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An Intelligent Transportation System for Safety and Integrated Management of Railway Crossings

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***Abstract*—**Railway crossings are complex entities whose optimal management cannot be addressed unless with the help of an intelligent transportation system integrating information both on train and vehicular flows. In this paper, we propose an integrated system named SIMPLE (Railway Safety and Infrastructure for Mobility applied at level crossings) that, while providing unparalleled safety in railway level crossings, collects data on rail and road traffic and provides value-added services to citizens and commuters. Such services include for example alerts, via variable message signs to drivers and suggestions for alternative routes, towards a more sustainable, eco-friendly and efficient urban mobility. To achieve these goals, SIMPLE is organized as a System of Systems (SoS), with a modular architecture whose components range from specially-designed radar sensors for obstacle detection to smart ETSI M2M-compliant camera networks for urban traffic monitoring. Computational unit for performing forecast according to adaptive models of train and vehicular traffic are also included. The proposed system has been tested and validated during an extensive trial held in the mid-sized Italian town of Montecatini, a paradigmatic case where the rail network is inextricably linked with the fabric of the city. Results of the tests are reported and discussed.

***Keywords*—** Intelligent Transportation Systems (ITS), railway, railroad crossing, smart camera networks, radar obstacle detection, 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 crossing can be a place of numerous and severe accidents, having causes ranging from faults in barrier closing to incorrect behavior of pedestrians and drivers, who can get trapped on 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. Based on these considerations, it is clear that a railway crossing is a complex entity, whose management cannot be addresses solely from the railway perspective but analysis of vehicular flows should be encompassed.

With the aim of achieving this purpose, in this paper we propose an integrated system named SIMPLE (Railway Safety and Infrastructure for Mobility applied at level crossings) that manages both information on train and vehicular flows. While providing superior 24/7 safety in railway level crossings, our integrated system collects data on rail and road traffic and supplies an umbrella of value-added services to citizens and commuters. In particular, SIMPLE includes an in situ monitoring platform made of networked devices of various typologies. Besides conventional COTS sensors, it uses specially designed radar sensors to detect and early notify, through the railway signaling network, 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. 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.

On the base of adaptive models, learned from the context, prediction on barriers closing times and road level of service are derived, together with suggestions for alternative routes, so as to mitigate the impact of rail crossing closure. Besides being divulgated through VMS, such provided information can be accessed by the users using smartphones and via the web.

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, we describe the crossing level monitoring system, whose main actor is represented by a new radar sensor for obstacle detection in the crossing area. The road management system is presented in Section IV by describing its devices, which consist in i) the specially designed smart cameras, ii) COTS cameras and iii) the M2M GW. 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 lab- and field-testing while Section VII ends the paper discussing the applicability of our solution.

II. Overview of System Architecture

SIMPLE is composed by several entities, which have different functionalities. It has then been decided to organize

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the overall system in a modular way as a System of Systems (SoS). This is advantageous for what regards extensibility, adaptability and configurability of the full platform. Fig. 1 shows the main building blocks of SIMPLE architecture.

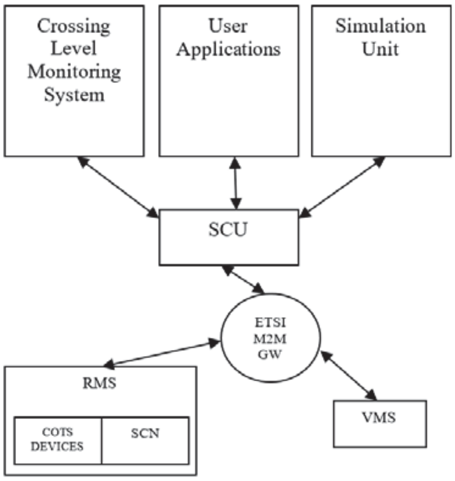

Fig. 1 Architecture of SIMPLE

The Service and Control Unit (SCU), the core of system, collects traffic and crossing level information and provides data to users by web user interface.

ETSI M2M Gateway, Road Monitoring System (RMS) and Variable Message Road Signs (VMSs) are deployed along the road network nearby the monitored railway crossing. This Area, where components listed above are deployed, is called M2M Area Network due to the reason that inside this zone the communications protocol between each component with the M2M Gateway are ETSI M2M standard compliant (see e.g. [4]).

The communications between the components of the M2M Area Network is ensured by WIFI connectivity (apart from VMSs which adopt a 3G data connection). The VMSs provide information to users regarding the railway crossing status and a forecast about the time of closing of level crossing barriers.

The SCU receives information about railway crossing status from the Crossing Level Monitoring System (CLMS). In order to provide that information to users by the VMSs, the SCU sends this information to the ETSI M2M Gateway which forwards them to the VMSs. The Road Management System is composed by Smart Camera Network (SCN) and Commercial Devices (COTS DEVICES). The ETSI M2M Gateway receives traffic information (vehicles counter and change of directions) from RMS and forwards them to SCU.

III. 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.

A. Radar Subsystem

Among several possible technologies for obstacle detection, radar has been chosen as a reliable solution 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. In the design of the radar, several aspects have been considered including sensor dimension, target dimension, target speed and range and weather conditions. On the base of these considerations, a radar working in the X band (which is scarcely affected by atmosphere conditions) and using a Linear Frequency Modulated Continuous Wave (LFMCW) principle has been selected. Both 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. Range and azimuth resolutions, measuring respectively about 30cm and 2 degrees, are obtained by means of a 500MHz bandwidth transceiver and a 45cm wide patch antennas array. Fig. 2 shows the developed prototype.

B. Processing Subsystem

In a radar system detection and classification of a target is based on its Radar Cross Section (RCS), which is a measure of the power of the electromagnetic wave reflected by the target towards the radar receiver with respect to the incident power from the radar transmitter. The RCS for a target of a given size and shape is very strong for targets made of conductive materials or very dense materials like stone and wood but drops quickly as the target density lowers.

This behavior allows for a low false alarm rate in a radar system due to extensive but very low-density objects (potentially not dangerous) like plastic bags, paper sheets or empty cardboard boxes, further improving availability.

An on-board system for target detection has been developed for target detection. 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 processing chain carried out by the sensor can be divided in two main functions: the Obstacle Detection function and the Diagnostic function. The first one, after gain calibration and transformation to the range-azimuth domain, employs filters for the detection of moving and still targets. On the basis of detected targets, a second level detection is used and leads to a fine decision about the current status of the crossing area. The diagnostic function is used instead to detect the faults that can occur in the system: it identifies malfunctioning of the analog electronics, measuring gain and noise, reveals physical obstructions of the antennas, measuring the power of the coupling signal, and checks the focalization functionality, using a reference target.

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 forwards information of interest to the SCU.

Fig. 2 Radar sensor

IV. Road Management System

A. Smart Camera Network for Pervasive Traffic Monitoring

The main sensors for the monitoring of the traffic accessing the railway crossing are based on the SCN, whose sensor nodes have been developed and deployed according to the specific need of the project. 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 Fig. 3, the key feature is represented by the electronic board specifically designed in order to face 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.

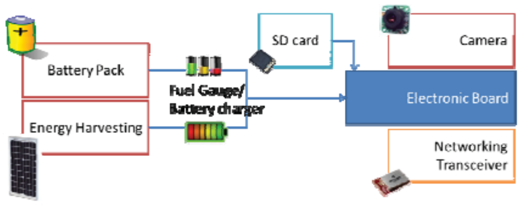

Fig. 3 Architecture of the smart camera

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 recharging 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 network, an additional IEEE 802.11 module is also available for Wi-Fi connection.

Through the micro-SD the board can be updated simply by changing the card, or remotely modifying the content via network.

The final sketch of the designed and implemented board as described above is shown in Fig. 4. Methods for vehicle detection, classification and count (see also [5], [6]) have been developed and integrated with suitable communication protocols to send the measures operated by the smart cameras to the M2M GW.

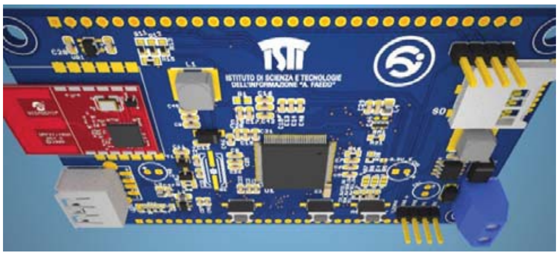

Fig. 4 Layout of the smart camera board

B. Additional 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 showcase 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 implement also tracking algorithms that allow full analysis of roundabout, which is an important feature for modeling (and, hence, forecasting) urban traffic.

C. M2M Gateway

The ETSI M2M Gateway is the core of M2M Area Network because each device inside RMS, each VMSs and the SCU communicate via ETSI M2M protocol.

Within the scope of SIMPLE project, VMSs and COTS Devices are not ETSI M2M compliant Devices. Therefore the communication with the Gateway must be ensured by a software modules (required by the standard) called Gateway Interworking Proxy (GIP). That means that the application on the COTS devices communicate via a proprietary protocol with GIP which communicates with the Gateway via ETSI M2M protocol. In case of VMSs it is the same as COTS devices but the communication is performed in opposite way. The main functionalities of the Gateway are:

- allow the devices inside RMS to sends traffic information to SCU;
- allow the SCU to sends crossing level information to VMSs.

An application can communicate with another application through a ETSI M2M Gateway by a Request-Response protocol. The operations that an application can perform on the Gateway are:

- create - creates a resource on the Gateway;
- retrieve – get information about a resource;
- update – updates a resource on the Gateway;
- delete – deletes a resource on the Gateway;
- subscription – allows a subscription of a resource on the Gateway. That 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 Gateway can perform is the notification. When an application made a subscription to a resource and the resource changed, the Gateway must notify this change to the application.

Main resources manage by a ETSI M2M Gateway are:

- Applications;
- Containers;
- Content Instances;
- Subscriptions.

Below are listed the operations that two applications must do to communicate with each other (application A wants to send an information to application B).

Application A:

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

Application B:

- Create an "Application" resource (for instance id: "monitorId");
- Create a "Subscription" resource for "containerId" resource created by Application A;
- Every time Application A creates a content instance, Application B will receive a notification from Gateway and will do a retrieve request about last content instance.

In SIMPLE project 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.

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 web user interface depending on user profile. For example, a system administrator can access to every system's feature, while another user can only access a restricted set of functions (i.e. not allowed to access to users management function).

SCU main capabilities are:

- Collection of data from Road Monitoring System about traffic information;
- receive data from the Remote Station of the Crossing Level Monitoring System about crossing level status information;
- sends traffic information to Simulation Unit (which is described in detail in the following section V.B);
- receives the simulation's results from Simulation Unit about current and the level of traffic congestion and about railway crossing status;
- sends information about railway crossing status to ETSI M2M Gateway;
- provides web interface to the users.

The SCU features are implemented by a web application, which must be run on an open source application server (JBoss).

In order to access to system provided features 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 to the features.

Depending on user profile available features are:

- Manage 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 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. Communication protocol between SCU and Gateway is ETSI M2M complaint.

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 forecast traffic level congestion. The communication between SCU and Simulation Unit is a http REST protocol. In details, the SCU is a server and the Simulation Unit is a client. In order to receive data information captured from RMS, the Simulation Unit must send a GET request to SCU; instead to send the result of simulation it must send a POST request.

The SCU keeps on to collect and to aggregate traffic data provided from Gateway until the Simulation Unit downloads them by a GET Request. After receiving a GET Request from Simulation Unit the SCU will reset 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 Gateway crossing level status information for VMS (which are described in V.C). The message about crossing level status information that the SCU can send to Gateway 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 of interest.

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 employ SUMO [7] 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.

C. Provision of Information Services and Variable Message Signs (VMS)

The VMSs provide information to vehicular users about the railway crossing level status. They receives the information from Gateway. 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.

VI. Experimental Results and Validation

A. Laboratory Integration and Testing

Laboratory testing have been generally conducted over the single components and, then, integration testing with the SCU has been performed.

For what regards the radar sensor described in Section III, special attention has been given to testing its Safety Integrity Level (SIL) features as defined in the CENELEC European Standards [8]. Indeed, aiming at realizing SIL 4 architecture (which is the highest safety integrity level described in the standard), a number of simulations with statement and branch coverage besides static code analysis using automatic tools and synthesis flow verification (“diversity” applied on FPGA designs) has been performed.

The lab tests and integration for the SCN described in Section IV.A were conducted in two phases: first, a series of separate validation tests regarding communications, and image processing was successfully performed on the single components, then integration tests were performed using specific components allowing for input/output data tracking, and known visual sequences for the classification algorithm. The architectural setup designed for the road management unit is shown in Fig. 5; this architecture, designed for the laboratory integration tests, was also used for the deployment in the field tests.

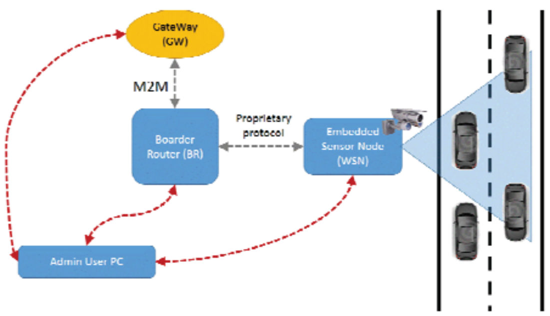

Fig. 5 Set up of environment for SCN lab testing

Testing of the SCU has been performed on system modules functionalities. In details:

- GUI functionalities;
- ETSI M2M Gateway functionalities;
- GIP for VMSs functionalities;
- GIP for COTS devices functionalities.

GUI functionalities tests have been performed in order to validate:

- User management capabilities (account create, account delete and account modify);
- User profile;
- Railway Crossing level selection functionality;
- Railway crossing level monitoring status.
- Current and forecast traffic level congestion;
- Messages notification capabilities;
- Alternatives paths.

The phase related to the validation of the ETSI M2M Gateway functionalities has been performed at operations level such as create, retrieve, update, delete, subscription and notification of resources via ETSI M2M protocol.

The test phase on VMSs and COTS GIPs devices has been conducted with Gateway support and with a simulator. In this case, tests covered the following capabilities:

- The simulator has created Application resource on Gateway;
- The simulator has created Container resource on Gateway;
- The VMS GIP has created Application resource on Gateway;
- The VMSs GIP has created Subscription resource on Gateway for the container created from simulator;
- The simulator has created a content instance on Gateway inside the container;
- The VMSs has received the notification for change from Gateway;
- The VMS GIP has translated the message from ETSI M2M protocol to proprietary protocol and has sent the message via TCP connections;
- The message was received from TCP client (i.e. netcat application).

A similar procedure was performed on COTS devices GIP tests. After each single system component has been validated, a session of integration tests has been performed in order to verify the overall system functionality. Finally, a test about data consistency after reception has been executed (i.e. data generated within the RMS were successfully evaluated by Simulation Unit).

B. Field Tests

After laboratory testing, SIMPLE has been tested and 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. A quadrangular focus area has been selected and configured (as shown in Fig. 6). Then, 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. 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.

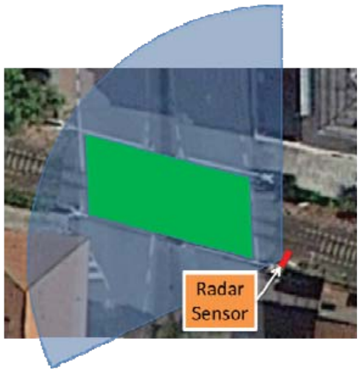

Fig. 6 Installation and setup of the radar sensor

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 of the SCN (featuring 4 smart cameras) and of the M2M Gateway required less than a day of work. A sample of the installation deployed is reported Fig. 7 in which all the sensor node electronics is included in the camera case; the M2M Gateway, enclosed in a metal box, is also anchored on the same pole.

The final printed and developed board used for the field test in each of the deployed smart camera nodes is shown in Fig. 8.

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, yet retaining a very high reliability ratio and performance.

For what regards the SCU and the global integration, the field tests session has been performed similarly as the integration tests performed 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.

Fig. 7 An installed smart camera and the ETSI MSM Gateway installed on an existing pole during Montecatini trial

Fig. 8 The smart camera main electronic board

VII. Discussion and Conclusions

In this work, we have presented SIMPLE, an integrated system that offers simultaneous and coordinated management of both railway level crossing and surrounding road traffic. The system features a new radar sensor that provides superior safety in detecting lost loads or vehicles trapped in the level crossing barriers, which are the causes of most railway accidents and fatalities. The radar, designed according to a set of functional and safety requirements, implements a SIL4 architecture according to applicable CENELEC standards.

A road monitoring system, based on novel paradigms of the IoT and including an ETSI M2M compliant SCN and Gateway, is included for pervasive monitoring of traffic in the city.

On the base of the data collected by the sensor deployed on the field, a suitable computational unit performs simulations and provide forecast both on railway circulation (and thus level crossing closing times) and on road circulation.

In particular, thanks to its specially-designed models exploiting both real time and historical data, SIMPLE is capable of generating alerts and suggestions for best route selection, that the drivers can view as messages displayed on variable message signs (VMS) or through the internet (using a browser or mobile apps).

In this way, SIMPLE can effectively contribute to a safer and more sustainable mobility in complex urban environments. Indeed, the system has been successfully validated during a trial held in Montecatini, Italy, showing the applicability and adaptability of the proposed technologies to real scenarios.

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References

[1] R. Ramchadran, "FPGA based SOC for railway level crossing management system," International Journal of Soft Computing and Engineering (IJSCE), vol. 2-3, pp. 134–137, 2012.

[2] P. V. K. D. Yugandhar, "An enhanced railway transport system using fpga through gps & gsm," International Journal of Soft Computing and Engineering (IJSCE), vol. 2-6, pp. 185–188, January 2013.

[3] A. Tsiftsis, G. C. Sirakoulis, and J. Lygouras, "FPGA design of a cellular automaton model for railway traffic flow with GPS module," Lecture Notes in Computer Science, vol. 6530, pp. 373–384, 2010.

[4] Wu, Geng, et al. "M2M: From mobile to embedded internet." Communications Magazine, IEEE 49.4 (2011): 36-43.

[5] M. Magrini, D. Moroni, G. Pieri, O. Salvetti, "Real time image analysis for infomobility," *Lecture Notes in Computer Science*, vol. 7252, pp. 207–218, Emanuele Salerno, A. Enis Çetin, Ovidio Salvetti (eds.), Berlin: Springer Verlag, 2012.

[6] M. Magrini, D. Moroni, G. Pieri, O. Salvetti, "Lightweight computer vision methods for traffic flow monitoring on low power embedded sensors," in *Proc. VISAPP 2015 - 10th International Conference on Computer Vision Theory and Applications,* Berlin, Germany, 11-14 March 2015, vol. 2 pp. 663-670, José Braz, Sebastiano Battiato and Francisco Imai (eds.), SCITEPRESS - Science and Technology Publications, 2015.

[7] Behrisch, Michael, et al. "Sumo-simulation of urban mobility-an overview." SIMUL 2011, The Third International Conference on Advances in System Simulation. 2011.

[8] CENELEC, EN. "50129." Railway Applications-Communication. Signaling and Processing Systems-Safety Related Electronic Systems for Signalling: BSI (2003).