Prototype Design and Continuous Monitoring for Bridge Safety by using IOT

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***Abstract*—This paper describe a proposal for an Internet-of-Things (IoT) based measurement system for remote monitoring of bridges, which aims to record: (i) the impact of vehicles with bridge guardrails, (ii) several environmental parameters, (iii) the expansion of structural joints, and (iv) the traffic load and dynamic weighing. All of these data are collected by a gateway and send to an Internet connected Server for real time processing of the received information. The adopted sensors and measurement systems are Commercial off-the-Shelf (COTS) available and their choice is described. A discussion of the sensing limits of each measurement system is also presented.**

Keywords—Sensors, Instrumentation, Internet-of-Things, Remote Measurements, Structural Health Monitoring.

I. INTRODUCTION

Currently, a bridge play an important part in the transportation infrastructure which is widely used for the development of social and economic activities of a country [1]. For example, Italy has a lot of long-span bridges used in both ruttier and railway transportation, which require regular monitoring and maintenance. Novel systems, such as those using IoT technology, could be adopted in order to monitor the state of health of the bridges in real-time by a centralized traffic management [1], [2]. A lot of these bridges are located in a remote area (e.g. outside of localities) therefore a difficulty in collection of data is present. In literature, survey ideas regarding the development and assessment of measurement systems for Structural Health Monitoring (SHM) are presented [3]. Moreover, SHM systems which are based on a Wireless Sensor Network (WSN) are presented in [4], [5]. Measurement systems for Intelligent Traffic System (ITS) deployment which are basically used for vehicular traffic monitoring are reported in [6]. Although, in particular, an integrated management system relying specially for remote monitoring of bridges is not available on the market. This is mainly due to the fact that each bridge has its peculiarity on the infrastructure role and this aspect requires customization during commissioning procedure.

Keeping in mind, in this paper, the ideation of a novel IoT based system, which can be utilized for monitoring several their performance/cost per 1km.

ong-span bridges located on remote areas, by means of a single base station with complete wired/wireless considerations, including energy efficiency, is presented. The rest of the paper is organized as follows. In Section II, a brief overview of remote sensing by means of IoT technology for traffic safety and infrastructure monitoring is mentioned. The proposed IoT system is shortly mentioned in Section III. The associated sensors and measurement systems are briefly explained in Section IV. Last Section of the paper presents the conclusions and future work.

II. REMOTE SENSING BY IOT

According to the existing scientific literature, IoT devices are being used as smart, reliable, and low-cost technologies that may be used for measurement/actuation tasks [6]. Thus, for ITS systems, in order to fit into the emerging IoT paradigm, they must attach to inherent requirements which are typically compel by the: (i) available resources for data processing,
(ii) memory, (iii) power consumption, and (iv) not least, their security. The adopted IoT devices for ITS embeds sensors at least used for the following sensing/actuation categories, such as for: (i) safety, (ii) diagnostic, (iii) traffic, (iv) assistance,(v) environment, (vi) user. The safety sensors are used for sensing and observing accident hazards and unusual traffic events almost in real-time. Data collecting in real-time for providing information about the status of the roads/highways is done by using diagnostic sensors. Traffic management is performed in order to monitor the traffic conditions in specific zones by using traffic monitoring sensors.Assistance is done by real-time support by using data collecting from centralized control system which aims to provide technical support for the road/highways users. One of the most important aspect is related to the monitoring of environmental conditions along the road/highway side which can offer to drivers alerts/warnings services that could help/enhance the trips. Not least, in case of commercial road/highway users, data collecting from the
In [3] section the authors mentioned the design and the the importance of measurement uncertainty evaluation (i.e.experimental evaluation of WSN prototypes for measuring that are part of the Wireless Active Guardrail System (WAGS). The WAGS represents an innovative WSN for ITS, infrastructure, allowing increasing traffic safety on roads, by monitoring: (i) vehicle speed, (ii) proximity between vehicle and guardrail,
(iii) impact of a vehicle with the guardrail, and (iv) several

environmental parameters. In particular, in [3], the authors have mentioned their solution for the adopted designs of WSN prototypes for dealing with speed and proximity measure-ments. Moreover, in [7] - [12] the authors have been presented the analysis of the uncertainties of the measurements for the proposed traffic safety WSN measurement nodes. Thus, the measurements are analysed by means of a network of wireless sensors mounted on a road/highway guardrail. The considered traffic safety measurements were: (i) vehicle speed, (ii) vehicle

proximity to guardrail, and (iii) detection of vehicle impacts on the guardrail, where for each measurement type, (i) the description of the measurand, (ii) the measurement method and

the adopted sensors, and (iii) the evaluation of measurement uncertainties, were reported.

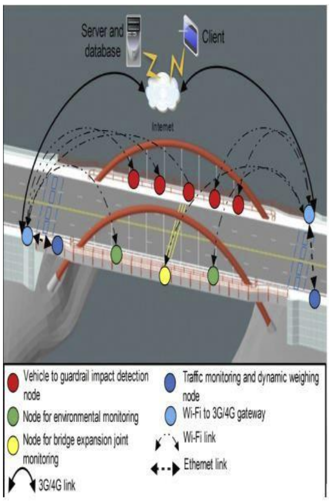

Fig. 1. The general architecture for remote monitoring of bridges.

In [11] the authors have mentioned the architecture of a WSN node for observing the concentration of carbon monoxide (CO), sulfur dioxide (SO2), nitrogen dioxide (NO2) and particulate matter (PM) environmental sensors. These nodes are aimed to be installed to estimate the air pollution on roads, highways, tunnel or bridges. A complete network of WSNs nodes for ITS using the measurement nodes presented in [3] and in [11] was mentioned in [10] and in [12]. Herein,[13], [14]) for the developed WSN node prototypes [7], [9], [11] is depending on prior enhancement of measurement signalquality, such as demonstrated in [15], [16].

Today, with the increase of microcontroller's processing capabilities, all these tasks for digital signal filtering and quality improvement became a must prior the evaluation of a measurement result. Moreover, regarding the security issues for remote communication of IoT devices for ITS infrastruc-ture, recently, several research directions are coming out on:(i) enhancing the wireline based secure communication [17], (ii) Radio Frequency (RF) spectrum allocation for autonomous vehicles [18], (iii) RF spectrum sensing technologies [19], and(iv) energy harvesting [20].We reach at a conclusion that, according to the surveyed literature, it can be observed the fact that the era of Internet of Things (IoT), however, is redefining the objectives and standards of remote monitoring systems.

III. THE PROPOSED IOT SYSTEM

The basic architecture of the proposed IoT system for remote monitoring of bridges is mentioned in Fig. 1. It consists of: (i) a sensing node for vehicle to guardrail impact detection, (ii) a sensing node for environmental monitoring, (iii) a sensing node for bridge expansion joint monitoring, (iv) a sensing node for traffic monitoring and dynamic weighing, and (v) a Wi-Fi to cellular communication gateway.

The sensing node for vehicle to guardrail impact de-tection aims to classify the impact in three typologies low, medium and high according to the acceleration magnitude due to the impact. Moreover, when an impact happen, it sends to the gateway an alert, via Wi-Fi, with the information related to the impact strength level. Those nodes are placed on the guardrail poles along the bridge.

The sensing node for environmental monitoring aims to measure: (i) the ambient temperature, (ii) the ambient relative humidity, (iii) the atmospheric pressure, and (iv) both speed and direction of the wind. Environmental sends the values associated to the measured quantities, periodically, to the gateway via Wi-Fi. The sampling period can be set by the system advisor. This node is placed on a mechanical support at the roadside. The aim of the sensing node to measure: (i) the displacement variations of the expansion joint, (ii) the tem-perature and relative humidity variations inside the joint, and (iii) the vibration level acting on the joint. The temperature and relative humidity measurements are sent periodically, according to the sampling frequency set by the system advisor.On the other hand, an asynchronous alert is sent if the displacement variations of the expansion joint are higher than a safety threshold value. This node is placed in the expansion joint area.

The aim of sensing node in bridge expansion joint monitoring are: (i) to measure the the speed of vehicles crossing the bridge, (ii) to count the number of vehicle that are crossing the bridge, (iii) to classify the vehicles crossing node for impact detection. At the exit size of bridge, the sensing node for environmental monitoring is on a support at the roadside.

In the following Subsections, a detailed description of the WSN nodes mentioned within the herein smart bridge prototype is provided.

A. The WSN node for environmental monitoring The sensing node for environmental monitoring consists of (see Fig. 3): (i) the Waspmote platform [23], (ii) the WS- 3000 weather station [24], (iii) the BME280 sensor [25], which embed on chip, a temperature, relative humidity and

atmospheric pressure sensors, and (iv) the Wi-Fi Pro interface [26]. In this specific, the Waspmote platform embeds the at mega1281 microcontroller working at the clock freqeuncy of 14.74MHz. Furthermore, an SD card of 16 GB for storing locally the acquired data is available. It has 7 analog inputs, 8 General Purpose Input Output (GPIO) pins, 2 Universal Asyn-chronous Receiver Transmitter (UART) interfaces, 1 Inter-Integrated Circuit (I2C), and an Universal Serial Bus (USB) communication interface.

The weather station WS-3000 consists of three different sensors: (i) a wind vane, (ii) an anemometer and (iii) a pluviometer. The wind vane consists of a basement that turns the road according to the number of vehicle axles, and (iv) to measure the weight of a vehicle crossing the bridge. In particular, if the weight of a vehicle exceed the weight limit for the specific bridge an alert is sent to the system advisor. Furthermore, all the measurements are sent to the gateway, periodically.The sensing part of the node is on the road surface, the data acquisition system is placed on a support at the roadside. For each bridge, the number of nodes for traffic monitoring and dynamic weighing is two, one placed at the entrance and the other at the bridge exit.

The function of gateway is to collects the data provided by the nodes and send them to the Server via Internet by means of a cellular (e.g. 3G/4G) communication interface. The gateway is placed on a support at the roadside, according to the covering area of the Wi-Fi network. The function of Server is to store the acquired data in a database. A client or the system advisor interface with the Server via Internet to get the stored information. All the nodes are powered by photovoltaic panels.

IV. SENSORS AND MEASUREMENT SYSTEMS

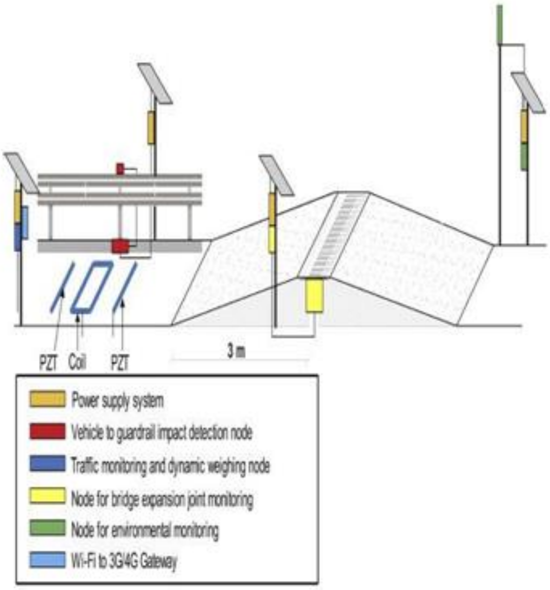

Fig. 2. The architectural overview of the first prototype of the proposed IoT system.

A prototype architecture, implementing the IoT system mentioned in the previous section, is depicted in Fig. 2. In particular, in this case an emulated one-way bridge is constructed with a single expansion joint. A single sensing node for traffic monitoring and dynamic weighing is placed at the beginning of the bridge. Moreover, at the bridge entrance, a guardrail is placed on the roadside, which embeds a sensing freely on a platform. The platform is made by a net of eight resistances that are connected to eight switches that allows to distinguish up to 16 different positions, with a resolution of 22.5°. The eight resistance combine form a voltage divider, thus the voltage divider output is proportional to the basement orientation. The anemometer embedded on the weather station provides a square wave output with a frequency proportional to the wind speed. In this specific, it consists of a reed switch normally open that close for a short time duration when the anemometer cover an arch angle of 180°. The sensitivity of the anemometer is 2.4km/h per turn and its speed range from 0km/h up to 240km/h.

The BME280 is a temperature, relative humidity and pressure sensor. The temperature sensor exhibits a measurement range from 0 deg c up to 65 deg C, with an accuracy of ±1 deg C. The relative humidity sensor has a measurement range from 0% up to 100% with an accuracy less than ±3%. The pressure sensor has a measurement range from 30 kPa up to 110 kPa. The measurement provided by the BME280 are sent to the host microcontroller via I2C interface. The microcontroller deliverd the acquired samples to the gateway via Wi-Fi by means of Wi-Fi Pro module. In particular, the Wi-Fi Pro module communicates with the microcontroller through to the UART interface. The power consumption in transmission is 350mA and in reception is 130mA.

B. The WSN node for detecting the vehicle-guardrail impacts

The architecture of the sensing node for detecting vehicle-guardrail impacts is depicted in Fig. 4. It consists of: (i) the Waspmote platform [23], as for the node for environmental monitoring, (ii) the current loop probe, (iii) a three-axis accelerometer, and (iv) the Wi-Fi Pro module [26].

The adopted three-axis accelerometer is the IAC-HiRes-I-03-400g by Micromega Dynamics [27], which pro-vides three output currents ranging from 4mA to 20mA according to the acceleration measured on each axis. The measurement range of the accelerometer is 400 g with a 3 dB cut-off frequency of 4 kHz and its sensitivity is 20 A/g.

The current values are converted in voltage values by means of the current loop probe [27]. The current loop probe provides the power supply to the sensor and converts the current in a voltage drop by means of a resistor. The three voltage drops provided by the current loop probe are acquired on three input channels of the Analog-to-Digital Converter (ADC) embedded on the microcontroller. Based on the voltage values acquired by the microcontroller, which refers to the accelerations along the three axes, the magnitude of the acceleration and its direction are evaluated. The acceleration magnitude is compared with two threshold values. If the measured acceleration is lower than the first threshold value, no alert message is sent to the gateway. If the acceleration is within the interval defined by the two threshold values, an alert message is sent to the gateway, containing the acceleration value, the acceleration direction and a label that contains the type of impact, in that case low impact. On the other hand, if the measured acceleration value is higher than the second threshold value, an alert message labelled as high impact is sent to the gateway.

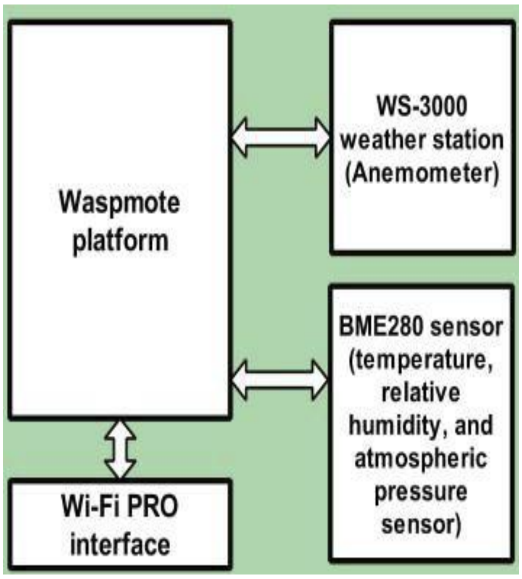

Fig. 3. The architecture of the WSN node for the environmental monitoring.

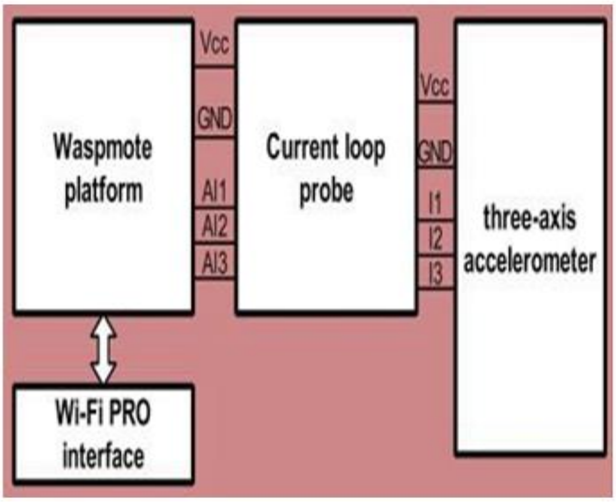

Fig. 4. The architecture of the WSN node for detecting the vehicle-guardrail impacts.

C. The WSN node for bridge expansion joint monitoring The sensing node used for bridge expansion joint monitoring (see Fig. 6) consists of: (i) the Waspmote platform [23], which embeds a low-range three-axis accelerometer, (ii) two temperature and relative humidity sensors, (iii) a LinearVariable Displacement Transformer (LVDT) with a current loop probe, and (iv) the Wi-Fi Pro module [26].The three-axis accelerometer LIS3331LDH by STMi-croelectronics [28], which is embedded on the Waspmote platform, is used for measuring the vibration acting on the joint during its normal working. The accelerometer communicates with the microcontroller via I2C interface. which provides a maximum measurement range of ±8 g with a maximum data rate of 1 kHz. The temperature and relative humidity sensor is the Decagon VP-4 [29], it communicates with the micro-controller by means of the SDI-12 (Serial Digital Interface working with a baud rate of 1200 Hz). The temperature sensor has a measurement range of 40 C to 80 C, with a accuracy of0.1 C. The relative humidity sensor exhibits a measurement accuracy of 0.1% for the measurement range from 0% up to100%.The LVDT LD630-100 used by Omega [30] is used for measuring the displacement up to 10 cm due to the movements of the bridge beams. It provides an output current from 4mA up to 20mA, with an accuracy of 0.02%, proportional to the displacements. Moreover, the 3 dB cut-off frequency of the sensor is 500 Hz.The current output is converted intoa voltage by means of the current loop probe, and then it is connected to an analog input of the microcontroller. The microcontroller continuously acquires the displacement measurements provided by the LVDT sensor and stores them in the local memory. The displacement measurements are compared with a threshold value, which identifies when analert message should be sent to the gateway due to a dangerous enlargement of the distance between the two bridge beams.

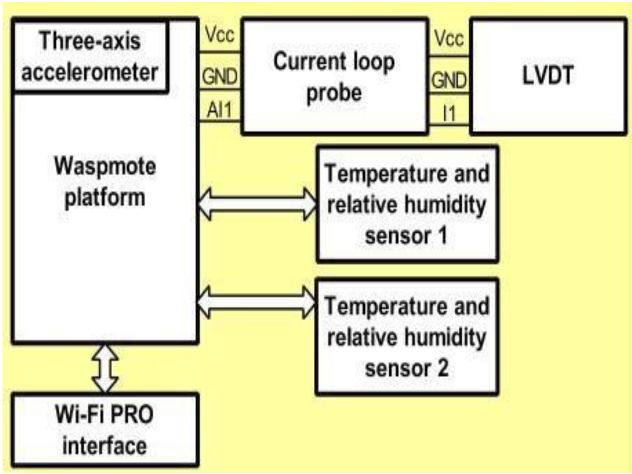

Fig. 5. The architecture of the WSN node for detecting the vehicle-guardrail impacts.

Fig. 6. Scenario for vehicular traffic monitoring and dynamic weigh-in-motion measurements, [31].

D. The WSN node for vehicular traffic monitoring and dynamic weighing The HI-TRAC TMU4 [31] is a traffic monitoring and dynamic weighing system that provides (see Fig.): (i) weight in motion measurements of the vehicles that cross the road, (ii) counting and vehicle classification, and (iii) vehicle speed measurements. It consists of two piezoelectric sensors and an inductive loop sensor placed into the road structure. The piezoelectric sensors provide a voltage proportional to the weight of the vehicle crossing the road. This voltage is acquired and the weight of the crossing vehicle estimated. Furthermore, the speed of the vehicle is estimated by measuring the delay between two peaks of the piezoelectric signals.

The inductive loop sensor is used for vehicle counting. The measurement range of the vehicle speed is from 1km/h up to 240km/h with a measurement accuracy of ±1.5%. The weight in motion measurements exhibit an accuracy of ±5% for the measurement range up to 44 000 kg. Furthermore, the system is able to identify the following vehicles: (i) motorbike with a classification accuracy higher than 95%, (ii) cars/vans at the 97%, (iii) articulated Heavy Goods Vehicle (HGV) at the 99%, and (iv) buses and coaches at the 97%.

V. CONCLUSION AND FUTURE WORK

In this paper, a sketch of an IoT based measurement system for remote monitoring of bridges has been presented. Moreover, the general architecture together with its technical implementation are explained. The adopted measurement systems are designed in order to be easy for embedding them into the proposed IoT system.

The main challenge remain how to produce the optimal design of the entire power supply system (see Fig.2) which should guarantee the working functionality of all the proposed WSN nodes.

Based on the implementation of the proposed IoT based measurement system for remote monitoring of bridges, future work will be focused on the deployment and testing on site the measurement WSN nodes.

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