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ROAD TRAFFIC MONITORING USING IMAGE PROCESSING—A SURVEY OF SYSTEMS, TECHNIQUES AND APPLICATIONS

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ABSTRACT

Following their earlier research work associated with the development of the TRIP System at Sheffield University/UMIST the authors are engaged in a re-evaluation of image processing applications in transportation engineering. Existing image processing techniques applied to traffic data collection involve only low level image interpretation of sequences of images. Although primitive these techniques have enabled useful parameters such as vehicle speed, counts and lane occupancy to be measured effectively. It is believed, however, that future image processing systems will require additional built-in intelligence to cope with more sophisticated applications.

This paper will provide a review of the experience of a number of groups active in image processing research in the transport field. It will go on to comment upon the short-falls of existing equipment and processing techniques. These considerations were taken into account during the development of the TRIP II system, which will then be described. The paper will go on to suggest methods whereby some of the inadequacies of past systems may be overcome in the light of trends in computing equipment, special purpose hardware and enhanced processing technique and machine intelligence.

In order to achieve near real-time operation past systems have concentrated upon applying differencing techniques to small samples of video images. Conventional systems have often been based on purpose built computers and application specific algorithms. However the TRIP II system takes full advantage of the area sensing capability of video images. The approach is different since the hardware is based upon an inexpensive IBM PC/AT microcomputer. The software provides an alternative means of processing complex pattern information by simulating the operation of a neural network. The vehicle detection algorithm relies on the ability of the TRIP II system to learn from examples and discriminate between complex patterns within video images of traffic scenes. Over the past decade many image processing systems for traffic monitoring have been designed and implemented. The paper will finally go on to outline the range of applications for such image analysis systems.

Keywords Traffic control; road traffic; computer applications; pattern recognition; image processing; neural netwoork

INTRODUCTION

Effective traffic data collection is the cornerstone of the successful planning, maintenance and control of any modern transport system. Traffic surveys form a major part of the traffic engineer's work and are of fundamental importance since most design problems require a detailed knowledge of the operating characteristics of existing and future traffic movements. The results of various traffic studies are used throughout the transport planning process. The desire for more automated methods of data capture and analysis coupled with developments in micro-electronics has thus led to a good deal of research activity in recent years, with the aim of applying new technology to traffic data collection.

The past decade has seen an enormous increase in the use of video equipment for traffic monitoring and control. Surveillance of motorways, tunnels and urban streets is on the increase. In addition video equipment is used for a wide variety of traffic surveys. The spatial characteristics of road traffic are required in order that new control strategies can be developed. Hence the interest in area-wide sensors, e.g. video-cameras, which are capable of providing a range of information impossible to achieve with the current range of highway based "point" detectors, e.g. loop-detectors or ultrasonic detectors.

It would be extremely useful if a video camera "vision" system could be set up to view a stretch of road without causing any disturbance to traffic flow, but at the same time capable of providing the required traffic flow measurements. Video image analysis is concerned with the automatic extraction of useful information from video pictures. This should be carried out without undue interference from the numerous irrelevant events and objects occurring simultaneously within the traffic scene. Not only is this difficult to achieve but image sequence processing involves a large amount of data.

This paper will provide a review of the experience of a number of groups active in image processing research in the transport field. It will go on to comment upon the short-falls of existing equipment and processing techniques. These considerations were taken into account during the development of the TRIP II system which will be described. The paper will go on to suggest methods whereby some of the inadequacies of past systems may be overcome in the light of trends in computing equipment, special purpose hardware and enhanced processing technique and machine intelligence.

DIGITAL IMAGE PROCESSING AND COMPUTER VISION

Why use image analysis? What has happened to generate so much interest in image processing research for traffic engineering applications? Firstly, the established trend of falling prices for video equipment has lead to an enormous increase in the use of video equipment for traffic monitoring and control. Secondly, image processing hardware costs have fallen while computational power has increased, making automatic video scene analysis a realistic possibility.

Surveillance of motorways, tunnels and urban streets is on the increase and video equipment is used for a wide variety of traffic surveys and research. Unfortunately, however, most video systems rely heavily on manual abstraction of information from the video pictures. In the majority of control centres banks of video monitors are simply used to verify incidents reported by staff or members of the public, rather than as a means of identifying impending problems.

Over recent years there has been evidence of a growing interest in methods whereby video images might be automatically analysed to provide monitoring systems. The authors, in common with research groups in the UK and overseas, have been developing such automatic systems.

It is important before proceeding with this paper to highlight the difference between Computer Vision and Image Processing as discussed here. Computer Vision is concerned essentially with emulating the process of human vision within a computer system. Within computer vision, scene interpretation is the process of describing an assemblage of objects in terms of their identities, position, orientation, juxtaposition and semantic associations. This is considered to be a "high-level" process. Image processing on the other hand involves the manipulation of the two-dimensional representation of a scene and may simply involve the detection of a change in light intensity at some point within a scene. So while computer vision is focussed on the task of "understanding" scene content, image processing may be conceptually rather trivial. In practice, however, true computer vision systems do not exist at present.

REVIEW OF IMAGE PROCESSING SYSTEMS

During the past decade a variety of systems have been developed with traffic data collection in mind. Early attempts date back to 1973 and have been reported by engineers from the University of Tokyo. Several other research groups in Europe have reported on work of a similar nature to the Japanese group. In each of these cases image resolution, both spatial and temporal, has been sacrificed in an attempt to keep the image data flow compatible with the processing capabilities of the systems. The US Department of Transportation was between the mid-1970's and the early 1980's funding research into image processing applied to freeway surveillance at the Jet Propulsion Laboratory (JPL) in Pasadena. The JPL approach was to try and track vehicles as they passed through the scene. Vehicle tracking has been attempted elsewhere, but each time with only limited success. Some of these early systems were described in DICKINSON and WATERFALL (1984). It was concluded at the time that the desire for high resolution systems which operate at high processing speeds could not be satisfied, and that significant constraints would have to be applied to the image scene although much raw data would thus be sacrificed. Because of this most traffic data collection systems would inevitably exhibit little intelligence.

During a six year period between 1980 and 1985 the Sheffield University/UMIST Traffic Research and Image Processing Group undertook a programme of research directed towards traffic data collection. SERC and TRRL provided funds which enabled the authors and their colleagues to develop the TRIP video image processing system (DICKINSON et al 1985, ASHWORTH et al 1986). The TRIP System is a flexible software based image processing development system designed with the specific aim of automatically detecting vehicles on multi-lane highways. It has enabled raw video images to be captured and stored for subsequent analysis. It was thus possible to examine various problems and later improve the detection algorithm by repeatedly analysing the same images. During extensive site trials undertaken on an urban road and a motorway, and carried out under a variety of ambient lighting conditions, it was possible to detect 99% of vehicles and measure individual vehicle speed to an accuracy of between +/-8% and +/-17%. Since their move to Edinburgh the authors have continued to investigate the use of image analysis in the field of traffic engineering and they are currently implementing an improved version of the TRIP algorithm at Napier Polytechnic.

Other recent systems based on "windowing" have been adopted by researchers at University of Newcastle and UCL in an attempt to increase overall processing speed. In the case of the Newcastle work SERC is supporting the development of an automatic counting system based on the use of a video recorder and IBM micro-computer. Problems of changing ambient lighting would be minimised by "careful selection of site and survey time". The system is named TULIP and is capable of monitoring up to three lanes, although not operating at video frame rate when monitoring three lanes (ROURKE 1989). Data collection is a two-stage process. Firstly a video recording of the traffic scene is obtained and secondly the video tape is played back and analysed by the computer. Under favourable lighting conditions and with good camera position counting error of better than 2% can be achieved. The next stage of research is to extend and develop techniques for real-time monitoring of pedestrian movements.

An SERC funded project with the aim of tracking vehicles through junctions has been recently completed at UCL (HOOSE and WILLUMSEN 1987). Encouraging results were achieved during limited five minute trials, but understanding of the scene was sacrificed in an attempt to operate in real-time. A windowing system was used to detect vehicles, automatic background scene updating was not performed and problems associated with occlusion and shadows were identified as areas in need of further attention. Currently researchers at UCL are looking into the application of video image processing to incident detection on high speed roads (HOOSE 1989). A system making use of a commercially available image processing subsystem with a microcomputer host has been reported. The algorithm is based on the use of spatial information from the video images.

ABRAMCZUK(1984) described a research programme which attempted to measure a global statistic which would indicate disturbance within traffic flow on a length of motorway. The research formed part of the EUCO-COST 30 Project on motorway surveillance and incident detection. Again only window data was used and a reliable measure of area-wide parameters was not produced.

JPL have investigated the use of cross-correlation search techniques for tracking vehicles. The vehicle would firstly have to be detected by some means, after which its description in the form of a grey-value sub-matrix of the image is stored together with its location. When the next image is captured the "signature" sub-matrix is correlated with the image matrix and the best-match new location is determined and recorded. The system can from past experience only accommodate some change in the vehicle grey-value signature as it tracks the vehicle through a sequence of images. Additional problem with this type of system is that is computationally expensive. Subsequently tracking was abandoned, because of the high cost and unreliable operation under changing lighting conditions, in favour of a more modest sampling system for vehicle detection and velocity measurement. Detection error of less then 2% has been reported under sunny weather conditions.

The most recent reported research aimed at tracking vehicles through junctions made use of the RAPAC system (HOUGHTON et al 1987). The system was designed to perform on-line industrial inspection but has been modified to track several vehicles concurrently through a road network. The processing falls into two parts; firstly feature highlighting and extraction, carried out by the RAPAC image processing system; and secondly vehicle tracking, carried out with a 5MHz 8086-based microcomputer. The algorithm used was similar to many previously used, being based upon a thresholded difference image. A novel background updating algorithm refreshes the reference frame approximately once per minute. The near real-time operation of the system depends to a large extent on the use of special purpose dedicated hardware. A more recent report on "Automatic vehicle recognition" has been given by HOUGHTON et al (1989). The system is capable of providing limited vehicle classification based on a vehicle outline matching technique.

Software developments concerned with the analysis of time varying images (NAGEL 1984) suggest that by isolating prominent features on a vehicle, e.g. corners of the bodywork, more reliable tracking of vehicles could be achieved. Before this can be done, however, some form of edge detection must be carried out. Those edges which represent prominent features can then be matched from frame to frame and feature displacement can be determined. Feature matching software should be more robust than systems dependent upon analysis of grey-value images since edges are less affected by changes in lighting and therefore pixel intensity. This technique is the most computationally demanding, and at present is at the fundamental research stage. In the future, however, this technique may be the most attractive.

A more "intelligent" model-based approach to the recognition of London Buses has been reported by HOGG (1984). An attempt is made to match objects in the scene with a three dimensional template of the bus. The problem with such an approach if it were to be applied generally is that a precise template would be required for each vehicle make and model. This highlights the ultimate need for an understanding of the function of the object rather than a knowledge of its precise geometric form.

A novel processing technique has been adopted by BLOSSEVILLE (1989) in the TITAN system. TITAN is capable of firstly identifying the traffic lanes on the road and secondly detecting the vehicles present. The system makes use of local minima and maxima, obtained using geometrically adapted filters and morphological transformation, for detection. This enables the system to detect stationary as well as moving vehicles. Lane detection is first performed by capturing and processing a series of images. Subsequently each picture is analysed one at a time. The positions of identified vehicles are also used to build vehicle trajectories. Vehicle identification errors, on a single picture basis, of about 3% has been reported but this is very much improved when the trajectories of vehicles are used to eliminate false detections. Work on detection of traffic queues in congested traffic conditions and night time observation has also been reported.

A comparative study of five different types of image processing equipment from different manufacturers has been reported by SHIMIZU (1989). The experiment set out to determine the performance, accuracy and feature of particular equipment and to investigate the adaptability to traffic control applications. Accuracies for traffic volume and speed measurements of better than 90% and for space occupancy 80% were reported. The low detection accuracy can be attributed to the relatively simple but easy to implement algorithm employed.

Automatic traffic data collection using aerial video images has been reported by BECKER (1989). A method developed at the University of Karlsruhe enables a range of traffic parameters such as speed distribution, density and overtaking to be determined. Video recordings are obtained from flights and the images are analysed off-line on a DEC PDP 11/73. Multiple passes are made during trials both with and against traffic flow. Image registration is performed by identifying and matching fixed points on the road using correlation technique. A combination of different image processing techniques, including differencing, binarisation and correlation, has been used for vehicle detection. Flight speeds were choosen such that every vehicle would be included in at least three processed images. A study of observation on 50 flights, alternating back and forth with and against traffic stream, over 4 km of road revealed that the measured traffic density changes systematically between successive passes. This change of observed traffic density was due to the relative speed between the aircraft and the observed traffic. It has been shown that this variation can be corrected by correlation. Limitations include the non-automatic data transfer of selected images from video tape and off-line analysis (approximately 60 hours of processing for 1 hour of observation).

A research group from the University of Leeds is currently working on an evaluation of a vehicle registration numberplate matching system (WILLIAMS 1989). The C.R.S. numberplate recogniser unit has been evaluated with flow rates up to one vehicle per second under "ideal conditions". Early work on vehicle numberplate recognition, which employed dedicated hardware for locating the numberplate, had been attempted by another British research group with an aim of identifying stolen vehicles or vehicles with illegal numberplates. The prototype system had a working range of about 4 metres and was able to read more than 50% of vehicle registration numberplates correctly. Trials under laboratory conditions showed the system under evaluation was able to read more than 60% of the numberplates correctly. Site trials have yet to be completed. Problems with the existing syntax forcer, which improves reading accuracy, and a way of reducing the problem has been reported.

CAPABILITIES AND LIMITATIONS OF EXISTING SYSTEMS

Compared with total research effort in the field of computer vision that directed to traffic data collection has been very limited. The question that remains is what has been accomplished? This section looks at the success and lessons to be learned from a decade of research into vehicle detection from video pictures.

What applications are technically possible using video image processing? The following tasks have been achieved with some degree of success by research groups throughout the world.

1. the collection of count, speed, length and lane occupancy information
2. the automatic surveillance of a length of motorway and associated incident detection systems
3. monitoring the movement of vehicles and pedestrians within a junction for data collection and traffic control purposes
4. vehicle classification - registering vehicle shapes and selective vehicle detection
5. vehicle registration numberplate reading

Why if we can undertake these tasks are there few commercial systems capable of producing these data? The answer lies in the desire for not simply a technically feasible system, but one which is also low-cost and capable of operation in real-time. Such systems are not yet widely available. Although computing power of modern devices has increased dramatically conventional computers are not designed to handle two-dimensional data and are often incapable of processing the extremely high data-rate generated by video image digitising equipment. For this reason many of the groups involved in this area of research have by necessity developed special purpose image processing hardware.

Existing image processing techniques applied to traffic data collection involve only low level interpretation of sequences of images and hence exhibit little intelligence. A number of systems have, however, been successfully applied to well defined applications by using the video image as a programmable light sensor in which only limited portions of the full image or "windows" are observed. In general the use of these "windowing" systems is limited to occasions during which environmental conditions are favourable. The shortage of suitable processing power in the early systems undoubtably led to a preponderance of simple algorithms, while the lack of a thorough understanding of the video images has meant that a number of practical problems remained unresolved. It is believed that future image processing system will require additional built-in intelligence to cope with more sophisticated applications. This in turn calls for the development of systems capable of analysing complete images rather than "window" data. By developing a system capable of higher level of image interpretation of area-wide scenes, applications such as in-vehicle vision system, pedestrian and vehicle tracking, congestion monitoring, selective vehicle detection and vehicle classification, become realistic.

Computer design engineers have developed several computer architectures in an attempt to produce efficient multi-processor systems. One approach is to connect several special purpose processors to a high-speed bus (internal computer communication system), to which are also connected various memory units. The processors will usually be specialised units each optimised for a particular image processing function. A major difficulty in this type of system is to design an efficient method of splitting the algorithm which will ensure that all the processors are usefully employed all of the time. This approach has been adopted by HOUGHTON et al (1987) in the design of the RAPAC System.

A second type of multiprocessor architecture is the array processor where each point in the image array has its own processor and a limited amount of memory. The CLIP system, used by researchers at UCL, is one example where each processor is interconnected to its eight neighbours as well as image memory. Array processors are single instruction multiple data (SIMD) devices. A control unit broadcasts the first instruction to every processor in the array simultaneously and each processor executes that instruction using data from its own local memory and that of its immediate neighbours. A second instruction is then broadcast and so on until the complete programme has been performed.

The third and final architecture is known as the pipeline architecture. Data are entered into the first processor in the pipeline as a continuous stream of pixel values. This processor will contain sufficient memory to hold part or even a complete image and will perform a simple operation on the incoming pixel stream. The output pixel stream is then fed directly to a similar processor which will generally be programmed to perform a different function. The procedure is continued until processing is complete. Every processor sees every part of the picture and once the pipeline is full every processor can be kept busy all the time. The early Sheffield University/UMIST system (DICKINSON AND WATERFALL 1984) was of this architecture.

Image processing architectures based on combinations of the above are continually being developed and refined, while research into special-purpose hardware also continues. A good deal of the responsibility for these developments has been shouldered by the aerospace industry and medical research. However, many of the groups involved in traffic monitoring have also been developing novel computer architectures, sometimes at the expense of algorithm development. One critisism that might, with some justification, be levelled is that researchers have been motivated more by a desire to design novel computer systems than by a wish to solve real traffic problems. Many traffic engineers only become involved with image processing applications at a late stage by which time hardware design decisions have already been made. One of the reasons why some of these hardware orientated configurations have not been completely successful is that they are not accompanied by sufficient appreciation of the complexity of the problem of image interpretation and the needs of a specific transportation application.

Falling hardware costs are now making a wide range of special purpose image processing boards commercially available. Some of these board-level products could usefully be applied to traffic monitoring applications. This applies particularly to the single board products, which can cost under £1000 and are available for the IBM PC and other machines. It is possible today to do things with special image processing boards which could only be done with a £50000 system just a few years ago. These developments bring into question the value of spending time developing dedicated hardware at the feasibility stage as so many have done in the past.

The lack of processing power in the past has created a mass of simple algorithms. A majority of these algorithms have tended to perform inadequately when applied to real-world situations for a number of reasons. Many systems failed because of the inability to accommodate the significant fluctuations in environmental conditions experienced when observing traffic. A lack of overall understanding of the video image has meant that the problem of occlusion cannot be resolved. Thus when individual vehicles move together and tend to overlap within the video image the system is incapable of separating them. Several researchers have identified the problem of classifying moving parts of the image into areas representing vehicles and areas representing shadows of vehicles (SAXTON 1984, TAKABA and OOYAMA 1984, and YOSHIDA 1986). Classifying a scene into vehicles and shadows is crucial to effective detection and tracking.

To summarise, therefore, existing image processing techniques applied to traffic data collection involve only low level interpretation of sequences of images and hence exhibit little intelligence. A number of systems have, however, been successfully applied to well defined tasks by using the video image as a programmable light sensor in which only limited portions of the full image or "windows" are observed. In general the use of these "windowing" systems is limited to occasions during which environmental conditions are favourable. In addition, such systems become confused by shadows, cannot cope with unstable camera mountings, and do not operate in real-time. It is believed that these problems must be addressed and this will require image processing systems with additional built-in intelligence. This in turn calls for the development of systems capable of analysing complete images rather than "window" data.

In general, the solution to real-world image processing problems depends on an ability to handle video images of typical traffic scenes in which light levels vary continuously causing shadows and reflections. Figure 1 shows typical images obtained from a traffic surveillance CCTV camera. The TRIP algorithms, described in detail in DICKINSON (1986), are the only ones known to the authors that have proved capable of firstly removing unwanted shadows from images and secondly of operating over periods during which light levels varied significantly.

THE TRIP II SYSTEM

The aim of the TRIP II system is to facilitate the development of algorithms that will take full advantage of the area sensing capability of video images. The system is built around readily available off-the-shelf components. A fast IBM compatible PC acts as the host to an image processing module. The image processing module consists of an analogue to digital converter (ADC) to digitise an incoming video signal, frame stores for image storage, three digital to analogue converters (DAC) for pseudo colour output display, a high speed on-board processor for partial processing, an advanced graphics and CRT controller which provides all timing signals. This is a two-board module which plugs in two sixteen bit expansion slots in an IMB PC/AT. Images can be digitised at a maximum resolution of 512 by 512 pixels. The PC can set up the module to perform partial processing relieving itself to carry out higher level data analysis if required.

An interactive algorithm development environment based on an enhanced version of the TRIP system software has been implemented on the PC. A radically different approach has been adopted for vehicle detection. The TRIP II system is different from many earlier system since it is based upon inexpensive equipment and processes images by simulating the operation of a neural network. The vehicle detection method relies on the ability of the TRIP II system to learn from example and discriminate between the learnt patterns, in this case patterns representing vehicles, within video images of traffic scenes.

CURRENT RESEARCH

The authors are currently involved in an investigation into the application of neural-network pattern recognition techniques to the solution traffic monitoring problems. These techniques can give a machine the ability to learn from history or examples. The model of brain neurons, which the system simulates, can be thought of as a set of nodes or neurons inter-connected by communication links. Figure 2 illustrates a typical simulated neuron. Each input (synapse) is weighted by w_i which may be positive or negative. The output is a function of the sum of all weighted inputs. In the simplest case f can be a straight forward threshold function. There may be one or more layers of inter-connections between the input and output each associated with a transfer function which determines the state of an output according to a set of inputs. Such a system typically has to go through a training phase to "learn" the patterns that represent the objects that it is attempting to recognise, although the network can be preprogrammed in applications where the learning capability is not required.

The universal nature of neural network processing capability, with possible local and global as well as hierarchical organisation, suggests that the technique is potentially suitable for applications ranging from low level image processing through intermediate feature extraction to high level vision processes. Conventional image analysis techniques used in vehicle detection assume that the input will be predictable. These assumptions form the basis of the algorithms which are built into each system. In such systems a specific problem is tackled in an inflexible way. For example in template matching (HOGG 1984) a template has to be created for each type of vehicle to be recognised. The problem with such a system lies in the fact that there are many geometrical shapes for vehicles contained within the same vehicle class. The advantage of the connective approach or neural-network technique is one of self organisation and the ability to learn from its own experience. Systems based on these techniques are therefore particularly suited to solving problems which are not well defined and where a rigid algorithm would prove unsuccessful.

A simple single layer neural network simulation has been set up to demonstrate the learning capability. The system can be trained to examine a sample area of the image and recognise the front of vehicles. The experiment has shown that the technique can be applied, using low cost microcomputer based image processing hardware, to real-time counting of vehicles. This process can also be applied to the classification of vehicles. A video signal from a video recorder is fed into the system and digitised by the frame grabber. The operator then captures 16 examples of a variety of vehicles contained within each of three classes of vehicle (cars, medium goods and heavy goods vehicles). Partially processed versions of these raw images then provide reference data for the detection and classification system. As each vehicle appears in subsequent images it is compared with the reference data for all vehicle classes and the system finds the best match. Figure 3 shows examples of typical images used to generate classification data. The bar graph in each picture shows the characteristic signature generated by the mapping function.

Although the current system analyses window data the principle can be extended to cover the entire image for other applications. One such important application is that of congestion monitoring, since any disruption to flow on our major road network can lead to severe delay and an increase risk of accidents. Figure 4 shows examples of a subjectively defined highway flow classification. In this case rather than measuring precise numbers of vehicles and traffic speed the system attempts to emulate the process adopted by an operator in a control centre who might observe traffic conditions and make judgements based on his subjective interpretation of the scene. The "bar meter" on top of each picture indicate an arbitrary global level of congestion which may be translated to a concept similar to the level of service.

The research groups at Napier Polytechnic, University of Newcastle and University College London have been working in close collaboration with the aim to design and implement image analysis algorithms for a wide range of transport applications, using low cost equipment. A SERC research grant has recently been awarded for the collaborative research work between the three institutions.

FUTURE POSSIBILITIES

The need for a greater understanding of sequences of complete images was identified earlier. The implementation of such a system would be radically different from that adopted by others active in the field of traffic data monitoring using video image processing. The usual approach involves the use of the video image as a programmable optical "point" sensor. However, the full potential of automatic image analysis will only start to be achieved when the uniqueness of video, its area sensing ability, is utilised. By developing a system capable of higher level of image interpretation of area-wide scenes, applications such as vehicle guidance, vehicle tracking, highway monitoring and selective vehicle detection, become realistic.

Another more ambitious application might be the creation of an automatically driven vehicle. Since driver error is a contributary factor in a high proportion of accidents such a system when fully developed would have the potential to improve safety significantly. Conventional methods used for guiding vehicles automatically make use of fixed track, painted lines on the roadway, beams of electromagnetic radiation or buried wires. In each case the vehicle is constrained to a fixed and usually limited network. It would be useful to have an in-vehicle vision system which might undertake vehicle guidance, read signs, detect pedestrians and stationary objects.

The level of difficulty involved in extracting such information from an image varies. Sensing and identifying the boundaries of roads and recognising obstacles to be avoided should be relatively straightforward. Recognition and interpretation of road signs, including traffic control and route information would be considerably more difficult, but feasible. Finally, the anticipation of traffic behaviour as performed by humans, e.g. making allowances for young pedestrians near the kerb or vehicles about to cross traffic lanes, involves a level of computer understanding that is unlikely to be attained for many years.

The most immediate application for such an image analysis system would be to assist drivers of vehicles on motorways. Here the environment is more constrained than would be the case on an urban street and so the image analysis problems can be overcome. The human driver would operate under normal conditions. However, if avoiding action was called for, or if the vehicle was found to be straying from a given lane the supervising computer vision system would provide the driver with a warning or draw attention to lane change manoeuvres. The system would be suitable for installation within vehicles to improve the safe and efficient movement of traffic.

CONCLUSIONS

In this paper it has been shown that traffic observed by video cameras or captured on video tape can now be counted automatically, in real-time. Estimates of individual vehicle speed, length and occupancy can also be made from sequences of video images. In addition, the image processing techniques being used for vehicle detection are being developed for a wide variety of additional applications.

It is clear that potential exists for the application of image processing techniques to video pictures of traffic. It is equally apparent that the development of an operational system will not prove a simple matter. A number of problems must be solved before fully reliable real-time in-vehicle systems, pedestrian and vehicle tracking, congestion monitoring and incident detection systems become readily available. The full potential of image processing will only be realised when full scene analysis is undertaken. The neural network or connective approach appears to be applicable to the wide range of real world applications described above and for which there are no well defined solutions.

Advances in microelectronics will continue to make available more powerful hardware. It is evident that much effort will be required to provide suitable image analysis techniques for these applications. More robust algorithms will be required to satisfy the more demanding tasks described above; algorithms that can interpret objects within the scene rather than simply detecting rapid changes in pixel intensity. It is in the area of algorithm development for specific traffic monitoring application that the greatest challenges lie. Active research world wide will help to provide the missing link between the existing manual/semi-automatic data abstraction and the much desired fully automatic system.

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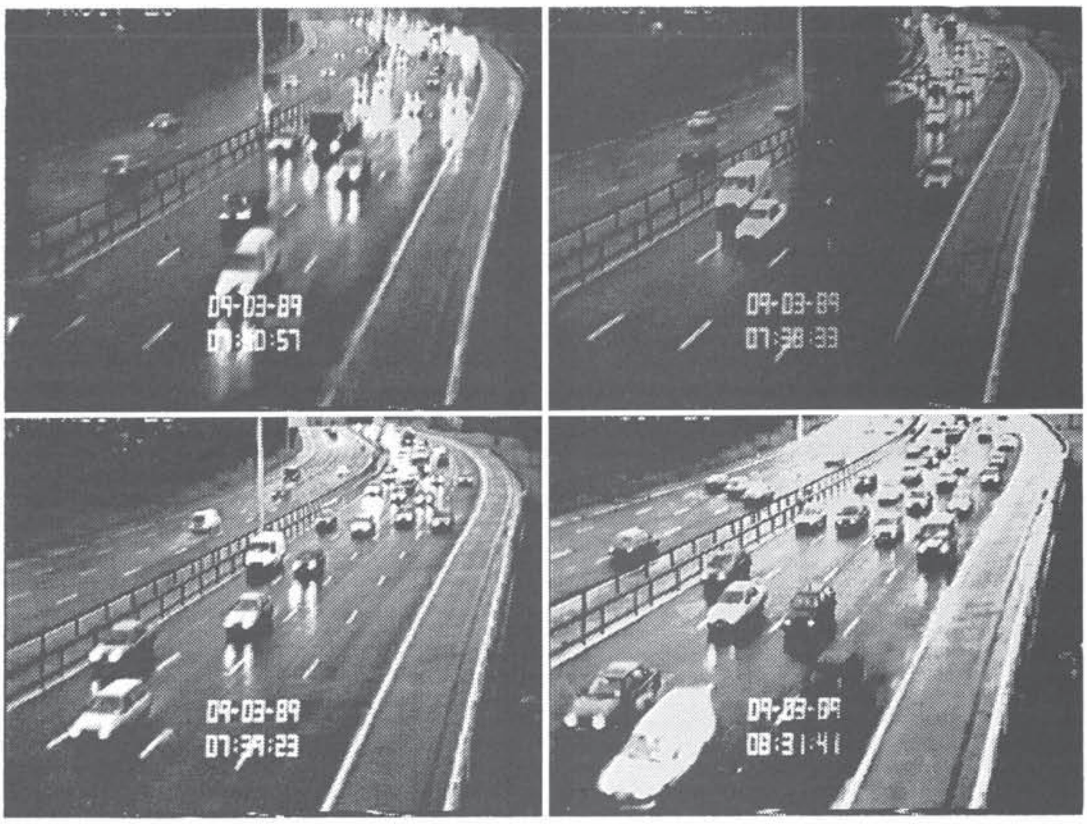

Figure 1 Typical images obtained from a traffic surveillance camera, note the dark band (top right) caused by the wiper in operation.

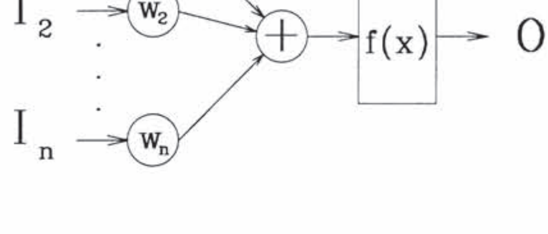

Figure 2 Model of a typical simulated neuron

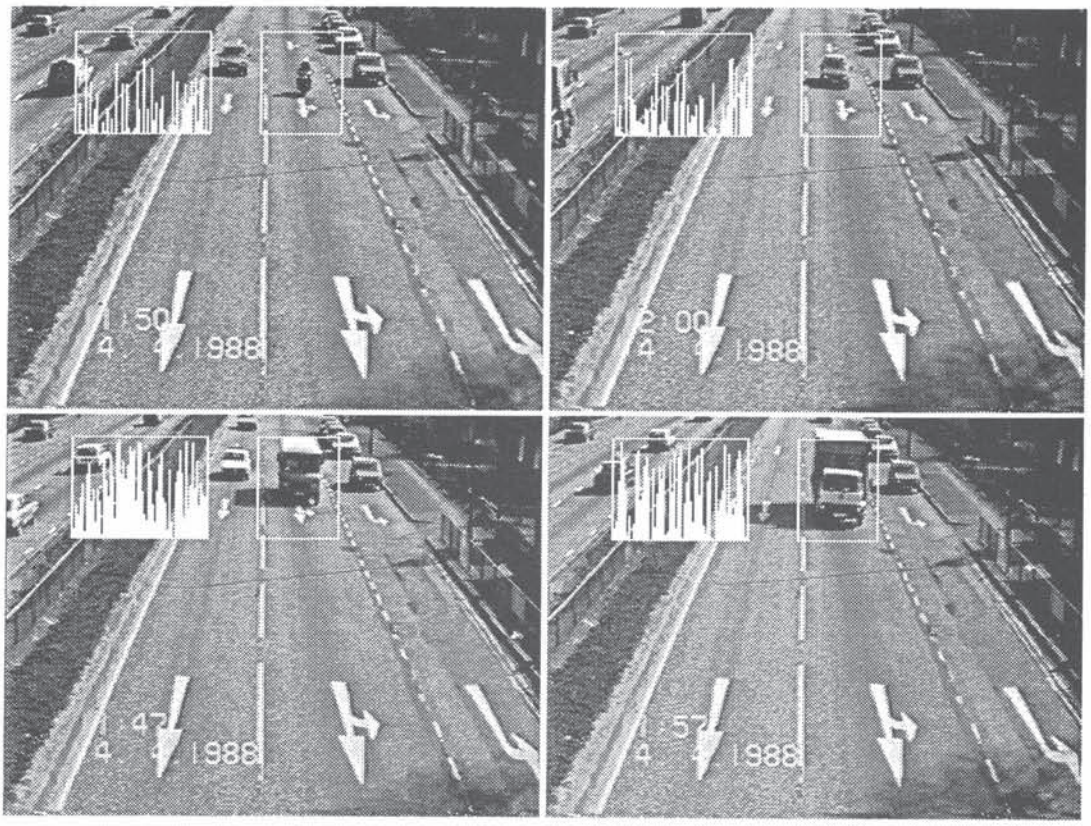

Figure 3 Images used to generate classification data

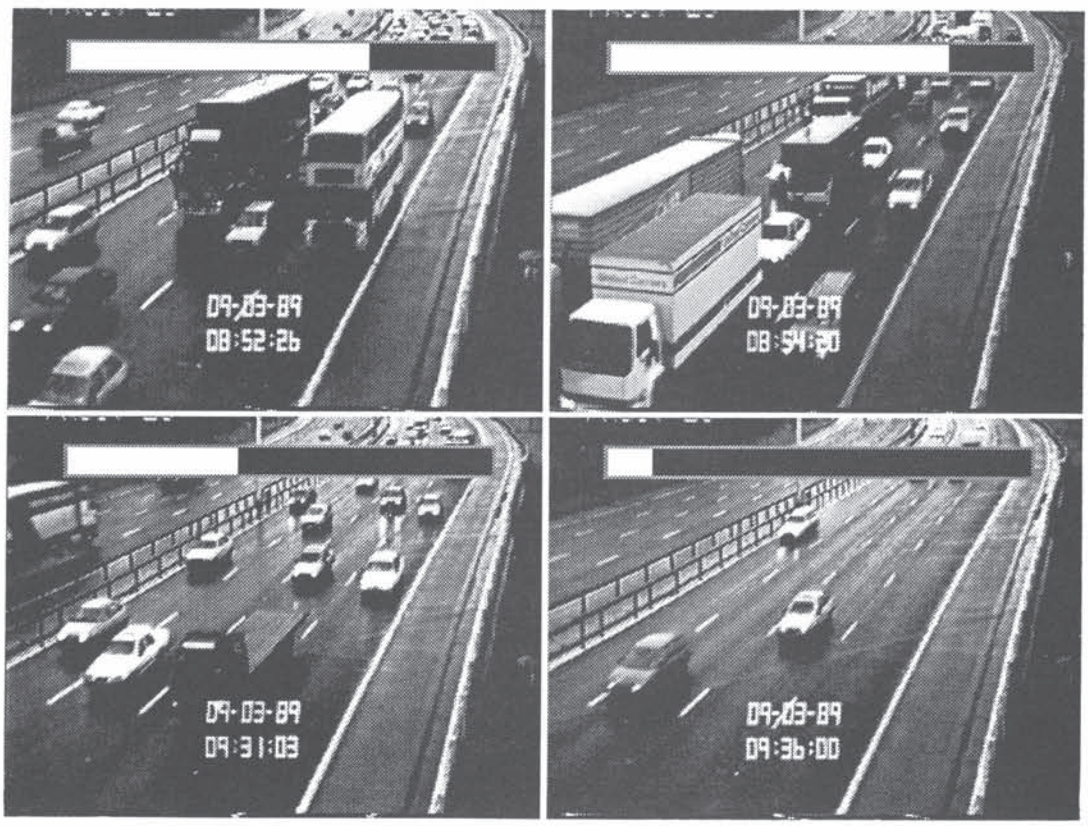

Figure 4 Example of flow classification for congestion monitoring