Smart Structures and Systems, *Vol. 17, No. 5 (2016) 743-751*
DOI: http://dx.doi.org/10.12989/sss.2016.17.5.743

Synergy of monitoring and security

Sara Casciati[1], Zhi Cong Chen[2], Lucia Faravelli[3] and Michele Vece*[3]

[1]Department of Civil Engineering and Architecture, DICAr, University of Catania at Siracusa, Piazza Federico di Svevia 1, Siracusa 96100, Italy
[2]Institute of Micro/Nano Devices and Solar Cell, College of Physics and Information Engineering, Fuzhou University, QiShan Campus, Fuzhou 350108, China
[3]Department of Civil Engineering and Architecture, DICAr, University of Pavia, Via Ferrata 3, Pavia 27100, Italy

(Received February 11, 2015, Revised January 20, 2016, Accepted February 6, 2016)

Abstract. An ongoing research project is devoted to the design and implementation of a satellite based asset tracking for supporting emergency management in crisis operations. Due to the emergency environment, one has to rely on a low power consumption wireless communication. Therefore, the communication hardware and software must be designed to match requirements, which can only be foreseen at the level of more or less likely scenarios. The latter aspect suggests a deep use of a simulator (instead of a real network of sensors) to cover extreme situations. The former power consumption remark suggests the use of a minimal computer (Raspberry Pi) as data collector.

Keywords: critical asset tracking; crisis operation; GNSS sensor; wireless sensor network; ZigBee

1. Introduction

Security is a timely research issue that is supposed to develop the technologies and knowledge for building capabilities needed to ensure the security of citizens from threats such as terrorism, natural disasters and crime. A non-minor issue is the need to respect fundamental human rights including privacy. Thus, the use of available and evolving technologies cannot be managed in a general framework, but one is rather committed to deliver mission-oriented research results to reduce security gaps. This was the spirit of the European calls in the area within the seventh framework program (FP7). Since a parallel European investment was to develop industry pull applications and services for the European EGNOS (European Geostationary Navigation Overlay System) and GALILEO satellite systems, a well promising idea was to "design, realize, test and validate in simulated and real world scenarios GALILEO-ready tracking/positioning solutions for critical asset tracking and crisis management". The delay in the GALILEO realization, however, suggested to work in the present scenario with a ready option to commute to GALILEO.

The European Union FP7 project named "Satellite Based Asset Tracking for Supporting Emergency Management in Crisis Operations (SPARTACUS)" is currently in progress (Spartacus Project 2015). The project aims to develop "satellite-based applications" in order:

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*Corresponding author, Ph.D. Student, E-mail: miche.vece@gmail.com

http://www.techno-press.org/?journal=sss&subpage=8 ISSN: 1738-1584 (Print), 1738-1991 (Online)

- To track, trace and localize critical transport assets especially in case of major failure of existing networks,
- To track the flow of relief goods from the sending side to the receiving ones, and
- To support coordination and ensure the safety of first responders in disaster management operations (Casciati *et al.* 2014).

It is worth noticing that “satellite based” applies to two different approaches, the first relying on satellite images (Gamba and Casciati 1998, Casciati *et al.* 2014, Bortoluzzi *et al.* 2013) and the second one exploiting all the potential of GPS (Global Positioning System) signals (Casciati and Fuggini 2009, Casciati and Fuggini 2011, Wu and Casciati 2014). The project is focused on the latter facility, and the role of the authors within this FP7 action is the implementation of a local low power wireless communication network. More in detail, it is to develop a mobile communication infrastructure on site by integrating terrestrial wireless access technologies with satellite backhauling ones in which the low power local communication network is required to connect GNSS (Global Navigation Satellite System) based tracking units and a centralized collecting unit.

This paper provides first a sketch of the adopted system architecture (which is still covered by a confidential agreement within the project partners) and focuses then on the devices whose integration was designed and implemented by the authors to fulfill their tasks within the project.

2. General framework

At present, most investigation efforts aim at improving the current framework related to the exploitation of the potential offered by the satellite network. Indeed, the coordination of operations in emergencies, based on precise positioning and timing systems, can find help in the transfer of information coming from a network of units reading the Global Navigation Satellite System (GNSS). Commercially, most GNSS signal generators and record/playback systems are designed specifically for high volume production test applications of devices that use commercial GPS, SBAS (Satellite-based augmentation systems), GLONASS (GLObal NAvigation Satellite System), GALILEO and other GNSS receivers (Brown *et al.* 2011). The quality of these commercial systems continues also to increase with the addition of new GNSS signals and features (GPS World 2013), but despite all the flexibility provided by these commercial systems, there is still a need for full access to GNSS signal simulation environments, for some GNSS developers, to generate their own customized simulation scenarios (Casciati and Fuggini 2009).

As well known in literature (Casciati and Fuggini 2011, Wu and Casciati 2014, Brown and Gerein 2001), Global Positioning Systems (GPS) offer a valid solution because this technology covers a large area and it is suitable for the monitoring of constructions requiring accuracy of centimeters and which are characterized by a large own period. The main feature of GPS units is to rely on internet for transferring the local information to a recording nucleus. However, in any disaster area, it is likely that the existing terrestrial communication network and power grid be unavailable as consequence of the catastrophic event. Therefore, a reliable asset tracking system requires full independence of those terrestrial networks, especially in terms of communication.

With reference to Fig. 1, for sake of simplicity the reported applications are relevant to transportation units represented by either a train or a truck. Many GNSS based tracking units are expected to be placed in any considered transportation vehicle, thus the conventional cabling method would suffers problems due to inflexible installation and negative impact on the vehicle structure (Wu and Casciati 2014).

The local wireless communication network (Casciati and Wu 2012, Casciati *et al.* 2012, Casciati and Chen 2011) could use internet technology but:

- It must be replaced by a different technology in case of failure after the catastrophic event which generates the emergency,
- The replacing technology should guarantee the service for 24 hours without relying on any external power source, and
- The network should have encryption function(s) to ensure a high security.

In synthesis, the project SPARTACUS is supposed to implement solutions for location awareness, in the context of crisis management, based on existing (GPS, EGNOS, and EDAS, i.e., EGNOS Data Access Service) and incoming (GALILEO) satellite services and technologies providing precise tracking/positioning, ensuring no lacks of communication and no gaps of information in coordination actions.

Fig. 1 makes explicit the three application areas and the security aspect is not a minor issue in selecting the system architecture.

This paper details the way to achieve a link to the positioning data transfer, with a NMEA (National Marine Electronic Association) protocol, from a GNSS sensor to a credit-card sized computer (Raspberry Pi) used as data collector of a reliable and independent wireless communication network.

3. Benefits from a wireless sensor network

Seldom one knows a priori when and where a catastrophic event will occur. This means that it is very important to know exactly where a train is at the disaster occurrence to stop other trains directed to the affected area.

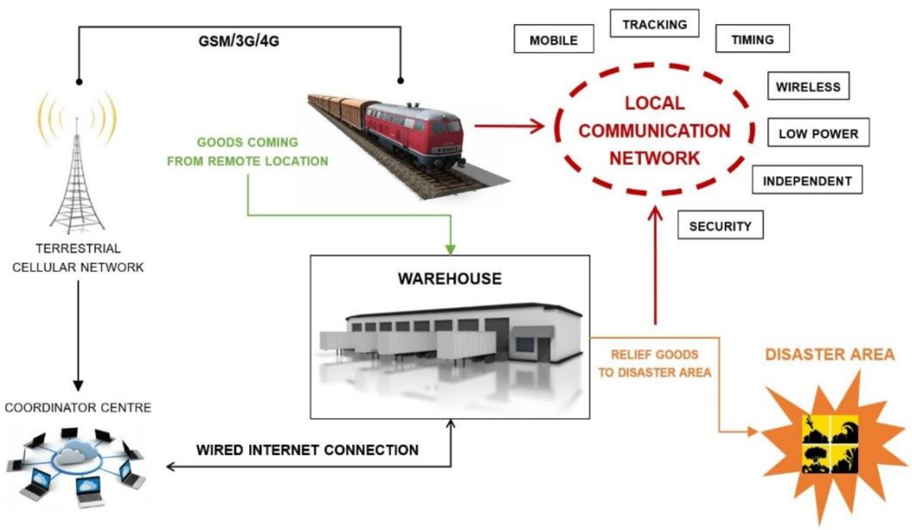


Fig. 1 Overview of the SPARTACUS project goals

Therefore, a GNSS receiver and sender is demanded to always know where the train, or better any single wagon, is located at any time of his travel. In particular, when the surveillance of the trend of a datum within a wagon is necessary during the travel (such as temperature, humidity and so on) the system needs a wireless sensor network to communicate this information to a control center mounted on the train. Moreover, it is worth noticing that an important aspect in the transport of critical goods is represented by a stable communication during the whole travel. Therefore, the project has to offer a reliable surveillance system with a Wireless Sensor Network (WSN) and the data have to be collected continuously in a collecting unit in order to send all the required information to a remote site.

4. System architecture

In Fig. 2, one sees the deployment of the sensor units along a train. Each device has to be linked by a transfer board to a telecommunication item sending the signals to a global collector. It is worth noticing that the links are in parallel to avoid the link failure in a chain system. If the distance requires it, a bridge repeating the signal can be introduced by a relay. The standard ZigBee wireless data transmit technology is adopted thanks to its network capabilities and because it offers a great trade-off in terms of power, range, data rate, and security (ZigBee Alliance 2015).

The developed system architecture consists of inertial sensors with internal GNSS receiver and wireless data transmit devices connected to a hardware interface, as shown in Fig. 2.

In Fig. 2, it is possible to see the complete functional configuration for a train: yellow blocks are the tracking units and the green block is the local communication and collection unit. In detail, the GNSS sensors acquire their positions from the GNSS satellites signal periodically and send the position data to the centralized collecting unit through the multi-hop ZigBee mesh network. In order to pass the collected data to the remote center, the collecting unit is connected to the internet through a satellite backhauling device. In this way, a local existing terrestrial communication infrastructure can be avoided. The choice to adopt this type of system is based on the ownership of containers, wagons and locomotives, which can be different and, usually, train components are mixed. Therefore, the network is provided by: (i) a tracking unit for each element, (ii) an internal unique identification code for each unit, and (iii) an internal position recording for each container, wagon and locomotive. In this way, precise positioning and timing of all these components can be carried out both in near-real time and post-deployment for analysis and additional verification.

In order to satisfy all the requirement of the project, the selected devices are: (i) an inertial sensor with internal GNSS receiver provided by SBG Systems, as shown in Fig. 3 (Ellipse AHRS & INS 2014), (ii) a credit-card sized computer, i.e., the Raspberry Pi Model B (Raspberry Pi 2015), and (iii) GBAN ZigBee Wireless Data Transmission Devices (GBAN 2012).

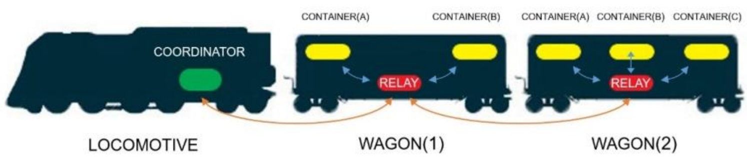


Fig. 2 System architecture

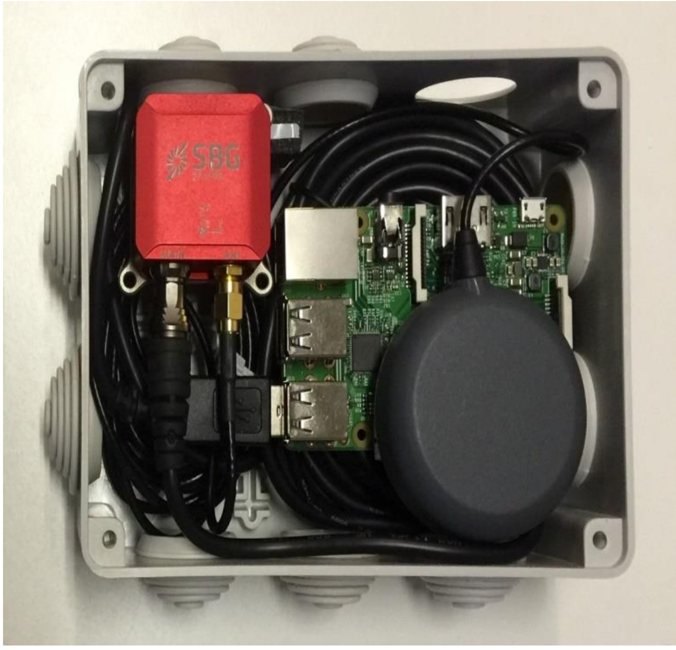


Fig. 3 The sensor device with its own antenna

The Raspberry Pi is powered at 4.94 V and the current consumption, when the SBG Ellipse is configured with 1 Hz sampling rate and the ZigBee device is always powered on, are also measured. Power consumption is almost 400 mA and, therefore, it is convenient to use an external battery (ROMOSS Sailing 5) of 13000 mAh that outputs 5 V while able to deliver up to 2000 mA of current output. In this way, the entire system provides an autonomy of 33 hours.

In comparison with similar past experiences on different sensor units, the main difference to be emphasized is the different character of the sensor output, which was analogic and is now digital. It comes via the NMEA format, which is briefly introduced in next section.

5. NMEA messages

The NMEA-0183 messages (Trimble 2015) allow external devices to use selected data collected or computed by the GNSS receiver. All messages in the above format begin with $ and end with a carriage return and a line feed. Data fields follow comma delimiters and are variable in length; null fields still follow comma delimiters, although they do not contain information, and an asterisk delimiter with a checksum value follow the last field of data. The checksum is the 8-bit exclusive of all characters in the message, including the commas between fields, but not including the $ and asterisk delimiters. The hexadecimal result is converted to two ASCII characters and the most significant character appears first (Trimble 2015). The NMEA messages handled by the sensor are the following:

- GGA (Global Positioning System Fix Data) for position and altitude,
- RMC (Recommended Minimum Navigation Information) for horizontal, velocity and course,
- GST (GNSS Pseudorange Error Statistic) for position error statistics,
- HDT (Heading-True) for true heading, and
- ZDA (Time & Date) for UTC time data.

In the case under study, the required messages (RMC and GGA) are achieved using the configuration settings of the sensor within the proprietary software. An example of a RMC message string is $GPRMC,123519,A,4807.038,N,01131.000,E,022.4,084.4,230394,003.1,W*6A and in Table 1 the message fields are reported in detail.

When NMEA-0183 output is enabled, a subset of NMEA-0183 messages (version 3.01) can be sent to external instruments and equipment connected to the receiver serial ports. The output data transmission is provided by an USB 2.0 interface, which is compatible with the data collector (Raspberry Pi Model B) input ports.

6. The data collector

The Raspberry Pi is a credit card-sized single-board computer developed in the UK by the Raspberry Pi Foundation with the intention of promoting the teaching of basic computer science in schools. The Raspberry Pi is based on the Broadcom BCM2835 system on a chip (SoC), which includes an ARM1176JZF-S 700 MHz processor, VideoCore IV GPU. It was originally shipped with 256 megabytes of RAM, later upgraded to 512 MB. The system has Secure Digital (SD) or Micro SD (Model A+ and B+) sockets for boot media and persistent storage (Raspberry Pi 2015). Fig. 4 shows the chosen model with a view of its components: a micro USB power supply, an SD card slot, an RCA video and audio jack output, two USB 2.0 and Ethernet ports.

The Foundation also provides Debian and Arch Linux ARM distributions for download and several tools are available for Python as the main programming language, with support for BBC BASIC (via the RISC OS image or the Brandy Basic clone for Linux), C, C++, Java, Perl and Ruby. The RasPi can support USB mouse and keyboard. For USB devices drawing more than 100 mA, a powered USB hub is strongly recommended.

Table 1 GPRMC message fields

Field	Meaning
0	Message ID $GPRMC
1	UTC of position fix
2	Status A=active or V=void
3	Latitude
4	Longitude
5	Speed over the ground in knots
6	Track angle in degrees (True)
7	Date
8	Magnetic variation in degrees
9	The checksum data, always begins with *

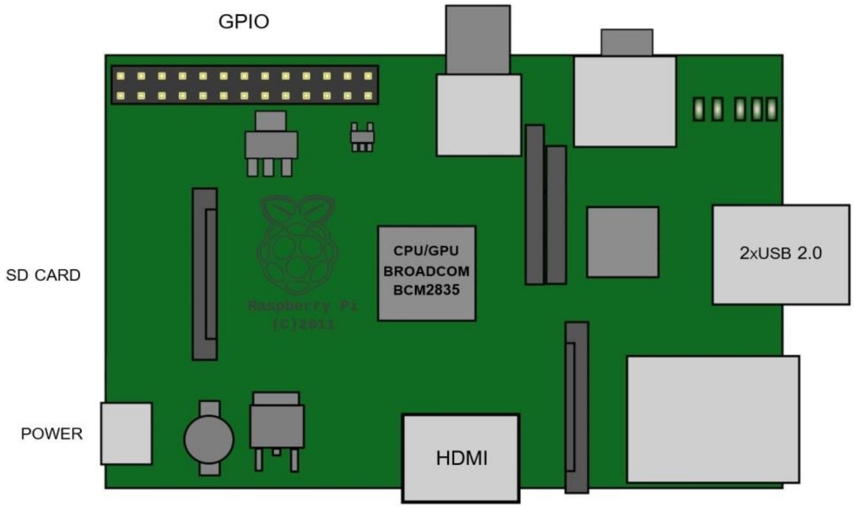


Fig. 4 Raspberry Pi Model B

7. The wireless data transmission devices

The ZigBee standard network is a low-cost, low-power, wireless mesh network. ZigBee operates in the industrial, scientific and medical (ISM) license-free radio bands: 868 MHz in Europe, 915 MHz in the USA and Australia and 2.4 GHz in most jurisdictions worldwide. Data transmission rates vary from 20 kilobits/second in the 868 MHz frequency band to 250 kilobits/second in the 2.4 GHz frequency band. ZigBee networks are secured by 128-bit symmetric encryption keys. Its transmission distances range from 10 to 100 meters line-of-sight, depending on power output and environmental characteristics. In order to have a longer range, an external radio power amplifier can be adopted with ZigBee compliant transceiver. However, for the case study, the maximum range is enough since the distance between a locomotive and wagon, or between two successive wagons, is not higher than 25 meters. There are many ZigBee compliant transceivers and protocol stacks offered by different companies, which can implement the ZigBee network. The chosen device for the project is the GBAN GB-RFTO, based on CC2530 SoC (CC2530 Software Examples User’s Guide 2011) that enables robust network nodes to be built with very low total bill-of-material costs. The CC2530 has various operating modes, making it highly suited for systems where ultralow power consumption is required, and short transition times between operating modes ensure low energy consumption.

8. Experimental results

The field tests reported in this section cover the area around the urban canyon of Pavia (Italy) in order to ensure the positioning accuracy of the adopted system and the transmitted data integrity.

The tracking unit is placed inside a car to reply the train motion profile and the entire system is supplied directly from the power supply of the vehicle. The NMEA sentences are stored in the SD card inside the data collector (Raspberry Pi) and they are compared with a reference track from Google Earth, as shown in Figs. 5(a) and 5(b).

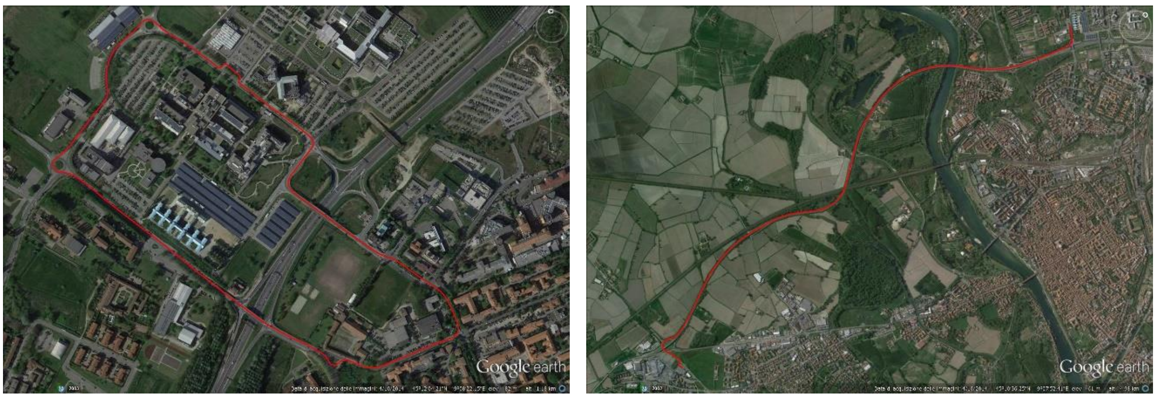
A wide experimental campaign is carried out in order to validate the positioning and data collection capabilities of the entire system. In particular: (i) the position accuracy is checked thanks to the comparison between the two tracking systems, (ii) the correctness of the message transmitted is obtained by the percentage of corrupted NMEA sentences for defined paths, and (iii) the robustness is verified providing positioning data within critical areas identified in Google Earth by plotting the tracking paths.

9. Conclusions

This contribution drives the reader across the selection path followed by the authors to achieve a preliminary solution for a low-power wireless communication network able to survive 24 hour without power sources and internet facilities. The task was carried out within the European FP7 Spartacus project. Mainly one adopts the ZigBee-based technology, i.e., CC2530 SoC transceiver and Z-Stack. More or less likely scenarios are addressed through the detailed study of communications protocols and reception systems to implement several functions, such as saving collected data that allow (one to set up) the data post-processing. The signal encryption for security motivations is a non-minor aspect of the design process.

Acknowledgments

The authors gratefully acknowledge the financial support provided by the Research Project (SPARTACUS - 313002) grant.



(a) Field test for urban environment (b) Field test for extra-urban environment

Fig. 5 Satellite images of the area under study

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