Internet Research

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Received 16 November 2009
Revised 12 January 2010
Accepted 13 January 2010

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Abstract

Purpose – Intelligent transportation systems (ITS) are defined as new infrastructures that combine people, roads and vehicles over the basis of modern embedded systems with enhanced digital connectivity. ITS is fast becoming a reality, favored in their development by the use of the internet. The purpose of this paper is to analyze the feasibility of road-traffic management systems, using the internet as the communication link.

Design/methodology/approach – A literature review is presented to give a background in the progressive role that ITS and road safety and control applications play in society. The combination of internet and the ITS architecture is covered, and an electronic prototype providing web services for road-traffic management is designed as an example. The scope of road traffic security research is extensive, and the use of artificial vision systems in road-traffic analysis (technology which is on the basis of the developed prototype) is also discussed. The hardware and software characteristics of the prototype are defined.

Findings – The paper provides new insights into the use of the internet for road-traffic management applications.

Research limitations/implications – The research is limited to one particular road-traffic management system. Results could be extended if more real equipments were analyzed. Also, end-users' perception and their acceptance of the new technology could be examined using an information system theory like the technology acceptance model.

Originality/value – The paper shows the utility of the internet in the development of novel ITS.

Keywords Traffic control, Control systems, Road transport, Intelligent agents

Paper type Research paper

Internet Research
Vol. 20 No. 2, 2010
pp. 154-168

1066-2243
DOI 10.1108/10662241011032227

Introduction

In recent years the World Health Organization (established in 1948 as a specialized agency of the United Nations serving as the directing and coordinating authority for international health matters and public health) has published world reports on road traffic injury prevention (World Health Organization, 2004). These reports underscore the concern that unsafe road traffic systems are seriously harming global public health and development, and contend that the level of road traffic injury is unacceptable and largely avoidable. For instance, the economic cost of road crashes and injuries is estimated to be 1 percent of gross national product in low-income countries, 1.5 percent in middle-income countries and 2 percent in high-income countries, being US$ 518 billion per year the estimated global cost. These reports emphasize that specific and important attention must be paid in the road traffic security research area.

The scope of road traffic security research is extensive, covering huge areas related to the development of novel intelligent transportation Systems (ITS). Vision-based technology is one of these areas, favored with the quick advance of embedded system-based technology experienced in the recent decades (Toral *et al.*, 2009c, d). Traditional techniques for road-traffic monitoring rely on sensors that have limited capabilities, and are often both costly and disruptive to install (Setchell and Dagless, 2001). The use of video cameras (many of which are already installed to survey road networks) coupled with computer vision techniques, offers an attractive alternative to traditional sensors. Video analysis in traffic application, and similar methods for measuring, analyzing and understanding traffic safety processes, is a relatively new research area in road traffic security (Esteve *et al.*, 2007). These electronic-based equipments with the ability of processing video signal, or vision-based intelligent sensors, have the potential to measure a greater variety of traffic parameters (Li *et al.*, 2004; Wang *et al.*, 2005). The applications of a fully developed system for video analysis in traffic application are numerous, starting from simple traffic observation (traffic counting, speed measurement or incident detection) to long-term studies (e.g. road user behavior, entry/exit statistics or journey times), while installation and maintenance may be performed without disruption of traffic flow.

The internet has turned into the most successful worldwide ubiquitous telecommunication network, offering a communication infrastructure that has changed the way people interact and live (Toral *et al.*, 2005; Barrero *et al.*, 2008; Toral, *et al.*, 2009a, b). This is especially true since the early 1990s, when the widespread use of the internet took place. The recent rapid development of wireless communication technologies is offering today new opportunities for the use of the internet as the basis of future ITS (Xia *et al.*, 2004). A vast variety of modern mobile devices can enable the internet for anyone at anytime and anyplace. As each vehicle becomes equipped with its own IP address and internet presence, a dynamic mobile wide-ranging network comes online, transforming road-traffic management systems into smart environments. In-vehicle digital environments, vehicle-to-vehicle communication and cooperation, or vehicle-to-transport infrastructure digital interaction will become a reality in the near future (Artemis Strategic Research Agenda Working Group, 2006), and will be the future of ITS. It is not difficult to deduce that internet will bring to the current road-traffic control systems more efficiency and efficacy, expanding IP-based applications to ITS architecture, if the robustness of these electronic equipments for the different communication link situations is guaranteed.

In accordance with all these previous considerations, a prototype of a novel electronic equipment for application in the ITS field using artificial vision is presented and evaluated. The prototype, named VisioWay® (www.visioway.com/), is an embedded system with internet and Bluetooth connectivity for building intelligent environments. It has been designed for being used for commercial purposes in traffic infrastructures, providing web services to the users of the infrastructure (traffic control centers, vehicles and pedestrians, principally) and preserving its robustness as intelligent sensor in IP-based networks.

The paper is organized as follows. First, the overall requirements of an embedded system with application in ITS area are presented. Then, a case study is analyzed: VisioWay® application in road-traffic parameter estimation using artificial vision techniques for detection, counting and classification of vehicles and for queue detection. Finally, the robustness of VisioWay® is analyzed in an internet-based network, and the conclusions are drawn.

Embedded systems in ITS

Embedded systems are everywhere, built into cars, roads, bridges and tunnels, into medical instruments and surgical robots, into homes, offices and factories, into airplanes and airports, into mobile phones and communication and virtual reality glasses, and even into our clothes. With the constant evolution of electronic devices and software technologies, there will be more and more embedded systems integrated into equipments. Nowadays, 90 percent of computing devices are included in embedded systems and not in personal computers. Their growth rate is more than 10 percent per year and it is forecasted to be over 40 billion devices worldwide by 2020. This type of equipment has evolved from stand-alone single-processor computers of the 1980s and early 1990s, to the special-purpose sophisticated fixed-function multi-processor systems of the present day, associated with an increasing communication capability. They are expected to evolve to the standard-based multiprocessor platforms and to *ad hoc*, opportunistic, adaptive, self-organising "processor ecosystems" of 2010 + .

ITS area is a clear example of embedded systems evolution. In the ITS area which involves industrial developments for automotive systems and public infrastructures, embedded systems engage with reduction of fuel consumption, pollution or road fatalities. Interconnection into networks of many devices is crucial, allowing vehicle-to-vehicle or vehicle-to-road infrastructure communication in the background of active safety systems. Embedded systems with application in ITS area demand networking capabilities because of the new opportunities for improved operation of safety systems in a smart environment context. A middleware layer is also required, allowing urban equipments to offer services to the rest of agents involved in the urban environment, and providing an ambient intelligence framework.

These requirements recommend the use of an operating system (OS) (see Figure 1). Although a multitude of embedded OSs are currently available (Wind River's VxWorks, Microsoft Windows CE, QNX Neutrino, etc.), Linux is firmly in first place as the OS of choice for smart gadgets and embedded systems. Some of the advantages of embedded Linux against proprietary embedded operating systems are vendor independence, time to market and low cost.

Potential benefits of embedded systems applied to urban environments and road networks include increased road network capacity, reduced congestion and pollution, shorter and more predictable journey times, improved traffic safety for all road users, more efficient logistics, improved management and control of the road network (both urban and inter-urban), increased efficiency of the public transport systems, and better and more efficient response to hazards, incidents and accidents (Fuchs and

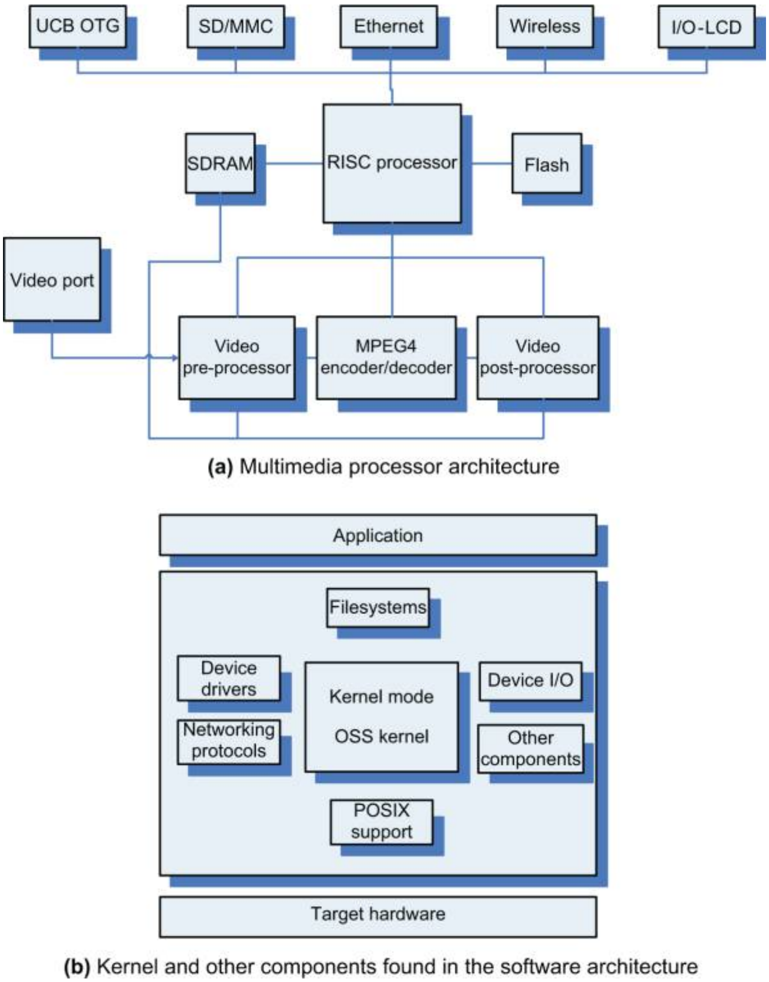

Figure 1.
A generic embedded system suitable for the ITS area: (a) multimedia processor architecture and (b) kernel and other components found in the software architecture

Bankosegger, 2009; Tuominen and Ahlqvist, in press). The majority of related works in the field of urban environments are usually related to vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communications (Hinsberger *et al.*, 2007).

Among these, the FleetNet project (FLEETNET, 2008) and its follow-up project Network on Wheels (NoW) (Festag *et al.*, 2008) investigate the integration of the internet and vehicular networks. This integration requires mobility support, efficient communication, discovery of services, and support of legacy applications. FleetNet uses an IPv6-based addressing solution to address the vehicles. The proposed architecture contains stationary internet gateways along the road with two interfaces connecting vehicular networks to the Internet.

Some other projects deal with cooperative systems in order to increase road safety and traffic efficiency. Cooperative Vehicle Infrastructure Systems (CVIS (www.cvisproject.org/)), SAFESPOT (Cooperative Systems for Road Safety, www.s afespot-eu.org/pages/page.php) and COOPERS (COOPerative systEms for Intelligent Road Safety, www.coopers-ip.eu/) are initiatives integrated within the European 6th Framework Program (Toulminet *et al.*, 2008). CVIS aims to design, develop and test the technologies needed to allow cars to communicate securely with each other and with the nearby roadside infrastructure. In order to reach this goal, CVIS uses the international standard Communications Air-interface, Long and Medium (CALM) range that is still under development (Han *et al.*, 2006). SAFESPOT aims to improve road safety by conceiving a safety margin assistant that detects critical situations in advance. Safety margin is the time difference between the time of detection of a potential danger and the time of real accident if nothing is done to avoid it. In SAFESPOT, this concept will be tested based on conception of cooperative system that will use V2V and V2I communication and IEEE 802.11p technology. In COOPERS' vision, vehicles are connected via continuous wireless communication with the road infrastructure. They exchange data and information relevant for the specific motorway segment to increase overall road safety and enable cooperative traffic management. In general, these developments are mainly focused on the vehicle as the central element of the urban environment.

VisioWay®, a novel embedded system for traffic control applications

A novel electronic equipment with implications in the ITS area has been developed, following the aforementioned guidelines (Figure 2). It has the following features:

- The Freescale i.MX21 multimedia processor is the core of the hardware system.
- Wire (Ethernet) and wireless (Bluetooth) connectivity is included.
- Interface to typical data storage media like USB or SD/MMC is provided.
- The embedded Linux OS (kernel 2.4.20) operates the hardware.
- Artificial vision algorithms have been coded for capturing information about foreground objects (typically vehicles) in a traffic scene.

The i.MX21 processor is based on the advanced and power-efficient RISC processor ARM926EJ-S core, operating at speeds up to 266 MHz. On-chip modules are provided, including LCD and MMC/SD controllers, USB controllers, CMOS sensor interface, and

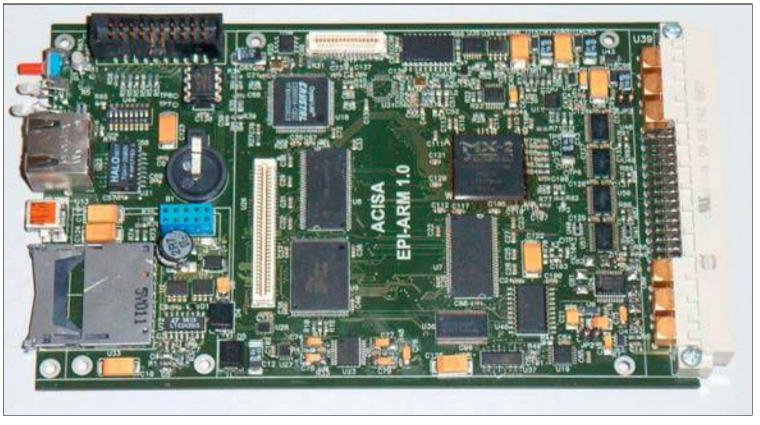

Figure 2.
VisioWay®: a novel embedded system for ITS applications

an enhanced MultiMedia Accelerator (eMMA). The CMOS sensor interface provides the capability to acquire digital images, typically BT656 or raw data streams in the RGB or YUV components, delivering them to the media processor. The eMMA module consists of video processor units and Encoder/Decoder modules which support MPEG-4 and H.263 real-time encoding/decoding of images from 32×32 pixels up to CIF format at 30 fps. The processor units are based on a preprocessor module, that resizes input frames from memory or from the CMOS sensor interface performing color space conversion, and a postprocessor module which takes raw images from memory performing additional processing of a MPEG-4 video streaming to de-block, de-ring, resize or color space conversion on decoded frames.

The prototype board is also provided with a mini USB-OTG connector, a SD card connector, a RJ45 Ethernet connector, a Bluetooth expansion connector and an analog video connector owed by a video decoder chip to allow analog video (PAL and NTSC formats) processing. On board memory allows video processing and OS storage. A $32M \times 16$ Flash memory is used to store the OS kernel image while two $16M \times$ 16SDRAM modules are used for video processing and for decompressing the kernel image. An ARM Linux (kernel 2.4.20) operates the i.MX21 video processor, allowing access to a wide variety of open source software modules (Figure 3).

Several processes and services are in concurrent operation with the main process (traffic-control application). These processes are:

- A watchdog process for rebooting the system when a periodic signal is not received from the main process.
- A MPEG server which operates as an interface to the i.MX21 MPEG hardware module for frame feeding from the application.
- A HTTP server for configuration and supervision purposes.

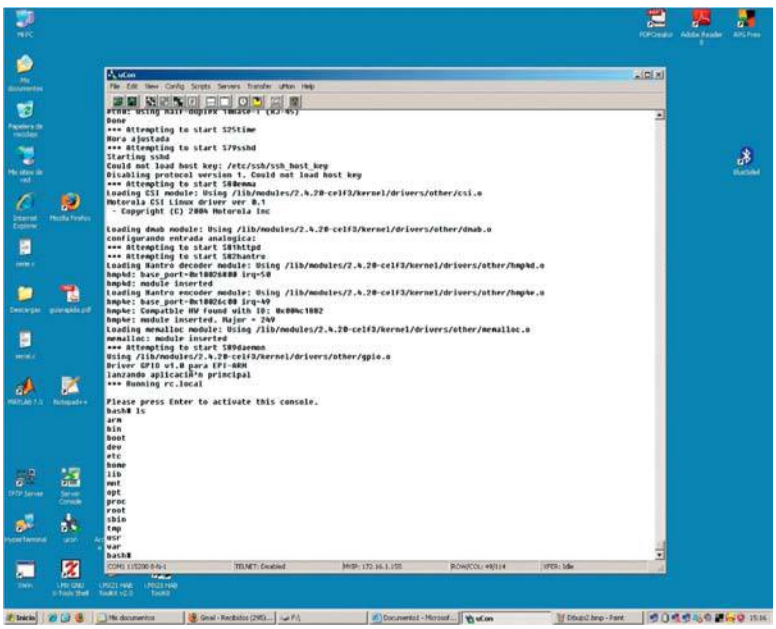

Figure 3.
Kernel prompt of the prototype

- A SSH server for remote logging into the system.
- A FTP server for upload and download operations.

The main process (traffic-control application) developed for the first version of the prototype is a road-traffic parameter estimation system, providing useful traffic information such as traffic flow, lane average speed and occupancy, or congestion levels. The data collection is based on the so-called detection areas. Each one of these areas or regions is a user-configurable polygon with arbitrary shape or size and an associated functionality. Three functionalities have been programmed: presence, directional and queue regions:

(1) *Presence*-detection functionality to inform about the presence or absence of vehicles according to a configured threshold. They can be considered as virtual loop detectors, quite similar in their behavior to the traditional on-the-road loop detectors buried under the road surface. An automatic vehicle counting mechanism is associated to this functionality.

(2) *Directional*-detection functionality to detect vehicles running in a configured direction. Only vehicles running in a configured direction are detected. Otherwise, they are ignored. This functionality is useful for selective vehicle counting in or near intersections, one-way violation detection, restricted turn infringement detection, etc.

(3) *Queue*-detection functionality to measure vehicle queue length and queuing frequency, typically in front of a traffic light.

These three functionalities can be combined, if desired, in the same detection area. The prototype has been installed for its preliminary analysis and evaluation in the metropolitan area of Seville, Spain. Figure 4 shows the prototype and its provisional emplacement. The HTTP server allows the complete configuration of the traffic scene, as well as the definition of the required detection areas. Figure 5 illustrates one of the screens in the system's configuration web page, with seven configured detection areas (polygons named "Espira i", i from 1 to 7, in Figure 6).

Region-based data estimation requires the detection of moving and still vehicles. Specific algorithms are behind the described region functionalities for traffic-data estimation, like background subtraction, shadow removal, robustness under progressive or sudden changes in lighting conditions, as well as more basic and general algorithms such us edge detection, neighborhood operations, image labeling or image thresholding, etc. The most time consuming algorithms are the background subtraction algorithm and the shadow removal algorithm. Both of them require complex heuristics and intensive floating-point operations, so the computation effort is large enough to prove the viability of the prototype as an ITS electronic equipment.

The background subtraction technique permits the extraction of moving objects from an image sequence obtained using a static camera. It is based on the estimation of the so-called background model of the scene. This model is used to obtain a reference image that is compared with each recorded image. Consequently, it must be a representation of the scene after removing all the non-stationary elements, and it has to be continuously updated to accommodate it to the changing lighting conditions or background textures. Surveys and details in the background subtraction and the background model construction algorithms can be found in the literature (Haritaoglu

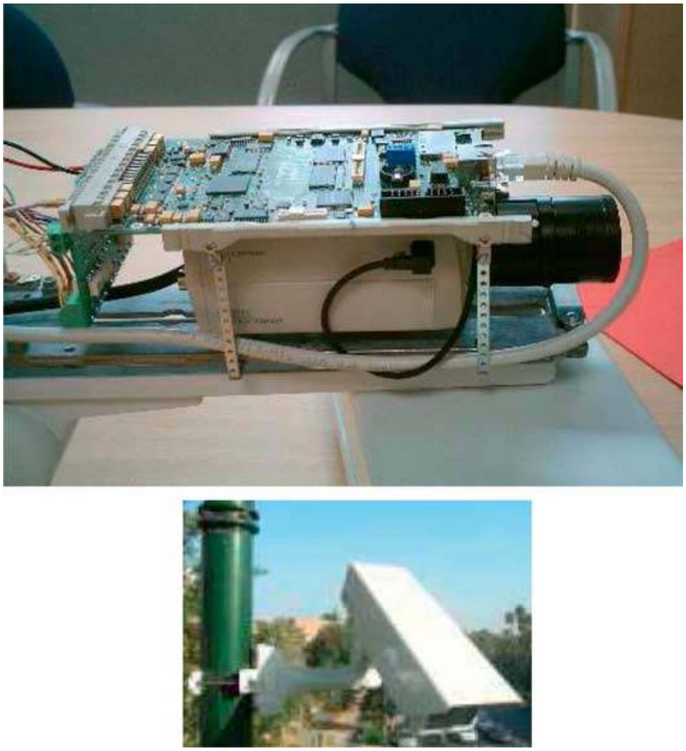

Figure 4.
VisioWay® prototype and its provisional emplacement

et al., 2000; Cheung and Kamath, 2004; Piccardi, 2004). In our case, the background subtraction for moving-vehicle detection is based on the sigma-delta background estimation algorithm (Manzanera and Richefeu, 2004), which provides a valid background model of the scene assuming at the pixel level that the background intensities are present most of the time. An improved version of this method has been implemented in order to properly cope with conditions of dense traffic flow.

The shadow removal algorithm deals with the shadow removal in unstructured scenarios (non-controlled lighting conditions). This task is very important in an ITS electronic equipment engaged with traffic data evaluation to avoid the shadow's influence in parameter estimation. Vehicle's shadows can produce erroneous detections in neighbor regions. An important issue when dealing with the shadow removal algorithm is to exploit the particular properties of the shadows to eliminate them or, at least, to reduce its presence in the image. Surveys of shadow detection and removal algorithms can be found in the literature (Stander *et al.*, 1999; Cucchiara *et al.*, 2003; Prati *et al.*, 2003). In our case, the shadow removal is inspired by a previous work (Jacques *et al.*, 2005).

A pseudo-code of the implemented main process, a traffic parameter estimation based on numRegions detection areas, is provided in Figure 6.

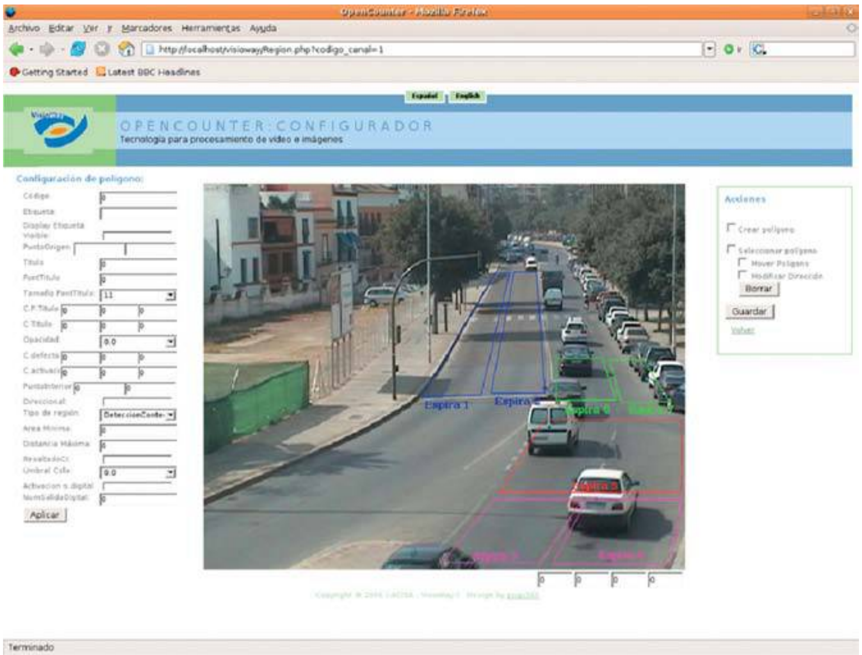

Figure 5.
VisioWay® HTTP-based configuration tool

VisioWay®, robustness analysis in IP-based applications

A real-time traffic parameter estimation system, working with an acceptable number of regions, has been implemented using the installed prototype. Specialized fixed-point libraries and many source-code and compiler optimizations were required for exploiting all the CPU performance. Five detection areas have been defined (Figure 7): two queue regions in front of a traffic light (R1 and R2), one directional detection region configured to count vehicles coming from the right side of the intersection (R3), and two presence-detection regions (R4 and R5). Notice that each detection area allows the estimation of instantaneous and time-averaged traffic data. Instantaneous traffic data can be overlaid on the image, like the display box in the upper-left corner of Figure 7, which shows real-time traffic data for each region. Figure 7 also details how the queue detection region is working. The left queue region (R1) has detected a vehicle queue, exceeding the given threshold, so the region is displayed in a brighter color. On the other hand, the right-most queue (R2) does not exceed its threshold so the queue length is shown in naive color. This figure also shows how the directional region (R3) is detecting a car coming from the right side of the image, which it is the predefined direction associated to the region.

Averaged data (over a given period of time) are also estimated and recorded on a log file and can be remotely downloaded using the FTP server. Different kind of information are recorded depending on the region functionality, like occupancy and vehicle counting data during a programmed period of time using presence-detection regions, directional vehicle counting data using directional-detection regions, and

```
while true
    Grab new image
    for (i = 1  to  numRegions)
        Clip image using region polygon
        Update background model
        Extract foreground objects
        Remove shadows from foreground objects
        Compute binary image: detection mask
        Perform intelligent clustering of fragments in detection mask: compact blob <=> single vehicle

        if (regionType == presence)
            Compute presence level
            Compare with associated threshold
            Update instantaneous and aggregated measures
            Update digital outputs
        endif

        if (regionType == directional)
            If (vehicle exits from region)
                Compare running direction with the configured one
                if (agreement)
                    Update instantaneous and aggregated measures
                    Update digital outputs
                endif
            else
                Update running direction
            endif
        endif

        if (regionType == queue)
            Compute level of short-term still presence
            Compare with associated threshold
            Update instantaneous and aggregated measures
            Update digital outputs
        endif

    endfor

    Overlay instantaneous data over image
    Send image to MPEG-4 encoder

endwhile
```

Figure 6.
Guidelines of the traffic-parameter estimation application

queue related parameters using queue-detection regions (average queue length, queuing frequency, etc.).

The prototype is connected to a private local area network (LAN), using its 10/100-Mbps Ethernet port and a RJ45 connector. VisioWay® has been designed to be installed across the city, and to be accessible through internet. Up to now, only several prototypes have been installed and the infrastructure necessary to have internet access is not available. Consequently, a private LAN based on the prototype plus various PCs has been implemented to analyze the performance of VisioWay® and to prove its robustness (Figure 8). The link speed and the device throughput on the private LAN have been analyzed.

Heavy network traffic is expected due to services like real-time video on demand and estimated road-traffic parameters delivery. Consequently, a multicast control mechanism must be applied to make an effective use of the available bandwidth (Sun *et al.*, 2003). An experiment has been done to prove the robustness of the prototype in congested networks with multicast video delivery. One PC is used for the network traffic monitoring running software, called monitoring program, based on libpcap libraries (Tcpdump/libpcap Project, n.d.). Libpcap utility is widely used for low-level

Figure 7.
Detection areas in the installed prototype: details of the queue and the directional regions behavior

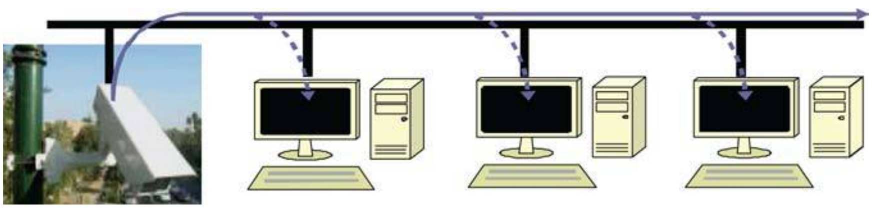

Figure 8.
Test bench using VisioWay®, data servers PCs, and a network traffic monitoring PC with a multicast control mechanism

packet monitoring and filtering. The main idea of this utility is to capture SOAP incoming and outgoing packets, and its main advantage is that the monitoring program can be completely independent from client code. Using libpcap utility, each bit sent or received on the physical link can be captured to monitor and analyze the whole LAN traffic. The other PCs work as Data Servers. Two tests have been performed:

(1) The congested network is emulated using the data servers, and the performance of VisioWay® is studied. Table I summarizes the test results. The processed frames per second (FPS) in the main algorithm do not change when modifying the network traffic, so it can be deduced that VisioWay® is robust in congested networks with a multicast control mechanism. Notice that this ability depends on the hardware design. The Ethernet controller included in VisioWay® analyzes network traffic at the network layer, avoiding the overload of the

VisioWay® CPU. The performance of VisioWay® has been also observed using an unicast control mechanism, to compare the results obtained using a multicast control mechanism in a less favorable situation. The unicast control mechanism is the simplest solution for video delivering, although it is not an efficient method (Sun *et al.*, 2003). The generated network traffic overloads the prototype CPU, and the processed FPS decreases till 5,57 FPS using an 8,000,000 bps network traffic addressed to VisioWay®.

(2) Real-time video delivery is forced and the VisioWay® performance is studied to show its characteristics. In this case, VisioWay® is configured for sending real-time video using UDP protocol. The real-time video (MPEG-4 elementary video using CIF format, at 384Kbps and 25FPS) is delivered to the network monitoring PC. Table II and Figure 9 summarize the obtained results. The time between packets is acceptable for most MPEG-4 players in the 85 percent cases without necessity of incoming buffers. These buffers, usually included in conventional MPEG-4 players, relax the random restrictions associated to the time between network packets.

Conclusions

In this paper, the use of the Internet as the communication link between ITS electronic equipments has been analyzed, and some guidelines for future research on the use of vehicles as nodes in an ITS network are given. The development of technology and embedded systems with enhanced communication and video processing capabilities is providing a revolution in the way we perceive the ITS area. Internet joins this revolution offering a successful communication link for novel electronic equipments with application in the ITS world. An IP sensor has been designed based on an embedded multimedia processor for road-traffic safety and control applications to prove these statements. The electronic equipment, an automatic video processing system commercialized under the name of VisioWay®, has been analyzed, and its utility in the ITS field has been studied programming a traffic-control application software on the basis of region-based data estimation

Table I. Performance of VisioWay® in a congested network with a multicast control mechanism

Test 1	No traffic	Multicast traffic	
Effective network traffic (bps)	0	960,000	8,000,000
Professed FPS	6.9		

Table II. Performance of VisioWay® as a real-time video supplier

Variables	Value
No. of packets	56
Average (s)	0.030153
Variance	0.001907
Standard deviation	0.043664
Maximum (s)	0.0260425
Minimum (s)	0.000080

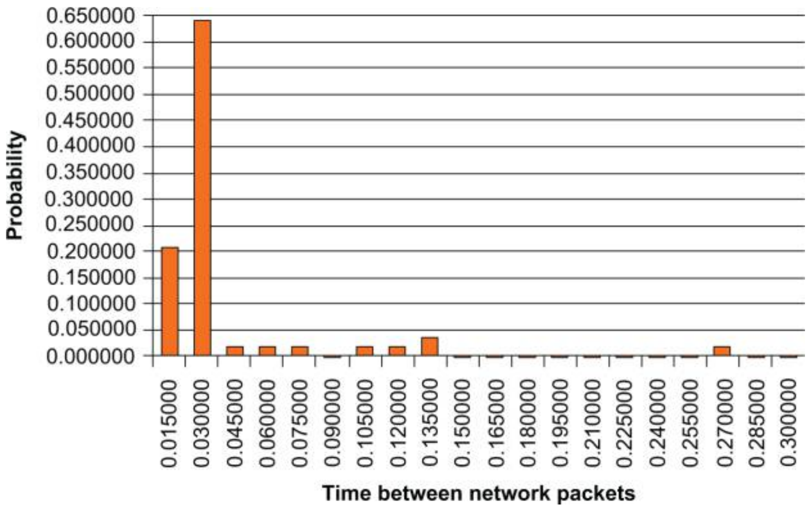

Figure 9.
Network traffic associated with video packets: time between packets probability density function

techniques. The viability of the prototype ITS electronic equipment as a real-time traffic parameter estimation system has been experimentally tested using an installed prototype. Finally, the device throughput on the internet has been tested to prove its effectiveness and robustness.

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