Smart Cities: Parking Monitoring through Smart Cameras

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***Abstract*—One of today's major problems in medium to large cities is pollution caused by urban traffic. There are various factors that negatively affect this problem. First of all, the constant increase in vehicles, and at the same time the reduction, for budget reasons, of the number of free parking areas more or less easily reached. Moreover, due to global events such as the economic crisis, there is a general reduction in the efficiency of local public transport. In this research, we present an approach to this problem that exploits the greater availability of IT structures and devices. The solution presented offers the possibility of improving one of the most burdensome aspects, namely the traffic generated by cars looking for a parking space through an integrated and automatic management of employment levels. The procedure is based on wireless smart cameras for monitoring public outdoor parking areas. The main strengths of this solution lie in the independence and scalability of the proposed architecture. Independence is ensured by the node's modus operandi, in which processing is performed on board the intelligent camera without the need for a video stream or operator intervention. Scalability can be achieved by designing low-cost nodes that can be connected in a sensor network that does not require high installation costs. Moreover, the possibility of making such processing nodes autonomous through the use of a photovoltaic panel allows them to be installed in even more flimsy situations.**

***Index Terms*—Real-time algorithms, Embedded systems, Intelligent sensors, Wireless Sensor Networks, Smart cities, Smart cameras, Vision sensors**

I. Introduction

Smart cities are increasingly composed of pervasive and ubiquitous computing devices and facilities which extend the monitoring capability but, in the meanwhile, their economy and governance need to be driven by creativity, and innovative entrepreneurship, yet performed by smart people. Two main factors should be met for an effective improvement in direction of building up a smart city: an increase of the extent of computing and digitally instrumented devices built into the very fabric of urban environments, and the degree of development of knowledge economy in the governance of the city itself [1]. Access to mobility resources is a key aspect of smart cities where the two above mentioned factors might have a great impact. In this paper, we demonstrate the opportunities offered by Wireless Smart Cameras (WSC), a particular kind of pervasive sensing and computing technology, in driving the transition towards Mobility as a Service (MaaS) paradigm, using the problem of parking resources as a guide example.

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Several works in literature report estimates regarding the proportion of cars traveling on urban streets during business days that are cruising for parking that is 30% or even higher [2]. In general an estimate of the number of cars searching for a parking is not easy, first because these are not different from other cars, secondly because the estimate is very variable due to the number of total vehicles cruising, to the number of available parking spaces and other factors [3].

In any case, it is clear that an automatic system capable of monitoring city streets and parking might be very effective in addressing this problem, for example by suggesting an area on a map where a parking space is more likely to be found. Several systems have been proposed and tested regarding smart parking or parking guidance systems [4], [5]; they usually obtain the availability information of parking spaces from deployed sensor networks, which could be based on data acquired from ground or other kind of sensors, and simply publish the parking information to drivers heading there [6], [7]. Other systems have very strict requirements, such as the the knowledge over all the vehicles looking for a parking [8], and are mainly based on optimizing an allocation algorithm. Another interesting and current issue regards algorithms managing pricing (i.e. variable price) and available resources (i.e. available parking and proximity) through a dynamic allocation and reservation [9], yet an important constraint is the capability to reserve a specific parking space.

In view of the previous considerations, the main contribution of this paper is to present an intelligent and scalable solution for active cooperative monitoring, based on wireless smart cameras and to study and experiment its applicability to a real urban environment represented by a mid size Italian city of art.

II. Materials

In this paper, smart cities monitoring is achieved through the use of WSC. A WSC is a camera equipped with an embedded unit for performing computer vision and image understanding tasks and a radio network interface to communicate wireless the output of its processing. In the context of this paper, WSC have been designed and used to provide a low cost and sustainable sensing technology with excellent scalability features to allow for pervasive monitoring in wide urban areas. Indeed, thanks to the use of properly designed WSC it is possible to obtain a number of advantages.

First, given the trend in the cost of hardware, smart cameras with adequate vision and computing capabilities can be manufactured at low cost. Being wireless, the installation cost is also lower, since no cabling is necessary. This makes CapEx (Capital Expenditure) costs low. Since cameras can be self powered e.g. thanks to the use of photo-voltaic panels, also OpEx (Operational Expenditure) costs can be cut down, accounting only for routine maintenance.

Secondly, computer vision has a greater ductility with respect to other scalar sensing technology. This means that the same camera can be used for addressing several application by changing the on board computer vision algorithm. Even, the same camera can provide additional services with respect to the ones it was meant for when installed. For instance, a camera installed for security and video surveillance can produce information about urban mobility as well.

Thirdly, several WSC can be put together to form a WSC network: since each camera views the observed scene from a particular perspective, together cameras can provide a more robust and complete understanding of a scene. The WSC network has also scalability features, since it is not necessary to transmit routinely the raw image data or video stream but it is enough to communicate the interpretation of the scene extracted by each camera, which can be encoded in a relatively small number of bits.

On the basis of such considerations, a custom WSC has been designed, implemented and tested. The prototype is based on an own designed embedded board (see Figure 1).

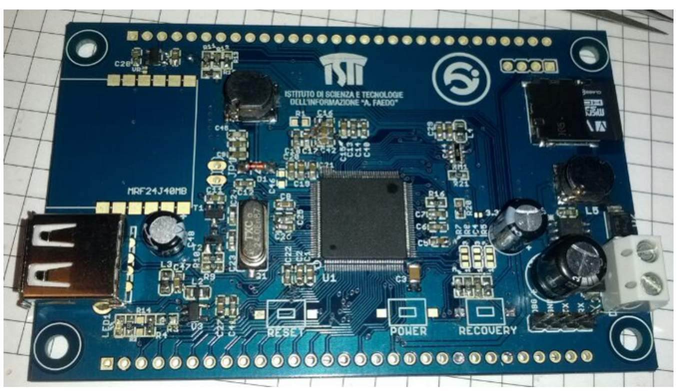

Fig. 1. The own designed embedded board.

The embedded board is powered by a *Freescale CPU* based on the ARM architecture, with support for MMU-like operating systems GNU/Linux. The chosen architecture has been proved to have an average consumption measured at the highest speed ($454MHz$) of less than $500mW$. A microSD slot is present, which is essential for booting the system, booting the kernel and file-system associated (EXT4); the board can be upgraded simply by changing the contents of the microSD. The *ArchLinux* distribution has been chosen as embedded Linux operating system. Development and deployments are currently based on Linux Kernel 3.14.39.

The core of this board has been already subject of experimentation in some previous works which were dedicated to show its suitability as an embedded processor for smart cameras in several applications. For instance in [10] it has been used for traffic flow monitoring while in [11] is has been integrated in a framework for management of urban railway crossing. In [12], [13] it has been used for monitoring of fast failures and geological risk, ending with a long lasting experimentation [14] in a segregated area during which autonomy was obtained relying on an energy harvesting system. In that case, a 3G network interface was used for communication. In [15], an application to smart video surveillance has been provided, using in this case wired communication based on IEEE 802.3. In [16]–[18], cooperation among the cameras was addressed in the framework of urban mobility, relying on a 6LOWPAN over IEEE 802.15.4, with connectivity provided through an external communication board.

The aforementioned works show that our proposed board is suitable for addressing disparate scenarios, relying on several communication technologies and showing an optimal autonomy grade thanks to successful long lasting outdoor experiments. In this paper, in order to address the problem of smart parking in a mid size city, we resorted to the configuration reported in Figure 2, in which the proposed board is integrated with a camera (by *ELP Corporation*) endowed with a 1/3" CMOS AR0330 sensor providing both still images and H264 video stream at full HD. Two optical lenses configuration have been considered, featuring also a $3.6mm$ fish-eye one for a wider field of view. Night vision is also available by removal of the IR-cut filter. The selected camera is compliant with USB Video Class (UVC) standard [19] which makes it possible to integrate the software with the embedded board, implementing both camera control and data acquisition.

For what regards network communication, besides the on-board IEEE 802.15.4 transceiver, an IEEE 802.11 interface has been added, since it allows for an easier and direct integration with Wi-Fi networks that are available in the urban scenario. This is achieved by connecting to an external USB module which is providing Wi-Fi connectivity.

The embedded board, the camera and the Wi-Fi module are housed into a poly-carbonate IP67 shield, which is subject to less electromagnetic attenuation with respect to metallic cases. The other important component of the WSC is the power supply and energy harvesting system that controls charging and permits to choose optimal energy savings policies. The power supply system includes a lead (Pb) acid battery pack and a module for harvesting energy through a photo-voltaic panel. For the experimentation, a $12V$ panel with a nominal power of $15W$ was used and managed by a regulator outputting up to $4A$ DC current. A $12Ah$ battery has been normally used for tests. The embedded board has also been used to measure the charging status of the batteries. To this end, an ADC Conditioning module has been used to adapt the voltage level of the power supply system to the voltage range of the board ADC input.

III. METHODS

The goal of this section is to introduce computer vision methods suitable for deployment on WSC and capable of ad-

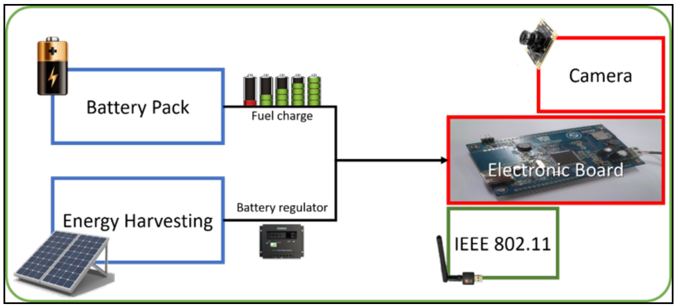

Fig. 2. Designed configuration for the Wireless Smart Camera (WSC).

dressing the parking lot monitoring problem for the detection of empty spaces.

Generally, visual analytic methods for assessing the status of a parking area and determining availability are distinguished into two broad groups, namely *car-based* and *space-based* approaches, with possible hybridization (see e.g. [20]). In car-based approaches, the algorithm searches for cars inside the image; all the found car instances are then mapped to existing and predefined parking spaces. By converse, in space-based methods, the algorithm analyzes a number of Regions Of Interest (ROI) in the images corresponding to the parking spaces in the physical world and assesses if these regions are occupied by some objects or not. Car-based approached are useful for inferring information besides the mere occupancy status, since they can be used to detect vehicles either misplaced or hindering the normal traffic flow. As a disadvantage, they usual require the analysis of the whole images or of large portions of them, resulting in a higher computational burden. By converse, in space-based methods most of the computation can be done only in the ROI; further, space-based methods sometimes can output if a parking space is not available, independently from the fact if it is occupied by a car or by a different bulky object (e.g. dumpster). Hybrid methods combining space- and car-based approach can be superior, especially if they rely on artificial intelligence paradigms capable of recognizing several class of objects, but they come at an additional computational cost.

On the basis of these considerations and aiming at an implementation deployable on embedded WSC, we decided to resort to a two-step space-based method. In our approach, the first step is to recognize changes in each of the monitored ROI using a lightweight but adaptive background modelling. If no change has occurred in the ROI (as it happens most of the times), no further computation is carried out. Instead, if a change has been detected in a ROI, a second step is carried out to extract features from the image to allow discriminating empty spaces from occupied ones.

For the first step, an adaptive background is computed because it proved to be the most robust for use in uncontrolled outdoor scenes. The background is continuously updated using both the previous background model and the latest acquired actual image. Among different models for updating, it has been decided to use a pixel-wise convex combination of the previous background and the current acquired image. A pixel is denoted has changed if its RGB value differs more than a threshold to the corresponding pixel in the background. If more than a certain percentage of pixels in the ROI has changed, then the ROI is marked as *changed* and the second step of the algorithm is performed on such ROI on the current frame and on subsequent ones until finally after a minimum time interval the ROI is marked again as *unchanged*.

The second and finer step is based on the combination of two different image analyses, considering that an empty space should appear as plain asphalt without nothing inside. The first is the so-called asphalt detection: periodically checking small rectangular asphalt samples on the driveway (using the current background image so that no moving vehicle is on the region of interest) we identify similar hue and saturation values in the rest of the image. For each ROI R_k the index $a_k(t)$ is computed. This index is proportional to the ratio of asphalt pixels with respect to the total number of pixels in the R_k. Then a very neat image of the contours of the vehicles is obtained with a Canny edge detection of the current foreground image. Similar to the first one the computed index $e_k(t)$ is proportional to the ratio of edge pixels in ROI R_k with respect to the total number of pixels in R_k. The combination of the two indexes as computed in Eq. 1 creates the final belief of the camera, which indicates the probability of the occupation of the parking space.

$$P_k(t) = e_k(t) \cdot (1 - a_k(t)) \tag{1}$$

Such probability $P_k(t)$ is converted into an occupancy status $Q_k(t)$, which becomes effective only after being observed consecutively for a specific number of acquired frames. In addition, for the implementation of a more robust algorithm that avoids meaningless oscillations, the above decision is further improved using two levels of thresholds $\varepsilon_1 < \varepsilon_2$, and considering the status of the space at the previous measure obtained at time $t-1$:

$$Q_k(t) = \begin{cases} 1 & \text{if } P_k(t) \geq \varepsilon_2 \text{ or} \\ & (P_k(t) > \varepsilon_1 \text{ and } Q_k(t-1) = 1) \\ 0 & \text{if } P_k(t) \leq \varepsilon_1 \text{ or} \\ & (P_k(t) < \varepsilon_2 \text{ and } Q_k(t-1) = 0) \end{cases} \tag{2}$$

The thresholds $\varepsilon_1, \varepsilon_2$ are set to a common value for all the WSC and the parking spaces. The status $Q_k(t) = 1$ denotes that the ROI R_k is busy, while the zero value means that the space is available.

When a parking space is monitored by more than one WSC, the final decision regarding its occupancy can be obtained also in a cooperative way, at an inter-node level. In particular, the final decision can be obtained aggregating all the beliefs produced by the different WSC (which are statically dislocated and have static tables of the monitored parking spaces) before determining the status by applying Eq. 2.

More in detail, if a parking space k is monitored by $n = n(k)$ cameras, and being $P_k^1(t), \ldots, P_k^n(t)$ the beliefs provided by each single camera at time t, then the aggregated belief $\bar{P}_k(t)$ is computed as:

$$\bar{P}_k(t) = \sum_{i=1}^{n} \omega_{i,k} P_k^i(t) \quad (3)$$

Where the $\omega_{i,k}$ are the non-negative weights and

$$\sum_{i=1}^{n} \omega_{i,k} = 1 \quad (4)$$

The weights $\omega_{i,k}$ are determined heuristically according to the goodness of the view from camera i of the parking space k. Practically, if the views are not excessively skewed, weighting by the normalized area in pixel of the various ROI can provide an acceptable weight initialization. The aggregated status of a parking space can be obtained by applying Eq. 2 to the aggregated belief $\bar{P}_k(t)$.

IV. EXPERIMENTAL RESULTS

The scenario used to test and evaluate the proposed solution was selected in the context of a project funded by the Foundation *Cassa di Risparmio di Lucca* in collaboration with the company Metro S.r.l. who is a concession holder for the municipality of Lucca for the design, construction and management of integrated parking systems and areas for vehicle parking in Lucca. The city of Lucca has the peculiarity of being enclosed by the famous intact Renaissance-era city walls. Within the walls some paying parking are available, both enclosed, street-side and curb-parking, but the vehicle circulation is only admitted for residents or access to those parking lots. The main goal of the experimentation was to monitor the availability of these parking avoiding cars to travel around and entering the streets inside the walls without the possibility to find a parking space. After preliminary evaluations, the case study location has been selected as the parking area located in *Piazza Santa Maria* (Saint Mary Square) right within the walls of the city. As can be seen from Figure 3, in this scenario different areas with parking spaces are monitored. This parking has several peculiarities: it is in a square but organized as a street side parking (blue part in Fig. 3 is the one-way road across the square), with some parking spaces separated from the others by the road. To be noted that some parked cars are outside legal parking spaces (the ones outside red areas), these are not monitored at this stage.

From a methodological point of view other peculiarities arise: due to the historical position of this area only few nodes could be deployed and had to be anchored on existing structures; the position of the monitoring cameras was sub-optimal also with respect to the height over the area. This latter constraint has placed a further difficulty from the point of view of the occlusion caused by the position of the parking stalls compared to available viewpoints. In Figure 4 a sample view from a deployed camera can be seen with an overlay of the resulting processing showing available and occupied spaces. As mentioned above in this figure the occlusion example can

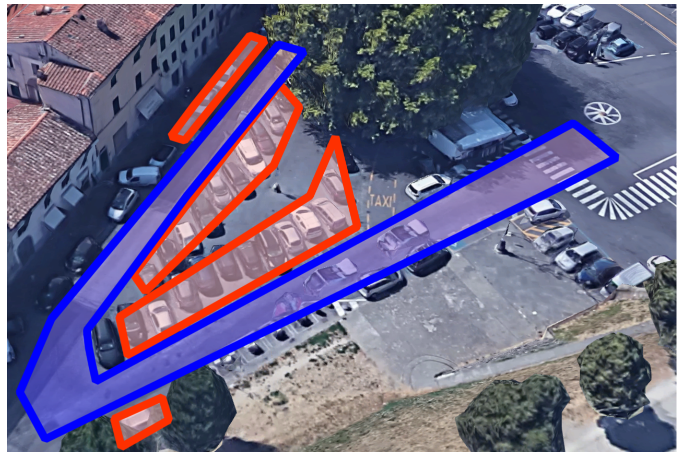

Fig. 3. Case study scenario a monitored parking lot within the wall of the city of Lucca.

Fig. 4. Sample of the interface with a view from a smart camera and the visualization of available and occupied parking spaces.

be seen: the third space from the right in the lower row is occupied by a white van, that is partially occluding the view on the parking space next to its right.

These constraints brought to a careful design of the attention and monitoring areas (i.e. the above mentioned ROI) of single spaces; particularly in the example of Figure 4, although there is a partial occlusion, the monitoring area actually occupied from the occluded vehicle on the right, covers around 80% of the size of the area, with respect to the total area of the ROI. Thus, the adaptive background model has been defined (i.e. the ROI positioning) and computed taking into account possible occlusions, up until the limits of a reduction in the detection ratio. A detail of this situation is shown in Figure 5: the green area representing the part of ROI actual covered by the occupying vehicle and the red area representing the occlusion part.

Fig. 5. Detail showing the overlapping and occlusion of a parking space with the portion belonging to the actual occupying vehicle.

A. Experimental evaluation

The Overall Error Rate (OER) is the metric proposed in [21] and is defined as the ratio of total errors (i.e., False Positive plus False Negative) and the total responses (i.e., False Positive plus False Negative plus True Positive plus True Negative):

$$OER = \frac{FP + FN}{FP + FN + TP + TN} \tag{5}$$

The method operates at frame level, meaning the output of the algorithm being the status of each space (i.e. available or occupied) based on the analysis of a single image; the lightweight image analysis, instead, is a time-related system. In order to compare the two methods, it seems reasonable to consider the output of each individual frame as a complete set of space states; thus the denominator can be considered as the multiplication of the spaces monitored and the total number frames analyzed:

$$ER = \frac{\sum_{i=1}^{Tot}(FP_i + FN_i)}{Tot * Spaces} \tag{6}$$

where $FP_i + FN_i$ is the total number of errors made when analyzing frame i, Tot is the total number of frames analyzed and $Spaces$ is the total number of parking spaces monitored.

The total number of parking spaces analyzed in this experiment regarding the city of Lucca is 30, the spaces are located in the areas shown in Figure 3. One of these parking spaces where reserved to disabled car parking. In total, for this first experimentation, a total of two days (from 9 AM to 5 PM) of acquisition where performed. The analysis was not performed at night in consideration of the fact that parking in these hours is free and unmonitored.

The average error rate achieved by the presented method is 0.65%. Although a number of papers in literature have been presented on the topic, a fair comparison is difficult to be conducted, since most of the approaches are far from being based on a *low-cost embedded platform*. Yet, their performance is not radically different from the one achieved by our methods, as an example, in [22] their method achieves an error rate of 0.4% while being based on high-end computing devices.

Fig. 6. Sample of three frames with a new detected vehicle entering and occupying an available space.

In the following Figure 6 a sample of three extracted frames from a single data-set is shown. The initial situation is shown in the upper frame, then the detection of a new vehicle approaching a free space (middle frame) and then occupying it (bottom frame), the parking space as been highlighted for an easier visualization and finally signaled as occupied.

V. CONCLUSION AND FUTURE WORK

In the frame of a reduction of urban pollution through traffic reduction, in this paper we propose an improvement to the monitoring of urban traffic and towards an increased smart cities capability. One of the goal, especially in historically sensible urban environment is the possibility (which is often a strict constraint) to use existing infrastructures and do not endanger the aesthetic aspect of the urban landscape. In this paper, we have presented a fully scalable and distributed architecture that is easily integrated with multiple sensing sources, and which is deployed in an urban environment exploiting existing infrastructures. One further evaluation which is planned for a next experimental session, is the measuring of results with an increased number of cameras and the computation of the same overlapping parking spaces as seen from different cameras. This feature is particularly effective when dealing with occluded vision (see Figure 5 as an example).

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