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FEASIBILITY STUDY OF ITS DRIFTING-OUT-OF-LANE ALERT SYSTEM

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INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS MANAGED BY THE TRANSPORTATION RESEARCH BOARD (TRB)

This investigation was completed as part of the ITS-IDEA Program which is one of three IDEA programs managed by the Transportation Research Board (TRB) to foster innovations in surface transportation. It focuses on products and result for the development and deployment of intelligent transportation systems (ITS), in support of the U.S. Department of Transportation's national ITS program plan. The other two IDEA programs areas are Transit-IDEA, which focuses on products and results for transit practice in support of the Transit Cooperative Research Program (TCRP), and NCHRP-IDEA, which focuses on products and results for highway construction, operation, and maintenance in support of the National Cooperative Highway Research Program (NCHRP). The three IDEA program areas are integrated to achieve the development and testing of nontraditional and innovative concepts, methods and technologies, including conversion technologies from the defense, aerospace, computer, and communication sectors that are new to highway, transit, intelligent, and intermodal surface transportation systems.

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EXECUTIVE SUMMARY

This final report describes results of the ITS-IDEA project, "Feasibility Study of ITS Drifting Out of Lane Alert System," contract no. ITS-5 The objective of this Type 1 project was to determine the feasibility of using either radio frequency (RF) or infrared (IR) technology to detect roadway boundaries. The work examined whether roadway boundaries can be detected by a vehicle that uses relatively low-cost electronics to sense suitable paint stripes as illustrated in figure 1.

Results indicate that both technologies may indeed be used to detect suitable paint stripes, but further refinement is necessary, and important issues remain to be addressed.

Two RF technologies based on metal detection techniques were tested. Both RF techniques use transmitting and detecting electromagnetic coils to probe the magnetic characteristics of the environment, but they differ in the type of signals used to excite the transmitter coil, and also differ in the signal characteristics observed by the detector as indicated in the figure below.

The first RF approach is based on a tuned frequency transmitter and detector system, commonly used in low-cost, commercially available, portable metal detectors. Although implementation in the form of a metal detector is not optimal for an ITS application, the test results confirm that it is possible to detect moderate amounts of iron filings, which are a candidate material to be mixed into roadway boundary paint. The continuous RF method is capable of detecting 20 gms of iron filing powder at distances up to six inches. This quantity can be detected whether the powder is concentrated in one spot, or spread out on an 8.5 x 11 sheet of paper. The laboratory tests also confirm that buried metals are easily detected. Steel reinforcements in the laboratory concrete floor are detected up to 8 inches above the floor. Therefore, methods to discriminate between roadway targets (boundaries) and other electromagnetic "trash" is necessary.

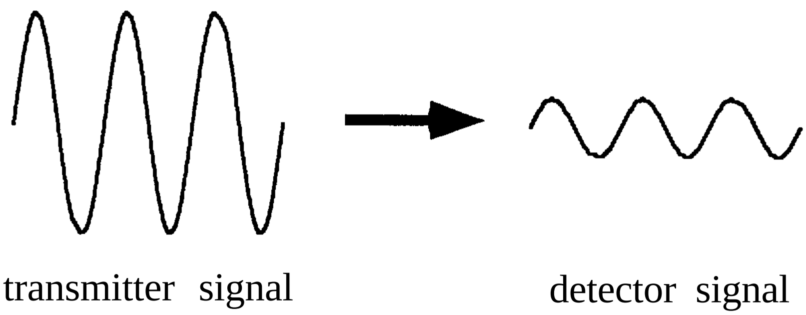
The second RF approach investigated uses an electromagnetic pulse. which generates in the target material eddy currents that in turn create a detectable field. In principle, different materials give different return signals, so discrimination between desired targets and other electromagnetic materials (roadway reinforcements steel, bridge steel, etc.) should be possible. The project work confirms that the pulse method can be used to detect steel. The pulse RF technology has not been tested as thoroughly as the continuous RF method, but detection of steel at a distance of 6 inches has been confirmed. Discrimination of different materials is theoretically possible, but hasn't been confirmed in this work. State-of-the-art metal detectors process only the information in the leading portion of the detector signal as indicated in the shaded portion in the figure above. More sophisticated signal processing would yield better discrimination between the target and other materials.

Selection and prototyping of a candidate IR technology as the edge of lane detection sensor was performed in parallel with the study of the RF prototype system. Infrared light emitting diodes and photo detectors of the type commonly found in remotely controlled consumer electronic products (e.g. TVs, VCRs) are used in the test circuit. The system consists of an oscillator operating at a fixed frequency to drive the transmitter diode(s) in a pulse fashion, and a tuned high gain amplifier in the detector. Detection of infrared energy by a simple threshold detector is unsuitable, since the outdoor environment contains a high level of IR energy. The use of a pulsed signal is an effective coding method to improve the selectivity of the system. The technique tested can be likened to amplitude modulation (AM) used in radio broadcast application. IR technology is feasible for detecting a roadway boundary, but high levels of background IR energy can confuse the system. In addition, the method is not suitable in weather conditions that obstruct the target stripe (e.g. snow), and does not perform well in rainy conditions. The IR detector system developed easily discriminates between light and dark backgrounds. Yellow or white backgrounds can be easily detected up to 12 inches away. If the detector is positioned at a 45_ angle to the target, detection is still achieved at a height 14" above the target. Much greater distances can be achieved with improved electronics, but this was not explored in this project.

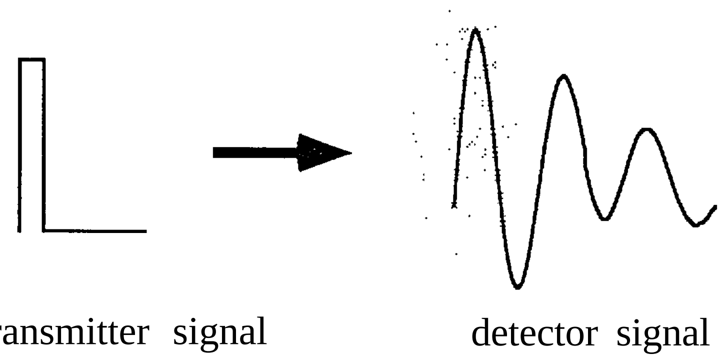
Four types of yellow paint, a glass bead additive, and iron tiling powder were used to construct two families of paint stripes, one suitable for testing IR detection, and the second one suited for the RF tests. Tests of the paint stripes reveal that yellow or white highway striping paint is detectable by the IR system without modification, and doping the paint with glass bead does not enhance IR detection. Although the RF techniques can detect iron filing material, the doping of paint stripes with iron filings is unsuitable, as the color change is significant, and it is difficult to achieve a sufficient concentration. Other electromagnetic sensitive materials should be investigated as candidates for use with lane marking paints.

It is recommended that further study of the RF technology be conducted. The investigators are advised that the U.S. Navy has a wealth of information in this area. This should be explored. The IR technology has certain benefits over RF methods, but is not suitable in inclement weather conditions. However, it remains a potential technology for applications where weather is not a factor. One such application is guidance assistance for highway painting striping equipment. The project investigation has studied a laser-based method under development by CALTRANS. The IR technology has a similar potential.

Continuous Excitation (First Approach)



Pulse Excitation (Second Approach)



Principles of electromagnetic sensing approaches

IDEA PRODUCT

This project investigates two concepts for low-cost automated systems that can sense when a vehicle drifts out of its lane and then alert the driver. Systems based on vehicle-mounted infrared (IR) or radio-frequency (RF) sensors that can detect reflective paint stripes on the lane boundaries are evaluated. The feasibility of different sensor designs and of paint modifications to improve stripe detectability are considered. It is envisioned that the alert system would be activated by the driver on the open road (like cruise control), or it could be automatically activated once the vehicle reaches a threshold speed. The essence of the system and its operation are illustrated in Figure 1.

CONCEPT AND INNOVATION

The concept of vehicle automatic guidance along a specially prepared highway has been experimentally proven. In fact, the automatic unmanned control of a vehicle on an ordinary highway has also been proven feasible using advanced electronic vision sensing and computer technology [3]. However, this technology remains economically and socially unfeasible at this time for guidance of individual highway vehicles. Most concepts require sophisticated and costly modifications to either vehicles, roadway systems, or both, and additionally, the public is not ready to mm over guidance of their highway vehicle to an electronic guidance system.

Two unique aspects of this IDEA innovation are the relatively low cost of modifications to either vehicle or roadway, and the fact that focus is placed on aiding the driver instead of performing driver tasks. The product serves only to alert the driver of vehicle drifting "out of lane." The innovation will not be capable of exercising control over vehicle functions or to perform corrective actions, such as steering the vehicle back into the lane. The level of technological sophistication in this product will not approach that which has been used in guided vehicle research, yet the output of the system will provide driver cues to correct vehicle heading, and thus reduce the rate of traffic fatalities.

The underlying technical principle is to use either RF or IR technology to detect either the presence or absence of the roadway boundary, as illustrated in Figure 2. The roadway boundary will be marked with either a ferromagnetic or IR reflective paint to be detected by the vehicle electronics. The roadway paint strip will require a new innovation, especially in the case of RF technology, but the basic principIe should be similar to that already used to apply paints with glass beads.

INVESTIGATION

Numerous highway accidents and deaths each year result from one-car accidents. These are usually the result of cars either drifting off of the road or out of their lane because of driver inattention, dozing or driving under the influence (DUI). In 1990, motor vehicle accidents caused 46,300 deaths in the U.S. [l]. Of these, 12,900 fatalities (or 28 percent) resulted from vehicles going out of their traffic lane and colliding with a fixed object in one car accidents. Hence, an ITS component designed into vehicles and highways to alert a driver when his or her **vehicle** drifts out of lane could potentially save many lives.

The work reported here represents an intermediate step on the path of ITS development which focuses on a "driver-aided" lane guidance alert system. The system appears to be technically and economically feasible with current technology, does not require the driver to relinquish control of the vehicle, and requires minimal modifications to the highway system. Exploring the feasibility of this system was the purpose of the research work reported here.

Objectives and Scope

The long-range objective of the investigation is to reduce instances of one-car accidents, and the resulting deaths, by developing a technically and economically feasible intelligent transportation system (ITS) drifting out of lane alert system. The specific objectives of this feasibility study are:

1. To perform limited theoretical analyses of two ITS models, i.e., an inductive sensor/ ferromagnetic paint stripe model and a infrared reflective paint stripe model, as a first step in evaluating the technical feasibility of using each model as an on- vehicle system to alert drivers when they drift out of their lane of traffic.
2. To design a research and development (R&D) test model of each system based on theoretical analyses.
3. To establish the primary operational conditions under which the systems must perform.
4. To conduct a laboratory testing program to evaluate the performance and technical viability of the systems.

Two detection techniques appear to be good candidates for low-cost realization of a road boundary detection system. The two techniques make use of radio frequency (RF) and infrared (IR) technologies, and the study is limited to these two technologies. Both schemes utilize sensor assemblies attached under each front fender forward of the front wheel wells of the vehicle, and both are designed to detect a special paint stripe as an indicator of the road or lane boundary. The study is limited to a laboratory tabletop investigation of the two technologies using laboratory model sensors and paint stripe markers.

Description of Operating Conditions

To be technically viable, the ITS systems under study must be robust and able to perform in a reliable manner under harsh "environmental" operating conditions. These include climatic operating conditions of,

1. Temperature extremes of -20-F to 120-F
2. Rainy conditions
3. Light ice/snow conditions
4. Foggy conditions
5. Morning frost and dampness on roadway
6. Daytime and nighttime operations.

and man-made highway operating conditions of,

1. Body/material of vehicle
2. Adjacent/nearby vehicles
3. Adjacent/nearby bridge curbs, guard rails, truss members, etc.
4. Bridge metal grid decks, armored joints, finger expansion joints, deck rebar, etc.
5. Pavement dowel joints
6. Varying pavement colors and textures
7. Stripes of paint/glass or thermoplastics.
8. Highway broken stripes
9. Old/degraded highway stripes (need restriping)
10. Stripes to be crossed when purposely passing other vehicles
11. Regions of no stripes, or change in striping pattern, such as at off ramps
12. Close proximity of dangerous drop-offs and obstruction to lane edge lines
13. Light dirt, debris, water on roadway
14. Highway joints, "potholes," patches, etc.
15. Limited closeness of sensor to roadway (approximately 6" minimum with 12" being preferable)
16. EM fields and noise
17. IR background and noise

The RF sensor will not be as sensitive to the climatic operating conditions as the IR sensors. However, the IR sensors are less sensitive than RF technology to most of the man-made operating conditions cited above. Table 1 lists the operating environmental conditions for the sensors, and indicates the anticipated sensitivity of each sensor (RF and IR) to the various conditions. The operating conditions marked by an asterisk (*) in Table 1 were tested in the lab during the investigation to verify and quantify their sensitivities. It should be noted that whereas one would like a sensor/lane marking system which will perform reliably under all conditions, a system which performs reliably under the most important operating conditions in Table 1 may still be a viable system.

Technical Issues and Testing Program/Results

Four types of yellow paint used for roadway boundaries and a sample of glass bead additive have been obtained from the Alabama Department of Transportation. The paint variations include a solvent-based paint (Type #897, not used in automatic spraying) and three water-based paints (Type #884, #886, #894). The glass beads are of the type used by the Alabama Department of Transportation (ALDOT) to increase the visible light reflectivity of the paint. In addition, iron filing powder appropriate for adding to paint is used. Using these materials, paint stripe samples are constructed by applying various combinations of paint and additives to the surface of thin wooden plates (4" W x 18" L). The wood plates are cut from 3/16" thickness wall paneling, and the paint samples applied to the raw side of the wood. Three families of paint stripe samples are constructed:

i) plain stripes with no additives (four types of paint in this class),
ii) stripes with iron filings mixed in, and
iii) stripes containing the glass bead additive.

The second class of paint stripe sample **is** unsuitable for certain testing purposes. The original intent was to support the testing of the RF-based techniques. However, viscosity of the paint changes dramatically as the iron filing powder is mixed in. Based on preliminary tests with the continuous RF detector and plain iron filings, a ratio of 20 grams iron filing to 125 ml of paint is selected. The doped paint can not be easily applied to the wooden stripes by hand and paintbrush techniques, and the iron filings tends to gather into "clumps" on the surface. If the mixture is thinned with additional paint, the density of ferromagnetic material is greatly decreased. An option for applying roadway paint over a layer of iron filings has been considered. That is, create a "sandwich"-like structure: apply a foundation of roadway paint to prime the surface, then immediately lay a bed of ferromagnetic material on the premiered surface, and finally spray-cover the ferromagnetic material with paint. Discussions with the ALDOT, however, raise concern that this striping system is not durable.

A second discovery concerning the iron filing doped paint is a change in color. The yellow paint color is lost. This problem can be resolved with an improved technique for doping, such as the sandwich scheme described above. The problem also raises the question of the long-term behavior of ferromagnetically doped paints, e.g. will the paint stripes "rust?" Other RF sensitive materials should be investigated as candidates for paint additives for the highway stripes.

TABLE 1 Drifting Out of Lane Detector Operating Conditions

Operating Conditions	Anticipated Sensitivity	
	EM Sensor	IR Sensor
Climatic		
Temperature (-20-F -120-F)		X
*Rain		X
Light Ice/Snow		X
Fog		
Morning Frost/Dampness		X
Day/Night		X
Man-Made		
Body of Vehicle	X	
Adjacent Vehicles	X	
Bridge Curbs, Guardrails, Truss Members, etc.	X	
Bridge Metal Decks, Joints, Rebar, Etc.	X	X
Pavement Dowel Joints	X	
*Varying Pavement Colors & Texture		X
Stripes of Paint/Glass or Thermoplastics	X[a]	
Highway Broken Stripes	X	X
Old/Degraded Stripes	X	X
Stripes Crossed When Passing Vehicles	X	X
Regions of No Stripes or Change in Strip Pattern	X	X
*Close Proximity of Danger to Lane Edge Line (can sensor act at an angle to give early alert)	X	X
Light Dirt, Debris, Water on Roadway	X	X
Highway Joints, "Potholes," Patches, etc.	X	X
*Limited Closeness of Sensor to Roadway	X	
EM Fields and Noise	X	
IR Background and **Noise**		X

[a]EM sensor will require new paint stripes (with magnetic material added to stripes).

A jig is used to permit the careful, reproducible positioning of the paint stripe models relative to the transmitter/receiver electronics. This jig, shown in Figure 3, consists of a horizontal aluminum channel supported by vertical, threaded steel rods. The height of the channel is adjusted by turning nuts on the threaded rods. The ahuninum channel is open in the center, allowing the transmitter and detector electronics to face downward, facing the target paint stripe sample. The channel is four feet long, so that transmitters and detectors can be positioned at different locations horizontally relative to the target.

RF Metal Detection Approaches

Two RF-based techniques are considered in the project. Both methods are similar in using a two-coil system to emit and detect electromagnetic radiation [4-7]. In these schemes, one electrically conducting coil is used to generate a time-varying magnetic field. A second coil is used to detect the presence of an RF field.

The simpler electromagnetic system (see first approach in Figure 4) excites the transmitter coil with an alternating current (ac), thus creating the RF field. Presence of ferromagnetic material between transmitter and receiver coils changes the magnetic reluctance, resulting in variations of the magnetic flux. A decision of whether or not a target is present is based on the strength of the detected magnetic flux. While this method is very simple and straightforward to fabricate, there are significant shortcomings. The variation in detected magnetic fields can be due to several factors such as increased distance between transmitter/receiver and target due to changes in the vehicle attitude, or variations in magnetic properties from one target material to another. It can also be difficult for this first technique to discriminate between different materials, e.g. iron filings vs. roadway reinforcement steel.

General feasibility of electromagnetic detection was tested in the form of a commercially available metal detector (Micronta(R) 4003). The battery powered unit was studied and then used to characterize the laboratory environment. Finally, different amounts of iron filings were used as targets for the detector. The metal detector unit excites the transmitter coil continuously at 15 kHz. In typical operation, signal magnitude in the receiver coil is about l/1000 that used in the transmitter. The manufacturer claims that typical sensitivity is approximately 5" for a US (25c) quarter.

The laboratory room in the Auburn University Electrical Engineering department is constructed of steel-reinforced concrete, and every section of the entire floor triggers the metal detector at the machine's lowest sensitivity setting. However, sensitivity of the system decreases rapidly with distance from the floor, as expected, and no triggers occur once the system is beyond 8 inches (20 cm) above the floor. No triggers occur over a clean benchtop, which is used as the baseline surface for further tests.

Results of detection test using iron filings are described next. Twenty grams of filings can be consistently detected at distances up to 6 inches (15 cm). The detector is capable of detecting the iron filings whether in a concentrated pile or spread out across a sheet of letter-sized paper (8.5" x 11"). However, the commercial detector is not effective beyond this range, regardless of the amount of iron filings used in the target as indicated in Figure 5.

No conclusive results can be obtained about detecting iron filing mixed with roadway boundary paint. As mentioned earlier, the chief difficulty lies in achieving a suitable viscosity for application while maintaining a significant density of ferromagnetic material. Slight amounts of iron filing powder rapidly thickens the paint, making it very difficult to apply. This points to a need to devise a different method for applying or fabricating a paint stripe with ferromagnetic properties.

A second, more sophisticated electromagnetic detection method uses a pulse signal (see second approach in Figure 4) to drive the transmitter coil, and relies on the different conductivity properties of materials [6]. When a time varying electromagnetic field impinges on a material, eddy currents are induced to flow in the material. These in turn cause secondary magnetic fields to be generated. As the eddy currents die out, the electromagnetic field they created also decay. Materials with higher electrical conductivities sustain eddy currents longer, so the associated field decays at a slower rate. Therefore, the second RF technique is sensitive to an electrical characteristic of materials, rather than the magnetic properties.

The principles of the second RF method have been experimentally verified in the investigators laboratory work. Detector signal shape varies with material, so greater discrimination is theoretically possible compared to the continuous excitation method. However, known methods described in the literature concentrate only on the early portions of the detected signal, due to limited capability of analog electronics [7]. Potential improvements are possible with spectral analysis, but that requires more sophisticated (and costly) analysis by sampling and digital signal processing.

Infrared Detection Approach

Both IR transmitter and detector circuits are designed to operate from standard automotive electrical voltage (12 V). Prototype electronics are shown in the photographs of Figures 6 and 7.

The IR transmitter circuit shown in Figure 8 uses a 555-type integrated circuit timer to produce a constant frequency pulse signal (approximately 4 kHz). Transistors Ql, Q2, resistors Rl-R4, RP, and capacitor C2 are used to tune the oscillator frequency and pulse duration. The output of the 555 timer (pin 3) controls the transistor Q3, which served as a switch between the 12 volt supply and the infrared light emitting diode (resistor R5 protects the IR diode from over-current). The pulse signal serves two useful purposes. First, the IR diode is transmitting only during brief instances, so that instantaneous transmitting power can be made very high, while the average power dissipated is much lower. Second, the pulsed IR signal is highly "artificial" in the sense that it is man-made, and remains easily distinguishable from high levels of constant or random "natural" background IR radiation.

The IR detector circuit shown in Figure 9 consists of an IR photodiode (Liteon(R) LT1032 or Panasonic(R) PN323BPA), a high gain amplifier "A," tuned amplifier "B," an envelope detector circuit (diode, capacitor, and resistor), and a comparator amplifier. The amplifier "A" has a high gain and a high input impedance to prevent excessive loading of the low level photodiode output signal. The detected signal is a pulse train that excites the tuned amplifier "B," which has a very high gain at the resonant frequency of the L-Cl circuit (tuned to match the transmitter frequency), but the gain drops greatly at frequencies above and below the tuned frequency. In this way, the detector is sensitive only to IR signals that match the transmitter frequency, so background noise immunity can be very high. The output of amplifier "B" is a sinusoidal signal that is half-wave rectified by diode D 1 and then filtered and threshold compared by amplifier "C." The threshold level is adjusted through potentiometer R6. The output of amplifier "C" is a high or low level that controls the output transistor Q, which serves as a switch for the annunciating device. In this circuit, the annunciator is simply a buzzer BZ1.

The IR transmitter and detector circuits perform well in controlled laboratory conditions. Results are summarized in Figures 10 and 11. Shown in Figure 10 is the detector output magnitude (amplifier B) for four different colors of paint stripe. A significant difference exists between reflections from yellow or white stripes vs. black or green stripes. Laboratory tests show that the addition of glass beads to the paint does not improve the IR system response. In fact, paint surface roughness introduced by uneven application of glass beads reduces the system response. This can be explained as the effect of energy scattering by the rough surface. The magnitude of the detector output signal as a function of detector angle with respect to the test sample is shown in Figure 11. From the tests, it is concluded that a system with "side-looking" capability, as illustrated **in** Figure 12, is feasible.

Such a system would provide earlier notification to the driver. Performance of both circuits can be further improved by adjustment of transmitter circuit parameters to achieve higher transmitting power, and redesign of the detector for greater sensitivity.

It is also noted in laboratory testing that the IR system can be "blinded" by excessive background energy. This can be observed by turning the electronic eye toward a window. The effect is analogous to a bright light being shined in one's eyes. Pulse modulating the transmitter signal is of no use for this problem. Signal strength must be reduced, e.g. like wearing sunglasses.

PLANS FOR IMPLEMENTATION

Two avenues of potentially fruitful research and hopefully later implementation have emerged from this study. One relates to making use of IR technology/ sensors and current highway paint stripes to improve highway paint striping maintenance operations. This and the entire area of highway maintenance activities should be carefully studied for ITS applications. This area could serve as a very useful test and development area for later ITS applications to vehicles using our highway systems. The other avenue is to further investigate the EM sensor and corresponding lane marking stripes. This system is better suited to the highway operating environment, and should be technically and economically feasible to employ.

Highway Maintenance Application

Following recommendations from Dr. Wojtek Wiercienski of the Ontario Ministry of Transportation, application of the technology to highway paint striping maintenance equipment was considered. Dr. Wiercienski indicated that Caltrans was working on a guided lane striping system. Upon contacting Caltrans, we learned that they are working with the Advanced Highway Maintenance and Construction Technology Center at UC Davis to use laser-guided automation of the outrigger (where the paint spray nozzles are located) of paint striping tracks to improve efficiency and safety. After learning more about Caltrans' developing system, it appeared that the paint striping operation was a good potential ITS application for the IR technology.

A field visit with a paint-striping crew of the ALDOT was taken in August 1994 to examine the issues of highway paint-striping, and to assess the feasibility of improving that operation with infrared-based guidance and control. ALDOT officials indicate that paint striping operations are quite tense and stressful for the paint truck driver and the paint stripe operator. Both must stop periodically and rest to get relief from the tenseness and ansiety. There is good potential for improving the productivity, quality, safeness, and reducing disruptions to the traveling public via the use of guidance aids. ALDOT officials indicate that annual highway paint striping quantities and cost for FY94 are as shown in Table 2. Additional costs for city and county highway systems would translate into large annual expenditures for this one maintenance item.

The investigators believe that there is a significant potential for improving the productivity, safety (for both the striping crews and the traveling public), and mitigating interference with traffic flow by automating part of the lane striping operation. The locations for use of sensors are indicated in the sketch shown in Figure 13. ALDOT officials indicate a willingness to modify one of their existing paint striping trucks, or to spec out an IR sensor/guidance assistance system for a new truck (the next time they order one) to test the system.

Enhanced RF System

Because the RF approach can operate under most any climatic conditions, and can be designed to perform reliably under most man-made operating conditions, the RF sensor-highway marking system should be investigated more closely to identify a reliable and feasible system. A stronger RF signal and an improved RF sensitive paint stripe additive are needed, and both are technically and economically feasible. Also, periscoping sensors could be used if necessary to improve the strength of the EM signal, and/or to position the sensor to provide earlier detection of approaching lane marking stripes. Mr. Milton Mills of FHWA has indicated that the U.S. Navy has performed much research in the RF area and has experience with many RF sensitive materials. Review of their work will be helpful in enhancing both the sensor and lane paint additive needed for a viable RF system. The attractiveness of the RF approach renders justification for further study and testing of this technology. Arrangements are currently being made to have a student do this further study next quarter.

CONCLUSIONS

Findings of this ITS-IDEA project are summarized as follows:

i) Two RF technologies for detection are analyzed - a continuous excitation and a pulse excitation. Both technologies can be used to detect iron filings, which may be suitable for mixing with roadway boundary paint.

ii) The continuous RF method, which was tested in the form of a commercial metal detector, is capable of detecting 20 gms of iron filing powder at distances up to six inches. This quantity can be detected whether the powder is concentrated in one spot, or spread out on an 8.5 x 11 inch sheet of paper. Laboratory tests also confirm that buried metals are easily detected. Steel reinforcements in the laboratory concrete floor are detected up to 8 inches above the floor. Therefore, methods to discriminate between roadway targets (boundaries) and other electromagnetic "trash" is necessary.

iii) The pulse RF technology has not been tested as thoroughly as the continuous RF method, but detection of steel at a distance of 6 inches has been confirmed. Discrimination of different materials is theoretically possible, but was not attempted. This method requires further development, and in particular, more advanced signal processing is required.

iv) The IR technology is capable of detecting yellow roadway paints (all four types tested), and is capable of discriminating between the paint and a dark background. The pulse modulation scheme for transmitting and detecting IR energy is feasible for this application. Yellow and white stripes are detected almost equally well, and can easily be detected up to 12 inches away. Black and green (grass-like color) give very low system response.

v) The IR detector can be positioned at a 45_ angle to the target, and detection is still achieved at a height 14" above the target. Much greater distances can be achieved with improved electronics, but this was not explored in this project.

vi) Present highway striping systems do not need significant modification to be detected by IR means. However, the IR method cannot be used where the stripe is obscured or in certain weather conditions such as rain or snow. The RF methods will require significant boundary marker modification, but offer the capability to be used in a wider set of environmental conditions.

vii) Addition of iron filing powder to roadway paint presents significant technical challenge. In particular, simple mising of powder with paint results in an unacceptably thick mixture for brush type application. Iron filing powder is not a suitable target material, and a design of an optimal RF target must be studied.

viii) Alternative RF sensitive materials should be tested to try to identify an appropriate material to add to highway stripings. The RF approach can be used in a wide set of environmental conditions.

ix) The IR technology requires good climatic conditions for reliable operation.

x) In the highway maintenance activity of lane restriping, good climatic conditions will always exist, i.e., this activity can only be performed when climatic conditions are good. Hence, application of the IR technology to assist in highway paint striping maintenance activities should be investigated.

TABLE 2
ALDOT HIGHWAY PAINT STRIPING”
QUANTITIES AND COSTS FOR FY94

Item	Quantity	unit cost	Total Cost
Striping Paint	1 10,866[b] gals	$4.25/gal.	$471,180
Glass Beads	720,630” lbs	$0. 18/lb	$129.713
Total Material Cost			$600,893
Personnel[d] + Equip. Rental Cost			$622,687
Painted Stripes in Place	110,866 gals. or 6,160 miles	$1 l.0365/gal or $198.63/mile	$1,223,580

[a]39,852 stripe miles or 27,000 lane miles in ALDOT’s system
[b]18 gallons of paint required per mile
[c]117 pounds of beads required per mile or 6.5 pounds per gallon of paint.
[d]4-man paint crews

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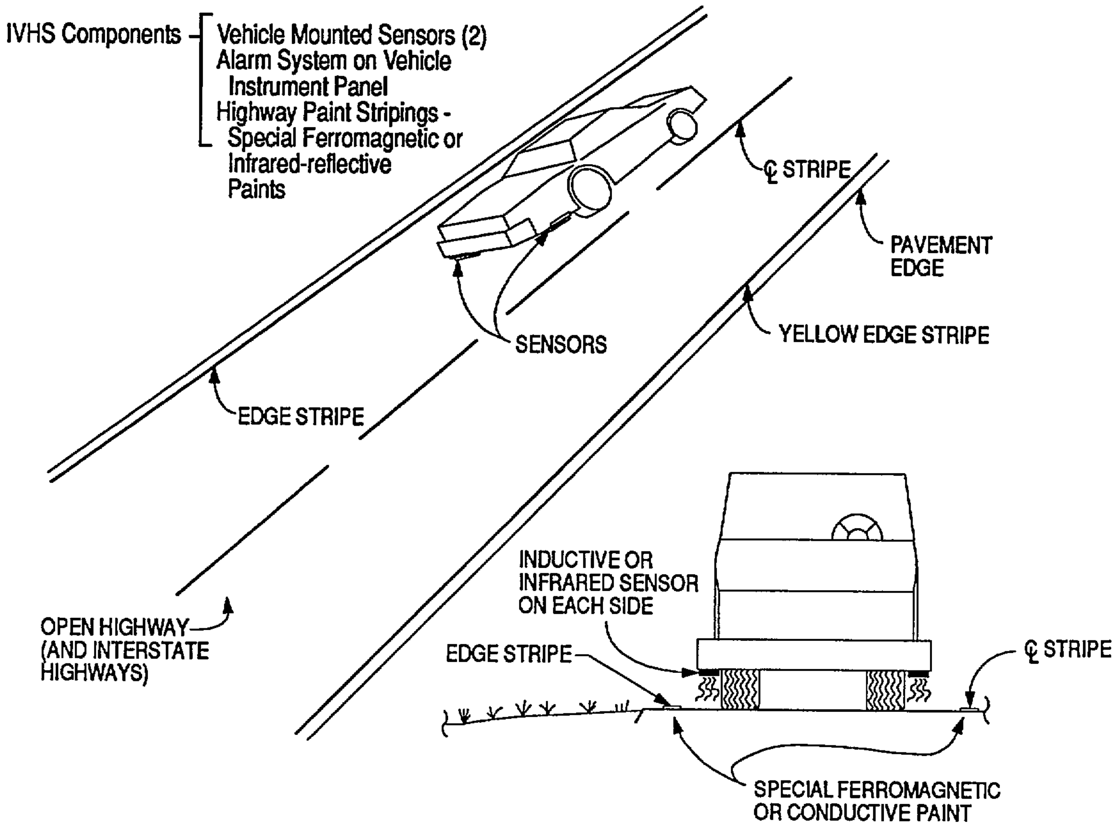

Figure 1 Illustration of IVHS Drifting Out-of-Lane Alert System

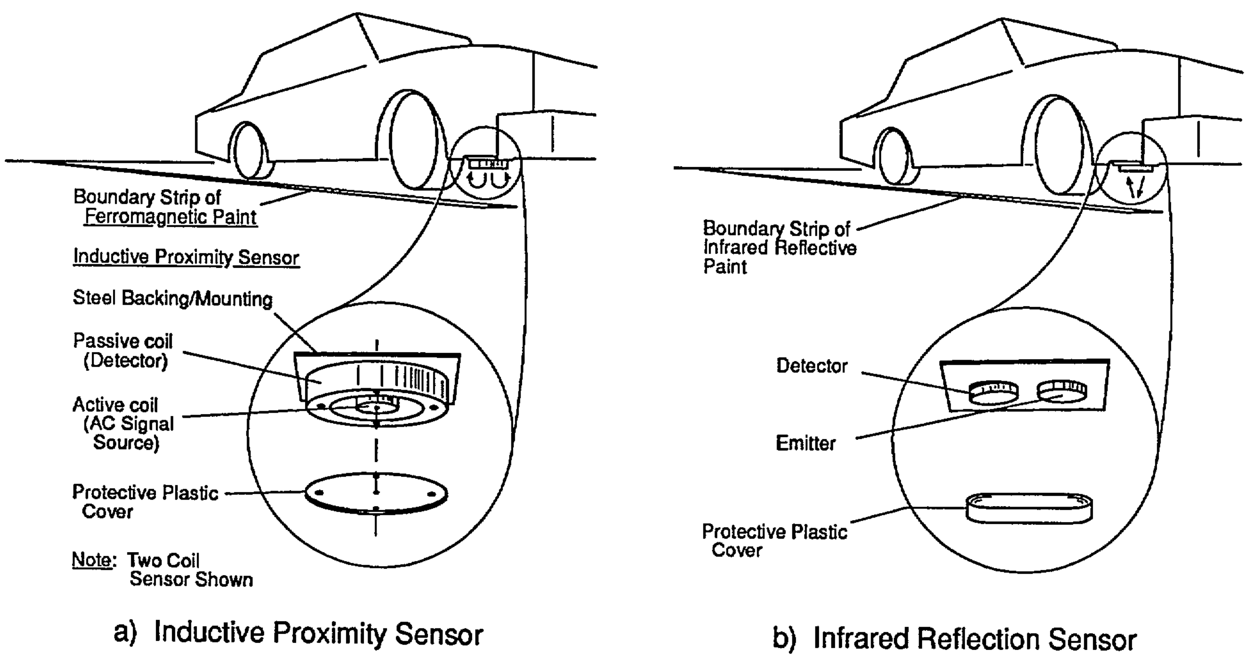

Figure 2 Illustration of Vehicle Mounted Detection Sensors

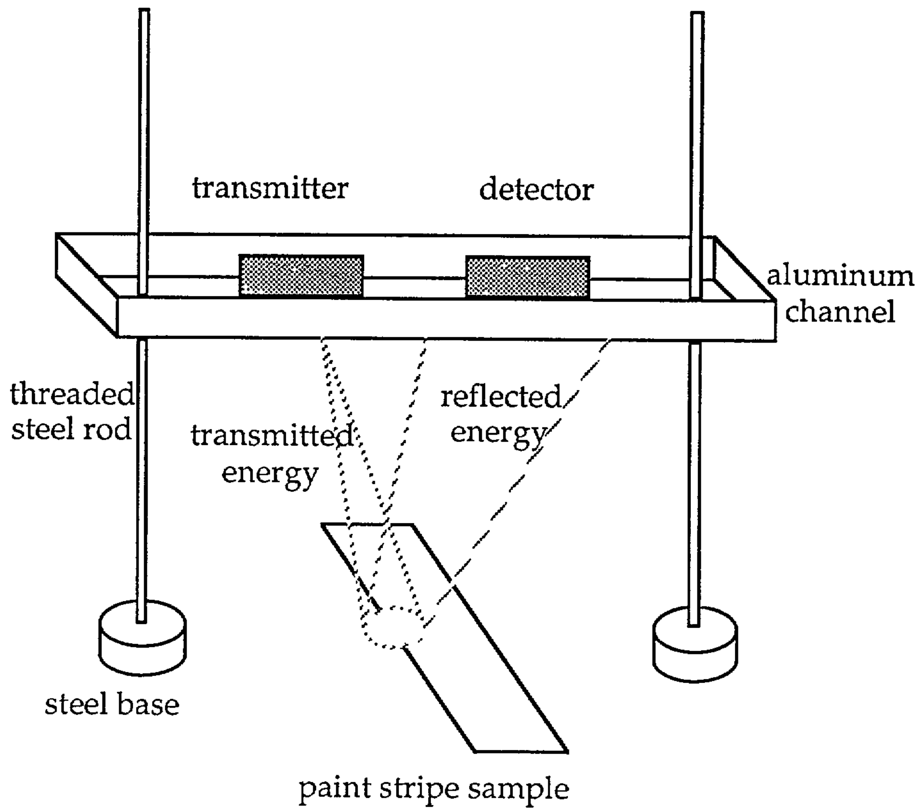

Figure 3. Sketch of jig constructed for benchtop tests.

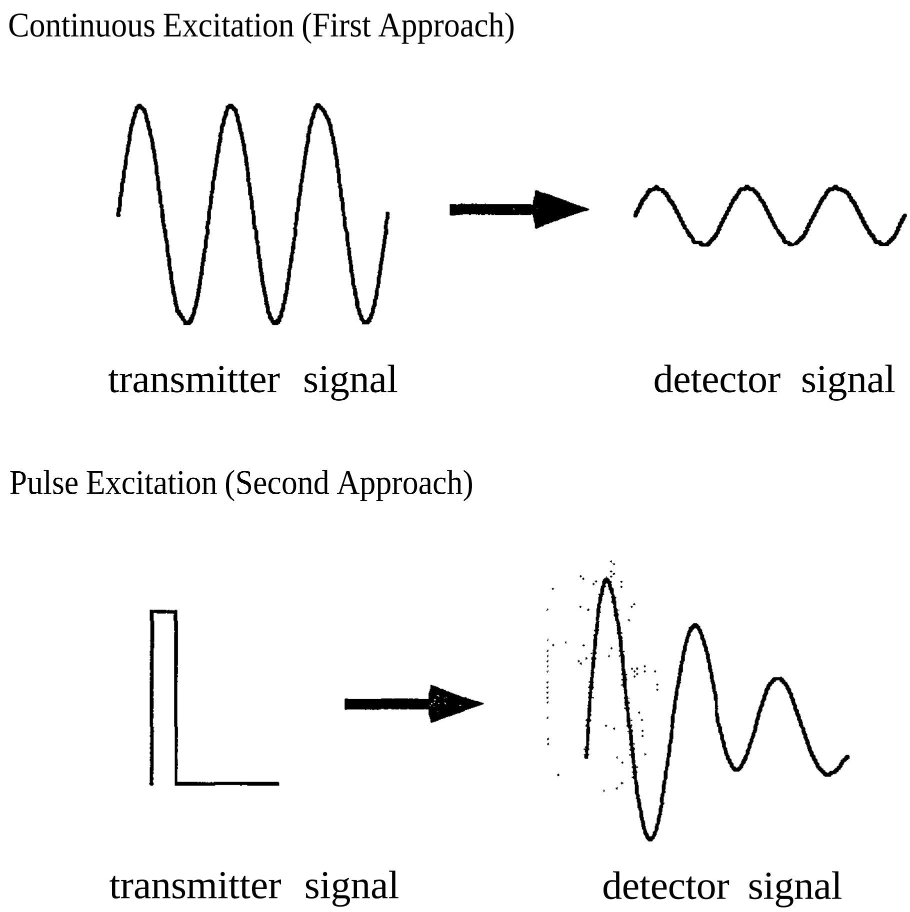

Figure 4. Principles of electromagnetic sensing approaches

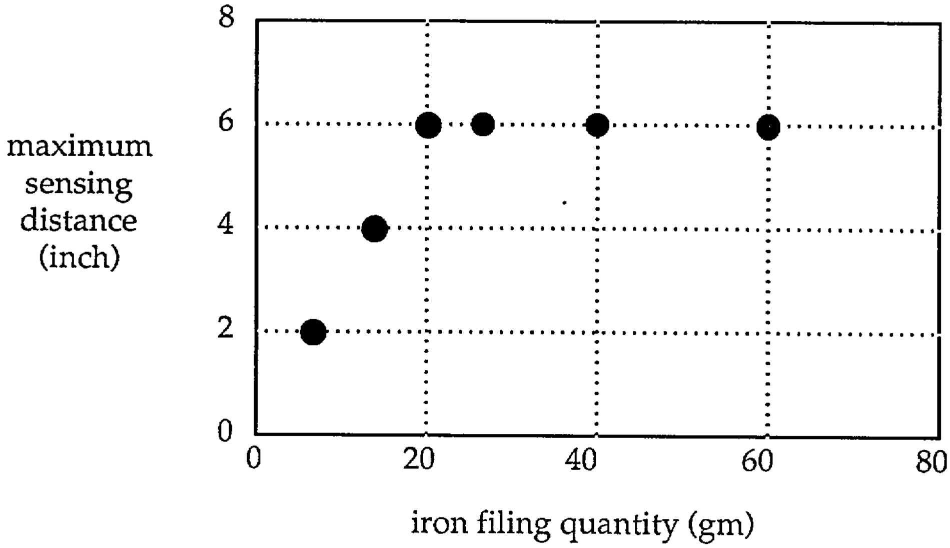

Figure 5. Response of EM system.

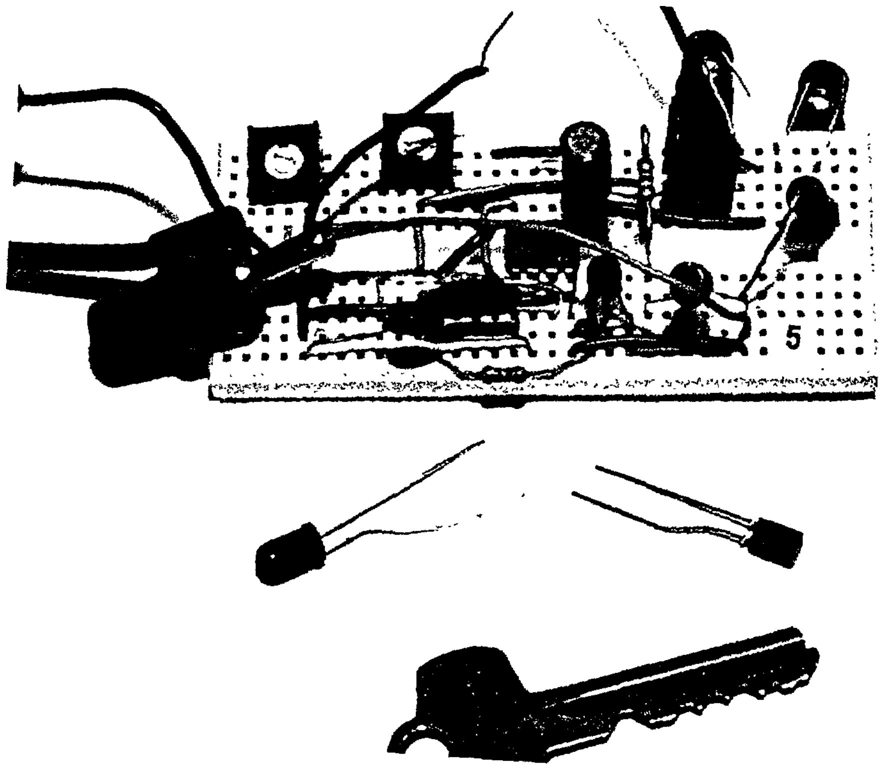

FIGURE 6. Photograph of prototype IR transmitter circuit with IR diododcs in foreground and room key for comparison.

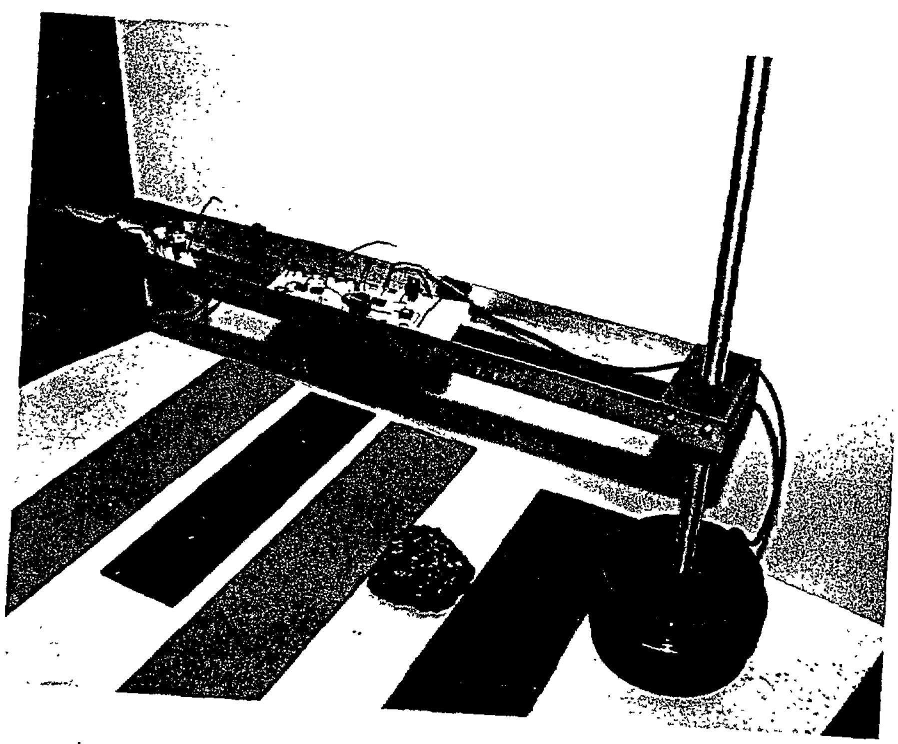

FIGURE 7. Photographof prototype IR electronics in test jig.

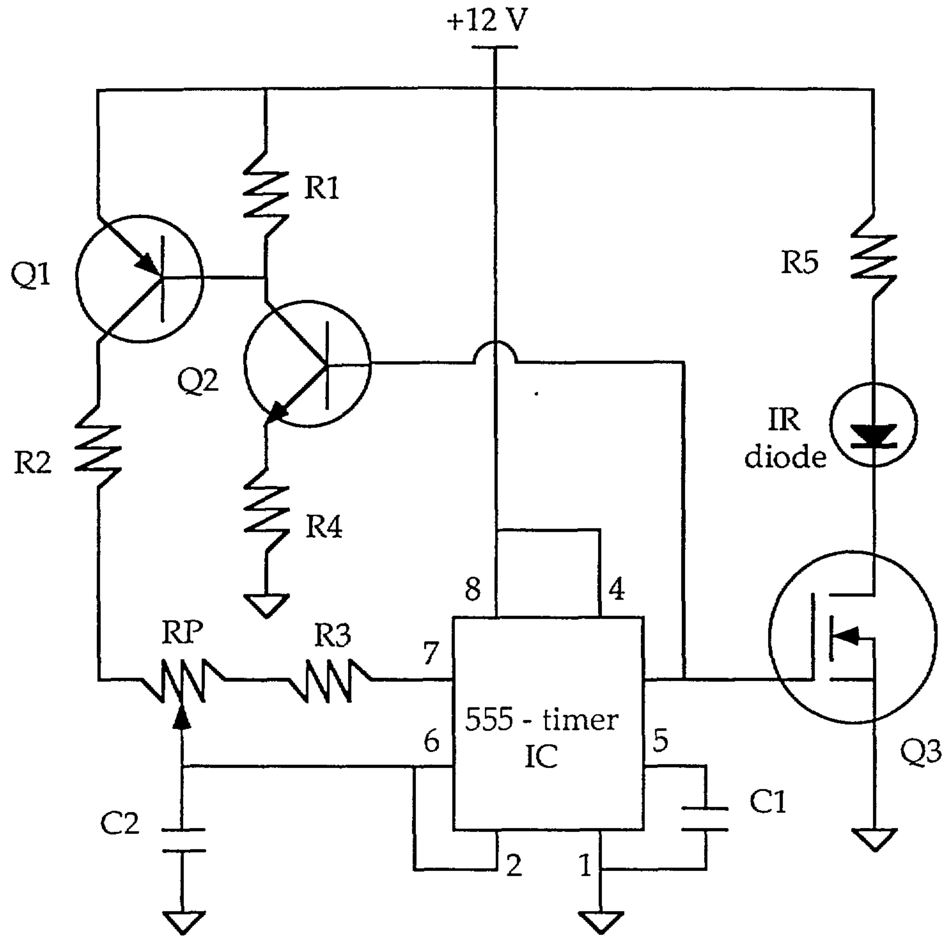

Figure 8. Schematic of IR transmitter circuit

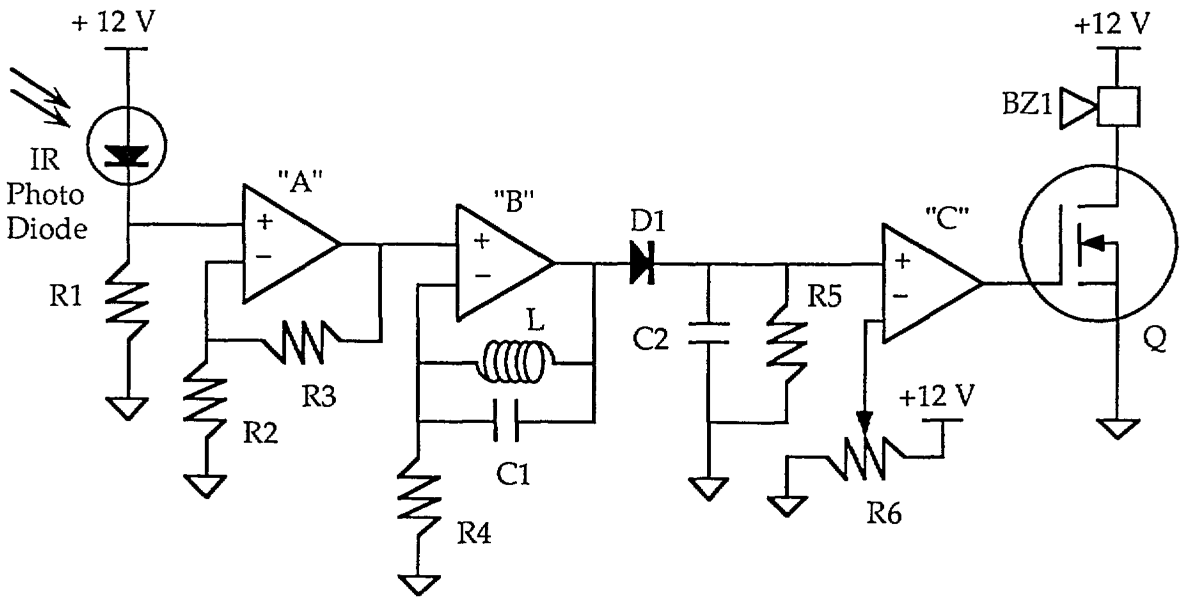

Figure 9 Schematic of IR detector circuit.

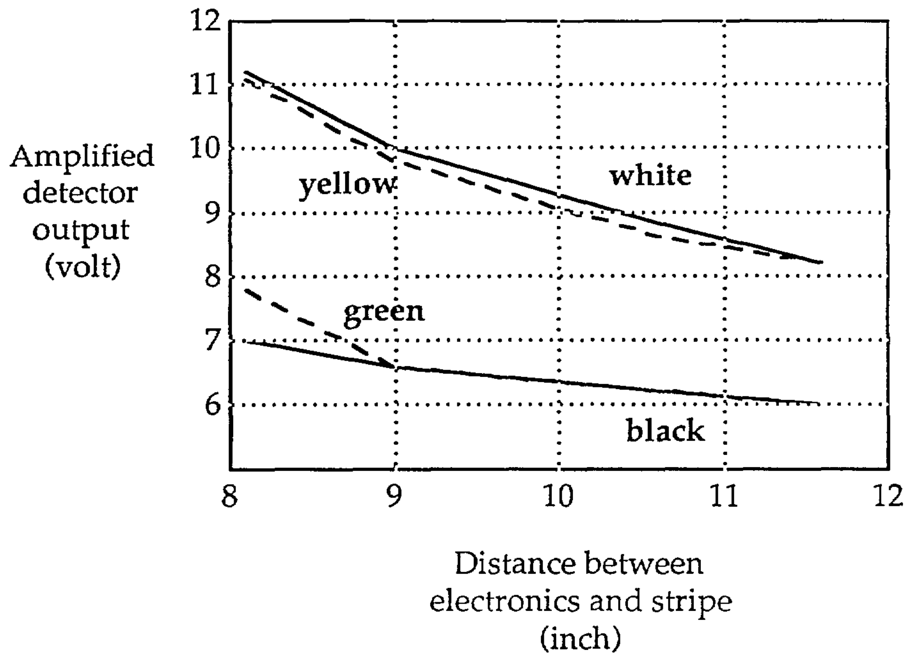

Figure 10 IR detector performance at different distances from target stripes. Four different colors are tested.

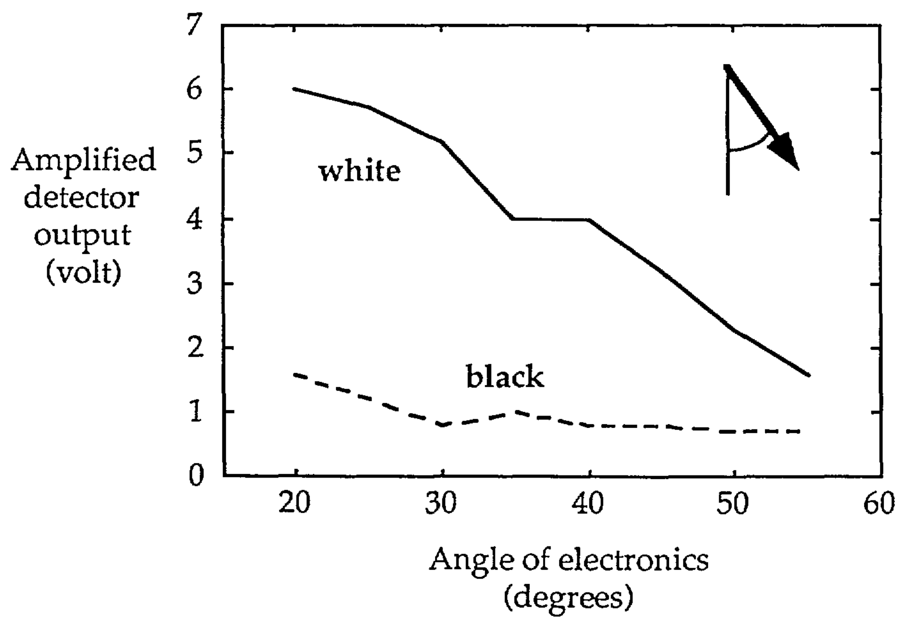

Figure 11 IR detector performance at different angles to the test sample. Electronics are 14 " above the table.

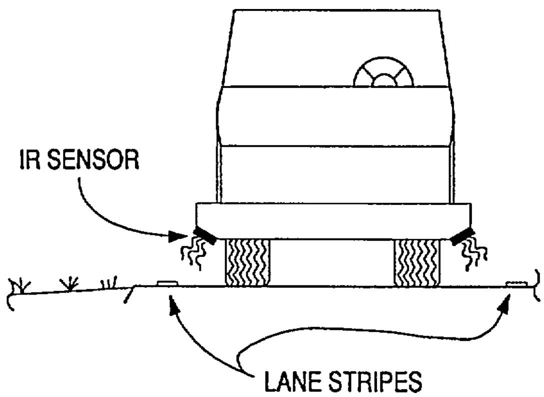

Figure 12 Side-looking IR Sensors

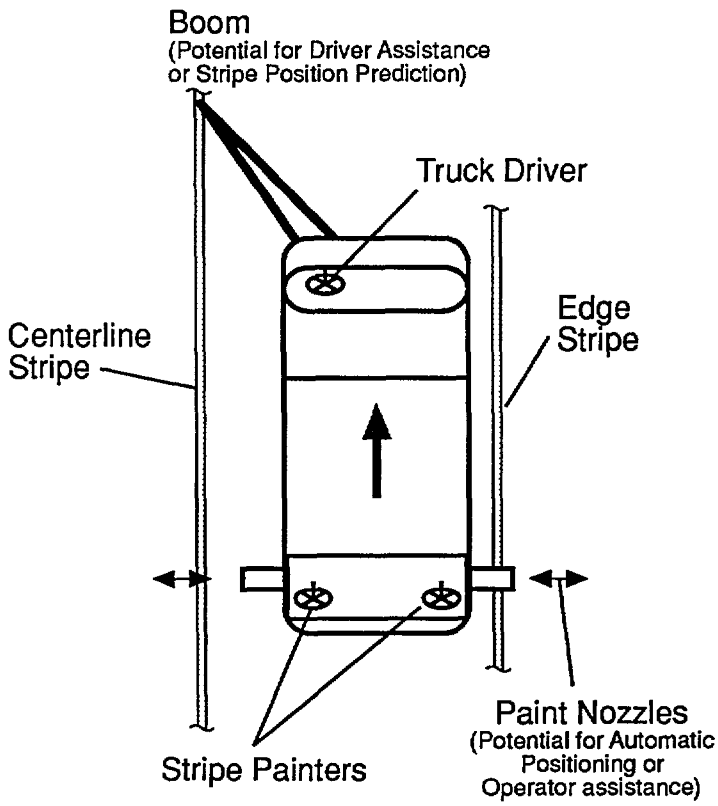

Figure 13 Potential Locations of IR Sensors to Enhance Paint Striping Operations