RFID Sensor Network for Workplace Safety Management


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Abstract—Large industrial environments are inherently complex systems to be monitored and controlled, given the presence of vehicles, people and industrial plants. In a context dominated by strict regulations for workplace safety, systems for monitoring and preventing workplace risks can have a particular importance.

This paper describes the work in progress on designing and implementing an RFID-based sensor network for workplace safety management. The proposed system is based on Body Area Networks and passive RFID tags and sensors. The goal of the proposed system is to offer a detailed, constantly updated overview of an industrial environment in terms of workplace safety.

Keywords—workplace safety, RFID, BAN, sensor networks.

I. INTRODUCTION

Industrial workplaces are inherently places with a high concentration of heavy machinery, fast moving handling equipments, high heat and pressure pipes, polluted and explosive areas, high working elevations, people movements and more in a relatively small area. Despite sophisticated innovations, industrial environments are still considered high-risk environments with serious work safety related issues and higher accident rates than other workplaces. The underlying causes are the danger of industrial work, the often inadequate management control, training and risk assessments combined with the increasing commercial pressure.

Industries have started applying ICT technologies for increasing profitability and responding to the growing need of safety concerns of the clients and operators. In this context, an application of particular importance is the design of an intelligent system for monitoring and preventing risks through the centralized use of sensor techniques and communication technologies.

The examples for personal protective equipment (PPE) management found in the literature generally include a portal with fixed antennas for environment management or recording and monitoring the inspection of safety items, or handheld equipment to track, read and manage performance procedures of workers PPE in a semi automatic manner; in some cases the development includes also the working garments management besides the PPEs [1]. The management related actions include alarm systems when the requirements of the safety management systems are not covered [2] or when the semantic information included in the location data indicates an uncovered risk in different applications as [3][4][5].

This paper presents the work in progress on designing and implementing a first working prototype of an RFID-based BAN sensor network for actively monitoring and preventing workplace safety risks in an industrial area. This study aims to investigate the real-time monitoring of the correct use of personal safety equipment by means of advanced sensor and communication techniques.

The paper is organized as follows: the next section presents a technological overview in the context of a deployment scenario for the proposed sensor network, including a description of the Body Area Network (BAN) concept as a solution to ensure higher safety levels for workers. The requirements and constrains are discussed in the third section while section IV covers the architecture of the sensor network and the work in progress. Finally, section V draws the preliminary conclusions and discusses our planned future work.

II. TECHNOLOGICAL OVERVIEW

The concept of safety is one of the predominant concerns in various industrial fields. In this particular context, specific safety measures have to be taken while handling and storing materials and during workers transit. The cause of personnel injuries or property damage may be of various nature: exposure to chemical carcinogens and mutagens, physical or biological agents, air or noise emissions, vibration, and ultrasonic radiation; accidents caused by contact with a mobile structure or moving vehicle. Therefore, personal protective equipment, such as clothing, helmets, goggles, or other garments designed to protect the wearer's body from injury should be worn appropriately.

Risk assessment in the workplace include procedures designed to determine the quantitative or qualitative value of risk related to a specific situation and a foreseen hazard. This may include the characterization of different parameters as the worker and/or machinery location, work equipment monitoring and several parameters regarding the specific risks such as concentration, temperature, posture, effort, work rhythm. Several of these values can be detected, measured and assessed through methodologies and procedures including ICT solutions.
When speaking of work safety issues, even with strict regulations and risk assessment studies, the human error plays a major role in generating potentially dangerous situations. Most of these accidents can be avoided or limited in damage when using personal protective equipment. For the case of a typical industrial environment the operators have to wear appropriate helmets, jackets and shoes.

A. Body Area Networks

In order to find an optimal solution which can be used to suit the safety requirements, this paper addresses an infrastructure of BANs. A BAN is formally defined by IEEE 802.15 as a communication standard optimized for low power devices and operation on, in or around the human body. Some of the more common use cases of BAN technology are: Body Sensor Networks (BSN), Monitoring, Mobile Device Integration, Personal Video Devices [6]. Sensors and actuators are the key components of a BAN used to describe wearable computing devices able to transfer data to a central unit through wireless links. A BSN is formed by a variable number of sensors, called Body Sensor Units (BSU), all read by a Body Central Unit (BCU). The BSUs acquire and collect specific data (e.g., body temperature, vital signs, distance from some reference sensors, etc.), processes them if necessary, and transmits the data via wireless links to a BCU. The sensor device design is usually composed by the sensor itself, a radio module, a micro-processor and an energy source.

III. REQUIREMENTS AND CONSTRAINTS

As mentioned in the introduction, the main purpose of this work is to improve the safety of operators in an industrial environment such as a cargo terminal. Personal protective equipment, like clothing, helmets, goggles, or other garments designed to protect the wearer's body from injury should be worn appropriately, according to specific regulations. For these specific needs we chose an infrastructure of Body Area Networks (BANs).

A. Requirements

The main protective items in most industrial environments consist of helmet, protective jacket and shoes, which is why we considered a BAN with sensors added or included in the protective equipment, as depicted in figure 1. The sensors have to be able to signalize the presence of the personal protective equipment on the worker’s body and also to have the capability to send some other useful data such as temperature and orientation.

Based on this comparison of these main wireless standards, we considered RFID technology with passive sensor tags [7], as the most viable alternative. This choice was motivated mainly by the fact that RFID does not require a power source for the sensors themselves, but only for the central unit. The main counter candidate from the battery-operated standards is ZigBee, a mature, low-cost and low-power technology, flexible and small enough to meet the imposed constraints but discarded for the necessity of having a power source.

B. RFID Technology

RFID technology is standardized for four frequency ranges, as presented in Table II. The wavelengths in the microwave (MW) range are absorbed by the human body, introducing severe limitations for the usage specific to a BAN. This made us take into consideration only the lower frequencies for the purpose of the present research activities. Among these frequencies, we opted for the UHF systems, taking into consideration the low data rate provided by the LF systems and the limited range of both LF and HF systems [8].

Among various commercially available RFID systems, a very interesting alternative is the platform called WISP (Wireless Identification and Sensing Platform) [9] [10]. WISP is a RFID technology combined with a series of sensors that are powered and read by the UHF RFID readers. To a RFID reader, a WISP is just a regular EPC gen1 or gen2 tag; but

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**TABLE I. MAIN WIRELESS STANDARDS – FEATURE CHART**

<table>
<thead>
<tr>
<th>Features</th>
<th>Bluetooth</th>
<th>ZigBee</th>
<th>Ant</th>
<th>RFID (passive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power profile</td>
<td>days</td>
<td>years</td>
<td>months</td>
<td>infinite</td>
</tr>
<tr>
<td>Nodes/master</td>
<td>7</td>
<td>64000</td>
<td>infinite</td>
<td>infinite</td>
</tr>
<tr>
<td>Range</td>
<td>1/10 m</td>
<td>70/100 m</td>
<td>7/30 m</td>
<td>4/10 m</td>
</tr>
<tr>
<td>Data rate</td>
<td>1 Mbps</td>
<td>250 Kbps</td>
<td>1 Mbit/s</td>
<td>100/1000 Kbps</td>
</tr>
<tr>
<td>Current (TX)</td>
<td>40 mA</td>
<td>35 mA</td>
<td>n.d.</td>
<td>&gt;20 mA (reader)</td>
</tr>
<tr>
<td>Battery</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>

**TABLE II. RFID TECHNOLOGY – CHARACTERISTICS**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Typical Operation Range</th>
<th>Typical Maximum Range in Open Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>LF 135 kHz</td>
<td>Near Field</td>
<td>50 cm</td>
</tr>
<tr>
<td>HF 13.56 MHz</td>
<td>Near Field</td>
<td>3 m</td>
</tr>
<tr>
<td>UHF 869 MHz</td>
<td>Near / Far Field</td>
<td>9 m</td>
</tr>
<tr>
<td>MW 2.4 GHz</td>
<td>Far Field</td>
<td>15 m</td>
</tr>
<tr>
<td>MW 5.8 GHz</td>
<td>Far Field</td>
<td>20 m</td>
</tr>
</tbody>
</table>

Fig. 1. BAN Sensor Network for Workplace Safety Management
inside the WISP, the harvested energy is operating a 16-bit general purpose microcontroller. The microcontroller can perform a variety of computing tasks, including sampling sensors, and report that sensor data back to the RFID reader. WISPs are built with light sensors, temperature sensors, and strain gauges. WISPs can write to flash and perform cryptographic computations. The WISPs do not require batteries since they harvest their power from the RF signal generated by the reader. The WISPs consist of a board with power harvesting circuits, demodulator, modulator, microcontroller, external sensors, and other components.

C. RFID Reader Constrains

The UHF RFID reader systems may create RF energy absorption, that can represent a significant impact to the human body when present in high densities and/or close proximities. Therefore, international regulations make use of the Specific Absorption Rate (SAR) parameter to induce constraints on the radiated electromagnetic fields in the proximity of the human body. SAR is the rate at which the body or tissues absorb RF energy when exposed to an electromagnetic field. A dosimetric measure that has been widely adopted for SAR calculations is the time derivative of the incremental energy \( (dW) \) absorbed by, or dissipated in an incremental mass \( (dm) \) contained in a volume element \( (dV) \) of a given density \( (\rho) \), which is expanded in equation 1 [11]

\[
SAR = \frac{d}{dt} \left( \frac{dW}{dm} \right) = \frac{d}{dt} \left[ \frac{dW}{\rho(dV)} \right] = \frac{\sigma}{2\rho} |E|^2, \quad (1)
\]

where \( E \) is the peak value of the magnetic field measured in V/m and \( \sigma \) the electrical conductivity of the biological tissue. Both \( \sigma \) and \( \rho \) depend on the type of the analyzed tissue. For the current study, the body is relevant as a whole, taking into consideration that the RFID tags are distributed all over the body. Therefore, the performed computations took into account the Whole Body SAR, where the human body is approximated by a cylinder composed by the skull together with two types of tissues (muscular and soft) with a high amount of water.

The SAR simulations were done considering a reader working at 869 MHz with a circular antenna polarization having a 6 dB gain. The values for the density and the electrical conductivity were chosen as \( \sigma = 0.65 \) and \( \rho = 1306 \) and the SAR was calculated as a function of the reader’s distance from the human body. Three different transmitting powers were taken into consideration, from a minimum of 0.2 W typical for portable readers, up to 1 W, the output power level of stand-alone RFID installations. The tag had a gain of 1 dB and a backscattering efficiency of -20 dB. The results of are presented in figure 3.

The most restrictive international limits for the SAR are the ones imposed by the FCC in the US, which state a limit value of \( SAR = 1.6 \) W/kg. The IEC (International Electrotechnical Commission) recommends a slightly higher value of 2 W/Kg, valid for the EU, South Korea and Japan.

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Using the graph in figure 3, one can observe that the FCC limit can be reached for a value of 0.6 W of radiated power only at a distance of 10 cm from the human body. For the 0.2 W the FCC limit is not a problem, which is not the case for 1 W of radiated power where the SAR limit is reached at around 20 cm. These figures highlight the main limitations on the number of readers or antennas to be used and their distance from the human body.

IV. SYSTEM ARCHITECTURE AND WORK IN PROGRESS

Inside the industrial environment the operators must wear the appropriate protective equipment such as helmet, jacket and shoes. The equipment forms a BAN, each item having an integrated RFID tag with a unique identification code. Specific items such as the helmet and the jacket also contain a sensor unit besides the RFID tag, used to collect sensing information. As shown in figure 1, two RFID tags are placed in the shoes, a WISP tag with temperature sensor together with a photocell are placed in the helmet for sensing the body heat and the presence of light inside the helmet. The jacket includes a WISP tag with a temperature sensor and an accelerometer.

The BCU in charge for collecting the data from the BAN is represented by fixed RFID readers placed in strategic check points of the industrial environment, for example on the bus carrying the workers to specific places and at the access points to cranes and heavy machinery. All readers are connected through an Ethernet port to a local LAN through which the status of the tags and the information returned by the various sensors can be read and stored in a database. A schematic diagram of this architecture is presented in figure 3. By constantly monitoring the check points, a human operator or a software can notice missing protective equipment and/or out-of-range output values of the sensors.
Based on this basic architecture for monitoring the use of personal protection equipment, we intend to develop a more complex system involving also active RFID tags placed on the transport means of the industrial environment and at the limits of hazardous areas. The work in progress includes building up risk-reducing policies based on the positions of the workers relatively to the transport means and the hazardous areas. Furthermore, in progress is also the development of mechanisms for preventing roll-over and crushing incidents by implementing acoustic and visual warning systems.

Another direction of development, currently under preliminary evaluation, is the use of portable RFID readers as a BCU within the BAN to monitor on a perpetual time basis the presence of the protection equipment, forwarding the received data via radio to a central unit. The current tests evaluate the feasibility of the portable reader in terms of battery life, deployment costs and reliability.

V. CONCLUSIONS AND FUTURE WORK

This paper presents the work in progress on the design and implementation of a working prototype of an RFID-based BAN sensor network for actively monitoring and preventing workplace safety risks in an industrial area. This first conceptual and technological analysis, together with the test implementation is the forerunner of a complex monitoring system in development to be implemented for the specific case of an industrial environment. Immediate steps will consist in considering extended use cases, limiting false alarms, testing feasibility and technological limitations.

Further development will consider also the social relationships among the distributed sensors. This approach, which is expected to guarantee a higher scalability and a better reaction to frequent state, is typical for the SIoT (Social Internet of Thing) paradigm [12][13][14].

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REFERENCES