An Internet of Sport Architecture Based on Emerging Enabling Technologies

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***Abstract*— Sports and recreational activities provide an interesting domain of research that includes several of the critical challenges for next generation of services. The adoption of emerging Internet of Things technologies into the field of sport could significantly improve the sport experience and also the safety level of team sports. To this purpose, this paper presents a novel Sport System based on the jointly use of different technologies, such as RFID, WSN, Cloud, and mobile. It is able to collect, in real time, both environmental parameters and players' physiological data via an ultra-low-power Hybrid Sensing Network (HSN) composed of 6LoWPAN nodes integrating UHF RFID functionalities. Sensed data are delivered to a Cloud platform where a monitoring application makes them easily accessible via REST Web Services. A simple proof of concept has demonstrated the appropriateness of the proposed system. This work represents a first real attempt to demonstrate the benefits introduced by the use of IoT technologies in sport environments.**

***Index Terms*—Internet of Things; Sport; Cloud; Wireless Sensor Network; mobile.**

I. INTRODUCTION

Recent advances in the design of Internet of Things (IoT) technologies are spurring the development of smart systems in many different domains, such as home and industrial automation, healthcare and wellness, smart grids, automotive, and many others [1]. Among these, sports and recreational activities represent two of the most rapidly growing areas for the adoption of IoT-technologies. They provide an interesting domain of research that includes several of the critical challenges for next generation of services in a variety of scenarios, such as health and rehabilitation.

In particular, football is one of the most popular sports in the world [2]. FIFA, the organization responsible for developing and improving the quality of football, has recently introduced many innovations, such as Goal Line Technology (GLT), which have improved the game experience. FIFA is also seeking to make football a healthy sport, through the definition of anti-doping regulations [3], and nutrition rules for football players [4]. Several researches about the frequency and nature of injuries, which occur during matches and training times [5], have been performed in the last years. Concussion, hypoglycemia, heartbeat irregularities and shortness of breath are some of the injuries to which players are subjected during a football match. The adoption of emerging IoT technologies in the football field could help coaches and doctors to identify possible emergency situations and promptly help a player in trouble.

Among all the IoT-enabling technologies, Ultra High Frequency (UHF) Radio Frequency Identification (RFID), and Wireless Sensor Network (WSN) represent two of the most promising candidates for the development of innovative systems. RFID is a low-cost, low-power technology, mainly consisting of passive devices, named tags, which are able to transmit data when powered by the electromagnetic field generated by a reader. Although the long lifetime of tags makes this technology highly suitable for the development of a variety of application scenarios, however, their reduced operating range (i.e. up to 10 m) limits the use of RFID solutions to object identification and tracking within quite small areas [6]. On the contrary, WSNs are self-organizing networks of small, low-cost devices that communicate in a multi-hop manner to provide monitor and control functionalities [7][8]. WSN motes usually integrate an IEEE 802.15.4 [9] radio enabling up to 100-m outdoor communication range (single hop). RFID and WSN represent two complementary technologies, whose physical integration might give new perspectives to a broad range of innovative applications [10][11].

On the other hand, to manage RFID and WSN devices in a unified manner, the adoption of widely recognized standards is advocated. One of the most used communication protocol in the IoT is Constrained Application Protocol (CoAP) [12]. Its primary objective is to provide a lightweight access to physical resources in order to meet the limited capabilities of embedded devices. According to the REpresentational State Transfer (REST) paradigm, CoAP allows sensor nodes to run embedded Web services, through which their resources can be easily manipulated. Furthermore, the development of REST-style IoT systems enables seamless interoperability with cloud services, thus guaranteeing the implementation of flexible and easily scalable solutions.

The described concepts have been already successfully applied for the development of innovative solutions in many different application domains. In particular, several papers focused on the use of IoT enabling technologies in pervasive healthcare applications have been recently published in the literature. A very interesting project is WSN4QoL [13].

WSN4QoL provides patients' monitoring and tracking through a three-tier system architecture. Specifically, a Bluetooth-enabled wireless body area network (WBAN) is used to connect some sensor nodes to a local collector which, in turn, sends measurements reports towards a gateway through a IEEE 802.15.4-based ZigBee network. Finally, the gateway performs local computation and forward data to the public IP network towards the professional caregivers for real-time analysis. In [14], a WSN architecture and smart mobile communication techniques are combined to monitor the health condition of patients and provide several effective healthcare services. More in detail, the proposed solution makes use of WSN devices to measure photoplethysmogram (PPG) signals and deliver them to a server through the Internet. An Android device is used to provide a mobile healthcare service by means of a customized application. An interesting attempt that aims to combine and integrate heterogeneous technologies is reported in our prior work [11]. More in depth, it describes a smart system based on UHF RFID and WSN solutions for the automatic monitoring and tracking of patients within hospitals. However, such system works properly only within a closed environment, such as a hospital, since it does not represent a scalable and flexible solutions, easily integrable into more complete and complex infrastructures.

There is a lack of literature on designing a health care system in the area of sport. In [15] the main research challenges related to the adoption of IoT architectures in the sport domain are presented and discussed. In [16], authors propose an IoT-based architecture for the sport of football, called IoT Football. The system aims to embed sensing devices, telecommunication technologies (e.g. ZigBee) and cloud computing in the sport of football in order monitor the health of footballers and reduce the occurrence of adverse health conditions. The described solution, however, is only at a first stage of development, since it was not still implemented and tested using real devices.

In this work, a novel IoT-aware Sport System is described and validated. It is able to guarantee innovative services for the automatic monitoring of players during a sports match, by exploiting the potentialities offered by the jointly use of different, yet complementary, technologies and standards, such as RFID, WSN, mobile, 6LoWPAN, and CoAP. Although the designed solution is generic enough to be applied to several team sports (i.e., volleyball, basketball, rugby, tennis), it has been customized and prototyped for the game of football, due to its great popularity. More in detail, the system is able to collect, in real time, both environmental conditions and players' physiological parameters via an ultra-low-power Hybrid Sensing Network (HSN) composed of 6LoWPAN nodes integrating UHF RFID Class-1 Generation- 2 (Gen2 hereafter) functionalities. In particular, two new kinds of WSN nodes are proposed. The former integrates an RFID Gen2 reader while the latter integrates an augmented RFID Gen2 tag in order to store sensor data and player information. In this way, physiological parameters of player can be easily retrieved by RFID Gen2 readers deployed near the benches. To simplify the storage and analysis of a great amount of data, the retrieved information are delivered to a cloud platform, where an advanced monitoring application makes them easily accessible via a set of REST Web services. In this way, during the normal situation, no WSN-based transmission is performed, thus reducing the node power consumption and limiting the impact on the network capacity. The designed system is also able to timely and reliably manage emergency situations. In this case, the WSN-based transmission is activated so as to promptly inform coaches and doctors in the field via Push Notifications on a customized mobile application. Doctors can also connect their smartphone to a portable UHF RFID reader and use the same mobile application to interact with players' sensor nodes during their interventions. Finally, the system allows also to retrieve and store important data about the environmental conditions, which could be used to provide alternative services to citizens or researchers, within the realization of a Smart City infrastructure.

The rest of the paper is organized as follows. Section II provides an overview on the architecture design. A more detailed description of the system is presented in Section III, while a prototype implementation of the proposed system is described and validated in Section IV. Concluding remarks are drawn in Section V.

II. System Architecture Design

The designed system has been put into effect according to the architecture illustrated in Fig. 1. As shown, it is composed of four main parts: (1) the Hybrid Sensing Network (HSN), (2) the IoT Smart Gateway, (3) the cloud platform, and (4) the user interfaces.

The HSN consists of an integrated RFID-WSN 6LoWPAN network composed of four types of nodes: (i) 6LowPAN Border Router (6LBR), (ii) 6LowPAN Router (6LR), (iii) 6LowPAN Router Reader (6LRR), and (iv) 6LowPAN Host Tag (HT). According to the 6LoWPAN standard, the 6LBR is in charge of connecting the network to the Internet by translating 6LowPAN packets into IPv6 packets and vice-versa, a 6LR describes a node able to provide forwarding and routing capabilities, while the 6LRR is defined as a 6LR interfaced with an RFID reader. Finally, an HT node identifies a typical 6LowPAN Host (i.e. a node without routing and forwarding capabilities) interfaced with an RFID Gen2 tag. The designed system assumes that 6LR, equipped with light, humidity and temperature sensors, are deployed along the perimeter of playing field in order to detect environmental conditions, while 6LRR nodes are placed on poles located near benches reserved for players. Indeed, the main function of 6LRR nodes is to identify and monitor players labeled with RFID Gen2 tags. More in detail, players wear a HT node capable to detect important physiological parameters, such as body temperature and heartbeat. During the match, sensed data are periodically logged on the memory of the RFID Gen2 tag. In this way, 6LRR nodes can retrieve such information when players approach the benches (as example, at the end of a playing period) and delivered to the IoT Smart Gateway.

In the envisioned architecture, IoT Smart Gateway is a more powerful device placed near the exit from the playing field. It is connected, on the one hand, directly with the HSN and, on the other hand, with the Internet through a 3G-communication interface. The gateway, therefore, plays the role of 6LBR, enabling the communication between HSN

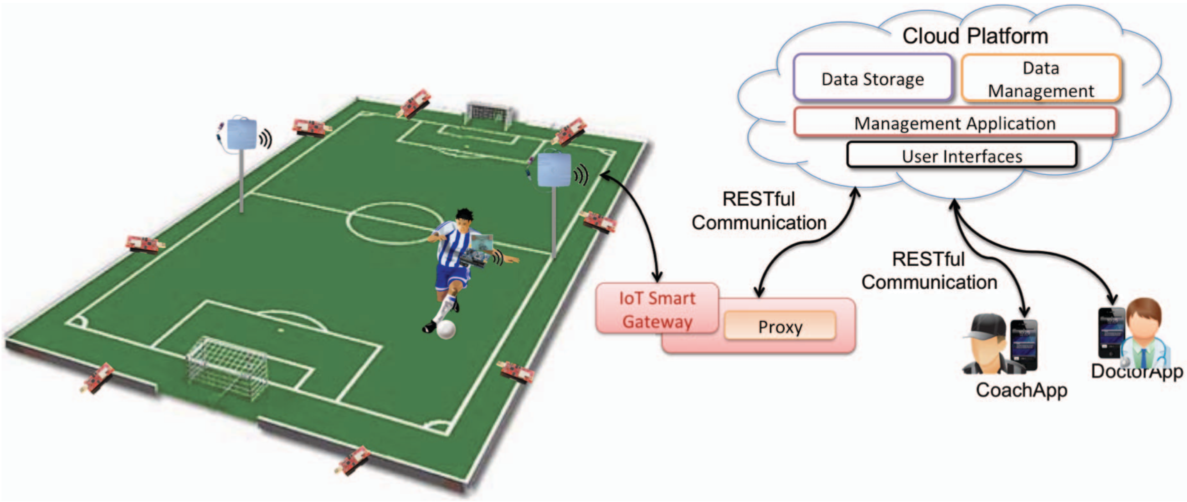

Fig. 1. Overall System Architecture

nodes and remote users. Moreover, the gateway enables the RESTful communication with the cloud platform.

This last one is equipped with three different modules: (i) a Data Storage Module, in charge of storing the received data; (ii) a Data Management Module, responsible to remotely control and manage sensors deployed in the field; and (iii) a Management Application (MA), able to execute the business logic.

In particular, the MA module plays a key role within the developed architecture. It is responsible to timely manage emergency situations. As previously introduced, in case of critical events, such as player's heartbeat irregularities, the HT node activates its long-range IEEE 802.15.4 radio transceiver to send a notification to the MA. This last module is able to analyze heterogeneous information (i.e., the environmental conditions as well as the player's physical condition) in order to detect potentially dangerous situations. In such a case, the MA exploits Push Notifications (PN) to inform the coach and the doctor in the field that the player needs to be immediately taken off the field and provided with medical support. This strategy allows the HT nodes to always use the RFID Gen2 radio interface for routine operations, e.g. data logging and identification, while keeping the IEEE 802.15.4 radio off for most of the time, thus maximizing battery lifetime.

To make the collected data easily accessible by users, two different mobile applications have been developed. In the designed architecture, doctors are equipped with a smartphone connected to a portable RFID Gen2 reader and running a customized application, named DoctorApp. Through this App, during the playing breaks, doctors can interact directly with the HT node worn by a player and check his physiological parameters by reading the most recent information stored into the memory of the RFID Gen2 tag or historical information stored into the cloud. The DoctorApp allows doctors also to update the tag's memory content with information to remind for the time of the football match (e.g. the time of the last check), and receive notifications in case of emergency. A different mobile application, called CoachApp, allows football coach to check data about the environmental conditions and to receive notifications when an emergency is detected.

III. System Details

In the following, implementation details on the designed software system are described.

A. Hybrid Sensing Network

Fundamental elements of the designed HSN are the HT nodes and 6LRR devices. This last ones consist of a commercial off-the-shelf (COTS) RFID Gen2 Reader interfaced with the XM1000 mote from Advanticsys [17] via the universal asynchronous receiver/transmitter (UART) communication bus. Specifically, the Sensor ID Discovery Gate UHF [18] reader has been used.

The HT node is a prototype device composed by three different parts: a dual-interface RFID Gen2 tag, a 6LowPAN node, and a multi-sensor board [11]. The dual-interface RFID Gen2 tag is a prototype solution equipped with a battery holder enabling an auxiliary BAP mode of operation in addition to the standard fully-passive one. The 6LowPAN node comprises a ST Microelectronics MB851 board equipped with a 32-bit ARM Cortex-M3 MCU embedding 16-KB RAM and 256-KB Flash ROM. The multi-sensor prototype board embeds four COTS sensors: (i) the Analog Devices ADXL345 I2C sensor, which is an ultra-low-power three-axis accelerometer; (ii) the MAX44009 sensor from Maxim Integrated, which provides ambient light measurements; (iii) the Bosch Sensortec BMP180, a temperature and barometric pressure sensor; and (iv) the PS25251 from Plessey Semiconductors, used as a dry-contact analog ECG sensor.

Furthermore, the REST paradigm, piggybacked on CoAP messages, has been exploited. CoAP design is similar to that of HTTP since it provides a request/response model interaction between two end-points and includes key concepts of the Web, such as URI and media types. CoAP also provides a resource observation mechanism, which allows a client to receive notifications upon every change in the state of resources it has previously subscribed to.

Three different kinds of resources can be identified in the proposed architecture: (i) health sensors, (ii) ambient sensors, and (iii) RFID-related resources. 6LR nodes scattered in the football field can monitor only environmental parameters and, therefore, expose just CoAP ambient sensor resources (e.g. `coap://[aaaa::1]/ambient/light` and `coap://[aaaa::1]/ambient/temperature`). In addition to such kind of resources, 6LRR nodes can expose an RFID resource (`coap://[aaaa::3]/RFID/reader`) which represents an aggregated information of tags read within the 6LRR RFID range. Finally, HT nodes also expose an RFID resource (`coap://[aaaa::3]/RFID/tag`, which identifies the memory content of the integrated Gen2 tag) in addition to both ambient and health (e.g. `coap://[aaaa::3]/health/heartbeat`, which provides sensor readings from the integrated 3-axis accelerometer) sensor resources. In this way, each resource can be individually accessed from anywhere in the Internet by using CoAP methods.

For the sake of simplifying the development of the proposed solution, we drawn on the implementation presented in [19] where Erbium (Er), a low-power REST engine for Contiki, has been extended to support conditional observations through a Conditional Observation Module. Such implementation has been adapted to our hardware. Specifically, in the proposed solution, the HT node embeds sensors able to monitor not only environmental conditions, but also vital signs, e.g. heartbeat, which should maintain predefined values in players with good health conditions. However, if their values fit outside a specified range, it might indicate the player needs attention. The use of conditional observation methods allows client applications to be notified only when critical thresholds are violated.

B. *Smart Gateway*

The Smart Gateway is another important element of the designed architecture. It works as a bridge between the HSN and the cloud platform. It has been realized by connecting a Rasperry Pi 2 Model B board [20], equipped with the Raspian operating system, to the 6LowPAN Border Router. The gateway has been also equipped with a 3G module, to guarantee data communication. Raspberry Pi is a credit card-sized computer powered by the Broadcom BCM2836 system-on-a-chip (SoC). This SoC includes a quad-core ARM Cortex-A7 CPU, clocked at 900 MHz. It is equipped with 1 GB of RAM and powered by a 5 V micro USB AC charger.

In our implementation, the Smart Gateway embeds a proxy subsystem, which enables transparent communication with CoAP devices. It has the burden of translating HTTP requests coming from the cloud platform into CoAP messages and vice-versa. It has been developed by using the Spring Framework and deployed on the Jetty application server installed on the Smart Gateway. The proxy logic has been extended by implementing a caching service, thus supporting multiple requests to the same resource and limiting the amount of traffic injected into the IoT peripheral network.

C. *Cloud Services*

In the proposed system, a cloud platform has been used to store and manage the information retrieved by the HSN and all the data related to players' health conditions. We deployed the proposed solution on Amazon Elastic Compute Cloud (EC2). Specifically, as previously introduced, the cloud platform has been equipped with the following modules: (i) Data Storage Module, (ii) Data Management Module, and (iii) Management Application (MA). In particular, the last one represents the functional core of the proposed architecture. More in depth, the MA registers itself as an observer to the CoAP resources exposed by HT nodes and to the RFID reader related resources exposed by 6LRR nodes deployed near the benches. In such a way, when a football player enters within the coverage region of a 6LRR node, all the information stored into the memory of the RFID Gen2 chip can be read and delivered to the MA for a further analysis. At the same time, the use of conditional observation methods allows the MA to be notified only when the value of player's physiological parameters fit outside a specified range, thus substantially reducing the number of notification messages in the network. The MA is also able to send Push Notifications to the mobile devices of coaches and doctors. To this purpose, we resorted to the Amazon Simple Notification Service (SNS), since it can seamlessly scale and add an abstraction level allowing programmers to use the same APIs for sending notifications on different platforms (e.g. iOS and Android).

D. *Mobile Applications*

Users can interact with the system through user interfaces, accessible via Web browser by both desktop clients and mobile devices. Such interfaces implement RESTful services, thus enabling the communication with the cloud platform. They offer two main functionalities depending on two possible client profiles:

- *Coach Interface.* This interface allows coaches to visualize current and historical information from environmental sensors, and data about players' performance as well. Coaches can interact remotely with the system by using the CoachApp, a customized Android application. As previously described, the App also allows coaches to receive notifications in case of emergency situations.

- *Doctor Interface.* This interface allows doctors to visualize information about players' health status. Furthermore, this interface allows doctors to directly access to the health sensor data of each patient wearing an HT node. Doctors can interact remotely with the system by using the DoctorApp, a customized Android application. As previously described, the DoctorApp also allows doctors equipped with an RFID-enabled smartphone to directly retrieve and manage player's healthy data stored into the tag's memory during the football match breaks. Finally, the DoctorApp provides PNs in case of emergency.

IV. PROOF-OF-CONCEPT

In this section, a prototype implementation of the proposed system is described and validated by means of a simple proof of concept.

Specifically, the ADXL345 digital 3-axis accelerometer connected to the multi-sensor board of the HT node has been exploited to detect possible heart problems and generate an alert. According to the algorithm proposed in [21], the signal is initially passed through a band-pass filter. Next, the algorithm computes the first and second derivative of the signal using two approximate 5-tap filters with integer coefficients. The results are added together and considered in absolute value. A 6-tap moving average is then applied, and the result compared against a threshold to detect any peaks that may indicate physiological issues. It is worth to notice that the aim of this paper is to demonstrate the feasibility of the proposed system. Therefore, the definition of specific, optimum algorithms to detect heartbeat irregularities is outside the scope of this work.

The considered validation scenario is depicted in Fig. 2. The two main actors are: (i) the HT node, in charge of monitoring the player's health status, and (ii) the 6LRR node, in charge of reading and delivering to the IoT Smart Gateway data retrieved from the memory of the RFID chip equipping the HT node. The RFID tag embedded into the HT node contains, in addition to player's physiological information, the Electronic Product Code (EPC), used to univocally identify the football player. A Nexus 4 mobile phone running Android 4.4.3 "KitKat" connected to the BlueBerry RFID Gen2 reader from TERTIUM Technology [22] is used as handled reader. The DoctorApp is installed on the Nexus 4 and uses the Wi-Fi or 3G Internet access. When an irregular-heartbeat event is detected the application receives the PN sent by the MA and notifies the doctor with a sound. The DoctorApp also allows the doctor to retrieve from the cloud further details on the occurred event and historical data about the player's health status.

To demonstrate the efficiency of the proposed system, two different use cases have been considered: (i) players' monitoring and (ii) emergency event handling. In the former, the following operations are performed:

1. the 6LRR identifies the player by means of his unique EPC and retrieve his current and historical health status by accessing the memory of the RFID chip equipping the HT node;
2. the 6LRR node sends a notification message containing the read data to the MA using a CoAP method. The MA application running on the cloud analyze the received data and store them.

In the latter, the following procedure is used to handle emergency situations:

3. the HT node detects the an heartbeat irregularity and activates its IEEE 802.15.4 radio transceiver to send a notification message to the MA;
4. the MA analyses the received data and send a PN to coaches and doctors in the field.
5. The doctor receives on the DoctorApp the emergency notification (Fig. 3a) and visualizes details about the emergency event by reading data stored in the RFID tag (Fig. 3b).

V. Conclusions

In this paper, a novel Sport System architecture for automatic monitoring of players has been proposed. To the best of authors' knowledge, this work represents a first real attempt

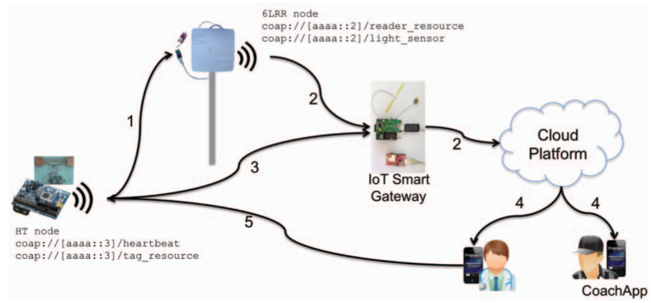

Fig. 2. Use case scenario

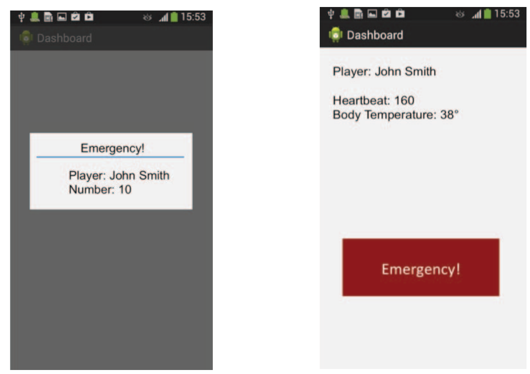

Fig. 3. Screenshots of the DoctorApp: (a) PN on the mobile phone; (b) visualization of details about the emergency situation.

to demonstrate the benefits introduced by the use of IoT technologies in sport environments.

According to the IoT vision, a complete network infrastructure relying on a CoAP, 6LoWPAN, and REST paradigms has been implemented so as to allow the interoperation among UHF RFID Gen2, WSN, and smart mobile technologies. Although the designed solution is generic enough to be applied to several team sports, it has been prototyped for the game of football, due to its great popularity. In particular, an ultra-low-power Hybrid Sensing Network (HSN), able to collect the real-time variation of any critical player' physiological parameter as well as of the environmental conditions, has been implemented. The sensed parameters are delivered to a cloud platform and made easily accessible via customized REST Web Services. To validate the proposed system, two different use cases have been implemented. The former deals with players' monitoring, the latter with the management of an emergency situation. The achieved results demonstrate the appropriateness of the proposed system.

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