Augmented Information Discovery using NFC Technology within a Platform for Disaster Monitoring

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***Abstract* - Catastrophic and accidental natural events (e.g., earthquakes, sudden floods, fires, etc.) and deficiencies in appropriate management activities require proper plans for disaster management and real-time definition of safe paths and escape routes. Emergencies can affect the structural health status of structures and infrastructures and, consequently, the safety in highly populated areas (e.g., urban contexts, occasional assembly points for crowds, theme parks, etc.) is compromised. Consequently, the use of a decision platform for the management of structures and infrastructures, which is able to gather real-time data from sensors and provide alerts and augmented information about safe paths, paves the way to the adoption of a proactive form of risk management. In this work, objectives were confined into the validation of a Near-Field Communication (NFC) system. Data coming from user smartphones using the NFC technology and sensor data deriving from the decision platform were used as input in a Machine Learning (ML) algorithm. Results show that the ML algorithm mentioned above is able to refine the safe path recognition strategy defined from the platform. In addition, the bidirectional and touch less NFC technology allows the delivery of alerts and disaster plan dissemination, also in the case of connectivity shutdown.**

Keywords - NFC technology, augmented information discovery; disaster monitoring; wireless sensors network; self-powered device.

I. Introduction

Catastrophic and accidental natural events (e.g., earthquakes, sudden floods, fires, etc.), and poor management activities, affect the structural health status of structures and infrastructures. Consequently, the safety in highly populated areas (e.g., urban contexts, occasional assembly points for crowds, theme parks, etc.) is compromised. If Information and Communication Technologies (ICT) infrastructures (based on internet of things, IoT, Artificial Intelligence, AI, and Big Data applications), are included in the emerging "Smart City" urban development approach, environmental benefits and future city sustainability and resilience will be effectively improved [1], [2]. In addition, if disaster management is carried out integrating artificial and human intelligence (e.g., applying the Disaster City Digital Twin paradigm; cf. [3]), the efficiency of real-time monitoring (using remote and social sensing), data analytics (aiming at visualizing human activities, damages, and relief needs across time and space), and scenario simulations (for training and planning purposes, and for various and fair allocation of resources) will be significantly improved. Subsequently, a proper information sharing among different systems and stakeholders will positively affect disaster management stages, such as disaster response, recovery, preparedness and risk reduction [4].

In order to face the problems above, Internet of Things Wireless Sensor Network (IoT-WSN) can be exploited. Noteworthy examples used to improve the emergency and disaster information management include 1) A WSN-IoT based on smart fire sensors, cameras, and a Convolutional Neural Network (CNN), acting as surveillance monitoring system for detecting disasters that occur in the remote area (e.g., a forest) [5]. 2) A WSN-IoT based on machine learning algorithms that run in a cloud server and includes a modular redundancy fault tolerant scheme to obtain accurate prediction from sensor data (gas and force sensors) managed by the ultra-low power MSP430 board and a Raspberry Pi, which was designed for early warning in industry environment [6]. 3) A WSN-IoT that uses the Advanced Adaptive Wavelet Sampling Algorithm

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(AAWSA) for prolonging lifetime and power consumption of sensor nodes that include several sensors (i.e., moisture sensors, pressure sensors, rain gauges, tilt metres, and strain gauges), which was developed for disaster prediction in urban regions [7].

Another solution can be represented by platforms, such as 1) The DECATASTROPHIZE (a.k.a., DECAT) platform that aims at managing disasters or multiple and/or simultaneous natural and man-made hazards by mean of a Geospatial Early-warning Decision Support System (GE-DSS) that allows early warning, decision making, rapid mapping, impacts assessment and mitigation, and geospatial data/information dissemination [8]. 2) A web platform developed by the Emergency and Security Coordinating Centre to improve the decision making process of the Canary Islands' Authorities, which provides geographical and temporal incident distribution, and is able to forecast and classify incidents [9]. 3) A Building Information Modelling (BIM)-based platform that was designed for building fire emergency management in a dynamic way, i.e. using building users' behaviour decisions (e.g., escape, wait for rescue, and fire extinguishing), fire and users' position, which plans action routes and provides visual route guidance [10].

Other important and innovative examples of ICT solutions for emergency management refers to 1) Smartphone-based information systems [11]. 2) Mobile post-disaster management systems based on free and open source technologies [12]. 3) Satellite remote sensing for disaster management [13]. 4) Exploiting data from social media [14]. 5) Using deep learning to identify survivors in debris from images gathered by smart infrastructures [15].

A different solution to address the aforementioned issues is provided in this study, also including a bidirectional exchange of information between a platform and its users, i.e. using the Near-Field Communication (NFC) technology [16]–[19]. In fact, this radio frequency (RF)-based proximity coupling technology allows secure exchange of information (e.g. for payment or ticketing), even in the case of interruption of Internet connection.

In the light of the foregoing, in previous works [20]–[23], an innovative WSN-IoT platform was designed as a decision support tool for a Italian theme park. The following section (Section II) summarizes the main innovations of the innovative platform cited above, and describes how the platform uses sensor data to carry out the main objectives of this study, i.e., (1) to derive safe paths to reach an available exit or an assembly point, and (2) to deliver this information to the platform's users. Subsequently, Section III includes the main results of this study derived from simulations. Finally, the last two sections contain the conclusions derived from this study, some anticipation about future works, and references.

II. Architecture/Platform Description

A. *Hardware: an innovative WSN-IoT*

Figures 1 to 5 illustrate the architecture of the system. The IoT-WSN proposed in this paper consists of wireless sensor units, which are fed using a photovoltaic energy harvester. The harvesting system has been tested and dimensioned using a photovoltaic emulator [24].

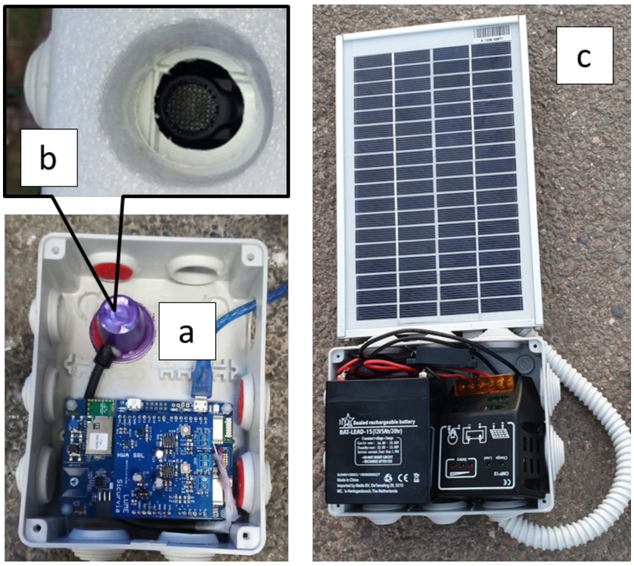


Fig. 1. Wireless sensor node: a) wireless sensor unit; b) additional microphone for structural monitoring; c) power supply unit.

Fig. 2. Example of wireless sensor units installed on (a) a masonry structure, (b) a light pole, and (c) a road pavement of the theme park.

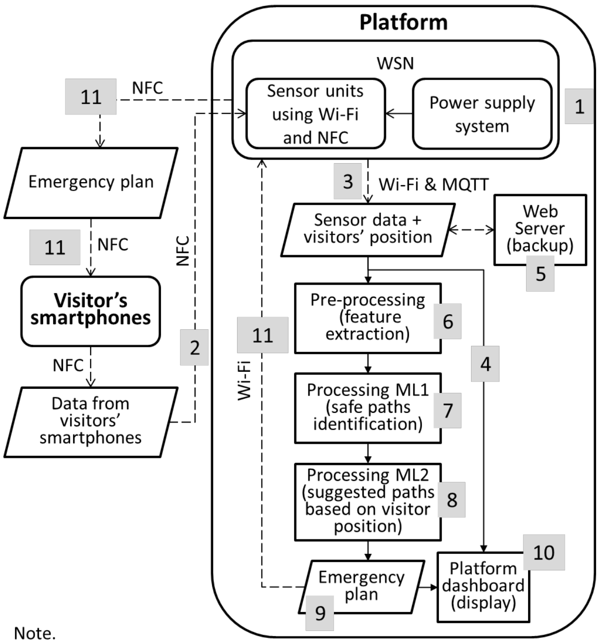
In more detail, Fig. 1a shows the wireless sensor unit. In the previous works cited above, an Arduino "LEONARDO" and a Raspberry Pi 3 (microcontroller boards) were used to gather data from several sensors and send these data wirelessly to a server, respectively. In the study presented in this paper, an evolution of the system mentioned above is presented. In particular, among the IoT solutions available on the market, an ultralow-power IoT board [25] (see Fig. 1a) was used to carry out both the above operations. The IoT board includes several Micro-Electro-Mechanical systems, MEMS, sensors (including one three dimensional, 3D, one accelerometer, one microphone, one temperature/humidity sensor, one magnetometer, and one barometer), and a microcontroller. The IoT board can transmit wirelessly the data gathered by the sensors, using different protocols, i.e., Wi-Fi, Bluetooth, and NFC allowing the transmission of data to the Cloud [26]. It important to underline that this latter protocol allows further applications, e.g., the interaction/exchange of information with the visitors of the theme park during normal and emergency conditions.

Note that, in order to carry out a more detailed monitoring, the IoT board was also equipped with a smoke sensor (to detect carbon monoxide, liquid petroleum gas, and smoke), a flame sensor, and an additional microphone. In more detail, Fig. 1b shows the bottom of the sensor unit box, where a hole allows the additional microphone to receive the vibro-acoustic response [27], [28] of the structure on which the unit is installed. Importantly, the microphone mentioned above is the core of the innovative monitoring method used by the platform. The additional microphone of the sensor unit should be able to receive the sounds that travel into the structure, and, for this reason, it is isolated from the airborne noise through a cover (inside the box) and isolating material (between the box and the structure).

Finally, Fig. 1c shows the photovoltaic panel (polycrystalline silicon, 5 W, 18 V) that, together with a recharge circuit (12 V, 20 A) and a battery (12 V, 12 Ah), was chosen as a power supply unit of the wireless sensor unit in Fig. 1a. Fig. 2 shows three wireless sensor nodes installed in different points of theme park, i.e., a masonry structure (historical military fort, see Fig. 2a), a light pole (see Fig. 2b), and a road pavement (see Fig. 2c).

B. *Software: The Proposed Platform*

The framework of the proposed platform is depicted in Fig. 3. In particular, the platform includes the WSN (described in the section above, see 1 in Fig. 3) and a procedure, consisting in several steps, which allows analysing the data collected by the WSN. Importantly, each sensor unit is associated to a given area and a given path. As mentioned above, the outputs of the platform are a useful indication for its users about the safe paths that allow reaching available exits or assembly points. The sensing nodes of the WSN gather data from the environment using their sensors, and detect the position of the visitor of the theme park exploiting the connection NFC/tag-smartphone (see 2 in Fig. 3). This information is sent (see 2 in Fig. 3), with adequate timing (e.g., every five minutes) and using the Wi-Fi protocol, to a local server for backup purposes (see 4 in Fig. 3), and to an open-source server-side platform (Thingsboard [29]) for controlling IoT devices and visualize the sensor data in real-time (see 4 in Fig. 3).



Note.
MQTT: Message Queuing Telemetry Transport. NFC: Near-Field Communication. WSN: Wireless Sensor Network. Wi-Fi: Wireless networking technologies.

Fig. 3. Framework of the proposed platform.

At the same time, the collected data (converted by the IoT board to text strings in JSON format) are sent to a web server using the MQTT protocol (e.g., the MQTT broker Eclipse Mosquitto™) for analysis purposes (see 5 in Fig. 3). Note that, sampling and data transmission frequencies are defined aiming at minimizing transmission cost, latency, network bandwidth and resource requirements, and at increasing data privacy and data transfer reliability.

The data stored in the web server can be accessed by an authorized customer of the platform (i.e., subscriber to a specific topic) for further analyses (see 5 in Fig. 3). First of all, the data are pre-processed in order to extract meaningful features (see 6 in Fig. 3) that can be represented by statistical indicators (e.g., maximum, minimum, average, root mean square, etc.). Secondly, after the extraction, raw data and features were used as input of a Machine Learning (ML) algorithm (ML1) for clustering purposes (see 7 in Fig. 3) using a Convolutional Neural Network (CNN), that is used to identify the alarm conditions associated to the sensor units of the WSN. Hence, the CNN returns all the possible combinations of alarms (31 permutations if 5 nodes are used), corresponding to a proper alarm state which is used, in a first instance, by the platform's dashboard to define an emergency plan. The emergency plan (see Figs. 4 and 5) indicates with a yellow triangle the point in which the alarm is active, and shows in green the safe paths, in red the unsafe paths, with a green arrow the available exits, with a red access denied signal the unavailable exit (closed), and with a green rectangular signal the assembly points. An additional ML algorithm (ML2, see 8 in Fig. 3) has been used in a CNN, also for clustering purposes, considering as input the alarm states and the number of the visitors of every node, acquired using NFC technology. The output of the algorithm are the classes that represent the suggested path for the visitors from node i to the point to be reached j (Exit or Assembly Point), taking into account the knowledge of the state of the structures and infrastructures that are inherited from the alarm states. Summarizing, the safest path is suggested, considering that the distribution of the visitors among the site could affect the speed of the flow to reach the available exit or, alternatively, the assembly points. All those information is updated in the platform dashboard (see 10 in Fig. 3).

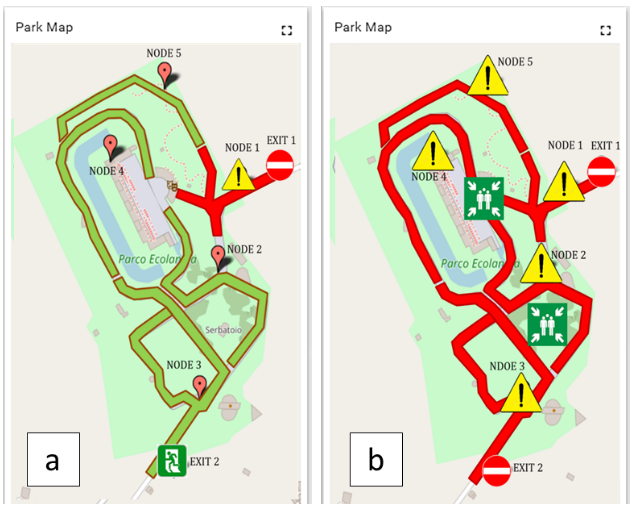


Fig. 4. Dashboard of the platform that shows (a) an active alarm at Node 1, and (b) alarms active in all nodes.

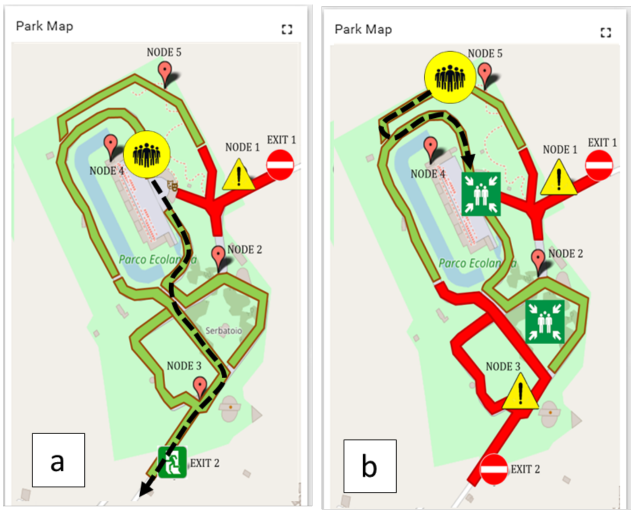


Fig. 5. Augmented information provided by NFC-smartphone connection based on the position of the user: a) Alarm at Node 1 and user at Node 4; b) Alarm at Nodes 1 and 3, and user at node 5.

Finally, considering the bi-directional communication feature, the NFC use is envisioned to provide useful information to the user (see 11 in Fig. 3). The nodes, in case of emergency and if a visitor of the theme park requires this information (i.e., placing the smartphone on the node closest to him), allow downloading (by the NFC tag) an emergency plan (as in Fig. 5) that shows visitor position, available exits (or assembly points), and the safest paths.

III. SIMULATIONS, RESULTS AND DISCUSSIONS

In this section the results derived from the simulations described above are reported. In the following paragraphs, the dataset generation, the description of the ML algorithms characteristics and the main results in term of model accuracy are reported.

A. Dataset ML1

The dataset for ML1 was created using a MATLAB script that generates, for each sensor, a suitable value in the range of operations using a random function with Gaussian distribution. Furthermore, some of the data is "faulted" to inject alarm conditions. The final matrix, which contains 32000 records of data (8 sensors for each of the 5 sensor nodes), has been randomized and standardized during the pre-processing task. The last column of the matrix represents, for each record, the labelled alarm condition.

B. Dataset ML2

As for ML1, the dataset for ML2 was created using a specific MATLAB script that "generates", for each alarm condition, a suitable value of visitors for each node using a random function with Gaussian distribution, in a proper range (max 100 visitors per node). The final matrix, which contains 32000 records of data (1 alarm condition, 1 visitor occupancy for each of the 5 sensor nodes), has been randomized and standardized during the pre-processing task. The last column of the matrix represents, for each record, the labelled suggested path for the visitors from node i to the point to be reached j (e.g. Exit) or Assembly Point).

C. ML1

The implemented ML solution implements a clustering algorithm in the form of a CNN with the following characteristics:

- Input size: 51
- Output size: 32
- Hidden layers: 55
- Batch size: 50

The optimizer function used is the Stochastic Gradient Descent (SGD), an iterative method for optimizing an objective function with suitable smoothness properties. The activation function used for hidden layers is the rectified linear unit (relu), the most commonly used activation function in neural networks, especially in CNNs. For the output layer, the softmax function was selected. Softmax takes as input a vector of K real numbers, and normalizes it into a probability distribution consisting of K probabilities proportional to the exponentials of the input numbers.

D. ML2

The solution for ML2 implements a clustering algorithm in the form of a CNN with the following characteristics:

- Input size: 7
- Output size: 11
- Hidden layers: 50
- Batch size: 50

The optimizer function used is SGD. The activation function used for hidden layers is relu, softmax for the output layer.

E. Results

ML1 and ML2 algorithms were tested using Keras, a deep learning library that allows for easy and fast prototyping.

The result for ML1, in term of test accuracy, is of 85%. While, ML2 provides a 63% test accuracy instead.

Furthermore, the results of the augmented information elapsed, e.g., the suggested path converted to a route map with enhanced safety information, is presented in Fig. 6 in the form of a smartphone screenshot.

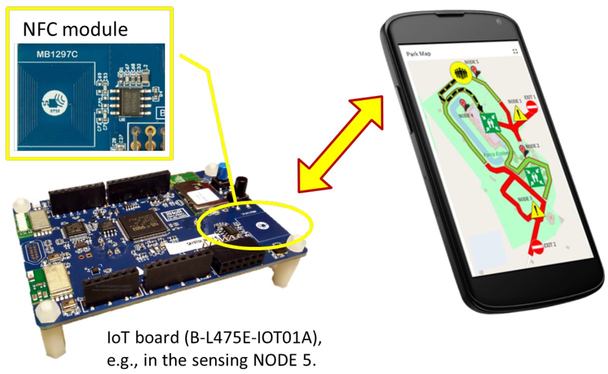


Fig. 6. Augmented information, based on the position of the user, provided by the NFC module-smartphone connection in the form of a smartphone screenshot.

Fig. 6 shows the IoT board used in this study, which is the core of the sensing node of the WSN described above. The figure above shows also a detail of the NFC module included in the aforementioned IoT board, which allows exchanging (within 10 cm) augmented information with users' smartphones. Note that, in the real application, the IoT board is enclosed in a plastic box, which does not limit the data transmission performances, and was not shown in Fig. 6 just to improve the illustration.

The envisioned application is powerful also in the case of network communication interruption, as the ML algorithms can be implemented in low computational and standalone devices as microcontrollers.

IV. CONCLUSIONS

In this study, a platform consisting of a system and algorithms that allow environmental and structural monitoring and emergency management is presented. Using two powerful ML algorithms, fed with simulated datasets, useful information is gathered from sensors (environmental and structure related) and, using NFC technology (number and location of visitors), to obtain alarm detection and safe path suggestion for users. Furthermore, the NFC technology allows the dispatch of the elapsed information to users that interact with sensor nodes disseminated within the monitored area. Raw and elapsed data are sent to a platform dashboard for online monitoring of environmental and structural conditions as well. Future works will include the obtaining of datasets with real data, the use of safe and minimum path algorithms for performance comparison, and the implementation on low computational devices as microcontrollers, which are powerful also in the case of network communication interruption because do not require remote data exchange.

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