Measurement 57 (2014) 1–14

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

# Prototype design and experimental evaluation of wireless measurement nodes for road safety

Pasquale Daponte, Luca De Vito, Francesco Picariello, Sergio Rapuano, Ioan Tudosa *

*Department of Engineering, Laboratory of Signal and Measurement Information Processing, University of Sannio, Piazza Roma 82100, Benevento, Italy*

ARTICLE INFO

*Article history:*
Received 3 February 2014
Received in revised form 11 June 2014
Accepted 17 July 2014
Available online 30 July 2014

*Keywords:*
Speed measurement
Distance measurement
Traffic information system
Embedded systems
Wireless sensor networks

ABSTRACT

The paper presents the design and the experimental evaluation of prototypes of measurement nodes that are part of the Wireless Active Guardrail System (WAGS). The WAGS is an innovative infrastructure, allowing increasing traffic safety on roads, by monitoring vehicle speed, proximity between vehicle and guardrail, impact of a vehicle with the guardrail, and several environmental parameters. In particular, in this paper, the designs and prototypes of the nodes dealing with speed and proximity measurements are presented. Then, all the phases of their experimental evaluation are reported and discussed.



## 1. Introduction

Although safe road traffic is a goal of governments and civil society all over the world [1], nearly 3400 people die on the world's roads every day [2]. Tens of millions of people are injured or disabled every year [2]. The speed of vehicles represents one of the basic risk factors in traffic safety, and therefore, the accidents (e.g. vehicle crashes, vehicle impacts with guardrails) depend by several factors [3]. For example, it is known that if the driven speed gets higher, the crash rate increases, and to this aim, a variety of countermeasures (e.g. by using remote and distributed measurement/actuating systems) should be taken into account.

In order to face this challenge, one of the main objectives is to improve the road infrastructure, such that it can have a protective role in preventing accidents. With the growth of technological development of the embedded systems, since past two decades, it was possible to implement and deploy the concept of Intelligent Transportation System (ITS) [3]. Due to the minimization of size and low power consumption of modern sensor technologies, it was possible to create new sensing systems which can be mounted among the roads in order to monitor them. Nowadays, different types of measurement systems, such as for: vehicle speed, traffic jam and air pollution, are available on roads as part of ITS. They are mounted by using additional mechanical structure elements or directly in road pavement, and an important observation, they are far spread from each other (e.g. as range, between hundreds of meters or kilometers) [3].

In this framework, a novel idea, consisting of a Wireless Sensor/Actuator Networks (WSANs or simply WSNs) for traffic safety has been proposed in the project called "*Design and prototyping of a new barrier based on an innovative concept of safety combining structural function (passive function) and active function*" [4]. The idea consists of designing an active infrastructure, embedded on the road guardrails, which is capable of monitoring the traffic on the road, the road conditions, and to take some actions directed to the prevention of collisions between vehicles

* Corresponding author.
*E-mail addresses:* daponte@unisannio.it (P. Daponte), devito@unisannio.it (L. De Vito), fpicariello@unisannio.it (F. Picariello), rapuano@unisannio.it (S. Rapuano), ioan.tudosa@unisannio.it (I. Tudosa).

http://dx.doi.org/10.1016/j.measurement.2014.07.005
0263-2241/

and guardrails, and to promptly alert an emergency system when an accident has happened.

This active infrastructure, called Wireless Active Guardrail System (WAGS), has been presented in [5,6]. In [6–9], two node architectures for traffic safety measurements and their roles have been described. Such nodes have been designed to measure: (i) the vehicle speed, (ii) the proximity between vehicle and guardrail, and (iii) the acceleration of the guardrail parts, subjected to an impact with a vehicle. In [7] a mathematical model for the measurement uncertainty, for each traffic safety measurement, has been presented. Finally, in [8], a preliminary work about laboratory characterizations of the developed speed and proximity measurement systems has been reported.

This paper aims of presenting and discussing the prototype design and the experimental evaluation of the developed speed and the proximity measurement systems. Laboratory tests and on field tests have been carried out, in order to assess the accuracy of the designed measurement systems and their actual applicability on the road infrastructure. The obtained results show that the proposed speed and proximity measurement systems can be suitable for a practical use, inside the WAGS.

After the introductory section, the paper is organized as it follows. In Section 2, an overall overview of the WAGS architecture is given. Then, in Section 3, the prototype design of the speed and proximity measurement systems is reported and discussed. The metrological characterization of the speed and proximity measurement system is presented in Section 4. The laboratory and on-field experimental investigation phases are described in Section 5. Finally, in the last Section, several conclusions are drawn.

## 2. The WAGS architecture

The overall architecture of the WAGS is shown in Fig. 1. It is mainly composed by a Wireless Sensor and Actuator Network (WSAN), with the aims of monitoring the road and detecting the impacts between the vehicle and the guardrail. The WSAN has a hierarchical structure, where a set of gateways are in charge of managing a sub-network of WSAN nodes, collecting data from such sub-network and delivering them to a Server, where they are stored and presented through a Monitoring Service System (MSS). Each sub-network operates with a mesh topology, where each WSAN node performs both the measurement and routing tasks.

Three types of nodes have been foreseen in each sub-network:

- The *traffic safety nodes* can contain: (i) a speed measurement system, providing measurements of vehicle speed in the point of the road where it is placed, (ii) a proximity measurement system, measuring the distance of the vehicle and the guardrail plate, (iii) an impact detection system, revealing a crash of a vehicle with the guardrail, and (iv) a signaling actuation, consisting of a light or acoustic system, which are in charge of alerting the driver if the car is going too close to the road limits or that an accident has happened further on the road. In the case a vehicle is approaching to the guardrail closer than a specified threshold, the traffic safety nodes noticing such information will communicate with the following nodes of the sub-network, which will activate the light or acoustic signaling. Such feature is useful when a driver is distracted or is suddenly falling asleep. Instead, when an accident happens, it is sensed by the traffic safety node closest to the accident place, and it is forwarded to the Server, through the gateway of the sub-network, in order to alert the road rescue, and to the previous nodes in the sub-network, which can in this way alert the upcoming vehicles' drivers, by light or acoustic signaling.
- The *environment monitoring nodes* are in charge of measuring environmental parameters which are related either to: (i) the environmental conditions, like temperature and humidity, and (ii) to the environmental pollution, such as the concentrations of harmful gases produced by road vehicles, such as carbon monoxide (CO), nitrogen dioxide ($NO_2$), sulfur dioxide ($SO_2$), and the concentrations of Particulate Matter (PM).
- The *gateway nodes* are in charge of coordinating a sub-network of other nodes, collecting data from the sub-network and delivering them to the upper levels of the WAGS.

When the WSAN nodes are deployed into a WAGS, in order to assure an adequate signal strength for the data transmission and quantities sensing, an optimal node placement should be taken into account. For example, in case of a highway, the placement range of the traffic safety WSAN nodes, depending on the sensed quantities, could be between 4 and 25 m, the environmental WSAN nodes in the range between 50 and 100 m. The gateway nodes can be placed at a mutual distance around of 500 m, depending on the used wireless communication technology. A slightly different type of WAGS architecture could be installed on classical roads, tunnels and bridges. In case of tunnels, several parameters like: the air quality, light conditions, temperature, humidity, the number of cars that pass at one moment of time that tunnel, and the prevention of an imminent collision with guardrail, can be monitored continuously [4].

As wireless communication links between WSAN nodes and between gateways nodes, the IEEE 802.15.4 standard was adopted allowing the usage of IPv6 (Internet Protocol version 6) based communication [4]. Currently, there are many standards and proprietary protocols for wireless telecommunications which uses the media-access controller (MAC) and the physical layer circuitry (PHY) accompanying the IEEE 802.15.4 radios. For example, a protocol like ZigBee uses its own arrangements of data packets to transfer information between wireless nodes, but does not use the Internet Protocol (IP) [10]. The IPv6 over Low power Wireless Personal Area Networks (6LoWPAN) telecommunication standard may be used as an alternative to ZigBee since it employs the IPv6 protocol and it can operate equally over IEEE 802.15.4 wireless connections. With a view to face with all challenges imposed by the sensing needs, flexible and modular hardware architecture of the