A Case Study in IVHS Implementation
AN IMAGE PROCESSING APPLICATION FOR I-15 HOV LANES

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ABSTRACT

In this study [1] we present our findings on image processing applications to the continuous and automatic monitoring and verification of the status of control devices and vehicle speed estimation on the Interstate-15 Reversible High Occupancy Vehicle (HOV) lanes as examples of "IVHS at Work." The overall goal of this study has been to supply additional enhanced monitoring capabilities for the current HOV operations. These capabilities have been intended to assist, rather than to eliminate the human operators from the loop. In the next few paragraphs we will describe this unique undertaking together with the issues related to the systems architecture, hardware and software components, the integration, image processing tools, and preliminary field test results.

1. INTRODUCTION

Continued growth in travel is severely straining the surface transportation systems throughout the world. The annual cost of congestion to U.S.A. in lost productivity alone is about $100 billion, exclusive of the costs of wasted fuel and environmental damage. In addition, more than 40,000 people are killed and another five million injured each year in traffic accidents [1]. In light of the above statements, "intelligent" surface transportation systems need to be developed, offering not only enhanced safety, but enhanced efficiency, mobility, and productivity as well. The Intelligent Vehicle-Highway Systems (IVHS) initiative lays the framework for the development of such systems. IVHS technologies and services will significantly enhance the efficiency of transit and commercial vehicle systems by providing accurate information on the location and status of vehicles and traffic conditions.

Image processing and data compression techniques are emerging technologies which now provide a wide range of additional possibilities for the requirements of road traffic detection, measurement and control, intelligent highway operations, design and operation of smart vehicles, and many other transportation related fields, in addition to numerous other engineering, medical, scientific, and information management areas.

In this study, we have been examining reliable, efficient, real-time image processing and compression systems for traffic surveillance to be used in emerging Advanced Transportation Management and Information Systems (ATM/IS).

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1. 1 Overview: The High Occupancy Vehicle Lanes, an 8.5 mile long two-lane reversible roadway for the exclusive use of high occupancy vehicles, occupy the center median of the Interstate-15, which is the principal North-South freeway in the inland portion of San Diego County and serves commuter, intra-regional and inter-regional travel. The traffic flow on these HOV lanes is controlled by a set of signals, indicators, and barriers. These are powered by electrical and air systems, and are operated by a set of local computer based controllers from the North Control Building and/or from the South Control Building, which are located near the north and south termini of the HOV lanes, respectively. These controllers communicate with the District 11 Traffic Operations Center (TOC) of the California Department of Transportation (CALTRANS) located approximately 10 miles south of the South Control Building. Orders to open and close gates, raise barriers, etc., are sent from the Traffic Operation Center to the field controllers using low speed communication lines.

Although the gates and barriers are equipped with sensors which detect their positions and report them back to the TOC controller, it is not currently possible to operate the HOV lanes without the visual verification of a CALTRANS employee, due to reported failures of the sensors and/or controllers. Moreover, this equipment is not capable of detecting obstructions and dangerous conditions such as vehicles blocking the HOV lanes, persons on the HOV lanes, etc. Finally, non-visual information is not widely accepted yet as evidence in courts.

An image processing system which will enable the TOC to obtain real-time traffic and road condition data has been installed to overcome these problems. The block diagrams of the equipment at the control buildings and the TOC are given in detail in [3] and will not be repeated here.

A menu driven application software platform which enables various image processing tasks using the mouse on the workstation has also been developed [3]. Through the use of this equipment, it is possible to verify the positions of the gates, barriers, and the Changeable Message Sign (CMS) messages. It is also possible to monitor the road for obstructions and dangerous conditions.

1.2 Importance of the Work to IVHS Designers and Signal Processing Community: We are continuously learning from our current work that real-time image processing and compression capabilities will have significant impact on numerous intelligent highway projects. The following are a number of areas being studied with some degree of success by research groups throughout the world: (1) Collection of count, speed, length and lane occupancy information. (2) Automatic surveillance of a length of an highway and associated incident detection systems. (3) Monitoring the movement of vehicles within a junction for data collection and traffic control. (4) Vehicle classification and selective vehicle detection. (5) Limited enforcement of traffic laws and issuing citations.

In addition there are a number of on-going projects in various academic and government research facilities: (1) Device control and monitoring. (2) Comprehensive traffic enforcement. (3) Toll collection. (4) Guidance of vehicles and navigation of ships under adverse weather conditions. (5) Night vision applications using infrared imaging systems. (6) Ergonomic TOC information displays. (7) Assistance to motorists.(8) Smart Vehicles.

2. SYSTEM ARCHITECTURE AND ITS COMPONENTS

Since this has been an integrated systems study it has tightly coupled hardware implementation, software development, and signal processing algorithm components. The physical system configuration can be broken down into two major building blocks. They are: (1) the field equipment and (2) the TOC equipment.

2.1 Field Equipment: The field equipment consists of (1) a set of monochrome and color video cameras and sensors appropriately placed near each entrance of HOV lanes, (2) video control, (3) image and data communications equipment which sends image signals from the field to the TOC and the necessary control signals between the North and South Control Buildings and the TOC facilities.

2.2 TOC Equipment: In a similar fashion, the components located at the TOC facilities are (1) image and data communications equipment which receives video/equipment control data and image signals from the field, (2) an image display and monitoring system, and (3) image archiving subsystems consisting of a very large digital data store and two computer-controlled S-VHS video recorders.

Once this video equipment selection is made the next step is to compute the rate of information to be transmitted from the field to TOC and the rate of information for the control signals in the reverse direction. To achieve our goals in a limited time frame, we have chosen a commercially available industry standard JPEG-based [4] image acquisition and compression subsystem and housed it in a Sparcstation. We have also developed all of the necessary device-level and the system-level software tools to interface the equipment both with the presentation system and the data communication system. We have developed a menu driven application software platform, where numerous tasks are performed using the mouse on the workstation. These software tools include: (1) image acquisition, (2) geometric correction to remedy optical aberrations in the lens systems of mono and color cameras, (3) image enhancement for adverse weather conditions, such as, rain, glare, and lack of sufficient lighting, and (4) feature recognition techniques specially developed for processing pictures coming from CMS units, pop-ups, on-ramps and entrances to the HOV lanes, and gate barriers. Presently, we are able to transmit imagery over telephone lines using a special communications protocol called PPP at about 14,400 b/s rate over phone lines.

2.3 Scenes, Rate and Image Resolution: The images acquired from the monochromatic cameras can be multiplexed four-at-a-time and transmitted in a quadrant-based fashion. The images acquired from the color cameras need to have higher resolution and quality. Each of these cameras has a set of fixed positions and a continuous monitoring capability to acquire images from groups of pop-up locations (both up and down), gate barriers (up, down or in-between), the HOV roadway, the I-15 and Highway-163 main lanes, and other scenes needed.

During each closing and opening of the HOV lanes the camera sweep times in the system specifications are such that every CMS message is appropriately updated, every pop-up is in its final position and every gate in its proper location. During any abnormal condition on any of the devices or on the roadway due to an incident the camera pointed at that location will have the full attention. Similarly, the rate of monitoring will be properly chosen during the scheduled maintenance procedures.

3. OBJECT VERIFICATION

In figure 1, we present a message sign verification example on a monochromatic image obtained by a camera located at the Changeable Message Sign #8. Here the top figure is the original image with some glare at the lower left area. After digitizing this image we have corrected geometric aberrations. Next, we have enhanced the edges and removed the glare using traditional image processing techniques, which is displayed in the bottom. The verification algorithm based on template matching yielded a 100 percent correlation with the previously generated template for that message, i.e., the message is correctly verified.

Similarly, we present an example of the pop-up verification procedure in figure 2. Here the top picture is acquired from a color camera. Next, we have isolated the area of interest for the verifier. Then the pop-ups are enhanced group at a time and they are reduced to one-bit resolution for the template matching stage of the process as shown in the bottom picture of figure 2. Finally, the verification result of 100% correlation for this pop-up group is obtained using a similar template matching algorithm.

Figure 1. CMS Verification on HOV Lanes

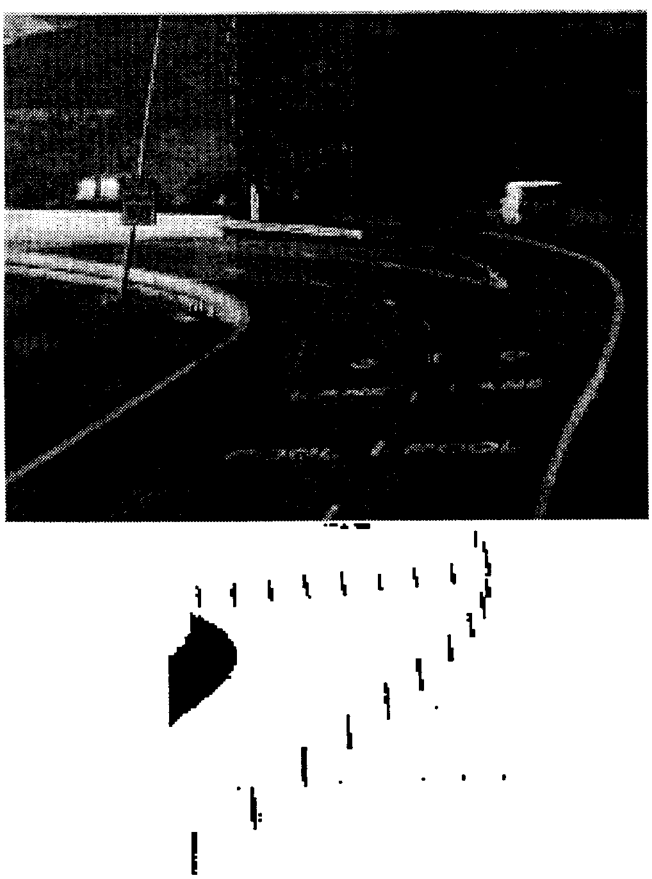
Figure 2. Pop-up Barrier Verification on HOV Lanes

4. VEHICLE SPEED ESTIMATION

One possible image processing application in traffic surveillance is vehicle speed estimation. Vehicle speed estimation is an important application used not only for speed enforcement but for traffic data acquisition as well. Since the main goal of traffic surveillance is to maximize the road capacity and minimize the delay, the acquired data can be used by traffic control systems to locate problems in traffic flow.

The average speed of a vehicle can be determined by using the simple approach illustrated in Figure 3. If the time the vehicle crosses the initial motion detection zone is t_1, and the time it crosses the final motion detection zone is t_2, the average speed of the vehicle in the intermediate zone can be given by

$$s = \frac{L}{t_2 - t_1} \qquad (1)$$

where L is the distance between these two points.

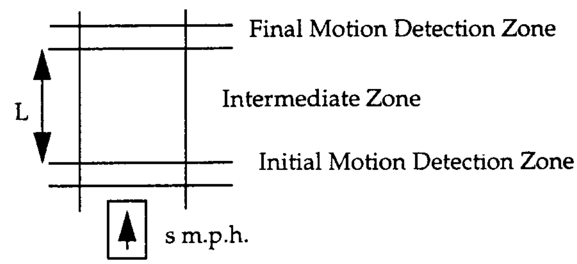

Figure 3. Vehicle Speed Estimation

This simple approach can be implemented using image processing techniques. A simple estimation algorithm in pseudo code is presented in Table 1. This algorithm is based on the assumption that there are no vehicles in the detection zone initially.

Table 1. Vehicle Speed Estimation Algorithm

1. Initialize *FrameRate*, *RoadLength*;
2. While (Motion not detected in initial zone)
   Iterate frame;
3. Set *InitialFrameNumber* to current *FrameNumber*;
4. While (Motion not detected in final zone)
   Iterate frame;
5. Set *FinalFrameNumber* to current *FrameNumber*;
6. $$Speed = \frac{FrameRate \times RoadLength}{FinalFrameNumber - InitialFrameNumber}$$

Errors in Speed Estimation: In the above approach, some errors are introduced in estimation due to reasons like temporal quantization, location of the camera and non-zero motion detection block size.

It can be shown that the upper limit of the percentage error in speed due to temporal quantization is given by:

$$\frac{\Delta s}{s} \times 100 \leq \frac{293 \times s}{f \times L}. \qquad (2)$$

where s is the speed of the vehicle in m.p.h., Δs is the error in speed, L is the length of the intermediate zone in ft., and f is the frame rate in frames/second. This implies that higher frame rates and longer detection zone should be chosen if higher accuracy is desired.

Some error is introduced to the estimation due to the location of the camera. We have obtained that the percentage error in speed due to the location of the camera is given by:

$$\frac{\Delta s}{s} \times 100 = -\frac{100 \times h}{(H-h)} \qquad (3)$$

where H is the height of the camera from the ground and h is the height of the vehicle.

Since a block of pixels are used to detect motion at initial and final detection zones, an additional error is introduced in estimating the speed. If the motion detection block size is MxN, the upper limit of the percent error in speed due to non-zero block size is given by:

$$\frac{\Delta s}{s} \times 100 \leq \frac{N}{K} \times 100 \qquad (4)$$

where K is the number of pixels in length L. It is worth noting that this error is independent of the speed of the vehicle.

Vehicle Speed Estimation Experiment: In order to determine the performance of this vehicle speed estimation algorithm, it is necessary to have access to a large database containing many vehicles travelling at various speeds which are accurately recorded. In our database we had only two such measurements. The actual speed of those two vehicles were both 65 m.p.h. and the algorithm has yielded an estimated value of 63.92 m.p.h. in each case. Here the algorithm has approximately corrected the errors from Eq. (3,4). However, it is not possible to correct the error due to Eq. (2), which turns out to be about 6 percent.

5. INTEGRATION WITH TOC OPERATIONS

The HOV image processing system is intended to be integrated into the overall TOC operations. The design of the various system components and the software platforms are already taking this into account. In all of our design choices we are leaving vertically upgradeable integration capability for the emerging TOC model of the concept 2010.

The user interface for the system is undoubtedly one of the most critical factors to be considered in the overall system design. The user interface must be extremely user-friendly and provide the following capabilities: (1) The ability for an operator to select and view a particular camera, and interactively position a camera to his desired location or to one of the predetermined locations. (2) The ability to selectively record images from a particular camera or camera groups, or the ongoing video operations. (3) Information concerning the status of the system, with respect to operation of the video imaging system, the real-time control computers, the peripheral subsystems, the network conditions, other traffic and statistical information, and the status of the server. We have attempted to address each one of these points in our user interface software programs and developed a library of tools, which can be called either manually or in a batch fashion from each application shell.

6. SUMMARY AND CONCLUSIONS

In this paper, we have attempted to present a proof of concept capability for continuous and automatic monitoring and verification of HOV control devices on I-15 and a vehicle speed estimation experiment as case studies in IVHS implementation. We have designed a system incorporating modern communication systems and algorithms, such as data communication at 14,400 B/s, fiber-optic links, accurate control of cameras from remote locations, low-cost microwave equipment, image processing algorithms for compression, enhancement, transmission, presentation, and verification.

The information presentation requirements of IVHS related technologies will require the development of new data processing algorithms and methods. In addition to multimedia information presentation, new methods for data gathering and distribution will need to be developed. Finally, the technology which will implement these methods must be low cost, high performance, and reliable. Development of these systems will require extensive research in the areas of data communication and compression, image processing, and real time control systems.

7. REFERENCES

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