classified as having either a continuous or discrete reference sub-system that can be active or passive in nature. The operations presented have been grouped as either a reference following sensor system, Section 3, or a passive reference/side-looking sensor system, Section 4.

2.1 DEFINITION OF PATH LATERAL GUIDANCES SYSTEM REQUIREMENTS

During the review and analysis of existing lateral steering systems elements of a PATE specification began to emerge. As the study continued more of the desirable points became clear. However, no one existing system provided the combination of features that were deemed important to PATH. The main items of the desired specification emerged-as shown on Fig. 1. A brief discussion of those items that relate to the roadway reference system follow:

SENSING REFERENCE SYSTEM - SPECIFICATION

- ACCURATE AND SAFE
- LESS INFLUENCED BY LOCAL FAULTS
- EASY TO REPAIR
- ALL WEATHER CAPABILITY
- POTENTIAL TO PROVIDE MORE INFORMATION
- INEXPENSIVE

Figure 1

Accurate and Safe: The reference must always be present and provide a constant signal or reference pattern that passing vehicles can rely upon. It can not be affected by type of road construction, maintenance or externalities, i.e. weather.

Leas Influenced by Local Faults: The reference should not be subject to total lose of use if an isolated fault occurs. It must be capable of providing enough data to permit continious vehicle guidance. Correction time to repair failuresin the reference subsystem is also important.

Ease to Repair, As there will always be a need to detour around local work areas, the reference system should be easy to relocate or modify. For example, the entire line should not have to be down if only a small part of the system is damaged. There should be a low coat method of providing temporary routing in case of emergency work, accidents or other interruptions to normal traffic flow, Repair that does not disrupt too much traffic is highly desirable.

All Weather Capability: It is very important that any devices suggested have all weather capability. There are several reasons for this but a major one is that PATH envisions a national program. History has shown that one state alone cannot control or greatly influence a national system. A paramount PATH goal is to encourage the private automobile and electronic supply industry to join Caltrans and the University of California address the urban congestion problem⁶ of today and tomorrow. The scope of activity must be national, thus it must work in all weather conditions. Manufacturers will not invest in a system that only has application in good weather conditions. Even in California, we have a pressing problem to better steer snow removal equipment in the Sierras. A near term demonstration of lateral guidance technology may be in the mountains.

Reasonable Coats: This is a very important criterion. Initial coats, parts and labor, and life maintenance coats should be attractive. The simpler the roadway reference the better the overall system becomes. Complexity in on-board equipment is leas critical, but even on-board sensor design should be simple. rugged and low cost.

Capable of Providing More Information, This item may be the moat important of the criterion, for unless data regarding downstream road geometry can be provided to the vehicle it is doubtful that an effective lateral guidance system will evolve. Drivers will not relinquish the control of their vehicle⁶ to a system that doesn't provide as good a ride as they can manually provide. As none of the existing systems provide that quality, a system must be developed that permits the vehicle to steer along the road rather than have to respond in real time to road irregularities as

they occur. There is no need to wait until a curve is encountered before starting to turn. This forecast type data must be provided in time to accommodate smooth curve negotiation,

3.0 REFERENCE FOLLOWING SENSOR SYSTEMS

High-speed, wire-following control of instrumented vehicles has been achieved using both one and two active-excited roadway-based wire reference with amplitude and phase-sensing sensors [11], [12]. This approach to vehicle lateral control has been well documented [6],

A similar approach, which employs painted lines on the roadway as a reference, was investigated.

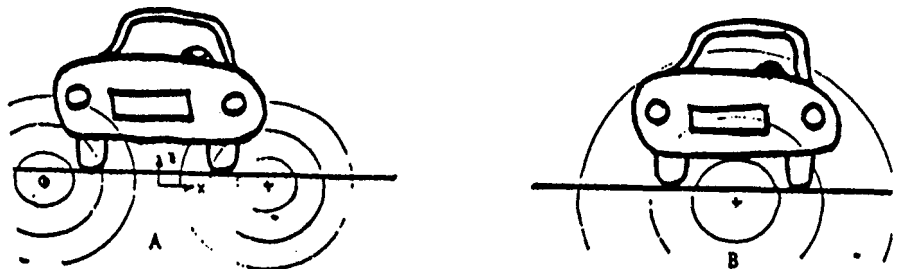
Techniques to provide steering for automatic vehicles using discrete reference markers along the road surface were investigated, Magnetic and optical sensors are two types used to measure the lateral offset as vehicles pass the markers.

3.1 Two-wire Amplitude Sensing

The reference consists of two wires as shown in Fig. 2A. Each wire forms a part of a closed loop and is driven by a generator. Currents are equal, but opposite in direction.

The sensor system consists of two coils mounted on the front centerline of the vehicles. A coil, mounted laterally, detects the x component of the field, whereas the other vertically mounted coil detects the z component of the field.

Within the range of acceptable linearity, the magnitude of the signal received by the coil indicates the distance from the center of the guided lane and the phase of the signal denotes the left-right direction from the reference.



WIRE REFERENCE

- ROADWAY POWER REQUIRED
- MAINTENANCE COSTS A FACTOR
- UNAFFECTED BY WEATHER
- AFFECTED BY ROAD REINFORCING MATERIALS
- ⊗ DIFFICULT TO CHANGE FOR ROAD REPAIR & DAMAGED WIRE
- ⊙ ENTIRE ROUTE AFFECTED BY ONE FAULT

Figure 2

3.2 One-wire Amplitude Sensing

The reference consists of a single current-carrying conductor positioned in the center of the guideway, as shown in Fig. 2B.

The sensor system consists of two sensing coils mounted on either side of the front, longitudinal centerline of the vehicle, with their axes horizontal above the guideway.

The one-wire sensor works on the same principle as the two-wire reference system.

Experimental results indicate fundamental weaknesses in these systems:

- a) a change in the wire current will cause a change in the gain or scale factor of the reference; and
- b) a more serious problem, called null shift - the magnetic field is distorted by conductive materials near the buried wire. Common examples are steel-reinforcing bars (rebars) used in roadway⁸ and bridge structures.

problem (a) could be overcome by either regulation of the wire current source or by using an automatic gain controller (AGC). However, solutions for the second problem have been more difficult. For example, tests on a section of highway, containing lateral symmetrical structural reinforcing exhibited several null shift over a 1-m section. At such points, the one wire amplitude sensing system with AGC performed reasonably well, but the same configuration was totally unsuccessful on highway⁶ with laterally asymmetrical reinforcing. Thus, research was conducted to develop a wire reference/sensor system with low distortion indications regardless of the pavement reinforcement design.

It is obvious that a loss of signal will result if the lateral displacement is greater than a certain distance,

3.3 One-wire Phase Sensing

Because a practical reference/sensor system must perform well on all types of roadway construction, the phase-sensing lateral position measurement technique attempts to overcome the null shift, as well as gain distortions.

The magnetic field in the immediate vicinity above the reference wire is more strongly influenced by the reference wire current than by the lower amplitude distributed currents flowing in any rebars in the road, consequently the field distortion is less, close to the reference-wire. This is consistent with the requirement for good phase-detector operation.

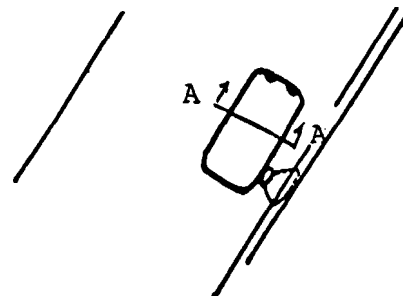
The one wire reference subsystem is employed in the one-phase sensing system.

The sensing subsystem consists of a number of vertically mounted coils⁸ positioned at equal intervals⁶ across the front center of a vehicle plus one horizontally mounted, phase reference coil.

Experimental data based on a system with 20 coils positioned on the vehicle at some 6 in. (15 cm) above the roadway reinforcing mesh, illustrated significant improvement in the null shift of that found with the one-wire phase sensing system. However, there are obvious practical complexities of a low clearance, multiple coil approach.

3.4 Video Line Following

Work has been conducted to determine the feasibility of a video camera which follows a painted reference line on the roadway [13], [14]. Fig. 3 is a sketch of this concept. The Australia Road Research Board developed a system that consists of a line scan video, high speed comparator and a lighting system [15].



LINE FOLLOWING

The basic transducer is a video camera, which provides an angular field of view of approximately 65degrees. Light sensitivity settings are provided and acceptable results are produced under any illumination levels, as a modified quartz halogen fog lamp provides adequate illumination if needed.

- ' AFFECTED BY WEATHER
- EASY REFERENCE SYSTEM
- ' FULL SCALE TESTING - O.K.

Figure 3

The reference line is a continuous or broken white separation lane line or a continuous road edgeline. The actual width of the line is not important since the measurement is made between the start of the scan and other outside edge of the white line.

A microprocessor-based data logging system was borne on the vehicle.

The camera is mounted 1.5 m from the road surface and has a field of view of approximately 2.2 m. The road surface in the field of view of the camera is effectively divided into 16 sections, each approximately 170mm wide.

The video camera has a 64 millisecond scan rate and its composite video signal is fed into a high speed comparator which is tied into the display,

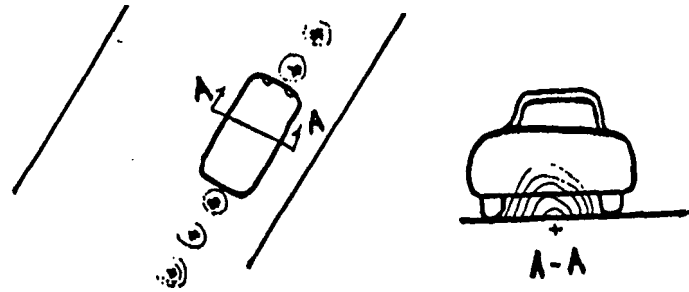
The system was operated successfully without adjustment for several months during a major field experiment (3 Km road section). The dynamic operation showed that any movement which changed either the horizontal or vertical angle between the road surface and the vehicle base produced errors in the dynamic conditions, but one of the main errors occur in the form of body roll, which was most apparent as the vehicle negotiated curves. Under the normal driving conditions, the error was less than + 30mm.

Temperature control and dynamic calibration of the system were also considered in the design of the circuits.

3.5, Discrete Optical Sensing system

An optical discrete sensing system was investigated by the Jet Propulsion Laboratory in the 1970's. Fig. 4 shows the system concept [16].

The reference subsystem consisted of a series of discrete markers placed on the road surface to delineate the vehicle pathway. The marker buttons were retro-reflective (appeared orders of magnitude brighter than the road surface).



REFERENCE MARKERS

The sensor was mounted 4-5 ft. above the road and focused such as to obtain a sharply defined field of view on the road. The image was a narrow strip (about 4 inches) in front of the vehicle and wide enough (about 3 1/2 feet) to cover the desired range in the lateral direction.

- * LARGE ERRORS IN CURVES (OPTICAL)
- * AFFECTED BY WEATHER
- * NO ROADWAY POWER REQUIRED
- * LOW COST
- EASY TO REPAIR DAMAGED MARKERS OR DETOUR FOR ROAD WORK

A defocused image generated an approximate linear output as a function of position. A split detector, with halves side by side, measured lateral position. Both a differential output and a summed output were generated and processed by the micro-processor controller, which outputs the required steering angle as a function of time,

Figure 4

Functionally, the sensor measured the lateral offset of the vehicle as it passed a marker. The controller converts the sensor signal to a time-varying analog steering signal. However, the value of lateral acceleration and jerk were limited by the controller, which also performed some safety-related logic.

Independent input of vehicle speed was needed to complete the data set.

The following results were obtained from system performance simulation:

- Under normal condition, i.e. 1 ft marker spacing and with measurement noises, the mean steady path deviation of the system was less than 0.23 ft (rms).
- Curve following a 10 ft radius path, under the same conditions, resulted in a large steering-state tracking error of 0.64 ft (19.5 cm), since the controller in effect "remembered" the data from the previous markers and was expecting a straight path.
- For this close-button spacing (1 ft), data acquisition was successful over a 35 deg. range of path angle.
- For a nominal 10 ft marker spacing, acquisition is successful over an angle range of 5 deg.

- Control could be maintained without exceeding a lateral acceleration of 0.02 g (0.196 cm/sec²) at 7mi/h after one fault measurement,

The simulation results indicated that the concept was feasible [17]. Unfortunately, the full-scale test program results were not reported.

3.6 Discrete Magnetic Sensing System

Lateral guidance by use of permanent magnetic markers has also been investigated [18]. The reference system consisted of a row of magnetic steel nails, which were buried in the center of a roadway lane. The magnetic field of the markers was perceived by two coil sensors on board the vehicle. Control strategies of the system were similar to the aforementioned optical sensing system, ref. 3.5.

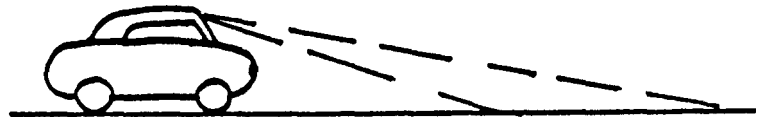
Due to the semipassive nature of the magnetic nails, the distance between markers could be larger than with the optical markers, and the system would be less influenced by weather and debris.

3.7 Optical Steering System

All of the foregoing systems have a major common fault. They deal in real time and attempt to read a reference in the roadway as the vehicle passes over the reference point. Data must be collected, analyzed and steering correction instructions calculated and sent to the vehicle actuators as fast as possible. Even with today's high speed processing capabilities there is a noticeable delay.

Thus the ride is jerky and the systems have a tendency to oversteer and thus create another deviation from the reference to be corrected. As this process is time dependent, it gets worse with increased speed. Thus **systems** that can look forward provide a little more time for processing and correcting position,

The concept of the optical system is shown on Fig. 5. The Japanese have been investigating this type of system for obstacle detection [19], but one can envision it also being used in lateral control. Advantages of no road power and limited forward information appear clear. However, the drawbacks of weather effects and the inability to see around large obstacles or sharp curves appear to eliminate this approach for **PATE** type application.



OPTICAL SYSTEM

- NO ROADWAY POWER REQUIRED
- AFFECTED BY WEATHER, LARGE VEHICLES & SHARP CURVES
- RAPID COMPUTER PROCESSING REQUIRED
- PROVIDES LIMITED FUTURE INFORMATION

Figure 5

However, a recent "Autonomous Mobile System" has been successful in overcoming many of these drawbacks. The German Ministry of Research and Technology has sponsored research in computer vision technology to achieve simultaneous lateral guidance, longitudinal control, obstacle detection and traffic sign recognition. Daimler Benz has been coordinating the work of two teams of German researchers [26].

The University of Munich (UniBwM) scheme, data processing hierarchy is shown in Figure 6, utilizes a series of windows to determine path finding along a roadway. Figure 7 illustrates how each window tracks a portion of the road boundary and another window depicts the proper line position of the vehicle. By use of a complex road model that continuously compares road boundaries and upcoming curves with current vehicle position and movement characteristics, the vehicle is maneuvered into proper position. One can readily appreciate that a limitation of this approach is the data processing capability of the on board processors.

This UniBwM system has been successfully tested at speeds up to 60 mph.

The other German system is under development by Fraunhofer-Gesellschaft Karlsruhe (IITB) and proposes to use stereo image processing. Images will be generated by two or more video cameras so as to obtain 3-D pictures of the upcoming roadway. The 3-D images will be processed on a frame by frame basis and vehicle control will be affected through an on board interpreter and vehicle controller, which are currently under development. Again, the big challenge in this system is the ability to obtain and analyze the large amounts of data needed to provide real time guidance of the vehicle.

These systems would overcome the line of sight and weather limitations of the optical sensing system presented in Figure 5, but the reliability and cost aspects of the significant on board data processing capability would be a major concern for **PATH** type application.

3.8 Critique of Reference Following Sensor Systems

The wire-reference lateral guidance is very often recommended for AHS application because the accuracy of the system has been proven both by theoretical analysis and by experiment. This principle has been used for a wide variety of applications ranging from low speed electric tractors operating at about 3-6 miles/hr. in warehouses and factories, to high speed test automobiles operating without drivers (60 miles/hr. or more). Now, this technology has been deployed for electronic track-guidance busses in Europe (5).

The wire-reference sensing systems are inexpensive and simple. However they are subject to some constraints. The buried guide wire must be continuous and must provide a return current path, as would be found in a loop route configuration. Spurs or other road configuration that use the same path for both directions would be awkward to implement. The wire must also be led around manhole covers and gratings in the roadway surface, possibly conflicting with the most desired path. Changes in the location or alignment of the guide line, once installed, are somewhat difficult because a new saw cut must be made and a new section of wire spliced onto the old, which is then cemented into the groove.

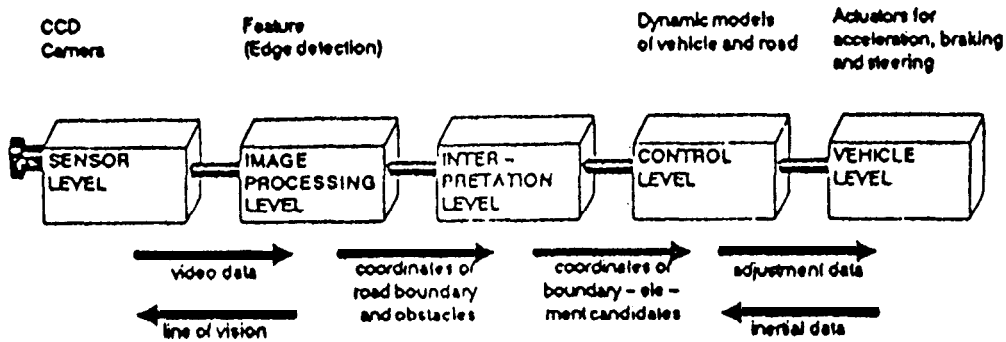


Figure 6 Hierarchical processing scheme .

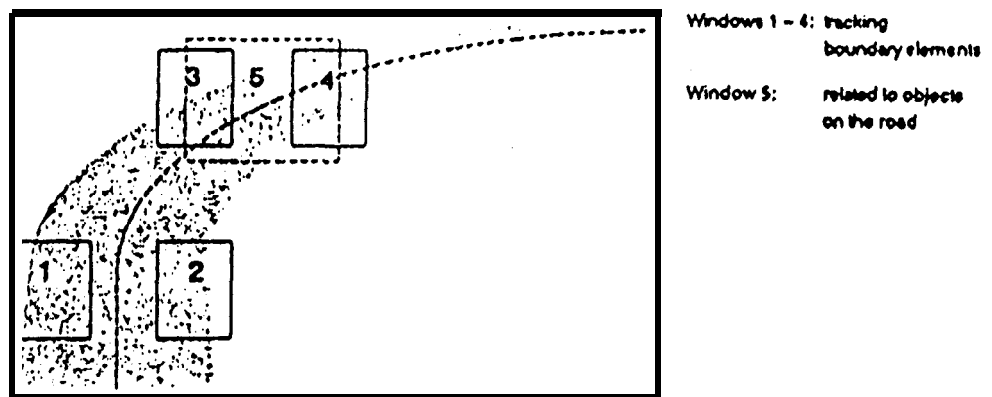


Figure 7 Window configuration

Figure 6 and 7 are by Hans-Georg Metzler, Daimler Benz A.G in SAE paper 881167 presented at the Future Transportation Technology Conference in San Francisco, 8-11, 1988

The video system could also be used for vehicle positioning. Clearly, the system would be easy to use because the guideway is very simple. However, its efficiency would be affected by dirt or ice on the surface of the roadway.

Installation of the discrete markers appears to be practicable and low cost and their presence would not interfere with traffic. Road changes or marker damage would only impact the system operation locally at the affected point. Installation of temporary marker⁸ could lead vehicles around a construction area even without removing markers already in place in the affected area. The system offers flexibility.

Accuracy of lateral position is dependent upon marker spacing, especially in steering through curves.

The optical discrete markers are less noisy and thus capable of a more repeatable measurement. This helps the system accuracy. But one unsolved problem is that the optics are very sensitive to dirt or ice on the roadway.

The forward looking optical system has shortcomings due to weather limitations and its inability to see through large vehicles or around curves.

Whereas, a magnetic discrete sensing system is less influenced by dirt or ice, they produce some noise. Whether this system could be used in conjunction with the PATH non-contact electrified propulsion system is under investigation under another PATE project. It should be noted that the discrete magnetic markers do not have the inherent disadvantage found in the wire reference systems regarding sensitivity to reinforcing materials used to strengthen the road. Since they are based on permanent magnetic properties, there is no alternating current to induce electric fields in these other metallic materials that could be in the road.

Probably one of the biggest advantage⁸ of a discrete marker (there are many technologies that could be used for the markers/sensors) approach is that the road need not be powered.

4.0 PASSIVE REFERENCE/SIDE-LOOKING SENSOR SYSTEMS

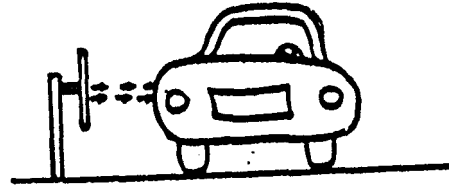
Mainly to overcome the problems of active guideways, work has progressed with several concepts to use transducers/receivers that look sidewise from the vehicle to a reference wall/screen and maintain a fixed separation to provide the steering function. These systems have the ability to send out and receive an energy wave that reflects off of a reference barrier. On-board calculation then provide instructions to the vehicle controls to maintain the desired lateral position of the vehicle.

4.1 TWO FREQUENCY RADAR SENSING SYSTEM

The use of a side-looking radar in conjunction with a sidewall reflector is one means of obtaining lateral position information for use in vehicle automatic lateral control. Mayhan [20], at Ohio State University, examined many radar systems and concluded that the following are a few of the most promising systems that might be utilized:

- 1) a continuous-wave (CW) radar
- 2) a two-frequency radar
- 3) a AM-CW radar
- 4) a two frequency Doppler radar
- 5) an FM-CW radar
- 6) a short-pulse baseband radar

After detailed examination, both the AM-CW and the two-frequency radar were judged to show most promise for the AHS application [21].



RADAR

- ' NO ROADWAY POWER REQUIRED
- ^m SOME WEATHER AFFECT
- * PROHIBITS TURNS & INTERSECTIONS
- * LOW SPEED TESTS O.K,

Figure 8

The general configuration of the two-frequency radar is shown in Fig. 8. The vehicle maintained the desired lateral position by reflecting radar signals from a sidewall reference system. An on-board controller determined the calculated side distance and instructed the vehicle control actuators to make any needed lateral adjustments to maintain the desired position on the roadway.

In the Ohio State University work; the radar was mounted about 3 feet above the the road, Separate transmitting and receiving antenna were used.

The two frequency radar was designed to work at X band (10.5 Ghz), because at this band the antenna had reasonable directivity and was of moderate size suitable for mounting on a vehicle.

Experiments were performed to evaluate the performance characteristics at two frequencies, 60Mhz and 300Mhz. The larger frequency provided better accuracy, Since the higher position accuracy is very desirable in a steering application, 300 Mhz was selected for use in the prototype..

The reference subsystem was a reflecting metallic wall or screen and this limits the flexibility of system use. Without complexity, this system can not serve well in areas with intersections or other lane discontinuities (i.e. freeway exits) or where it is anticipated that vehicle8 will have lane changes. Thus it does not meet the basic PATE requirement of an evolutionary implementation on existing urban freeways.

4.2 ACOUSTIC SENSING SYSTEM

Acoustical energy has been used as a sensing means for vehicle detection in number of different ways. Recent development8 have produced this technology to automated lateral sensing and control [22], [23]. The experiments of Clemence

and Hurlbut at Ohio State University [24] have demonstrated that accurate measurements could be obtained using acoustic ranging.

The acoustic lateral sensor system has external mounted acoustic transducers on the vehicle such that measurements could be made from a pair of transducers installed at the front or both ends of the vehicle, as shown in Fig. 9. Each transducer would be capable of duplexing - i.e. transmitting pulses and receiving echoes from a reflector subsystem. Pulses contain a series of discrete signal 8.

The investigators envisioned reference targets as a small diameter rod which gives minimal disturbance

to the transmitted and reflected pulse. While it was realized that ranging to targets only along one side of the road is possible, ranging to both side of the road offers advantages in accuracy and reliability. For this reason, the targets were placed along both Side8 of the road. The targets offsets are determined to be 1 ft by 1 ft to minimize the errors.

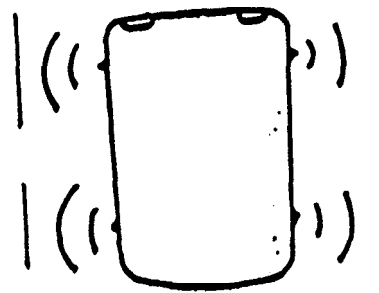
The acoustic ranging entails transmitting a high frequency acoustic pulse and measuring the round trip time required for this pulse and return to the source. For this time measurement, existence of and estimated distance to the objects- (e.g. other vehicles, obstacles) can be determined through the estimated velocity of sound.

The experiments were performed using a Polaroid ultrasonic transducer and the associated breadboard electronics [14]. Measurement were taken on the effect of target range, incidence angle and offsets.

As a lateral guidance concept, the ultrasonic has the same inherent problem cited above for side looking radar and thus doesn't meet **PATH** goals.

4.3 CRITIQUE OF CONCEPTS

The method of obtaining lateral position from a positive guideway was suggested as a great enhancement of the eventual implementation of AHS [25]. The radar sensing system uses this kind of passive reference system and all active elements are vehicle based. As for the accuracy of eventual radar systems, it appears that with some redesign, performance should eventually be better than obtained from these experiments.



ACOUSTICAL SYSTEM

- ' A REFLECTOR SYSTEM REQUIRED
- ' NO ROADWAY POWER REQUIRED
- ' NOT AFFECTED BY WEATHER
- " ACCURACY ??
- ' AFFECTED BY NOISE

Figure 9

However, in the course of the full-scale testing, it was determined that the rigidity of the reflection surface must be maintained in order to provide sufficient signal level at the receiving antenna. This could mean that a lot of maintenance may be needed with this type of system. The system would also need a reference wall for every lane, if it is to be used in the urban area. This does not appear practical in areas of intersections or freeway exchanges,

The acoustic sensing principles have been successfully applied as vehicular detector⁸ for traffic control. In light of this, the technical risks involved in applying this technology to automated vehicle systems appears low. The potential low cost of an acoustic measurement system make it an attractively alternate to other more expensive systems. The ability to use the same ranging system to satisfy the requirements of longitudinal navigation as well as lateral control could reduce overall system development and maintenance cost.

However, there exist several drawbacks to the use of acoustic ranging. One is the sensitivity of the velocity of sound to the local air properties, and the accuracy of the system is affected by target angle of incidence and offset relative to the center line of the beam. The acoustic system is range limited (30-40ft) due to the high attenuation of the sound pulse by the air. The signal-to-noise ratio of the received echo can also be reduced by precipitation and high frequency external noise sources. Doppler shift is another consideration.

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