An Infrastructure for Integrated Management of Urban Railway Crossing Areas

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***Abstract*— In this work, we present SIMPLE, an integrated platform that offers simultaneous and coordinated management of both railway level crossing and surrounding road traffic. The platform features a new radar sensor that provides superior safety in detecting lost loads or vehicles trapped in the level crossing barriers as well as a road monitoring system, based on novel paradigms for the IoT and including an ETSI M2M compliant Smart Camera Network (SCN) and Gateway. On the basis of the data collected by the sensor deployed on the field, a suitable computational unit performs simulations and provides forecast both on railway circulation (and thus level crossing closing times) and on road level of service. Results collected during a field test are reported and discussed.**

Keywords—Railway; Railroad Crossing; Smart Camera Networks; Real-time Traffic Optimization; IoT; ETSI M2M; Transport Safety

I. INTRODUCTION

Railway level crossings have high impact on urban mobility, both for what regards safety of passengers and citizens and for the complex interactions with road traffic and congestions. Indeed, rail crossings can be a place of numerous and severe accidents, having causes ranging from faults in barrier closing to incorrect behaviour of pedestrians and drivers, who can get trapped in the crossing area. Indeed, as reported in [1-3], accidents at level crossing in Indian railways are accounting for 49% of total fatalities in railway transport during the last decade. In urban scenarios, traffic congestions in the surrounding road network is also correlated with railway crossing accidents; indeed, the presence of a queue often prevents careless drivers to leave the crossing area in time when barriers are closing, thus clogging train transit. In addition, changes in closure times (due e.g. to train delay) might result in unpredictable effects on normal road traffic flows that can propagate from the crossing zone to nearby areas and, even, to other geographically distant parts of the city.

These considerations show that railway crossings are complex entities whose optimal management cannot be addressed unless with the help of an intelligent transportation system capable of integrating both the railway and road perspectives.

With this aim in mind, we propose an integrated infrastructure capable of giving a holistic view of both railway and road status in an urban area thanks to a network of embedded devices for pervasive monitoring of train transits and vehicular flows, augmented by suitable forecasting services. Such services allows for a better understanding of traffic situation based on historical and real-time data collected both in situ and by mash-up of third party web resources.

The proposed infrastructure, named SIMPLE (Railway Safety and Infrastructure for Mobility applied at level crossings), contains several innovation points that are addressed in this paper. First, SIMPLE employs state of the art M2M communication paradigms. This shows the applicability of such protocols to the ITS domain; in particular SIMPLE devices talk natively with a M2M Gateway, while legacy systems may be easily integrated by providing suitable adapters. Secondly, SIMPLE leverages on innovative embedded vision technologies; specially designed sensor nodes are used to build a Smart Camera Network (SCN) devoted to traffic assessment in areas critical for railways crossings. Third, a new radar sensor is integrated for providing superior safety in railway crossing by detecting possible obstacles between the barriers of the crossing. Fourth, all such components of the platform have been tested and validated during an extensive test exercise held in the mid-sized town of Montecatini, Italy. The experimental activities showed the effective impact of the aforementioned technologies in the ITS domain.

The paper is organized as follows. In Section II we provide an overview of SIMPLE architecture, introducing the main involved entities. Then, in Section III, the road management system is presented by describing its devices, which consist in i) the M2M Gateway, ii) the specially designed smart cameras and iii) COTS devices. In Section IV, the railway crossing monitoring system is discussed, whose key component is represented by an FPGA-based radar sensor for obstacle detection. In Section V, the core components devoted to data integration and to the provision of services are finally described. Section VI reports the results of field testing while Section VII ends the paper discussing the applicability of our solution.

II. Overview of Infrastructure Archietcture

SIMPLE is composed by several entities, each of which implements specific functionalities. It has then been decided to organize the overall in a modular architecture containing subsystems with well-defined responsibilities and interfaces. This is advantageous for what regards extensibility, adaptability and configurability of the full platform. Fig. 1 shows the main building blocks of SIMPLE infrastructure. Starting from the bottom, the two subsystem for in situ data collection are reported, namely the Road Monitoring System (RMS) and the Crossing Level Monitoring System (CLMS). In such systems, besides conventional COTS sensors, we use specially designed radar sensors to detect and early notify obstacles on the level crossing area as well as a network of pervasive smart cameras based on Internet of Things (IoT) paradigms for assessing traffic levels on roads around the city.

More in detail, in the RMS a specially designed device named M2M Gateway (GW) is in charge of orchestrating the communications. Indeed, the RMS represents an example of M2M Area Network, since inside this zone the communications protocols between each component and the GW are ETSI M2M standard compliant (see e.g. [6]). The RMS is composed by s Smart Camera Network (SCN) and commercial sensors (COTS sensors). In addition, the Variable Message Signs (VMS) are included in the RMS with the aim of providing information to users regarding the railway crossing status and a forecast about the time of closing of level crossing barriers. The CLMS is in charge instead of the monitoring the actual crossing level area. It includes a radar sensor for obstacle detection as well as a system for detecting the barriers status. Besides being connected to the rest of the SIMPLE platform, the CMLS is linked to the railway signaling system for safety-critical communication of anomalous events.

At the medium level, a modular and standard-based Service Control Unit (SCU) integrates data collected in situ together with other information obtained through the connection to third party services e.g. to railway operator for real-time train traffic data. The SCU also provides data to users by a web user interface. Indeed, User Applications might be implemented on top of the services provided by the SCU. Furthermore, a Simulation Unit in included in the architecture. Such unit is in charge of instantiating forecasting model based on the data provided by the SCU, in order to estimate traffic and barrier closure times.

In the following sections, the components included in the platform will be described and discussed in more detail.

III. Road Management System

In this section, we detail the components of the RMS, namely the M2M gateway, the Smart Camera Network, the COTS sensors and the VMS.

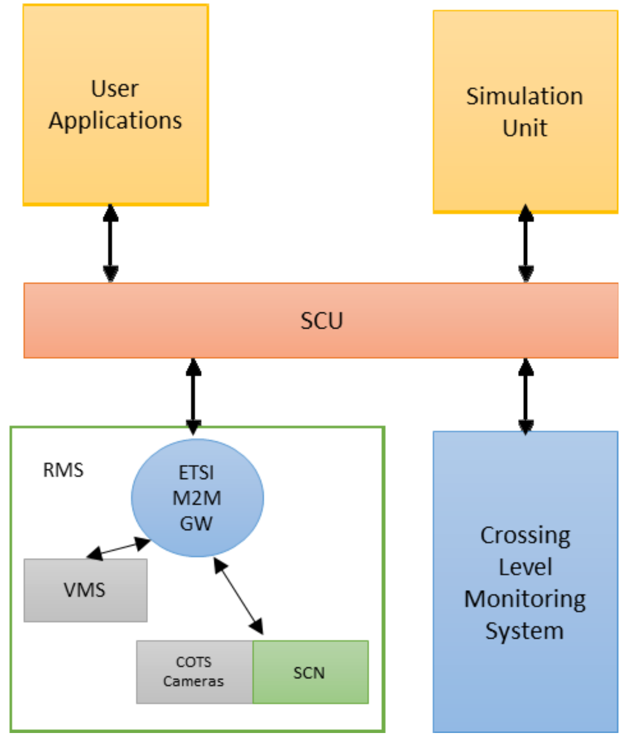

Fig. 1. Architecture of SIMPLE

A. M2M Gateway

The ETSI M2M Gateway is the core of M2M Area Network, since both the SCU and each device inside the RMS communicate via ETSI M2M protocol with the GW.

Within the scope of SIMPLE project, VMSs and COTS Devices are not natively ETSI M2M compliant devices. Therefore the communication with the GW must be ensured by a software modules (required by the standard) called Gateway Interworking Proxy (GIP). That means that the applications on the COTS sensors communicate via a proprietary protocol with GIP, which in turn communicates with the Gateway via ETSI M2M protocol. In case of VMSs it is the same as COTS sensors but the communication is performed in opposite way, since COTS sensors are producers of information while VMS are consumers.

In brief, the main functionalities of the Gateway are to allow the devices inside RMS to send traffic information to SCU and to allow the SCU to send crossing level information to VMSs.

In ETSI M2M standard, an application can communicate with another application through a gateway by a request-response protocol. The operations that an application can perform on the gateway are the usual of creating, retrieving, updating and deleting a resource. Furthermore, it is also possible to subscribe to a resource: this means that if an application performs a subscription to a resource, the application will receive a notification in case of changes of the subscribed resource.

The only operation that can originate from a gateway is notification. When an application made a subscription to a resource and the resource changes, the gateway must notify this change to the subscribed application.

In ETSI M2M, the resources to be managed are organized as applications, containers, content instances and subscriptions.

Without entering into the implementation details, which are out of scope for this paper, we show the meaning and actual use of such resources by means of a basic example. In order to let two applications communicate with each other (application "A" wants to send an information to application "B"), it is necessary to perform the following steps, each of which involves on operation on a resource. The producer application "A" performs the following operations:

- Create an "Application" resource (for instance id: "sensorId");
- Create a "Container" resource (for instance id: "containerId") inside "sensorId";
- Create one or more "Content Instance" resource inside "containerId".

The consumer application "B" has to perform the following workflow:

- Create an "Application" resource (for instance id: "monitorId");
- Create a "Subscription" resource for "containerId" resource created by Application "A";

At this point, every time Application "A" creates a content instance, Application "B" will receive a notification from the gateway and will do a retrieve request about last content instance.

In SIMPLE platform, COTS devices and smart cameras have to communicate the traffic information to SCU; in this case applications of RMS have to do the same operations as Application "A" and the SCU has to do the same operations as the Application "B".

In order to communicate crossing level information the SCU needs to execute the same operations as Application "A" and the VMS have to do the same operations as Application "B".

B. Smart Camera Netowrk

The main sensing technology for monitoring the traffic accessing the railway crossing is based on a SCN, whose sensor nodes have been developed and deployed according to the specific needs of the platform. With respect to traditional visual sensing devices, the one described is designed and implemented taking into account low-cost, low-impact and scalability requirements. One of the challenges was, for instance, the usage of already existing infrastructures (e.g. public road illumination poles or vertical traffic signs) for mounting the smart cameras. The SCN nodes were designed as independent and reconfigurable devices in order to make them scalable for several different monitoring conditions.

The architectural design of the smart camera is shown in Fig. 2, the key feature is represented by the electronic board specifically designed in order to manage on-board both vision processing and wireless data transfer. In this way, the visual processing performed on-board allows for a more powerful computation balanced with a low cost and a performing computational hardware. There is no need to transfer large images, only the information arising from the on-board visual processing is sent to the upper level of the network where all different data are gathered and managed.

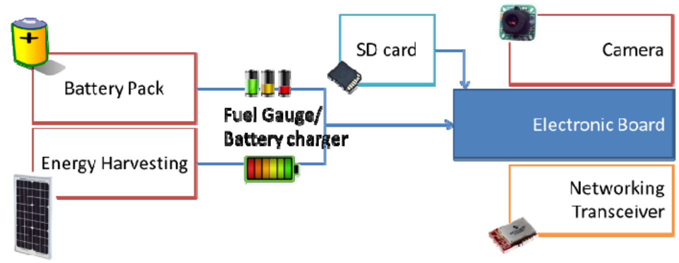

Fig. 2. Architecture of the smart camera

The embedded electronic board is in charge of i) camera acquisition and processing of the images, and ii) communication management via the networking transceiver. The power supply unit is composed by a rechargeable battery pack combined with an energy harvesting module (e.g. a photovoltaic panel), all ruled by the battery charger on the embedded board, making the whole node autonomous. Finally, a micro-SD card is placed on the board for the storage of particular images of interest, and also used for the setup and configuration of the algorithms used in the visual processing.

In order to obtain the maximum flexibility and a good performance/consumption ratio, a Freescale CPU was used based on ARM architecture for the board, working with a GNU/Linux operating system. The maximum power consumption without transceiver working is lesser than 500mW. The board is equipped with: a RS232 serial port, an SPI for the transceiver, USB for the camera, IEEE 802.15.4 transceiver module. For communication, an additional IEEE 802.11 module is also available for Wi-Fi connection, which has been adopted for usage in SIMPLE platform.

The board can be updated simply through the micro-SD slot by changing the card, or remotely modifying the content through the network.

The final sketch of the designed and implemented board as described above is shown in Fig. 3.

Methods for vehicle detection, classification and count (see also [7], [8]) have been developed and integrated with suitable communication protocols to send the measures operated by the smart cameras to the M2M GW.

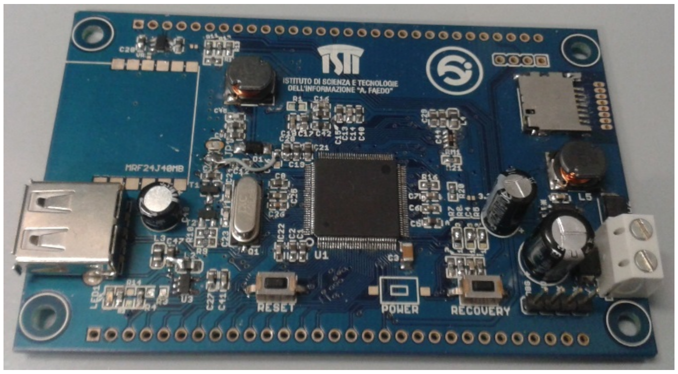

Fig. 3. Layout of the main board of the smart camera

C. COTS sensors

Besides the SCN for traffic monitoring, several other COTS sensors have been considered and integrated. The main purposes have been to gather additional traffic data and, at the same time, to highlight the flexibility of the proposed data acquisition system that is ready to integrate legacy systems as well as modern sensors. In this framework, the V-Matrix traffic analysis system has been included. It is a commercial system based on video technology; with respect to the previous approach based on the distributed nodes of a smart camera network, video streams are sent to a central computing unit that is located road-side. Using computer vison methods, the central unit is capable of detecting and classifying vehicles. It implements also tracking algorithms that allow full analysis of roundabouts, which is an important feature for modeling (and, hence, forecasting) urban traffic. The central unit includes an ad hoc GIP for enabling ETSI M2M compliant communication with the GW.

D. Variable Message Signs (VMS)

Commercial VMSs are integrated in the platform and provide information to vehicular users about the railway crossing level status. They receives the information from the GW. In order to allow the communication from Gateway, a GIP has been implemented. In this way the GIP communicates with the Gateway via ETSI M2M protocol and with the VMSs via TCP client-server protocol where the GIP side is a TCP server and the VMSs are the clients. Connection between VMSs and GIP is ensured by a 3G data connectivity that guarantees a wider coverage compared to WIFI.

IV. Crossing Level Monitoring System

The crossing level monitoring system is a modular system that can be used to control multiple railway crossings distributed around an urban center in order to detect obstacles and anomalies in their actual crossing areas. The system consists in a set of networked radar sensors, having both sensing and on-board processing capabilities, connected to a so-called Remote Station that is in charge of communicating with the SCU. In addition, radar sensors are connected directly to the railway signaling system to promptly notify the presence of obstacles.

Radar has been chosen as a reliable solution for this safety critical component with respect to optical or ultrasound sensors, since it is less sensitive to weather conditions (such as rain, hail and snow) as well as strong sun glares and environmental noises and vibrations. Both radar range and azimuth resolutions have been chosen matching typical vehicles and obstacles dimensions, in order to optimize SNR, and to avoid false alarms due to vehicles and people moving outside the level crossing barriers.

An on-board system for target detection has been developed. Instead of using a traditional DSP architecture for the signal processing algorithm implementation, all the processing chain has been implemented within a single FPGA which furthermore manages the low level HW interfaces of the system. This HW solution was preferred to a possible software solution because of the real-time constraints together with the huge amount of calculations required by some processing algorithms such as FFT. The algorithm has been announced in [4][5] and full details will be published elsewhere.

Whenever an obstacle is detected by the radar system and the barriers of the crossing are closed, a message is sent to the railway signaling system to stop train circulation. Similarly, such information is sent to the Remote Station, which, in turn, make available to the SCU all the information of interest.

V. Data Integration and Services

This section relates to the SCU plus all the connected services for simulation, forecasting and the actual provision of information.

A. Service and Control Unit (SCU)

The SCU is the main system component and offers several services to users by a web user interface depending on user profile. For example, a system administrator can access all system's features while another user can only access a restricted set of functionalities (e.g. he is not allowed to access users' management function).

SCU main capabilities are:

- Collection of data from Road Monitoring System about traffic information;
- Collection of data from the Remote Station of the Crossing Level Monitoring System about crossing level status information;
- Dispatching of traffic information to Simulation Unit (which is described in detail in the following section V.B);
- Collection of simulation results from Simulation Unit about current level of traffic congestion and railway crossing status;
- Dispatching of information about railway crossing

status to ETSI M2M Gateway;
- Provision of web interface to the users.

The SCU features are implemented by a web application, which can be run on a Java EE application server (the open source server JBoss was selected for deployment).

In order to access the features provided by the platform, the user shall register to the SCU. Once system administrator accepts the registration, the user is able to log in to the system and access the resources.

Depending on user profile, available features are:
- Management of users account (system administrator only);
- Selection of railway crossing;
- Monitoring of railway crossing status;
- Monitoring of current traffic congestion level;
- Forecasts about traffic congestion level;
- Alternatives paths;
- Notification messages.

In order to provide to user information about current and a forecast of the level of traffic congestion, the SCU needs to exchange data with the Simulation Unit and the M2M Gateway. In details, the SCU will receive traffic information from the Gateway whenever a sensor of RMS sends some traffic data to Gateway. In order to do so, the SCU must preliminarily perform a subscription to resources from which it wants to receive traffic data. Since Communication protocol between SCU and Gateway is ETSI M2M complaint, subscription is achieved thanks to the methods reported in Section 0.

The traffic data received from Gateway must be sent to Simulation Unit. After completing the simulation process, the Simulation Unit sends the result back about current and forecasted traffic level congestion. The communication between SCU and Simulation Unit is achieved by means of HTTP REST protocol. In more detail, the SCU is a server and the Simulation Unit is a client. In order to fetch the data information collected by the RMS and stored in the SCU, the Simulation Unit should issue a GET request to SCU; on the converse, the Simulation Unit invoke a POST request to send the result of simulation back to the SCU.

The SCU keeps collecting, aggregating and caching traffic data provided from GW until the Simulation Unit downloads them by a GET Request. After receiving a GET Request from Simulation Unit, the SCU will empty the cached data structure about traffic information.

The Simulation Unit can send by a POST Request the forecast about next railway crossing level closing.

In order to receive information about crossing level status the SCU must receive data from Remote Station of the CLMS. The communication between SCU and the Remote Station is made by a proprietary TCP client-server protocol. In details, the Remote Station is the server and SCU is the client.

Periodically the SCU connects to Remote Station and receives the crossing level current status.

The users can access to SCU service by a web browser using a HTTP protocol.

In the end, the SCU must send to the GW crossing level status information for VMS (which are described in III.D). The message about crossing level status information that the SCU can send to GW are:
- Crossing level is down;
- Crossing level is up;
- Crossing level closing at hh:mm

B. Simulation Unit

Among the various components of SIMPLE system, the Simulation Unit is a computational unit exploiting models for analyzing the status of both railway and road traffic and for providing adequate forecast, in order to optimize traffic management. The unit physically consists in a dedicated server, which communicates with the SCU using the protocols described in Section V.A. It integrates two main applications, namely the Train Tracking and the Traffic Model applications.

The first one has the main goal of forecasting the closing times of level crossing barriers. To this end, the application connects automatically to third-party services provided by the railway operator and fetch data regarding train positions and possible delays along the railway network.

The software analyzes the position of the train and, based on historical data regarding the network of interest and on its current status, a forecast of the closing time of the level crossing is produced.

The second application is devoted to traffic model and forecast on the level of services along the road surrounding the railway crossing. The applications employs SUMO [9] software for simulating the urban road network. An algorithm based on a historical-inertial paradigm is then used for actual forecast of traffic. Such an algorithm can be calibrated using real observation carried out during a period, thus exhibiting good adaptability features.

VI. EXPERIMENTAL RESULTS

After laboratory integration and testing, SIMPLE has been validated during an extensive trail held in the mid-sized Italian town of Montecatini, Tuscany during December 2014. This urban center is quite a paradigmatic case, with the railway line splitting the city and with some level crossings that often create congestion downtown. Indeed, due to architectural constrains in the city center, it is not straightforward to find alternative ways or to build underpasses/overpasses in order to get rid of railway crossings.

The field trial included the actual deployment of all the components described in this paper, including radar sensor, smart camera nodes, COTS cameras and VMS.

More in detail, one radar sensor has proven to be sufficient for monitoring the designated crossing level. Several occupation tests of the area with obstacles of different size and material have been conducted for simulating trapped vehicles and lost load. All tests have been successful. In addition, in accordance to CENELEC European Standards [10], a number of simulation has been conducted besides static code analysis to assess the achievement of Safety Integrity Level (SIL) 4. Such kind of testing is useful towards a future certification of the equipment. Finally, the radar sensor has been connected to the Remote Station, which in turn has been able to transfer the data to the SCU with low latency.

Regarding the road monitoring system through the SCN, it has been tested and validated during the trial, focusing on the road network surrounding and afferent to the level crossing. It has been tried to use existing infrastructure, showing that the proposed system is adaptable to disparate situations without requiring major work. Indeed the full installation, configuration and testing of the SCN (featuring 4 smart cameras) and of the M2M Gateway required less than a day of work. No extra maintenance activities have been required during the test exercise.

For the evaluation of the SCN performance, during the field tests several controlled and not controlled sequences were used from real traffic situation, and cross correlation of the results was performed yielding very efficient performances.

For what regards the SCU and the global integration, the field tests session has been performed similarly as the integration tests conducted previously in the lab. Main differences regarded the fact that samples provided by the RMS, railway crossing level status, traffic simulation, congestion level and simulation have been now related to a real situation.

In particular, the Simulation Unit has been fed with real data coming from the real scenario; the provided forecasts have been compared to the actual situation observed in situ by the operators. It has been verified that the Train Tracking application is able to provide the correct forecast for barrier closing times (average uncertainty level of 30'') while the Traffic Model application has shown good capability in running microsimulations every 60'', thus producing near real time traffic forecast.

VII. CONCLUSIONS

In this paper, we have presented a platform devoted to the integrated management of railway crossings in urban areas. The platform is composed of several advanced technological components and make use of modern standard for M2M communications. In particular, ETSI M2M has been successfully applied to this ITS domain and was shown capable of integrating both i) prototype sensors based on embedded computer vision and ii) legacy systems for sensing and actuation.

The effectiveness of the approach has been showcased by an extensive global test held in a typical urban scenario.

In such a real deployment, we had to face several logistic, technical and legal issues in order to be able to have the system working and installed. The solution of such issue was not always straightforward and lead to some delay. However, at the end, it was managed to have the full system installed and operational in the city.

In the future, it is expected to deploy the developed components in further contexts, such as multiple railways crossing and more complex vehicular monitoring to fully demonstrate the scalability and adaptability features of the proposed solution.

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