Enabling Low Cost Smart Road Traffic Sensing

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Abstract

Accurate traffic monitoring is a key aspect to develop Smart Mobility services. A road traffic monitoring system based on a network of sensors capturing together information from wireless interfaces of the devices inside the vehicles and also data about noise level is introduced here. This type of sensors obtain accurate road traffic flows and allow noise maps, that can be further analyzed to provide advanced services for mobility and pollution in the roads. Our main goal here is to develop such sensors at low cost with commodity devices, so as to boost their utilization.

1 Introduction

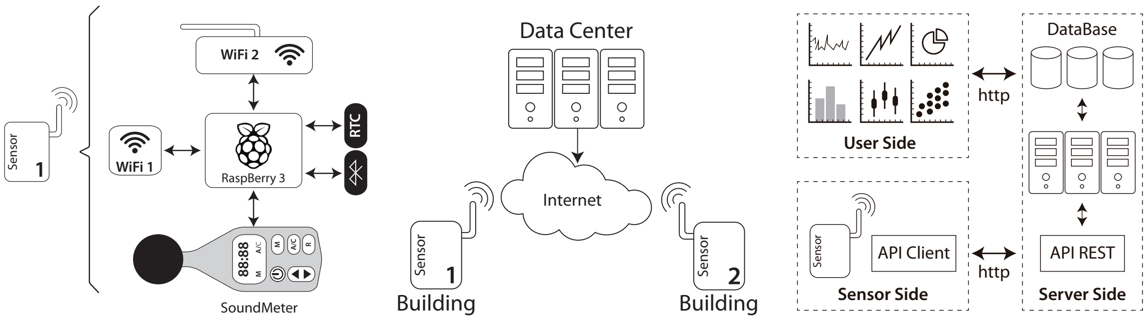
Smart Mobility based on smart traffic management systems is a key aspect in the development of Smart Cities. Intelligent systems able to detect, predict, and efficiently manage different road traffic situations would provide the city agents with decisive improvements, such as, the reduction of travel times and greenhouse emissions. These systems are principally based on accurate traffic monitoring. Nowadays, traffic monitoring systems utilize expensive and road intrusive devices, e.g., loop detectors, or even no sensing is done because of the high expenses incurred by the hardware platform. Existing traditional systems obtain very precise road traffic density measures (e.g., number and type of vehicles). However, they are unable to identify vehicles individually, and therefore, they cannot obtain information about traffic flows. Thus, technologies based on video license plates recognition are also used for this purpose. But then there is a main drawback of a high cost and a too much variable accuracy. Are there any option to loop sensors and cameras that is, at the same time, low cost? Some researchers have proposed similar systems based on detecting Bluetooth (BT) signals and identifying vehicles and pedestrians by the hardware MAC addresses of their devices [1]. This low cost alternative is experiencing a fast development since it is very cheap and easy to maintain. However, its accuracy depends on the market penetration of the target BT devices (detection rates between 5% and 12%) [3]. Some recent studies have considered Wi-Fi (IEEE 802.11 wireless based) signals to track pedestrian to overcome the inaccuracy of BT based sensors because this kind of wireless communication is highly used by the users [2]. Besides, many car manufacturers include wireless access points as part of the equipment of their cars.

In this work, we propose detecting vehicles by capturing the wave signals generated by the smart devices which are located inside of the vehicles, e.g., on-board units or cellphones. Since applications in smart city should show a holistic vocation, we also include a noise sensor to monitor acoustic pollution. We present an innovative road traffic monitoring approach that combines information sensed from different sources in order to improve the accuracy of the measurements, and therefore, the information about the road network status. The proposed sensor captures information from wireless devices (BT and Wi-Fi) and road traffic noise. The use of the two wireless technologies allows a greater collection of MAC ids, while the noise sensor links the monitoring to sustainability. The noise level on the road can be used to estimate the road traffic density and the speed of the vehicles. In addition, our system serves to compute the level of noise that negatively affects the citizens daily life.

2 Sensor and System Architecture

In order to overcome the high cost and limitations of traditional traffic data collection methods, the presented sensor utilizes broadly used low cost technologies. Figure 1a shows the block diagram of the designed sensor. As it can be seen, the sensor is integrated by three wireless interfaces: two for wireless network connections (WiFi 1 and WiFi 2) and one for BT; a Real Time Clock (RTC); and a noise sound meter. These devices constitute the core of the system, since they are responsible for the capture and measurement of the data processed by the sensor. All these devices are controlled by a Raspberry Pi 3 small computer, which is responsible for filtering and temporarily storing the data generated.

To carry out the monitoring of road traffic, we have used the architecture shown in Figure 1b. A set of sensors (at least two) is needed to collect the road traffic data and flows of vehicles. Periodically (by using the WiFi 1 interface), such data is transferred through Internet to a data center where it is aggregated and subsequently analyzed. Different types of information are obtained, such as: noise maps, number of vehicles circulating in certain areas of the city, etc. A client-server model is used to transfer data from the sensors to the data center (see Figure 1c).



(a) Sensor block diagram (b) Wireless sensor network (c) Data flow in the network

Figure 1: Different elements and views of the road sensor system

3 Sensor Operation

The developed sensor retrieves three types of data: noise level, MAC addresses of the nearby BT and Wi-Fi devices. The first type of data is obtained by using a sound meter, which measures the level of noise twice per second. These measurements are utilized to compute the equivalent sound pressure level (L_{eq}), which expresses the mean of the energy perceived by an individual in an interval of time, measured in decibels (dBa) [4]. This information is used to build noise maps of the area.

Many mobile devices utilize BT technologies to transfer data between each other when both are paired, but before starting the communication they have to be in *discoverable mode*. When a BT device is in such a mode it disseminates information, as its name and MAC address. Thus, to detect a BT device the sensor scans to such a information about the nearby devices. Then the sensor stores this information with the exact time for further analysis. The communication range of BT devices conditions the results, which in our outdoor experiments was about ten meters.

Wi-Fi technology is used to detect additional devices even they have not BT enabled. Wi-FI devices that implement the 802.11 protocol constantly transmit beacons that include its MAC address. The Wi-Fi interface of the sensor is operating in *promiscuous mode* to intercept all the beacons in the air. Once a beacon is captured by the Wi-Fi interface, the MAC address, and signal strength are extracted and stored.

The combination of these three types of data allows us to provide a global knowledge of the road traffic status: we sense *data*, convert it into aggregated *information* and then build *knowledge* out of it. The current number of the devices detected by a giving sensor is a measurement of the road traffic density. The accuracy of this metric can be improved by using the noise level returned by this sensor. Indeed, the road traffic flows can be inferred by determining the trajectories of the devices followed throughout our sensor network in a giving time window. Evaluating the MAC addresses allows a fine evaluation of the flows since they contain the type of device (e.g., cellphone, wearable, vehicle, etc.). Moreover, further analysis of this information can be carried out to get the most used roads, the faster routes, the most noisy places, etc.

4 Traffic Monitoring System Design Optimization

The sensor system proposed here presents several challenges. On the one hand, the design of the platform (number of sensors and their location) to maximize the quantity and the quality of the sensed information (i.e., coverage), while minimizing the costs of depployment. In order to help the system designers, a multi-objective optimization problems has been defined to obtain a set of efficient solutions (Pareto front) that provide different trade-offs between the sensor system coverage and deployment costs. The Pareto front is computed by applying a MOEA (Multi Objective Evolutionary Algorithm).

On the other hand, the treatment of the big amount of data collected by the sensor system to generate useful knowledge (e.g., finding vehicular flows, generating noise maps, discovering the correlation between different variables such as noise and road traffic density, recognizing traffic jams, etc.). By coupling Machine Learning techniques and metahuristics (Particle Swarm Optimization and Gentic Algorithm), it is possible to generate the knowledge by requiring bounded computational resources.

5 Experimental Analysis

In order to evaluate our approach, we have performed a preliminary experimentation by installing two sensors (named S01 and S02) nearby along the *Jiménez Fraud St.*, which has a two-way traffic road typically used to enter and exit the university campus at Málaga. The sensors were located in two corners separated by 500 meters. The monitoring was carried out during 20 minutes, beginning at 15:15h of a working week day (rush hour for work and start of the afternoon classes). The aim of this experimentation is to analyze the capacity of our system of obtaining traffic density measures (number of devices), vehicle flows information, which is one of the main assets of this approach, and noise generated at certain points. Figure 2 summarizes the experimental results.

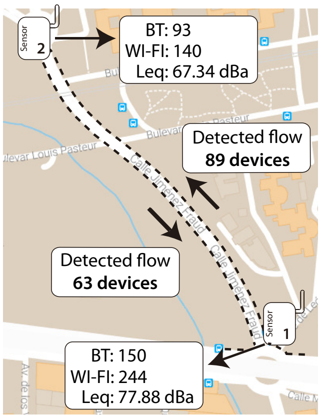


Figure 2: Results

Regarding traffic density, S01 and S02 sensed 384 and 243 devices, respectively (394 Wi-Fi and 133 BT). These results were expected because *i)* S01 corner is at an intersection of roads with high road traffic density and *ii)* the number of BT devices sensed was lower. Two different flows were analyzed: the first one comprises vehicles entering the campus (from S01 to S02) and the second is the opposite one (from S02 to S01). As a result, 89 devices moved from S01 to S02 (70 Wi-Fi and 19 BT) and 63 from S02 to S01 (all detected via Wi-Fi sensing).

Finally, regarding to the noise, S01 got higher noise values (Leq=77.9 dBa) than S02 (Leq=67.3 dBa) for these experiments, exceeding both the 55 dBa by recommended World Health Organization (WHO). Density of vehicular traffic was significantly associated with S01 excessive noise level.

6 Conclusions

The initial experimental results show that the presented architecture provides information about road traffic density, road flows (speeds, routes, etc.), and noise level. We are working now on extending the network with more sensors in order to obtain information from other points of the road network. Besides, we are analysing the use of metaheuristics to address the optimization problems of deploying the sensor system (MOEA) and treating the sensed data (PSO and GA).

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