Developing vision-based and cooperative vehicular embedded systems for enhancing road monitoring services

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Abstract

This paper presents a generic processing architecture as well as tools and approaches for supporting road monitoring services. More precisely, a small-scale simulator is presented for experimenting the design and the implementation of vision-based vehicular embedded systems in indoor environments, i.e. a test bench for embedded system laboratories. This simulator employs embedded electronic systems, sensors as well as hybrid communication and computational technologies. In particular, these technologies are exploited in order to produce our cooperative and real-time embedded system for enhancing road monitoring services. This type of simulator can be used for developing a variety of innovative road monitoring services based on the detection of dynamical points of interest. Notably, a system has been implemented in the case of a simulated road service to aid police agency for the recognition of wanted individuals and stolen vehicles. Experimental results show the potential of the simulator for fostering the development of a next generation of vehicular embedded system as well as for the emergence of participatory road services.

Keywords: sensor networks, cooperative monitoring, vision-based recognition systems, vehicular embedded systems.

1. Introduction and Motivation

Nowadays, a huge amount of general public vehicles are equipped with Global Positioning Systems (GPS). Such embedded systems are relatively efficient for storing the position of specific and static Points Of Interest (e.g.; home

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or shop addresses). However, such systems cannot determine the location of dynamical Points Of Interest (e.g.; individuals, vehicles). The new generation of general public vehicles includes a set of sensors (e.g., laser sensor or cameras) which are notably exploited for facilitating the parking of the vehicles. However, vehicle cameras could also be used in complement to the GPS for detecting and localizing dynamical POI’s (Points Of Interest). Moreover, sets of vehicles could also be exploited for mutualizing and sharing relevant information such as detected available parking places or traffic accidents across new road services. For these reasons, our major contribution consists of presenting a proof of concept for the design of a generic processing architecture as well as for the creation of a small-scale simulator which aim i) to develop innovative real-time road monitoring services (e.g., based on dynamical POI’s) ii) to elaborate adapted embedded vehicular systems.

In Figure (1a), we illustrate a type of generic architecture that could be used to foster the development of participatory monitoring systems. More precisely, the embedded vehicular systems that are equipped with cameras can be exploited for collectively surveying street roads. The flow of image that is filmed by the moving vehicles can be sent in real-time to Road Side Units (RSUs) and then relayed to online cloud computing systems by exploiting wireless data transfer technologies. According to the developed services, the analyzed information can either be sent back to the drivers for navigation needs (e.g., traffic information), or directly exploited by monitoring entities such as insurance companies or police agencies (e.g., accident information).

Additionally to our major contribution, promising scenarios of enhanced video-based road services are depicted in Figure (1) and described in more detail below.

**Sc.1: Finding available parking areas** (Fig.1b). The vehicles circulating in road streets and available parking places are detected by exploiting lateral cameras (see camera field of view colored in blue). Then, the approximate position of the detected available parking areas is localized by the vehicle GPS’s and is broadcast to neighbor vehicles. Drivers having activated their parking functionality can then receive the signal in real-time and be guided to an available parking place.

**Sc.2: Reducing vehicle collision risks** (Fig.1c). Once the camera of a lead vehicle detects color changes of a traffic light, this vehicle communicates this information to the succeeding vehicles. Then, the succeeding vehicles can
accordingly adapt their speediness and can thus limit collision risks. In case of a detection of an accident from a leading vehicle, associated images can be relayed to the succeeding vehicles for alerting on the situation.

**Sc.3: Monitoring meteorological conditions** (Fig.1d). A vehicle network is exploited to determine the meteorological conditions according to the camera observations. Areas having bad visibility can be geolocalized for generating real-time meteorological micro-maps. Then, surrounding vehicles can select routes bypassing areas mainly affected.

**Sc.4-5: Localizing stolen vehicles/wanted individuals** (Fig.1e-1f). A vehicle network is employed for collecting license plates of vehicles (Fig.1e). The detected license plates and their corresponding approximate GPS locations are sent to police agencies. Then, they are compared to a local reference database containing license plate of stolen vehicles. If a vehicle is identified, then it will be automatically localized. A similar approach can be employed for geolocalizing wanted individuals (Fig.1f).

2. Related Work

At present, innovative technologies appear for the transfer of information from Vehicle-to-Vehicle (V2V) as well as from Vehicle-to-Infrastructure (V2I). Notably, Vehicular Ad-hoc NETworks (VANETs) are designated as promising communication and routing protocols. Moreover, powerful technologies also appear in the field of computer science for extending the computational capabilities. More precisely, Cloud Computing Systems (CCSs) and popular CSS providers (e.g., Amazon, Google) are actively employed for analyzing big data and for supporting mobile applications and real-time services.

In particular, communication and computing technologies are conjointly exploited for developing Intelligent Transportation Systems (ITS) as well as robots and automation systems. Additionally, the new generation of vehicles are equipped with intelligent embedded systems connected to cameras in order to improve the vehicular navigation (e.g., comfort and security options). Notably, Advanced Driver Assistance Systems (ADAS Systems) are developed for aiding drivers in their maneuvers (e.g., self-parking) and displacements (e.g., automatic lighting, obstacle and collision avoidance).

To the best of our knowledge, road monitoring services that deal with the conjoint use of vision-based and cooperative technologies have not received a lot of attention. Charbonneau et al. proposed a CCW (Cooperative Collision Warning) system deployed on vehicles using VANET (vehicular Ad-Hoc network) communication and vision based monitoring system. To this end, they designed a unified model in which the data collected from the VANET communication and the vision system are combined in order to more accurately estimate the location of neighbor vehicles. The authors demonstrated that including a vision based monitoring system increases the effectiveness of the proposed CCW system.

Obst et al. proposed a vision-based multi-object tracking system for checking the plausibility of vehicle to vehicle (V2V) communication. The proposed work intends to improve the efficiency of the Cooperative Awareness Messages (CAMs) service provided by V2V systems. Similarly as in, the authors developed a multi-sensor fusion algorithm to exploit the data collected by the different sensors (CAMs and camera).

Gerla et al. and Weng proposed a mobile cloud system with the aim of providing a set of services to the customer. The system can be seen as a processing pipeline with three main components namely the customer service, the cloud service provider and the vehicle cloud. Typically the customer asks, through the customer service, for a specific service that is sent to the cloud service provider. Then, the cloud service provider identifies the group of vehicles that meet the customer’s needs, sends them the request and get their feedback which is delivered to the customer.

For the deployment of the system the authors proposed two specific services both dedicated for surveillance. In the first service named photo shooting service the group of vehicles provide real time photo shots (i.e. photo taken following the customer request) of a given urban landscape. In the second service named forensic picture service the vehicles provide rather off-line photo shots (i.e. photo available before the customer request). Inspired from the work done in, Hussain et al. proposed a similar mobile cloud system with an extension regarding security and privacy aspects.

In the remainder of the paper, we present a generic processing architecture and a test bench that could be used for fostering developments of vision-based and cooperative services. Initial investigations of our framework were presented in France at a seminar on image analysis and at a conference on embedded systems. In this paper, the
work is reinforced and particularly insists on the potential of our research in applicative contexts (e.g., city monitoring or road traffic monitoring). Notably, the paper formalizes the problem statement in a better way by discussing and illustrating every identified road monitoring service (e.g., scenarios shown in (Fig.1b-1f)). In this regard, we would point out that the main difference between our works and those cited above lies in the service nature deployed in our system. Moreover, this paper provides technical and material specifications to build a small-scale simulator that can be used for in-situ research experiments and that is adapted to carry out demonstrations of technological advances in scientific missions. In this sense, we also exhibit for the first time a solid and transportable prototyping version of our designed simulator.

3. Proposed System and Experimental Results

(a) Designed processing architecture. (b) Designed dataflow diagram.

Fig. 2: Proposed generic processing architecture and data-flow diagrams.

In this paper, we design a system for enhancing real-time road video services. The proposed system is intended to be used with a vehicle fleet equipped with GPSs, digital cameras and wireless communication technologies. It is assumed that every vehicle can communicate and share information with surrounding vehicles by using VANET technologies (V2V communications). In reason of the computational limits of current in-vehicle embedded systems, every vehicle can also transmit information to external networks or processing centers for communication or computation needs by exploiting RSUs and CCSs (via V2I and I2C communications, respectively).

Accordingly, Figure (2) illustrates our generic processing architecture (Figure (2a)) as well as a data-flow diagram (Figure (2b)) that can be employed for supporting services previously identified (e.g., see Fig.1e-1f). Globally, the Figure (2a) presents a communication and computation architecture useful for carrying out the data transfer as well as the data analysis. The Figure (2b) shows a generic data-flow for potential vision-based applications. The georeferenced images are collected by vehicles and digitally secured. Therefore, this information is transferred from the vehicles to fixed relays (e.g., RSUs) and then transferred from these relays to CCSs. In a second time, the data are accessed by authorized entities and analyzed according to the query applications. In next subsections, we describe in more detail the implementation of the simulator, its associated processing architecture as well as service experiments.

3.1. Mechanical Implementation of the Simulator Platform

The Figure (3-left part) illustrates designed small-scale car pieces (Fig.(3a)) and its corresponding built car models (simulator platforms with embedded devices (Fig.(3b,3e))). The Figure (3b) depicts a built car mock-up in version1 (cardboard mock-up). The Figure (3e) shows the associated built car model in version2 (plastic prototyping) as well as its made-to-measure suitcase. The Figure (3a) shows a flip-up windshield adapted to tidy up the car platform in its
Fig. 3: (left part) Designed small-scale car pieces and its corresponding built car models (simulator platforms with embedded devices). (right part) Detailed parts of the developed vision-based embedded system (version2) and indoor configuration of the test bench for experimenting road video services in real-time.

<table>
<thead>
<tr>
<th>Resource types</th>
<th>I. Bare simulator platform</th>
<th>II. Computer hardware</th>
<th>III. Simulator suitcase</th>
<th>Overall system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plexiglass chassis</td>
<td>39.90 €</td>
<td>118.54 €</td>
<td>192.24 €</td>
<td>5.19 €</td>
</tr>
<tr>
<td>Total cost</td>
<td>158.44 €</td>
<td>197.43 €</td>
<td>36.62 €</td>
<td>412.49 €</td>
</tr>
</tbody>
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Table 1: Synoptic table including the raw materials (i.e., BOM) as well as the costs associated to designed simulator parts. We emphasize that the time required to manufacture parts I and III of the proposed simulator is estimated to 40h and 20h, respectively.

suitcase as can be observed in Figure (3d). Additionally, the Table (1) includes a Bill Of Materials (BOM) as well as the costs associated to major designed simulator parts.

3.2. Integrated Vehicular Monitoring System and Implemented Processing Architecture

In this part, we equip our simulator platform (Figure (3-left part)) with a designed vehicular monitoring system (detailed Figure (3-right part)) and we implement a generic processing architecture reproducing dominant VANETs and CCSs functionalities. In our current implementation the VANET is represented by one camera-equipped vehicle (HD webcam (see Fig.3c)) connected to a Raspberry Pi micro-computer (see Fig.3f)) and one RSU simulated by a remote workstation. A video projector (or a screen) is placed in front of the camera-equipped vehicle and a video associated to a vehicle itinerary is displayed (i.e., sequence of road images). In many cases, such data with their associated GPS information are archived online by mobile mapping laboratories and can be freely exploited for experimental research (e.g., videos from the Kitty research datasets1 13,14). The camera-equipped vehicle will then film the image sequence simulating thus a moving vehicle. An overall view of the simulator is depicted in Figure (3f). Furthermore, our CCS is composed of two nodes represented by two workstations. In order to come as close as possible to a real-world system in term of data transfer from vehicle to RSU and from RSU to the cloud we used WiFi adapters.

1 http://www.cvlibs.net/datasets/kitti/
Table 2: Time information associated to the data transfer and data processing for one image. Data is processed on Intel Core i5 workstations of 2.4GHz under Windows 8.1 64 – bit with 4GB of RAM.

The vehicular monitoring system that is integrated to the platform (plastic prototyping) is then exploited by using process management programs. The image geotagging is carried out by running a python script on the Raspberry Pi. A second python script is also deployed on the Raspberry Pi in order to send geotagged images, date and time information from the vehicle to the RSU (a workstation in our case) using FTP protocol. The RSU in its turn transmits the received data to the storage cloud (two workstations) using SSH protocol to ensure safe transmission. Once the data are received by the cloud, python scripts invoke recognition algorithms with respect to the targeted services. The data received by the storage cloud are in fact saved into file storage servers and the information resulting from their processing (extracted features) are indexed in a database server. We designed a RESTful API for accessing the database.

3.3. System Application and Evaluation

The service experimented in our system corresponds to scenarios (4-5) which are mainly dedicated for the police service as raised in the introduction section. More specifically, the processing algorithms invoked in the storage cloud take as input the sequence of geotagged images received from the VANET and give as output a set of possibly extracted faces, OCR-based license plates and GPS information. Based on Emgu CV platform, we use C Sharp to deploy suitable recognition algorithms. Here, we assume that this latter library meets our needs in term of algorithm efficiency and computational time. The output data obtained by using the detection algorithms are then compared to a reference database generated by an operator. If any matches are found regarding faces and/or license plates, then they are geolocalized thanks to their GPS information, and labeled in real time on a Google map-based application. Table (2) summarizes the transfer time of a 16.5KB image (resolution of 640x480) between the different components of our system and its processing time with respect to faces and license plates extraction.

4. Conclusions and Future Works

In this paper, we have designed and implemented a low-cost simulator for supporting the development of experimental in-vehicle monitoring embedded system and road monitoring services. We have also demonstrated the feasibility of our system (proof of concept) by deploying two road monitoring services (Sc.4-5). Through these services, we have shown that our system can support the detection and the geolocalization of dynamical POIs having different natures (human faces, vehicle license plates).

Next work will be focused on the optimization of our service-oriented architecture by using ns2 or ns3 Network Simulators. In addition, we plan to transfer our current monitoring system on two chassis that will be setup on vehicle windshields for studying the performances of the two experimented services in real mobile conditions (two moving nodes). Also, research will be led in machine vision for automatically detecting available parking areas and developing the parking service (Sc.1).

2 http://www.emgu.com/
3 http://nsnam.isi.edu/nsnam/
4 http://www.nsnam.org/
5. Acknowledgements

This work is part of the SAVEMORE project. The SAVEMORE project has been selected in the context of the INTERREG IV A France (Channel) - England European cross-border co-operation programme, which is co-financed by the ERDF.

References


http://www.savemore-project.eu/