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A Review of Sensing Techniques for Real-time Traffic Surveillance

[1]David Dorantes Romero, [2]Anton Satria Prabuwono, [3]Taufik and [4]A. Hasniaty
[1]Department of Mechanical Engineering and Mechatronics,
Karlsruhe University of Applied Sciences, Moltkestr. 30, 76133 Karlsruhe, Germany
[2]Faculty of Information Science and Technology, Universiti Kebangsaan Malaysia,
43600 UKM Bangi, Selangor D.E., Malaysia
[3]Department of Electrical Engineering, Cal Poly State University, 1 Grand Avenue,
San Luis Obispo, CA 93407, USA
[4]Department of Electrical Engineering, Faculty of Engineering,
Hasanuddin University, Tamalanrea, Makassar 90245, Indonesia

Abstract: The paper presents a review of various sensing techniques for traffic detection and surveillance. Inductive loop detectors were extensively used for many years. Nowadays, several novel sensing techniques and wireless communication systems have been implemented. The conducted research has resulted in wealth of sensors, which are an essential part of real-time systems. A literature review is performed taking into account the new trends in the developed countries. Furthermore, a comparison between the different sensors is presented by pointing out the advantages and disadvantages of each sensor. Some future trends in this field are also discussed.

Key words: Real-time control, sensing techniques, traffic surveillance, video detection

INTRODUCTION

Technologies in sensors have been widely used on highways. Sensors get sampled real-time data in order to know the traffic status and then hold the control strategy. The effciency of a traffic detection system depends on not only the accuracy of the sampled information, but also the coverage over the transportation network. On the other hand, the use such technologies is also large investments. In the cities traffic jams end up always in a large number of accidents even at low speeds. The Federal Highway Administration report (Klein *et al*., 2006) states that there are three types of user groups for traffic data: (1) real-time traffic data collection and dissemination; (2) historical data collection and monitoring; (3) other industries such as data warehousing and geospatial data sharing.

The accuracy and coverage are often in conflict because the collection of high quality information is usually based on sophisticated and expensive technologies and thus limited budget will reduce the number of facilities. Moreover, due to the limited effective range of most sensors, the total coverage on a network of facilities usually requires a lot of sensors (Besari *et al*., 2008). Yang *et al*. (1991) conducted sound analysis on the impact of traffic point counts for origin-destination flow estimation. Kastrinaki *et al*. (2003) proposed a sensor implementation framework to maximize profits.

Loop detectors are the oldest sensor technology used in traffic surveillance. They are installed under the pavement on streets and when they are used, can provide information in real-time of traffic at that point in the road. However, it was found that the cost of maintenance and installation of these detectors could become uneven. Thus, the search for more economic alternatives was soon made. Other technologies, such as video, radar, microwave, ultrasound and acoustics have been developed and are coming to the market. These alternative technologies not only provide cost savings but also have the ability to obtain a wider variety of traffic and incident-related data. Figure 1 shows the general traffic detection process.

Video detection has been accessible commercially for several years and is gaining acceptance as more efficient when compared to induction loops. It may happen due to the technology of video image could provide a wide range of normal traffic information data, like vehicles flow, as well as the ability to control larger areas (Prabuwono and

Corresponding Author: Anton Satria Prabuwono, Faculty of Information Science and Technology,
Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor D.E., Malaysia

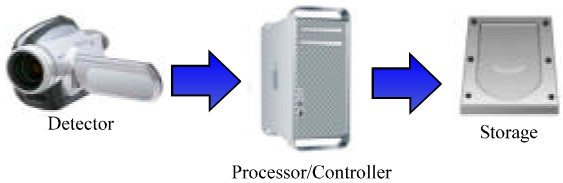

Fig. 1: General traffic detection process

Idris, 2008). Some latest detection technologies also monitor a large area, but in different way compared with video technologies. Another unique attribute of video detection is the capacity of sending over real-time images to a control room and hence providing extra information to the control center.

OBJECT DETECTION

Some of the actual techniques and approaches used for object detection are presented to give a general idea of the process.

Thresholding: It might be simplest one, but it is not so effective. It operates on unmoving images and based on the conception that vehicles are solid bodies or objects with backgrounds of different intensities. This method depends heavily on the threshold used (Akbar *et al*., 2008), which should be selected in an appropriate way for a specified vehicle and background conditions.

Multigrid identification: This method first generates a hierarchy of images at different resolutions. Next, an area search starts at the top level (coarse to fine). In case of compact objects diverging from the background, we can still distinguish in the low resolution image, but noise and minor intensity variations tend to vanish at this level. The low resolution image can directly get attention to the pixels that correspond to such objects in the initial image (Kastrinaki *et al*., 2003).

Edge-based detection: A method based on edge-type objects can be used with individual pictures or images in order to detect the vehicle's edge structure, or even more complex systems (Prabuwono *et al*., 2004). Morphological edge detection is being far and wide applied, due to its superior performance.

Stereo vision: Detection of both moving and static objects for traffic application has been also considered by using stereo vision systems. The difference between points in the two stereo images relates directly to the distance of the real location in three dimensions (3D) from the cameras. Then they infer that for all points lying on a plane, the disparity on the two stereo images can be related applying the Helmholtz shear equation (Kastrinaki *et al*., 2003).

SENSING TECHNIQUES

Video imaging processors (VIPs): Video systems whether for traffic surveillance or intelligent driving normally involve two main tasks of perception: (1) the inference of road geometries and (2) vehicle and obstacle recognition. There are many approaches to VIPs according to the authors, but summing up the information in articles related to this methodology can be said that there are two applications considered and needed the most; they are the road traffic detection and automatic vehicle guidance. Actual works use state of the art algorithms and tools for two main subtasks involved in situations, i.e., the search for automatic lane (lane estimation or central line) and vehicle detection (moving, stationary object or obstacle). Figure 2 shows a block diagram of vehicle detection system using video imaging processor.

Coifman *et al*. (1998) have launched the vehicle operator network of 13 Texas Instruments C40 Digital Signal Processing (DSP) chips. Heavy computational tasks in the tracking algorithm, convolution in the detector properties and correlation tracking function, are placed in the network of C40, which runs on a PC host. These kinds of systems are now being implemented in some traffic lights in order to check if the processing velocity is enough to be installed in complex highway crossroads.

For a video-based system to be an effective tool for monitoring, time imitating loop detectors or indeed the vehicle tracking, a system for video image processing must meet several stringent requirements (Kastrinaki *et al*., 2003):

- Automatic segmentation of each vehicle background and other vehicles so that all vehicles are detected
- Correctly detect all types of road vehicles, motorcycles, cars, buses, construction equipment, trucks, etc.
- Function in a wide range of traffic conditions: lights, congestion, varying speeds different lines
- Function under a wide variety of lighting conditions: sunny, cloudy, sunset, night, rain, etc.

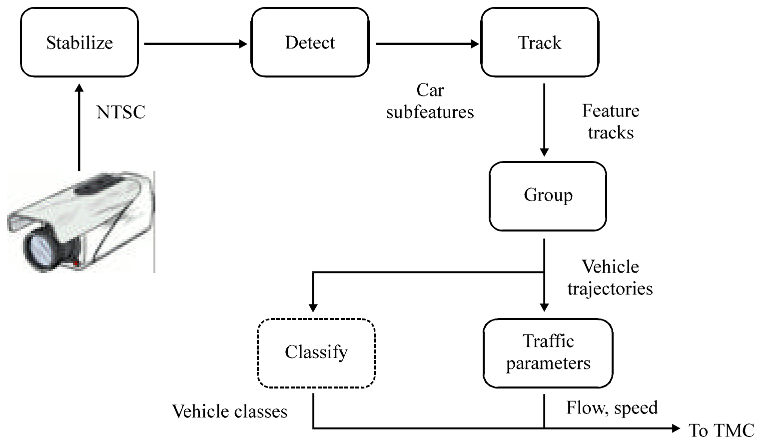

Fig. 2: Block diagram of vehicle detection system

Fig. 3: Video based process

- Operating in real-time. Meaning not only sending the correct data, but also time and managed programming is important

Figure 3 shows the display of sensing result using video based process (Klein *et al*., 2006).

Xie *et al*. (1994) presented an interesting analysis of video systems, making a classification of them in two categories depending of the situation. The first one is when a static camera monitors a scene of dynamic traffic. In this fashion, the camera is maintained static and generally has a high-quality view of the objects on the road due to its position.

Therefore, two-dimensional images may contain sufficient information for recognition (Pratomo *et al*., 2009) based on object model roads. The second is the chase in which one or more vision sensors are mounted on a mobile robot that moves in a dynamic road scene.

Inductive loop sensors: Vehicle detection loops are used to count the passing vehicles at a certain point. They are placed, for instance, right before arriving a traffic light and the management of highway traffic. Isolated, electrically conductive loops are installed underneath the road. A voltage is generated when a majority ferrous (containing iron or steel) the body goes through the wire or loop. An important point of this method is that while the inductive loop detectors only give direct information on the passage of vehicles and presence, other traffic flow parameters such as density and velocity are inferred from the algorithms that interpret or analyze measured data. When these parameters are calculated from inductive loop information, the values may not be suffciently detailed for some applications (such as prediction of incidents) or even worse, information available is insufficient to support the application.

The control units play an important role when the response time is critical (i.e., arrival and departure of vehicles). Real-time capabilities of the systems are then important in order to calculate speed from vehicles and detect occupancy. For systems used for monitoring of freeways such capabilities are a must. If the time for a pick-up is close to the time for dropout, little or no bias in the vehicle occupancy time is introduced. In case that a discrepancy is found, a correction for the bias is easily applied (Klein *et al*., 2006).

Magnetic sensors: A new promising approach is the one being conducted at Fraunhofer Institute in Germany (Grueger *et al*., 2001). The proposed system works under the assumption that the steel masses of the vehicles have an effect on the magnetic field of the earth. A fist prototype of this system has been realized which is capable to measure the traffic from an overhead position through a distance of at least six meters. The results from this research show the very good performance and are being tested now in external environments to ensure that the system performs well under real traffic conditions. Figure 4 shows sensing technique by using magnetic principles (Klein *et al*., 2006).

Laser sensors: Mecocci and Micheli (2010) are working on a vehicle identification system using laser sensors, which is capable of generate a 3D volume from it and also to compute the speed of the vehicle. The system gives reliable measurements and, in some way, accurate results even in stop-and-go traffic conditions. The system is composed of a laser camera AutoSense 600, along with a color television camera. The displacement of the color camera can estimate real-time information, which is used to correct the measurements obtained by the laser camera. Something really new about the system is that it can generate a standard 3D file and transfer it to a database,

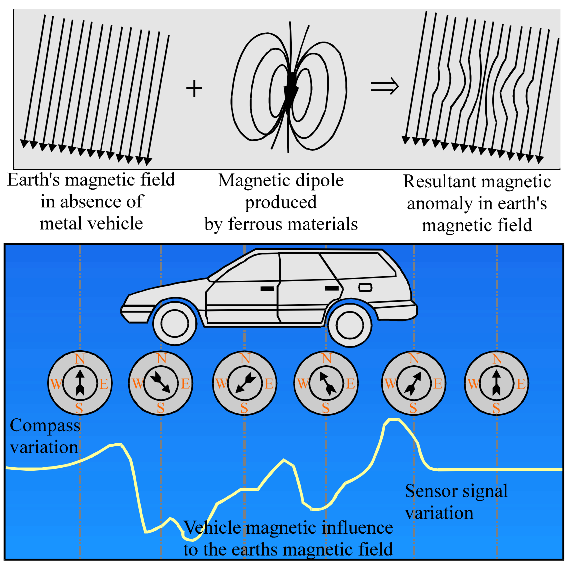

Fig. 4: Sensing by using magnetic principles

so that the system can update and take information from the control center about the geometry of the vehicles. Some results of this research are shown in Fig. 5 (Mecocci and Micheli, 2010).

Microwave RADAR: Microwave radar was first used for detection during World War II. The word RADAR means a device for transmitting electromagnetic signals and receiving echoes from objects of interest (i.e., targets) within its volume of coverage (Mirchandani and Wang, 2005) and was at first a short form for RAdio Detection And Ranging.

Novel techniques such as reported by Bertozzi and Broggi (1998) use waves between 0.4 and 11.8 inches. The correspondence for a frequency range would be from 1 to 30 GHz. Microwave sensors designed for traffic data collection in US roadside applications, but are limited by FCC regulations to operating frequency intervals near 10.5, 24.0 and 34.0 GHz.

The manufacturers of sensors are now meeting these necessities, but they still have to work other limitations like the transmission power and bandwidth, which are a little bit restricted nowadays. Because of the merging of embedded sensors, end users do not have to obtain licenses or specially designed test equipment to verify the output frequency or the power devices. The majority of sensors based on this principle are used in freeway applications. The majority of them transmit electromagnetic energy in the frequency X-band 10.52 GHz or higher frequencies to illuminate small plots of space with a given size antenna and therefore are capable of higher spatial resolution. These approaches are becoming more and more reliable with the time and also the prices are not so high compared to VIPs. Figure 6 shows car detection approach using microwave RADAR.

Ultrasonic sensors: Agarwal *et al*. (2009) proposed a new DAS (Driver Assistance System) based on cost-effective

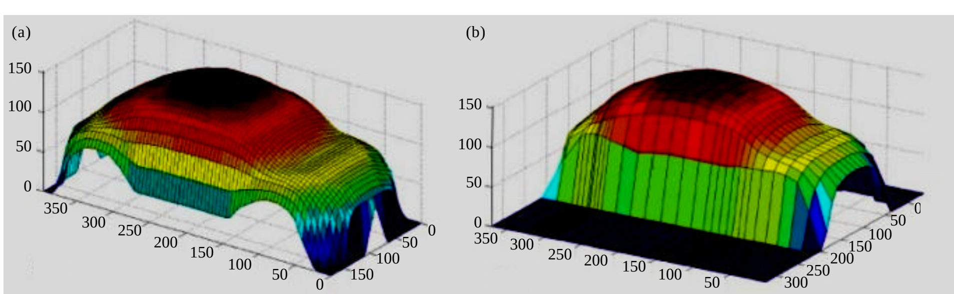

Fig. 5: Example application in a Volkswagen Beetle: (a) virtual vehicle and (b) 3D model

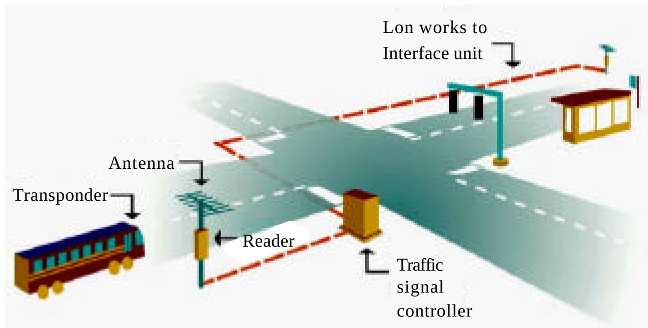

Fig. 6: Car detection using new microwave RADAR

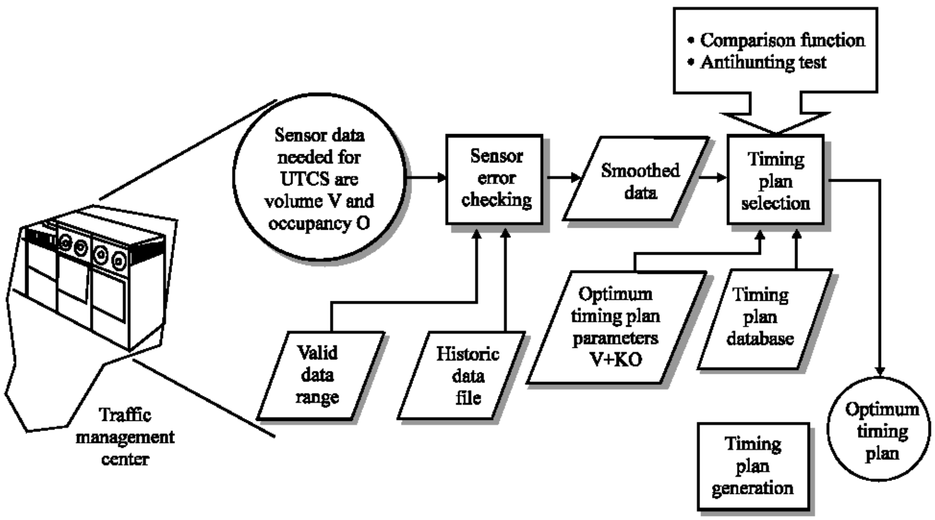

Fig. 7: Timing plan selection procedure

ultrasonic sensor for congested traffic conditions. This one has also potential to be used for parking assistance system. Ultrasonic sensors are used to sense obstacles, because they have a number of advantages over other types of sensors to detect objects in a close range. If we are interested of getting a more complete view of the field then multiple sensors are required. Furthermore, the interference is a common problem when there are multiple ultrasonic sensors are implemented.

A simple method based on the use of microcontrollers to reduce interference between the sensors is described, which is achieved by firing each transducer by a pseudo-random number of pulses for the echo of each transducer can only be identified. Today's DAS systems need more time to reliably detect objects, which makes them unsuitable, where time is critical. They propose also a method to reduce the time obstacle detection, but again, the robustness of real-time is not warranted. The cost of this high-performance system is reasonable. Always when a distance other than on the surface of the road fund is measured, the sensor interprets that measurement as the presence of a vehicle.

The ultrasound energy received is converted into electrical energy, which goes next to the signal processing. Timing plans are shown in Fig. 7 (Klein *et al*., 2006).

DISCUSSION

In this section we pointed out some of the advantages and drawbacks by comparing the different methods for traffic detection as shown in Table 1. Systems based on inductive dual loop detectors collect volume and speed information for both car and trucks and the equipment is also capable of connecting and reporting loop occupancy and average vehicle gap.

Loop maintenance and repair are significant operational costs. Some ultrasonic detectors will perform

Table 1: Comparison between sensors for surveillance

Sensor technology	Count	Speed	Classification	Multiple detection zone	Communication bandwith	Sensor purchase costs [(a)] (USD)
Inductive loop	√	√ (b)	√ (c)	x	Low	Low (500-800)
Magnetometer	√	√ (b)	x	x	Low	Moderate (900-3600)
Magnetic induction	√	√ (b)	x	x	Low	Low to moderate (385-2000)
Microwave radar	√	√	√ (d)	√ (d)	Moderate	Low to moderate (700-2000)
Active infrared	√	√	√	√	Low to moderate	Moderate to high (3300-6500)
Passive infrared	√	√	x	x	Low to moderate	Low to moderate (700-1200)
Ultrasonic	√	√	x	x	Low	Low to moderate (600-1900)
Video image processor	√	√	√	√	Low to high	High (5000-22000)

(a) Installation, maintenance and repair costs must also be included to arrive at the true cost of the sensor solution. (b) Speed can be measured by using two sensors at a known distance apart or estimated from one sensor. (c) With specialized electronics containing an embedded firmware that classifies vehicles. (d) With microwave radar sensors that transmit the proper waveform and have appropriate signal processing

better for occupancy, under the conditions that sensors are relatively close to the object. Some disadvantages of loop detectors are that by the deterioration of the pavement can affect them, as well as improper installation and climate-related effects.

Repair of streets and utility can also damage the integrity of the loop. Whereas, the video detection has a wider area of application and possibilities further developments (for example, automatic incident detection) but sometimes it is still not well understood when the system requires different cameras and different positions for each one.

It is sometimes assumed that, with the developments on computer vision, tasks should be really trivial. A vision-based system for such traffic applications must have the features of a short processing time, low-cost and high-reliability processing. Once that information is sent from the sensors it has to be processed.

Examples of successfully implemented systems in Europe and America are REALBAND, RHODES and GOLD, adaptive traffic control system that acts in a reactive and proactive way taking decisions based on the feedback. The algorithm of such systems is based whether on binary decision trees or on neural networks.

CONCLUSIONS

In this study, a series of state of the art and also novel techniques for traffic detection and surveillance were discussed. Almost all the existing surveillance approaches were covered. The sensors based on video cameras offer a relatively low installation cost with little traffic disruption during maintenance. In addition, other methods such as inductive loop, RADAR and microwave detectors suffer from serious drawbacks. One important aspect to consider in future works is the influence of vehicles passing at high-speed and how they can modify the period for the pulse-repetition. Timing is today still a limitation as well as algorithms to process the data. However, developments in this field will go further in parallel with the new smart cars, so we can be sure of its evolution.

Moreover, the research in this area points clearly to the so-called Intelligent Transportation System (ITS). Such systems will improve the current state of transportation by increasing computing and processing capability, communication protocols and power of detection.

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