Toward the Next Generation of Machine Vision Based Highway Surveillance Systems

This project addresses the problem of surveillance in an ATMIS. The lack of reliability and low accuracy of data returned by existing methods of surveillance prompts us to design a new generation of surveillance systems which is video image based and therefore nonintrusive. The system detects vehicles on the road and then tracks their progress through the field of view, allowing coarse information such as traffic speed and flow to be obtained. Furthermore, using detailed vehicle trajectory information already derived, the system will be able to detect incidents and provide additional information as to their type and possible cause. The system could be used for real-time highway or intersection surveillance, compression of data for remote graphical reconstruction, post-incident analysis and analysis of archived videotaped data.

What separates our system from video image based systems currently available is our use of state-of-the-art image processing and tracking algorithms, and advanced metareasoning concepts for situation assessment. Through this approach we aim to attain levels of accuracy and reliability that have not yet been achieved by other systems.

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Conference Update

PATH at IVHS America

The California PATH program will once again have a presence at the Fourth Annual Meeting of the Intelligent Vehicle/Highway Society of America (IVHS America) April 17-20 in Atlanta, Georgia. With the field of IVHS research expanding, this meeting provides ample opportunity to discover and discuss many aspects of current research and products. The meeting also allows us to show what PATH is and what impact we are having in the current IVHS research field. California PATH participation is widespread, with several researchers presenting papers in ATMS (Advanced Transportation Management and Information System) and AVCS (Advanced Vehicle Control System).

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<td>8:30-10:00 AM</td>
<td>Route Guidance Technology</td>
<td>An Adaptive Vehicle Routing Approach for IVHS</td>
<td>Hong X. Le, Bob Rea, Randolph W. Hall, California PATH</td>
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<td>10:30-12 noon</td>
<td>Education and Training</td>
<td>Responding to IVHS Training Needs: A Curriculum for 21st Century Professional Education</td>
<td>Paul P. Jovanis, Institute of Transportation Studies, U.C. Davis</td>
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<td>1:30-5:00 PM</td>
<td>The National IVHS Program Plan</td>
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<td>Evaluation of Field Operational Tests</td>
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<td>Donald E. Crain, ESL/TPR (Former PATH Director)</td>
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<td>IVHS Program Activities</td>
<td>(Panel)</td>
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<td>Evaluating Risks and Benefits</td>
<td>State and Property Dynamics: Public Transportation Impacts on Growth</td>
<td>Anand M. Hinnu, Emmerman Le Collecte, California PATH</td>
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<td>10:30-12 noon</td>
<td>AHS-Defining and Analyzing the System</td>
<td>A Functional Architecture for Automated Highway Traffic Control</td>
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<td>10:30-12 noon</td>
<td>AHS-Defining and Analyzing the System</td>
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<td>8:30-10:00 AM</td>
<td>ATIS User Issues</td>
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<td>Mohamed A. Mehd-Aly, Kenneth M. Vanghi, Paul P. Jovanis, Yusheng Xinan, ITS, U.C. Davis, Prof E. Hamann, University of Washington</td>
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<td>8:30-10:00 AM</td>
<td>ATIS User Issues</td>
<td>A Combined Transfer Behavior and System Performance Model with ATIS</td>
<td>Anand M. Hinnu, Emmerman Le Collecte, California PATH, Matthew A. Doh, Newsday Central Florida</td>
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<td>1:30-5:00 PM</td>
<td>Human Factors and Collision</td>
<td>Simulation Study of the Effects of Roadside Guidance Systems on Driver Performance</td>
<td>Paul P. Jovanis, Rakesh Shrestha, Yusheng Xinan, Ciao-Tung Yang, ITS, U.C. Davis</td>
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At the California PATH exhibit, PATH researchers will provide demonstrations and answer questions. Computer demonstrations will include California Advanced Driver Information System (CADIS), a driver simulator with route guidance; DYNAVIS Simulation, a dynamic visualization environment for AVCS design and evaluation; SmartPath, a simulation package for an Automated Highway System; Freeway Service Patrol Database, a user-friendly graphic interface to the enormous database of traffic information on a section of Interstate 880; SmartLink, a graphical interface simulator for demonstrating automated highway flow at a macroscopic scale; Electronic Yellow Pages, enhances pre-trip planning by allowing users to visualize the locations of interest in real-time presentations. Video presentations will include a demonstration of a Machine-Based Vision Highway Surveillance System and video of the PATH Lateral and Longitudinal Control Vehicle tests.

UC Berkeley's Industrial Liaison Program

March 9-10, 1994 marked the 15th Annual Conference of the Industrial Liaison Program. Over 400 interested parties descended on the Berkeley campus for the smorgasbord of presentations on research projects in progress at the College of Engineering, the Center for Particle Astrophysics, and added this year, the Center for Nuclear Physics. Professor Adib Kanians presented the Institute of Transportation Studies and explained its goals, purpose, and the significance of ITS research for the future. Professors from the Berkeley campus and researchers from PATH discussed latest developments and future directions of their research.

The forum also gave graduate students the opportunity to present their research work before an experienced and supportive audience.

ITS Extension Short Course on Automated Highway Systems

The short course offered by the Institute of Transportation Studies Extension Program in cooperation with PATH met February 1-2, 1994 at the Berkeley Marina Marriott. Sixty-five registrants from across the country attended the course to learn about the latest research in AHS. The wide range of topics included everything from system-level design concepts and safety analyses to specifics of vehicle lateral and longitudinal control and evaluations of the mobility and air quality impacts of AHS. The short course material is available from ITS Publications for $65, page 11 for ordering address.
Background

Motivation

The extent to which Advanced Transportation Management Systems can benefit the traveler is ultimately limited by the information with which the systems must operate. Accurate, reliable, and detailed knowledge of the state of traffic on important stretches of highway allows development of structure that is able to support transmission of data back to the Traffic Operations Center (TOC). To mitigate this requirement, several image processing systems have been developed to allow pertinent traffic variables to be determined locally at the cameras and thus reduce the quantity of data that needs to be sent back to the TOC. Unfortunately, the best systems currently available have been found to provide data that is inadequate in quality of detail and requirement for a dedicated high-bandwidth communication infrastructure. Using vehicle trajectory data, the second level of the system applies advanced symbolic reasoning techniques to deduce the state of the road at any time. This implies that not only are unusual traffic conditions such as incidents detected but their nature is also derived (for example, a car has stalled, or a truck has jackknifed). Furthermore, since the information

Advanced Traffic Management Systems that help drivers to decide how best to proceed to their destinations, aid detection and response to incidents and help reduce and prevent congestion. Therefore the first stage in design of any such system is surveillance.

As one example, Caltrans District 4's Cornerstone Project proposes to use several different approaches to surveillance and has already committed to implement two in particular: loop detectors embedded in the road surface, and video cameras mounted off the road. Neither of these two approaches has been completely satisfactory. Loop detectors are disruptive to install, subsequently expensive to maintain and ultimately provide sparse and unreliable data. Video camera based surveillance potentially requires construction of an enormously expensive communications infrastructure for immediate use.

The drawbacks of these two current approaches to surveillance prompts us to propose development of a more advanced surveillance system. Using video cameras as sensors we propose to develop a two-stage surveillance system. The first stage consists of state-of-the-art image processing algorithms that will detect and track vehicles on the road extremely accurately. From this information composite traffic variables such as flow and speed can be deduced reliably and also aberrant individual driver behavior can be detected. Vehicle trajectory and type information can be communicated to the TOC where the progression of vehicles can be reconstructed remotely. Note that this information is approximately three orders of magnitude smaller than communication of real time video frames, thereby precluding the

Figure 2: a) An image section with a moving car, b) the moving object mask provided by the motion segmentation step, c) the image location with well defined spatial gradient and temporal derivative, used as sample points to define d), the convex polygon enclosing these points of d), the final contour description by cubic spline segments approximating the polygon of d).

Figure 3: The upper image shows frame #64 of the sequence. The graph below shows a reconstruction of the SmartPath traffic simulator of this image (the geometry is slightly different due to the display of the SmartPath simulator).

7. Classify incident type (car stalled, truck jack-knifed, collision etc.).

In order to achieve these goals we recognize that we must address the following issues.

- Maintaining reliability and accuracy during changes in lighting conditions, especially during the dawn and dusk periods when traffic flow is often at its heaviest.
- Estimating during different weather conditions, including rain, snow and fog.
- Avoiding confusion due to shadows or reflections off wet road surfaces.
- Taking account of change in apparent size of vehicles as they move toward the camera.
- Ensuring that tracking is reliable even when traffic density is high.
- Maximizing the incident detection rate while maintaining a low false alarm rate.

Vehicle Detection and Tracking

An important component in tracking systems is track formation or initialization, for which we use a motion segmentation step. The simplest technique for separating moving objects from the stationary background is through examining the difference between each new frame and an estimate of the stationary background. Segmentation of moving objects in an outdoor environment also requires that the background estimate evolve over time as lighting conditions change. Thus changes in stationary parts of the image must be differentiated from changes due to moving objects.

The binary difference mask is then translated into distinct connected objects through merging of connected regions and elimination of small regions (see figure 1 pg 1). These connected objects are used as the tracking initialization.

Contour Extraction and Shape Estimation

Contour extraction is based on motion and grey-value boundaries.

Grey-value boundaries are obtained by thresholding the spatial image gradient. Significant motion areas are obtained by thresholding the time derivative of the image function. The convex polygon enclosing all the sample points of the locations that passed the first test for grey-value boundaries and motion areas is then used as an initial object description.

Figure 2 (pg. 4) shows an image section with a car (a), the detected image patch covering the image of the car (b), and the image location with well defined spatial gradient and time derivates constituting the sample
Fuzzy Logic Control for Platoons of Smart Vehicles

Traffic drivers highways around the world. Platoons of vehicles—high-speed groups of smart vehicles in single lanes—can increase traffic flow and mean speed on freeways. The nonlinear dynamics of a high-speed platoon on a complex freeway are complex. True math models can be hard to find. Fuzzy systems give a model-free estimate of a nonlinear control function.

Julie Dickerson, University of Southern California

A fuzzy system is a set of fuzzy rules that maps inputs to outputs. A fuzzy controller uses rules that act like the skills of a human driver. The rules have the form “If input conditions hold to some degree, then output conditions hold to some degree” or “If A, then B” for fuzzy sets A and B. Figure 1 shows the rules for a simple fuzzy controller for the speed of a car.

Each fuzzy rule defines a fuzzy patch or a Cartesian product of fuzzy sets in the input-output state space X. The fuzzy rules define patches that map the fuzzy input sets to fuzzy output sets. The fuzzy system approximates the fuzzy output curve, a process of “defuzzification.” Most fuzzy systems take the center of mass of the area under the fuzzy output curve (the centroid) or the peak of the output curve.

Input fuzzy sets (the R-part of the rule) can be combined using such logical operations as AND and OR. A more advanced velocity controller might have rules of the form “If the car is fast and the car is decelerating, then set the throttle to NO CHANGE.” As before, the system then defuzzifies the outputs of the fuzzy rules in the same way to compute the final output value.

The performance of a fuzzy system depends on its rules. Most systems begin with rules devised by experts. Engineers then tune the rules and fuzzy sets. Neural networks and statistical systems can help learn the rules from input-output data. These adaptive fuzzy systems can learn new rules or tune existing rules for better performance.

Fuzzy Throttle Controller

In a platoon, each car tries to travel at a desired platoon velocity and maintain a desired spacing. A lead car plans the course for the platoon. It sets velocity and car spacing, and picks which maneuvers to perform. Platoons perform four maneuvers: merge, split, lane change, and velocity change. A merge combines two platoons into one. A split divides one platoon into two. A lane change moves a single car into an adjacent lane. A velocity change speeds up or slows down the whole platoon.

The fuzzy throttle controller (FTC) performs longitudinal maneuvers for the platoon, such as merges and splits. Figure 3 shows the separate fuzzy subsystems for leader and follower velocity and for gap control. When the platoon travels at a constant velocity, each car uses its own velocity controller to maintain the desired velocity, using velocity and acceleration data from the car in front of it. The velocity controller output is change in the throttle angle.

The leader velocity controller controls the speed of the platoon leader. The gap controller controls splits, merges, and changes in spacing for follower cars. The subsystems work together to control the platoon, using the velocity and acceleration data of the controlled cars. The controllers change the throttle angle for all cars in the platoon.

Figure 4 shows the fuzzy rules used for the velocity control variables in the ith car of the platoon. The fuzzy rules and fuzzy sets define a control surface for the velocity controller. These rules relate changes in throttle angle to different combinations of d0 and d. The fuzzy system encodes “expert” knowledge for velocity control. It limits the size of accelerations and decelerations for different size changes in velocity. A human driver follows a particular acceleration profile for each situation. If he wants to speed up just a little, he will barely depress the accelerator, and the acceleration will be small. If he wants to greatly increase speed, then he uses a heavier foot, and increases acceleration.

When a platoon merges or splits, the gap controller in the lead car moves the car to the desired spacing. When the platoon completes the maneuver, the velocity controller in the leader maintains a constant velocity. There are three design rules for merges:

a) If distance error is Large Negative (LN), then accelerate to a catch-up velocity. Distance error $d(t)$ is the difference between the desired gap between the cars (and the actual gap).

b) If distance error is Medium Negative (MN), then decelerate slowly with drag.

c) If distance error is Small Negative (SN), then decelerate faster until desired distance error and velocity difference are reached. Splits use similar rules, but with acceleration and deceleration reversed.

The gap controller corrects the distance error when it is too large. The gap controller for platoon
fuzzy throttle controller has two subsystems that maintain the platoon. The gap controller keeps the cars at a constant distance from one another. The leader velocity controller keeps the platoon at a constant speed. The gap controller uses the differences in acceleration and velocity between cars and the distance error to achieve or maintain a constant spacing. A range-finding system on each car in the platoon measures the distance between the cars.

**Gap Control Test**

We tested the gap controller in a two-car platoon on highway 1-5 in Escondido, California. First we tested small platoons with a realistic car model. Then we put the controller in a full-size car. In this test, the follower cars got data only from their sensors, which measure the distance and the velocity difference between each car and the car in front of it. We estimate the acceleration input from the distance of the velocity measurements. The acceleration measurements are noisy, so we use only the signed sign of the acceleration.

We used a pulse-doppler radar system, which locks on a target on a car ahead, to measure the distance and the velocity difference between the computer-controlled car and the car ahead. The radar has a measurement delay of 0.05 seconds. The desired gap between the cars was 125 feet. Figure 5 shows data for the platoon as it accelerates onto the highway. The cars started with a separation of 10 feet. The fuzzy controller started when the follower car reached 25 miles per hour (the cruise control does not work below this speed). The platoon accelerated to 55 miles per hour in 20 seconds. Figure 5a shows the follower car gap as the platoon accelerates. Figure 5b shows the closing rate between the cars. Figure 5c shows the throttle value as the car accelerates. The follower car slowly dropped back from the lead car as the platoon reached the desired velocity, then fell back about 25 feet too fast, and finally corrected its position by giving itself a little more throttle.

**Conclusion**

The next phase of the fuzzy platoon controller will add brake and steering control so the platoon can maneuver on the highway. Tests on the brake/throttle controller will start this summer. We will also work on neural fuzzy systems that adapt to changes in the environment and car performance in real time.

The authors thank Jim Rowland and John Oaks of VORAD Incorporated, which provided the car and radar sensor for the gap controller test, for their help in testing our controller.
High-Level Reasoning Using Belief Networks

We now address the task of using vehicle track information to make high-level symbolic descriptions of vehicles and the traffic scene. To accomplish this, our symbolic reasoner uses multiple, per-vehicle dynamic belief networks with fast analyzing and flexible node semantics.

Concepts

Belief networks are directed acyclic graphs in which nodes represent random variables (usually discrete) and arcs represent causal connections among the variables. Associated with each node is a probability table that provides conditional probabilities of the node’s possible states given each possible state of its parents. When values are observed for a subset of the nodes, posterior probability distributions can be computed for any of the remaining nodes. This takes place using a compiled form of the belief network that is more suitable for propagating the influence of evidence to other nodes.

Dynamic belief networks allow for reasoning in domains where variables take on different values over time. Typically, observations are taken at regular ‘time slices’, and a given network structure is replicated for each slice. By explicitly modeling uncertainty, the interaction of low-level information from a variety of sources, and the effect of evidence accumulated over time, dynamic belief networks provide a flexible, theoretically sound framework for temporal high-level reasoning about traffic scenes. We have incorporated enhancements that improve the performance of belief network evaluation, that reduce the complexity of evaluation to be linear in the number of vehicles tracked, and that provide greater robustness by varying the semantics of network nodes from one time slice to another.

Results with Real-World Traffic Scenes

We have tested our system on several real-world image sequences, and we present here the results of one 20-frame sequence of a divided four-lane freeway. In Figure 3 (pg. 5), the upper image shows frame #6 of the sequence, and the graphic below shows a reconstruction of the SmartPath traffic simulator of the image (the geometry is slightly different due to the display of the SmartPath simulator). In the graphic, one vehicle has been identified by the symbolic reasoner as changing lanes, and the number in the signpost correctly indicates the number of vehicles that have passed since the beginning of the image sequence.

SmartPath is a microcomputer three-dimensional automated highway simulator developed at UC Berkeley as part of PATH.

Conclusion

We have demonstrated and validated the concept of a vision-based road surveillance system expanded with a symbolic reasoning component for an automatic traffic scene analysis in an Advanced Transportation Management System (ATMS).

For that purpose we designed a system for robust detection and tracking of multiple vehicles in real traffic scenes. The system provides tracks and shape description of vehicles which are fed into a symbolic reasoning component in order to extract high-level descriptions of the traffic scene. Symbolic reasoning of the vehicle tracks is performed by a belief network. Dynamic belief networks seem promising as a tool for integrating and analyzing low-level information provided by traditional systems, and for acting as a substrate for real-time decision-making systems. Their use in traffic scene analysis has a number of applications in monitoring and control. Recent and projected improvements in sensing and interpretation technology promise to allow real intelligence to be deployed in an ATMS.

PATH on Paper

Here is an update on some recent PATH publications.

A price list that includes research reports, working papers, technical memoranda, and technical notes can be obtained from the Institute of Transportation Studies Publications, University of California, 109 McLaughlin Hall, Berkeley, CA 94720. 510-642-3588, FAX: 510-642-1246.
Departures

The dust has settled from the previous quarter's busy hiring activity and we are sad to report that this quarter we have to say good-bye to Anthony Hitchcock, who will be returning to his homeland of England for retirement. Tony has enriched PATH's research program with his depth of knowledge and experience in transportation safety and his thorough, scientific approach to all research problems. He joined PATH in April of 1990 after serving as Head of the Transportation and Safety Group at the U.K. Transport and Road Research Laboratory for nearly eight years, where he was responsible for all U.K. government-funded research in the user safety and transit fields. He also developed and introduced to the U.S. the techniques now generally used for safety assessment of AVCS devices. At PATH he specialized in AHS safety. He demonstrated the efficacy of fault-tree analysis for verification for the safety of AHS designs and developed the technique of quantitative analysis of casualty rates in accidents which made it possible to compare the safety of different AHS operating schemes. We all wish Tony a safe return home and that he thoroughly enjoy his retirement.

Intellimotion is a quarterly newsletter edited by and designed by the publications staff (Bill Stone, Gerald Stone, Andrew Watanabe and Sara Martinez de Osaba) of California PATH.

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