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COMPLETION OF LASER-GUIDED LANE STRIPING SYSTEM (PHASE II)

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Executive Summary

Highway lane stripe painting is a very labor intensive process. In order to improve efficiency of the operation, reduce the impact on traffic flow and enhance safety, the University of California, Davis initiated a research project to automate part of the process. The contract was awarded to ARTI to develop a laser-guided lane striping system in 1990. The project had two phases. Phase I demonstrated the concept of a laser scanning system to detect pavement paint stripes. The objective of Phase II was to develop an operational laser-guided lane restriping system for a Caltrans MB stripe painting vehicle. However, the company ARTI was unable to complete this objective on time and within budget. The project was re-assigned to us with the objective of completing the laser-guided lane striping system developed by ARTI and integrate it to a MB paint stripe machine.

At the early stage of recovering the laser unit, efforts were concentrated on diagnosis and fixing problems to make the laser scanner work. Some of the problems were caused by system aging, while most of them are problems inherit from this particular design. In order to make the laser scanner work well enough to provide signals for analysis, the entire scanning system had to be modified. Tests were then conducted to evaluate the software and hardware, and to collect field data for analysis.

Field data indicated that the Laser sensor system is not sufficient to detect worn-out old paint stripes due to the poor signal-to-noise ratio. The signal amplitude varies greatly with the height of the scanner, and the current laser unit was found to be incapable of providing a good signal at a practical mounting height. Further more, the detected stripe position is very sensitive to the detection threshold level, which greatly affects the lateral accuracy of the guidance system. In addition, the laser scanner is subjected to vibration and temperature change due to the mechanical scanning and prism alignment system. The fundamental concept of using the laser mechanical scanner furnished by ARTI is inadequate to produce a signal quality at a high enough signal-to-noise ratio for the expected paint stripe conditions the equipment is to be used for.

In searching alternative ways of detecting old paint stripes, an attempt was made to explore the possibility of applying a vision-based technology developed at UC Davis for a precision cultivator. A field try-out test was conducted using this vision guided cultivator to trace the paint stripes. The results were very satisfactory even on the worn-out old paint stripes which could not be detected by the laser scanner.

Results of our investigation show that the current Laser-scan guidance system has many inherent problems, and the probability of success for developing such a system to an operable unit is low. On the other hand, our preliminary tests indicate that a machine-vision system using a video-camera guidance system can work well and has many advantages over the laser-scan system. It would be more logical to concentrate our effort on the development of the superior machine-vision system based on the technology available at UC Davis, which has a much higher probability of success. This vision system is based on currently available electronic hardware which is much lower in cost and easier to implement than the older vision system concepts that required much more sophisticated and expensive electronics.

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DISCLAIMER / DISCLOSURE

"The research reported herein was performed as part of the Advanced Highway Maintenance and Construction Technology (AHMCT) Center, within the Department of Mechanical and Aeronautical Engineering at the University of California, Davis and the Division of New Technology and Materials Research at the California Department of Transportation. It is evolutionary and voluntary. It is a cooperative venture of local, state and federal governments and universities."

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FINAL REPORT

Completion of Laser-Guided Lane Striping System (Phase II)

I. Introduction

Highway lane stripe painting is a very labor intensive process. In order to improve efficiency of the operation, reduce the impact on traffic flow and enhance safety, the University of California, Davis initiated a research project to automate part of the process. The contract was awarded to ARTI to develop a laser-guided lane striping system in 1990. The project had two phases. Phase I demonstrated the concept of a laser scanning system to detect pavement paint stripes. The objective of Phase II was to develop an operational laser-guided lane restriping system for a Caltrans MB stripepainting vehicle. However, the company ARTI was unable to complete this objective on time and within budget.

The objective of this project was to complete the laser-guided lane striping system developed by ARTI and integrate it to a MB paint stripe machine. This report summarizes the project activities, discusses problems identified and finally justifies development of a vision-based guidance system based on the existing technology at UC Davis.

II. Summary of Activities

The project started on October 15, 1996. The main components delivered by ARTI include an industrial control computer with a high speed data acquisition board, a sealed laser scanner and a cable connecting it to the computer. For the first 4 months, efforts were concentrated on fixing problems to make the Laser scanner work. Some of the problems (such as broken circuit board, broken pins) were due to system aging, while most of them (such as optical sensor misalignment, signal cross talking and trigger timing) are problems inherit from this particular design. Finally we had to modify the entire scanning system to make the laser sensor work well enough to provide signals for analysis. A simple test bench was set up and the software was digested and run in the lab for single scan and continuous scan. Two beams were evaluated for signal strength and operation.

The program was later modified to record the data with a paint stripe at various positions. We were unable to properly test the computer program due to the many hardware problems mentioned above. We stoped testing using the computer control as the high speed analog to digital (AD) board (by Data Translation) failed. Field data were then collected using only the laser sensor and an oscilloscope. The data indicated that the laser sensor was not able to detect worn-out old stripes due to a very low signal-to-noise ratio. A vision-based guidance system using a video camera was later tried out and the result was satisfactory.

III. Modification of the Laser scanner

In addition to the hardware problems, the construction and mounting of the electronics of the scanner unit as received from ARTI were unprepared for an operational field unit. There were various small circuit boards here and there which were attached to the frame with double-sided adhesive tape. Even the main 12 volt DC/DC converter was held down by adhesive tape. The 5 volt supplies for powering the mirror motor were not well constructed and generated excessive heat. The sensor used to report mirror position was inherently inaccurate and was held by a thin sheet metal bracket which was subject to vibration. The inappropriate cabling of the Laser power supply caused the scanner to buzz which caused intermittent scanning. Various hardware problems we encountered and the lack of a wiring diagram for the unit made it necessary to re-furnish the electronics before meaningful testing could be done.

The remodel began by removing all the electronics except the mirror drive circuitry and the sensor amplifiers. The wiring to and from the amplifiers was cleaned up and their flimsy sheet metal covers were replaced with a more solid housing which could be more easily removed to provide access to the adjustment of potentiometers and sensors. A compact 5 volt DC/DC converter was added to power the mirror drive circuitry and the wiring was cleaned up and tied securely to the frame. A photo sensor was solidly mounted to the frame in a position where it would intercept the laser beam just before it began to scan the viewing area. This would provide a stable and accurate synchronization pulse which would not be subject to vibration. The signal conditioning for this sensor and the circuitry for controlling the rest of the scanner unit were mounted on a single circuit board which was securely screwed to the frame. These improvements reduced the heat buildup in the unit. Finally, the connector which transferred power and control signals to and from the scanner was secured to the frame to minimize noise and wire fatigue due to vibration, and to make it easier to install and remove the scanner from its cabinet. A circuit diagram for the modified scanner was generated (see Appendix).

A 3.5 x 6 inch window on the top of the Laser scanner case was opened to allow the alignment of the optical sensors and other adjustments to be made without removing the whole unit out of the case.

IV. Assessment of the current Laser design

1. The Laser sensor system is not sufficient to detect worn-out old paint stripes due to the poor signal-to-noise ratio.

Figures 1 to 4 are sample data collected from roadways. Data in Figure 1 were collected from a white stripe in good condition at Norman Road off-ramp along Highway 5. Figure 2 was from a worn-out old stripe on an unused road near UC Davis Campus by Hutchson Road. It can be seen that although signals from stripes with good condition are OK, the signals from worn-out old stripes are too weak to be separated from noise. Data in Figure 4 were collected from a fairly good double yellow line on the same unused road near Campus.

The basic idea of the position algorithm is to compare a threshold value with the value of each scan point, and find the intersection of the threshold and the scanning curve, the position of the stripe is determined by averaging the two edges (intersections). For a saturated signal (curve for 20" height in Figure 8) or a nearly symmetric signals (Figure 1 from a good stripe) the center of the stripe can be determined effectively with this algorithm. The center value is not sensitive to the threshold as long as its value is set above the noise level or below the peak portion of the stripe signal. However, for the data shown in Figure 3 obtained from a double yellow stripe with clear edges, although the signal-to-noise ratio was not low, the threshold level greatly affects the center value of the stripe due to the irregular shape of the signal. For example, the center value of the first stripe is 0.6050 ms at threshold level of 1.8 volts and 0.5293 ms at threshold level of 2.7 volts, similarly the center value of the second stripe is 0.994 ms and 1.065 ms respectively. This is equivalent to a 2-inch variation in position detection. The sensitiveness of the detected stripe position to the threshold level would create difficulties in setting a desired threshold level for a continuous operation where the condition of stripes vary.

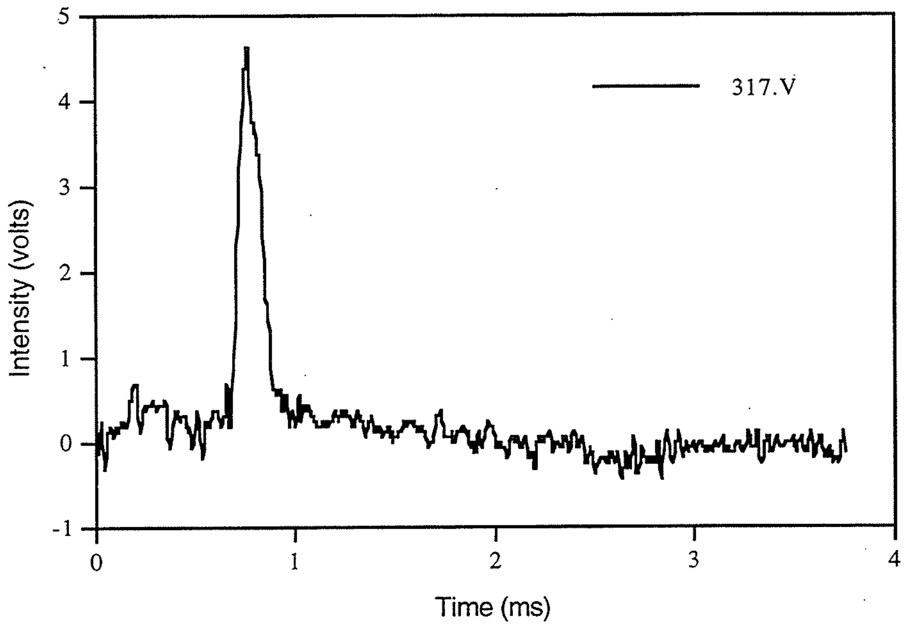

Figure 1- Sample scanning data from a white paint stripe in fairly good condition

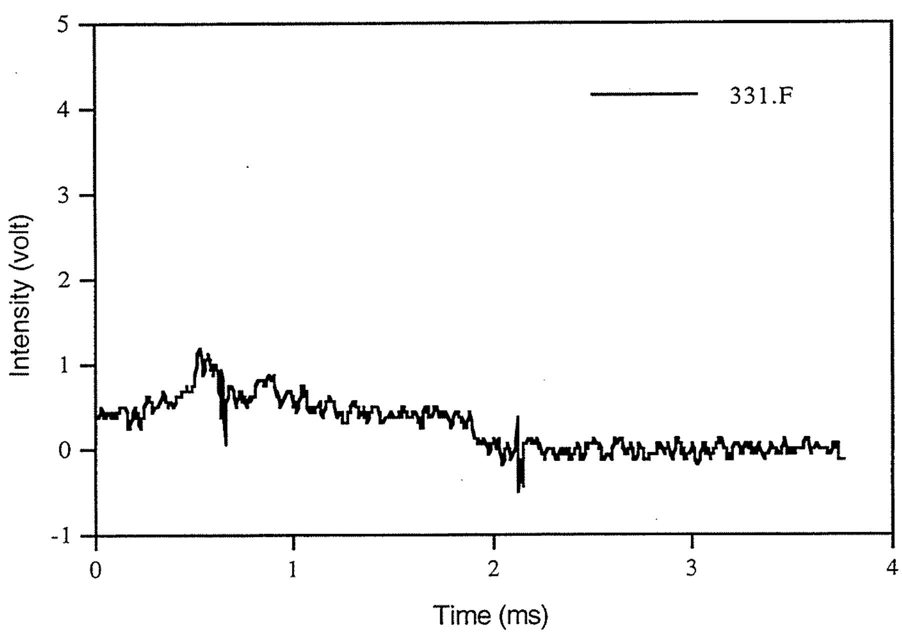

Figure 2- Sample data from a worn-out old paint stripe.

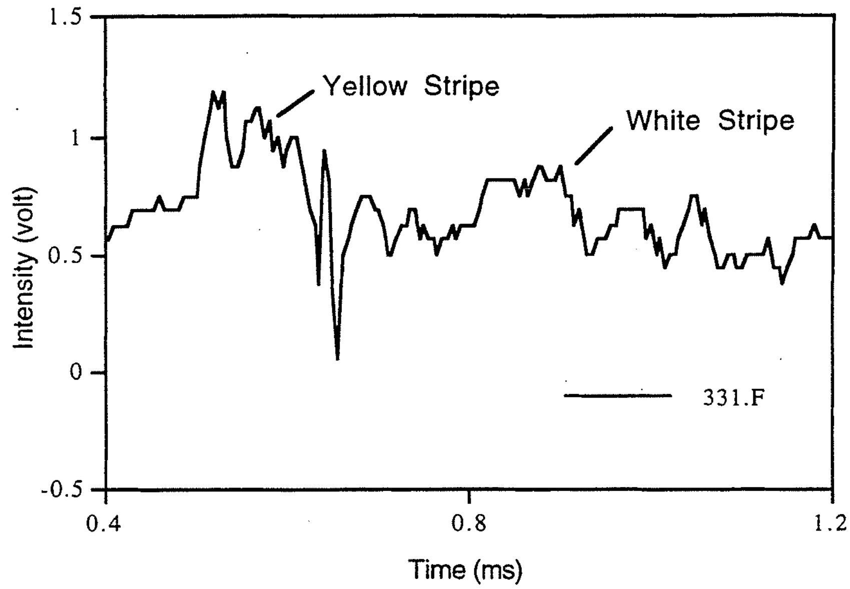

Figure 3- Rescaling of Figure 2

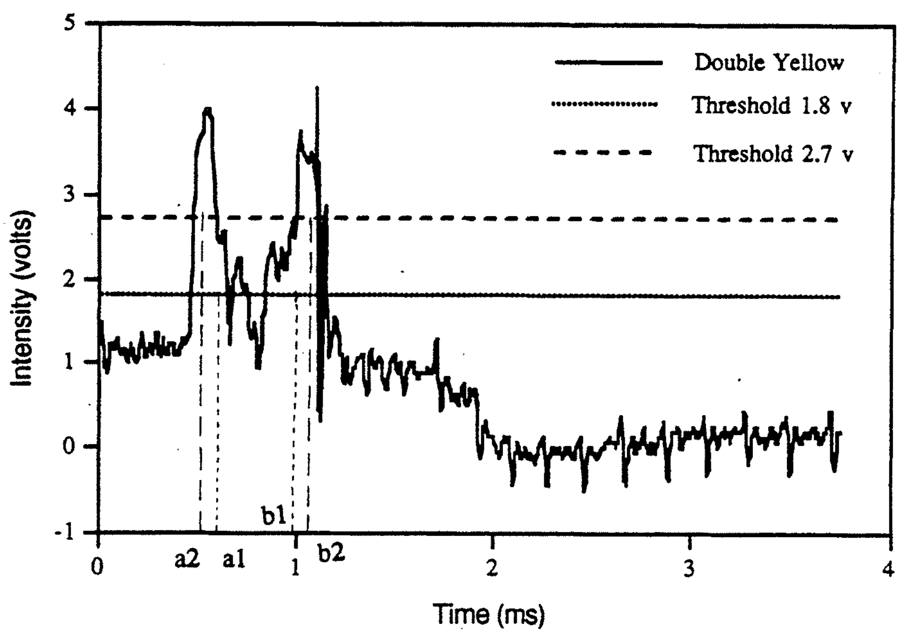

Figure 4- Sample data from a double yellow stripe

(a1 and b1 are the center values of the stripes at threshold level of 2.7v, a2 and b2 are the center values at threshold level of 1.8v)

Figures 5 and 6 are the data collected by ARTI from worn-out old stripes, of which the reflectivity was estimated to be 50% degraded. Figure 3 is a re-scaled curve of Figure 2 to show its similarity to the data by ARTI. It can be seen that both of the data sets have very low signal-to-noise ratio. The horizontal coordinate of Figures 5 and 6 is the number of data points and, the horizontal coordinate of data collected by us is time in millisecond. Both number of data points and time can be converted to the lateral distance of a stripe. The data by ARTI were included in their monthly report in March, 1991 to justify the improved algorithm. It was explained in the report that with the original algorithm the center of an old stripe was determined at 48.01 at threshold level of 400. While with the improved algorithm, a correct center position of 31.777 was predicted at threshold level of 350. Here a few fundamental signal problems are obvious. First, the center value of the stripe is very sensitive to threshold level, a significant difference in stripe position prediction (about 2.6 inches, assuming the data were from a 5 ft beam) resulted when threshold level was reduced from 400 to 350. Secondly, the signal-to-noise ratio was so low that a threshold level suitable for one case would not work on other cases. For example, a threshold level of 350 may be considered to be a desired value for the case in Figure 5 but it certainly would not work for the case in Figure 6 for it falls into its noise region. On the other hand, a threshold level between 600 to 680 may work well for the case in Figure 6 but it is beyond the signal level for the case in Figure 5. It would be impractical to continuously adjust the threshold level according to the changing signals during an actual operation, not to mention that it is very difficult to determine a good level even only for a single case. The fundamental concept of using the laser scanner furnished by ARTI is inadequate to produce a signal quality at a high signal-to-noise ratio for the expected paint stripe conditions the equipment is to be used for. While it is possible with more sophisticated computer signal processing algorithms to improve the signal-to -noise ratio, it may be better to consider systems which overcome this inherent deficiency.

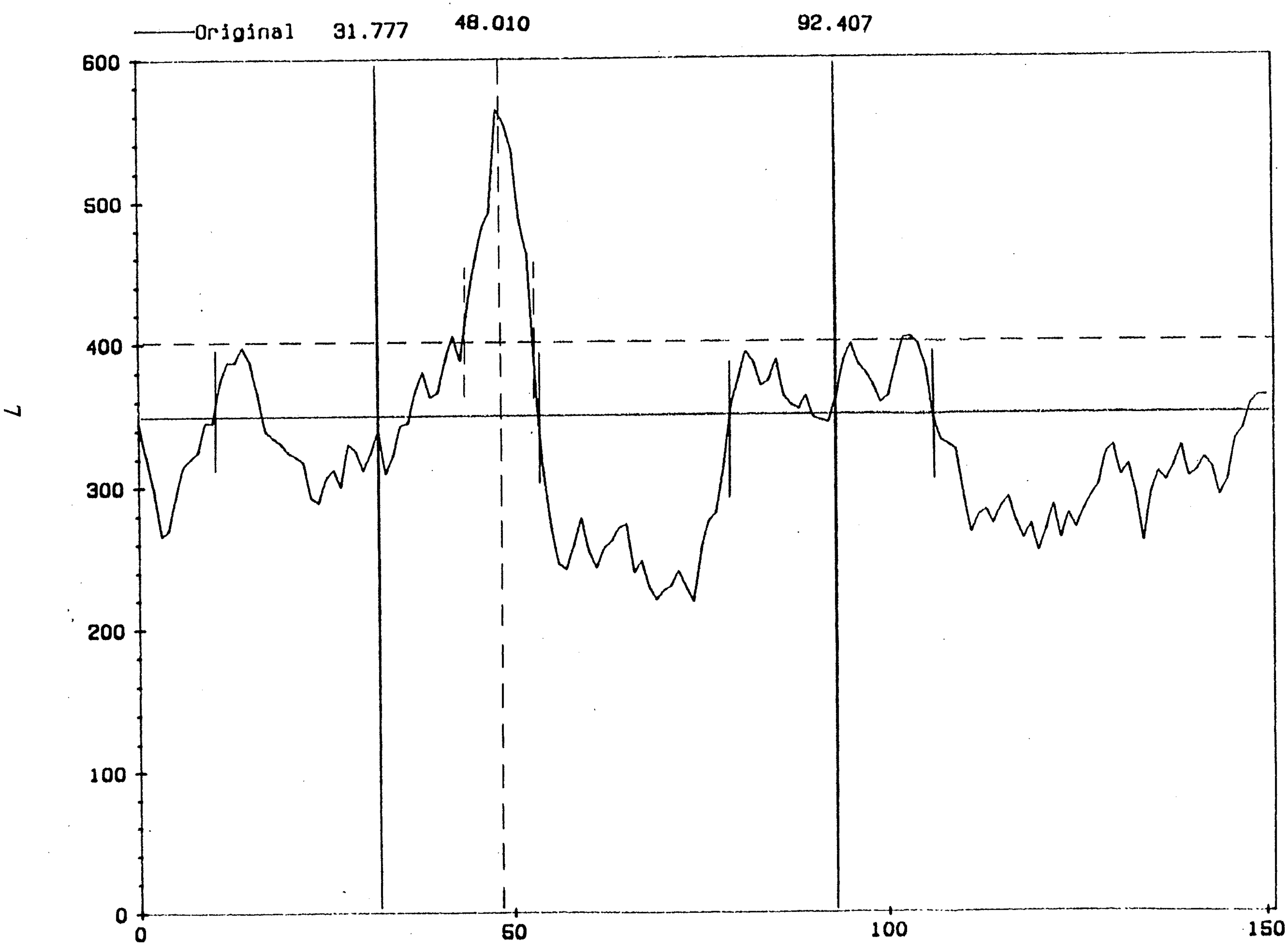

Figure 5- Scanning data (1) from a worn-out paint stripe, obtained by ARTI

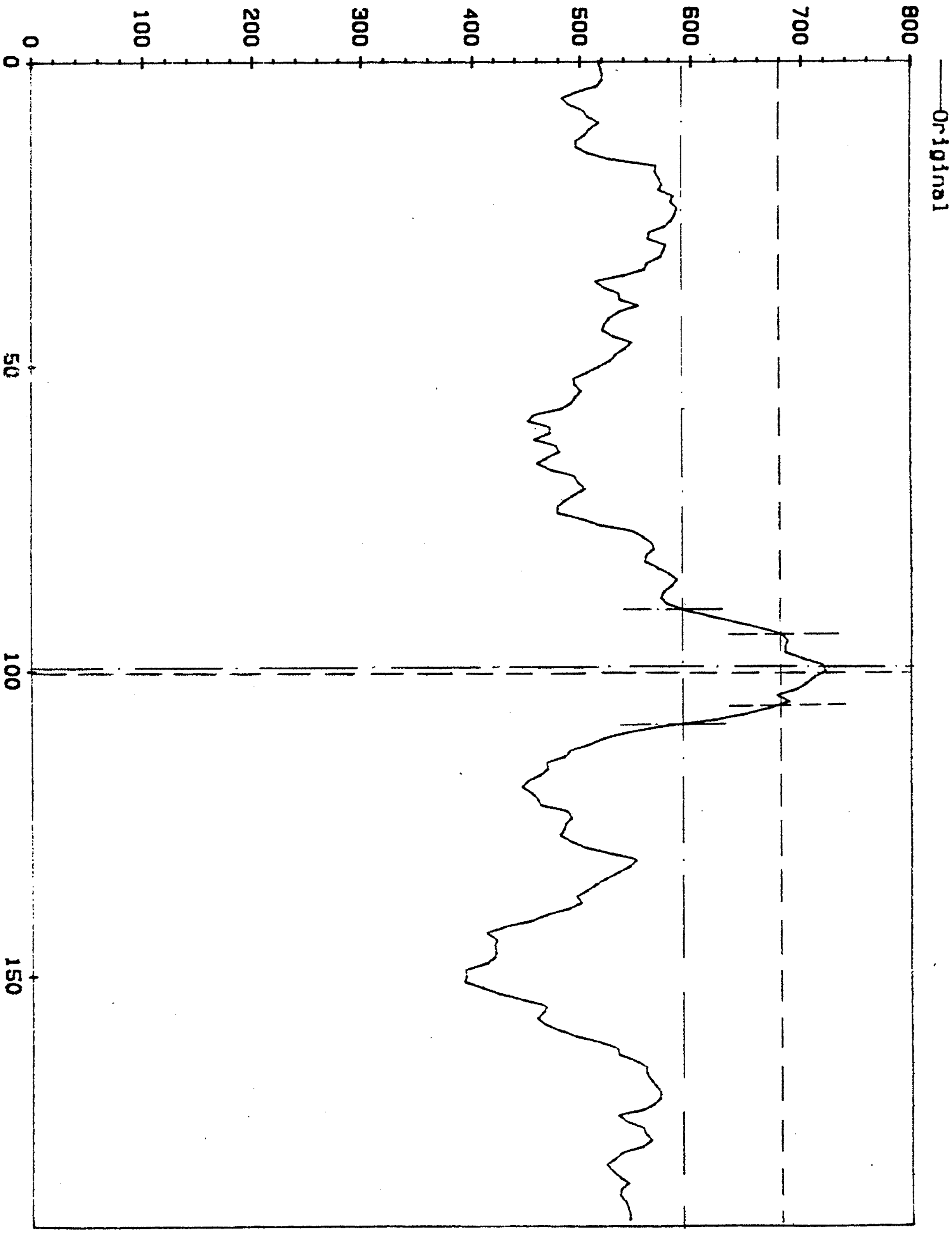

Figure 6- Scanning data (2) from a worn-out paint stripe, obtained by ARTI

2. Signal amplitude varies greatly with the height of the scanner and intensity of reflection.

Figures 7 shows the signals of a new stripe and a reflective marker which has the same width as the stripe (4 "). It can be seen that the signal of the marker is not only much higher in magnitude but also much wider than that of the stripe. Although the reflective marker can be recognized by software algorithm, this extreme indicates the significant effect of paint reflectivity on the scanned signals. Figures 8 compares signals of a new paint stripe obtained at two different scanner height, 20" and 34". It is obvious that the difference is tremendous. Although the signal obtained at scanner height of 20" is ideal, the one from actual mounting height on the MB machine (34") is relatively very weak. The construction of the MB paint striping machine hinders the scanner from being mounted at a height of 20 inches. Further more, it is not desirable to mount such a fragile unit with rotating mirror and prisms at such low height for highway operation. While a stronger laser or a better optical system design may solve this problem, the current laser unit was found to be not capable of providing a good signal at a practical mounting height.

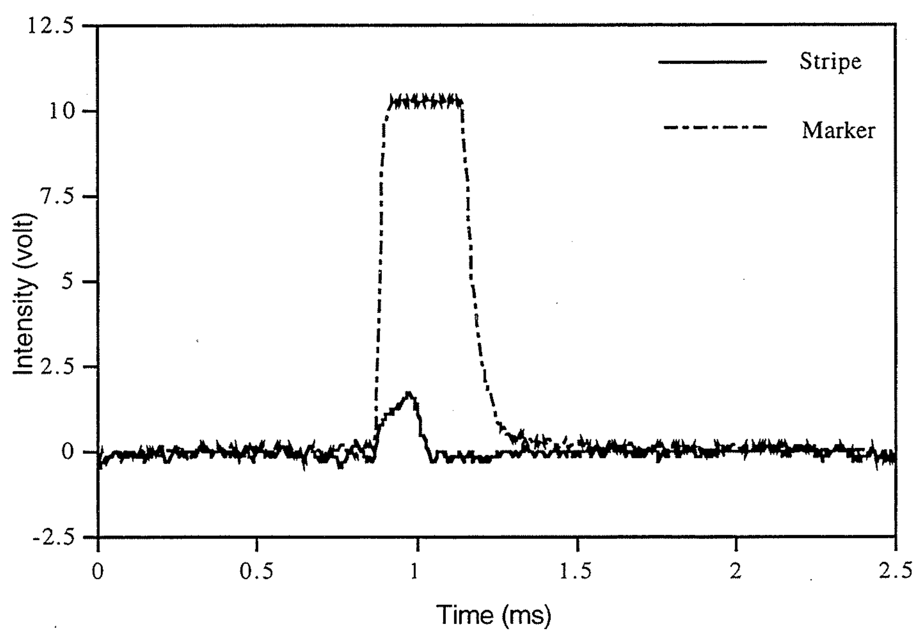

Figure 7- Comparison of data from a paint stripe and a reflective marker.

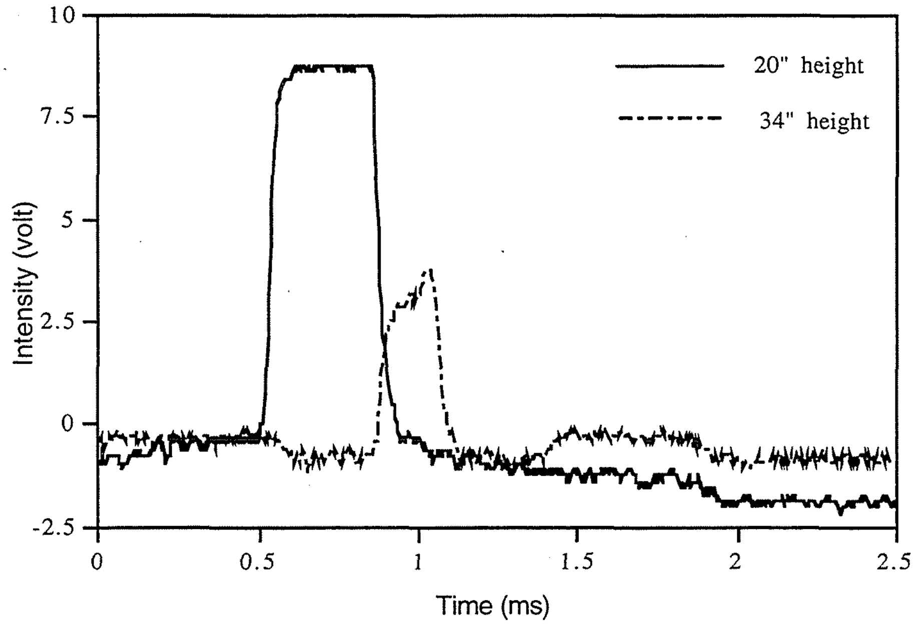

Figure 8 - Comparison of data of the same stripe at two different scanner heights.

3. The whole system is not reliable and durable.

a. The Laser scanner is an optical system which requires very precise alignment only achieved in a laboratory setting. In addition to the main components such as the laser unit, optical sensors, motor and octagonal mirror, it also consists of many pieces of optical lens, mirrors, prisms and filters, many of them are glued in place to meet the system requirements. These components may shift from their designed positions (due to temperature change and vibration) and, consequently, cause system problems. At the early stage of recovering the Laser scanner, the stripe signal could only be obtained from the 8 foot beam scan. ARTI immediately suggested that it was due to misalignment of the optical sensor. The procedure for alignment of optical sensors is tedious and requires special tools. The key steps in alignment are ungluing the aperture sheet, adjusting it to aim the laser spot and gluing it back in place. We have done the sensor alignment twice and consider it not realistic for Caltrans operation.

The scanning window was designed to be 3 feet wide for the 8 foot beam scan and 1.9 feet for the 5 foot beam scan. The actual measurement was 5 feet and 3 feet respectively. This might be also due to position shift of some of the components such as the prisms.

b. The mechanical parts of the Laser scanner is the motor and octagonal scanning mirror assembly which rotates at 1320 rpm. Like any mechanical system with rotating parts, especially when angle is involved, the Laser scanner is subjected to vibration. An 0.01 inch lateral vibration near the scanning head may result in 1 inch shift at the 8 foot beam scanning site. The scanner is to be mounted on the outrigger which moves laterally back and forth while the MB vehicle is operating at 40 mile per hour. The vibration level is more severe than 0.01 inches.

c. As mentioned in the proposal, the output signals are sensitive to temperature change shift (in addition to other factors) which affects the lateral accuracy. The narrow band filter (1 nm) is set to work at 632.8 nm only at 25 °C (77 °F) and shifts 1 nm every 5°C, which greatly weakens the signal and reduces the signal-to-noise ratio. The painting operation are certainly under conditions from noon in the hot summer when the ambient temperature may well exceed 43.3 °C (110 °F) to early morning in cold winter when the temperature may be way below 25 °C. A cooling/heating system, which is not available on the current unit from ARTI, will be necessary to assure its proper function. This, of course will add cost and complexity as well as increase maintenance problems to the system.

V. Preliminary field test of a vision based system.

In searching alternative ways of detecting old paint stripes, an attempt was made to explore the possibility of applying a vision-based technology developed for a weed removal machine. This experimental, vision-guided cultivator was designed and developed by the Department of Biological and Agricultural Engineering (David Slaughter and Paul Chen) at UCD. The new cultivator was designed to provide precise control of close cultivation tools to improve the effectiveness of mechanical cultivation when the crop is at the one to two true-leaf stage.

Color video images of paint stripes with various conditions were collected using a Sony 710 video camera and analyzed in the lab using the existing software to see if the stripes could be recognized. The results showed that the pattern of the worst worn-out stripes could be recognized without any problems. Thus a field try-out test was conducted using the vision-guided cultivator to trace the paint stripes along an unused road on Campus by Hutchson road and Campbell Dr. nearby. A small water container was mounted behind the camera and red-colored water was drained during test runs to trace the paint stripes. The results were very satisfactory (see photo in Figure 9) even on the worn-out old paint stripes which could not be detected by the Laser scanner (shown in Figure 2 and 3).

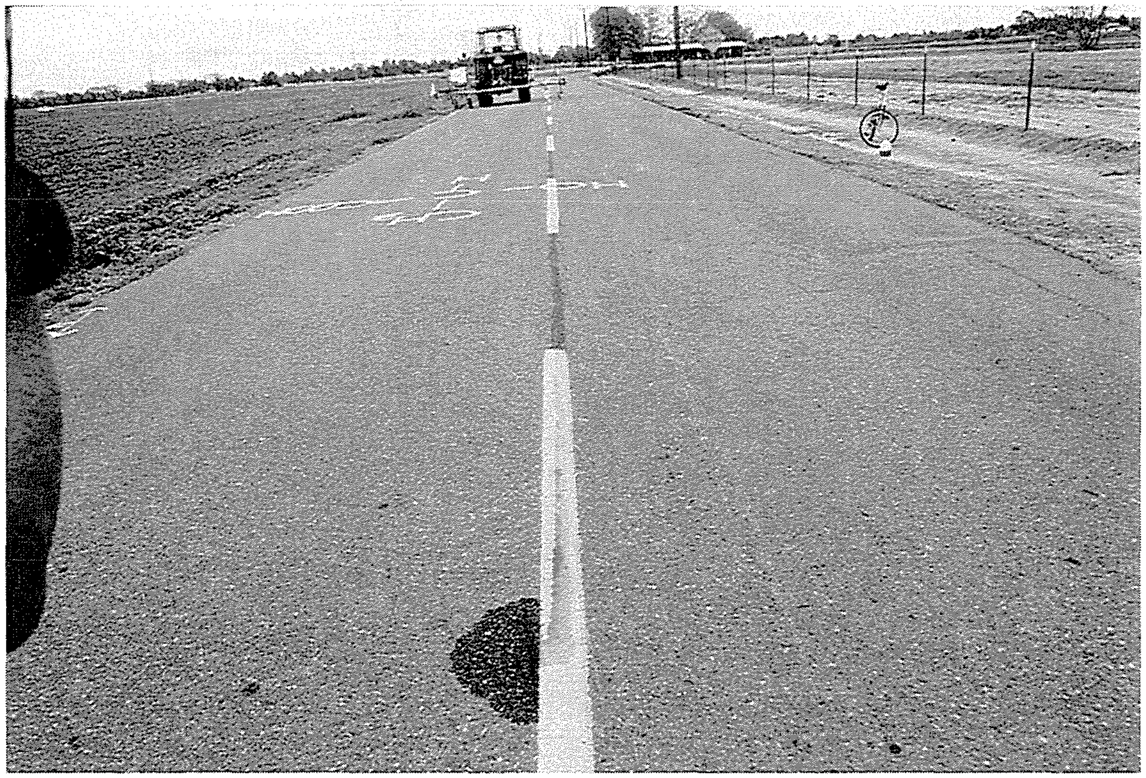

Figure 9- Field tests of a vision-based guidance system

VI. Recommendation

Results of our investigation show that the current Laser-scan guidance system is inadequately designed and it has many inherent problems. The probability of success for developing such a system to an operable unit is therefore low. On the other hand, our preliminary tests indicate that a machine-vision system using a video-camera guidance system can work well and has many advantages over the laser-scan system. It would be more logical to concentrate our effort on the development of the superior machine-vision system based on the technology available at UC Davis. This approach, in our estimates, has a much higher probability of success. This vision system is based on currently available electronic hardware which is much lower in cost and easier to implement than older concepts of vision system that required much more sophisticated and expensive electronics.

REFERENCES

1. Advanced Retro Technology, Inc., 1991. "Automated Paint Restriping Recognition and Guidance System: Phase I Final Report."

2. Advanced Retro Technology, Inc., 1993. "Proposal for Phase II for Paint Striping Guidance System."

Appendix — Diagram of the Laser scanner