LONGITUDINAL TRAFFIC CONTROL BY INFRARED SENSING

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Two different types of infrared remote-sensing systems for longitudinal traffic control have been studied to prevent rear-end collisions and breakdowns in traffic flow and to improve the quality and capacity of traffic flow. A prototype of the infrared source-sensor has been built and tested in freeway driving, and some basic research on a self-contained infrared remote-sensing system was carried out. Because a control system of the car-following type has to restrict itself to vehicles in the same traffic lane, the problem of target identification in freeway traffic has also been researched. It appears that the present driver information system provided by traffic signs can be improved considerably by infrared sensing for the spacing of vehicles and by lane coding for continuous driver information and proper target identification. The source-sensor system has the disadvantage that all vehicles must be instrumented to make up an effective sensing system. The self-contained system can be introduced by leaving it to the individual driver whether he wants to spend money for equipment providing more safety and easier driving. If all vehicles could be joined in an infrared longitudinal control system, traffic capacity could be increased to about 4,000 vehicles/lane/hour at 40 mph on urban freeways.

•A CONSIDERABLE range of useful information could in principle be made available to the driver to increase traffic flow and to prevent accidents. Because rear-end collisions occur most frequently on urban freeways and expressways and because the stability of traffic flow is rather sensitive to disturbances in high-density traffic flow, remote-sensing systems were specifically studied for such traffic conditions. The broader context of the capability and the cost of competing systems was considered in the evaluation of the concepts and devices for remote sensing between vehicles. Sound, radio communication, and radar were studied as alternative systems before infrared was chosen as the most economic and promising remote-sensing system. Sound and ultrasonic devices were eliminated because of the broad spectrum of traffic noise and more specifically the exhaust noise of the reciprocating engine. Measurements would have to be made against a high level of background noise, and therefore the instruments for reliable sensing would be rather costly and complicated. Radar also is rather costly, and identifying the relevant target in freeway traffic poses a difficult problem. Another consideration was that the remote-sensing system must essentially be a vehicle-contained system and that auxiliary roadside equipment must be kept to an absolute minimum. This condition precluded the use of a radio-controlled remote-sensing system.

The criteria for the highway traffic sensing system were concluded to be as follows:

1. The system must be a longitudinal control system if the improvement of traffic safety on divided highways is a primary objective (on rural Ohio freeways rear-end or stopped or stopping vehicle accidents form 36.4 percent of all accidents, and on the John Lodge and Ford Expressways rear-end collisions form about 60 percent of the accidents);
2. The system must be a longitudinal control system, which aids the driver or operates automatically, if the velocity of vehicles is to be increased safely; and
3. The system basically must be a longitudinal control system with a range of at least 160 ft if increased traffic flow and the prevention of traffic jams are major objectives (lateral control to facilitate lane switching, however, must also be considered).

Two variations of the infrared sensing system were studied, and a prototype of the source-sensor system was built and tested in about 1,000 miles of freeway driving.

INFRARED SOURCE-SENSOR SYSTEM

The infrared source-sensor system makes use of a pulsed infrared light beam in the preceding vehicle; the pulse frequency is proportional to the lead car's velocity. The infrared source of the first version, a $4\frac{1}{2}$-in. sealed-beam lamp with a maximum rated initial candlepower of 35,000, was mounted at the rear of the lead vehicle pointing opposite to the direction of travel. The beam spread of the maximum intensity zone was 11 deg in a horizontal direction and $\pm 4\frac{1}{2}$ deg in a vertical direction. A Wratten 87C filter was used in front of the source, and the emission of visible light was so small that it was not possible to detect the source in daylight or nighttime freeway driving under field conditions. Sources of higher intensity and gallium arsenide lasers were considered. However, no extensive experiments have been carried out so far.

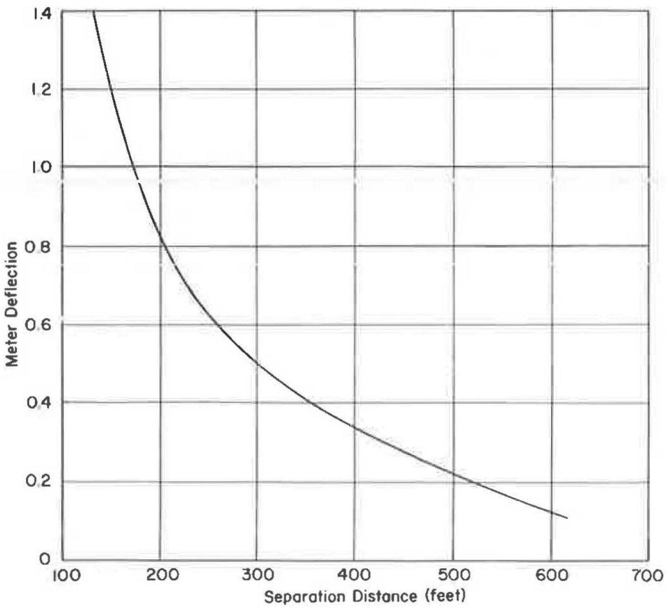
The pulsing of the source was provided by a rotating 3-bladed disk placed in front of the filter. This device kept the output of the source fairly constant because of a whipping and cleaning effect that prevented the accumulation of dirt and spray in adverse weather conditions. The 3-bladed disk was coupled to the output of a differential gear; one input was driven by a constant-speed motor, and a second input was coupled to the drive shaft of the automobile. The basic frequency supplied by the constant-speed motor served to identify the vehicle as a target and thus provided the necessary separation from other infrared sources like headlights of oncoming vehicles, advertising and traffic lights, or the low-standing sun. Through the second input of the moving vehicle via the drive shaft a speed-dependent chopping frequency was generated that was read by the sensor of the following vehicle. Most of the tests were carried out with a chopping rate from 40 to 130 pulses/second; that rate represented a speed range from 0 to 80 mph for the lead vehicle. Figure 1 shows the infrared source mounted in the rear of the experimental vehicle.

The sensor unit, shown in Figure 2, mounted under the front bumper of the following vehicle was designed to detect pulses emitted by the source of the lead vehicle and to convert this information to speed. The differential speed between the lead and the following vehicle was displayed on a meter. This output of the sensing equipment, however, can also be used to activate electrohydraulic elements for acceleration and braking control in an automatic longitudinal control system. Trailing vehicles can thus duplicate the acceleration pattern of leading vehicles with a delay of about 0.2 sec when spaced closely enough for the detector to lock on to the infrared source of the preceding vehicle. This distance was found to be about 400 ft for the prototypes tested in clear weather. As an additional safeguard, the intensity of the signal from the source of the preceding vehicle was also measured and was used to estimate the spacing between vehicles. Figure 3 shows a typical calibration curve for the distance-measuring circuit. The sensitivity, i.e., the change in deflection, is rather small at distances exceeding 250 ft. The system, however, becomes quite sensitive at distances below 250 ft, and at the critical spacings of high-density freeway traffic (about 50 ft) the system becomes very sensitive to changes in the distance to the leading vehicle. Figure 4 shows the traffic density and the average spacing of vehicles in freeway traffic for 4 operating regions. Because the intensity of the received signal is also a function of weather conditions, some adjustment of the sensing circuit is necessary to meet the safety requirement for driving in rain, fog, or snow. A driver, therefore, can adjust his instrument to warn him or to actuate the automatic deceleration system at a spacing he considers safe under the prevailing conditions. Although automatic adjustment to the prevailing weather condition would be highly desirable, no work has been done to develop any compensating instruments for changing weather conditions. It was found that weather conditions have a marked influence on the pulse-transmission characteristics at distances of more than 100 ft. At short distances this influence is somewhat reduced if a sufficiently strong source is used. The maximum range of the source system measured in a heavy snowstorm with stopped vehicles was about 900 ft.

Figure 1. Infrared source in preceding vehicle.

Figure 2. Detector mounted on following vehicle.

Figure 3. Calibration curve for distance measuring circuit.



The prototype of the source-sensor system needs further development. The most serious constraint is the fact that the system is not self-contained but requires a source in the lead vehicle and a sensing instrument in the following vehicle, and, for proper functioning of the longitudinal control system, all vehicles must be equipped with the necessary instrumentation. Furthermore, signals emitted by vehicles in adjacent traffic lanes can be picked up in curves, and they supply irritant information because the car-following control must be applied to vehicles in the same traffic lane only. The latter problem has been studied, and some research on traffic lane coding was carried out to avoid reaction to any irrelevant signals.

Thin metal stripes or metallic paint were used for lane coding to generate the communication code for a traffic lane. All vehicles in the same traffic lane can thus be tuned automatically to one communication language, and signals picked up from vehicles in adjacent traffic lanes will be ignored. Preliminary results suggest that specially designed metal detectors mounted on the underside of vehicles, preferably the rear axle of a car, can read the traffic lane code continuously from a moving vehicle. It is hoped that the lane-coding metallic paint pattern can be applied to traffic lanes with the help of existing lane-marking equipment. Another possibility is to attach a prefabricated plastic coding strip to the center of a traffic lane in a similar way as it is now done with plastic lane delineation stripes. Such a lane-coding system not only would facilitate the use of the longitudinal source-sensor control system but also could convey a multitude of information to the driver including messages that are now conveyed by traffic signs. It becomes increasingly difficult for drivers to perceive and react in time to traffic signs in high-density traffic flow. Forced lane changes, resulting in hazardous traffic situations, are quite frequently the result of the currently used freeway information system that hardly meets the requirements of high-density multilane urban freeway traffic. A passive lane-coding system will also have the advantage of low installation and maintenance costs in comparison with active highway information systems, such as roadside radio or computer-linked loop detectors. Tests also showed that the metallic coding stripe functions well with reinforced concrete roads because the coding stripe has a shielding effect and little background noise is picked up by the detector from the reinforcing steel.

SELF-CONTAINED INFRARED LONGITUDINAL CONTROL SYSTEM

Some research was carried out to develop a longitudinal control system that will give drivers the freedom of choice to equip their vehicle with an infrared sensing device that does not require any active equipment in other vehicles in sensing space and relative velocity between the lead and the following vehicle. The system works on the Doppler principle for distance measurement between successive vehicles in a traffic lane. A gallium arsenide source was used for the preliminary investigations. The performance of the system, however, was not satisfactory when the beam was reflected by conventional cat-eye reflectors from the rear of the leading motor vehicle. License plates designed like efficient corner reflectors were then used, and very encouraging results were obtained with this setup. Corner reflector license plates were chosen for the system because most of the states issue new plates every year and the introduction of efficiently designed reflectors for infrared sensing would thus not impose an unreasonable demand on the public. Furthermore, because license plates will be changed every year, it is expected that a good standard of the reflectors can be maintained and will make the system more reliable. Unfortunately, only a few stationary tests in adverse weather conditions were carried out with infrared equipment because of limited research funds. The results were encouraging, and it appears that the system can be developed to cover a range of 600 ft in fog. The background noise level in these first tests was high, and more powerful sources must be investigated before any decision on the design of the source can be made. So far a combination of gallium arsenide junction lasers seems to be the best choice.

ANTICIPATED SYSTEM PERFORMANCE

As stated previously, the infrared longitudinal control system has been developed to foster the following improvements in traffic flow: prevent rear-end collisions, prevent traffic jams, and increase traffic flow.

The evaluation of aerial photographs of freeway traffic shows that only about 60 percent of the drivers accept the safe car-following recommendation of one car length spacing per 10-mile increment in speed. Potentially unsafe conditions occur frequently if vehicles change traffic lanes. In studies of such situations, it was found that not only one car but also a number of vehicles can be involved in rear-end collisions under these conditions even if the driver is only forced to apply emergency braking. The most serious multiple rear-end collisions, however, were caused by fog patches drifting over a freeway that carries high-speed, high-density traffic. It is hoped that at least some of these accidents could be prevented by the infrared longitudinal sensing system, which can penetrate fog to some degree if the proper infrared window is chosen for the system.

A number of traffic experts have expressed their opinion that instability of traffic flow arises from the variance in response time of drivers to changes in the behavior of leading vehicles. Such "kinematic disturbances" are propagated and can lead to a breakdown in traffic flow, a condition that frequently occurs on urban freeways during peak-hour traffic. Here again, the infrared sensing system would provide a more uniform response to changes and thus reduce the generation and propagation of kinematic disturbances.

The efficiency of peak-hour urban freeway traffic is rather low, and freeway surveillance and control systems have been developed to improve the efficiency by controlling exits to freeways and restricting the traffic volume on the freeway to a load that is supposed to combine reasonable average speed with stability in traffic flow. Human efficiency in controlling vehicles in high-density traffic is not outstanding and can be improved by providing more and better information to drivers. A fully automatic longitudinal control system, however, will only be limited in its capacity by the response time of the electrohydraulic vehicle control system and by the requirements for stable traffic flow. An analysis of these conditions shows that, with a system response time of 0.2 sec and stable flow conditions, the capacity of a single freeway traffic lane can be increased to well over 4,000 vehicles/hour at 40 mph, as shown in Figure 5. Because the present maximum capacity for stable flow is about 2,000 vehicles/hour, the capacity of freeways can be doubled, leaving a very reasonable safety margin at 4,000 vehicles/hour/lane.

CONCLUSIONS

The techniques and instrumentation for infrared sensing have been developed to a high level during the past years, and applying this knowledge in infrared technology to highway traffic will definitely provide improvements in traffic safety and capacity. One of the most difficult problems of longitudinal sensing in highway traffic is to identify the proper target, i.e., the vehicle ahead in the same traffic lane. The source sensor system can very well be adapted to meet these requirements of automatic target identification by lane coding. The system should be very reliable, inexpensive, and easy to maintain in comparison with active coding systems. It also can be expanded to provide for other information displayed inside the vehicle and thus take over the function of traffic signs. The self-contained system is strictly a longitudinal sensing device that can be adapted to minimize errors in target identification at curves by having the source coupled to the steering system. This approach appears feasible, for properly designed freeways provide a sight distance commensurate with the design speed. However, more research is necessary, and the advantages or disadvantages of lock-on systems should be studied in more detail in field tests.

The range of infrared sensing appears to meet the requirements of freeway driving in adverse weather conditions, which is about 600 ft for a speed of 80 mph, though tests with reflectorized license plates are necessary.

Figure 4. Traffic density and mean spacing of vehicles at various speeds.

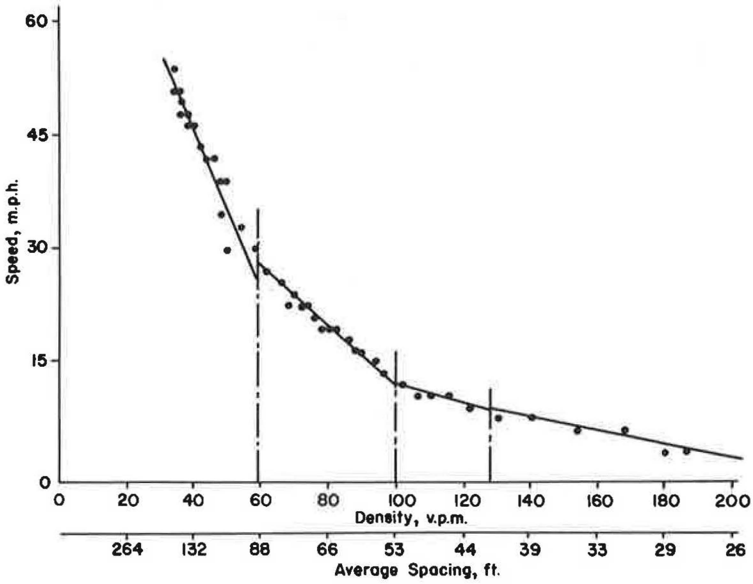
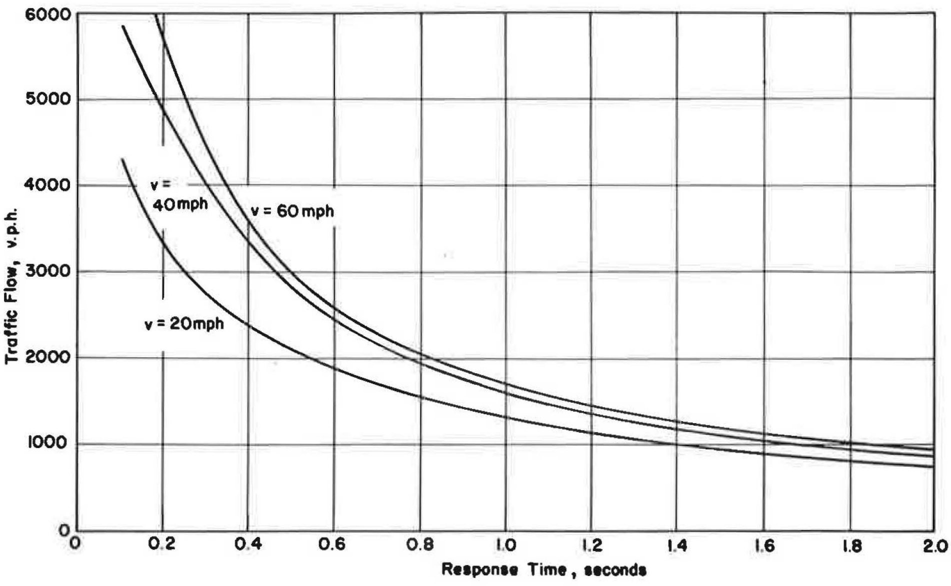


Figure 5. Traffic volume in relation to system response time for stable traffic flow.



The prototype of the source-sensor infrared sensing system was built for about $120. The self-contained system will be more expensive, but costs are expected to remain reasonable for the service and additional safety that will be provided by the sensing device. It appears that infrared sensing for longitudinal traffic control has a definite cost advantage over other possible systems.

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