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# Real-time personal protective equipment monitoring system

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ABSTRACT

The use of personal protective equipment (PPEs) in the construction industry is necessary to guarantee the safety of the workers. However, this equipment is not usually worn properly. Nowadays, the only control performed over the use of PPEs consists of a visual inspection. This paper introduces a novel cyber-physical system (CPS) to check in real time how the PPEs are worn by the workers. In order to perform such a control, an architecture composed of a wireless local area network and a body area network is considered. A system prototype was developed by using Zigbee and RFID technologies that support the deployment of both kinds of networks. The worker carries a microcontroller-based device that detects the presence of the PPEs and sends a report to a central unit where alerts and historical data are generated. This paper is basically aimed at introducing the monitoring system, describing its hardware and software components, and analyzing the coverage and consumption of the worker's device.



## 1. Introduction

In recent years society has been demanding enhanced mechanisms to prevent occupational hazards. The construction industry is a field with a particular interest in this topic. In this industry workers have to follow several working rules. If they are not followed, the responsibility lies with the construction company. Some of the most important rules on a building site are related to the use of protective elements, such as helmets, gloves, boots, goggles, harness, etc. These elements are collectively known as *personal protective equipment* (PPE).

To reduce the accident rate in this type of work, it is required the application of technical and organizational actions. Among these actions, there are several that involve the use of PPEs to prevent harm from uncontrollable risks. Hence, PPEs are the last line of defense for the protection of workers and, therefore, one of the elements an organization should pay attention to, since if they fail, the worker can suffer serious consequences.

The main problem of a PPE-based protection policy arises when workers do not use PPEs (on purpose or not) or when they use them inappropriately. The only current way to avoid this situation is through a visual inspection by a technician. However, this solution is ineffective, since such control is performed only at specific times and it does not allow the performance of PPE traceability or real-time monitoring.

One of the solutions to this problem consists in using smart devices that are embedded in clothing, which lie in the areas of wearable computing [1] and cyber-physical systems (CPS). This paper introduces a novel system that provides real-time information on the use of PPEs. This system is able to determine whether each worker is wearing the required PPEs, monitoring their presence and warning the worker if they are not properly used. The result of the monitoring process is collected at a central server which generates historical records, alerts and any other type of events required for the proper use of the PPEs. In the system proposed each worker wears a *body area network* (BAN) of sensors that is able to detect the presence of a PPE adjacent to certain parts of the body.

Although the implementation presented is innovative, similar developments have been used in other wearable computing applications: healthcare, games, context awareness and ubiquitous solutions, human activity analysis [2], energy efficiency [3], wearable gestural interfacing [4] and even for monitoring everyday activities [5].

As discussed in this paper, the system introduced integrates different types of networks and technologies. On the one hand there is a mesh network that provides communications support for a real-time view of the status of workers and their PPEs. Moreover, each worker needs to carry a personal network or *body area network* (BAN) device able to analyze the presence and location of the PPEs used.

Given this scenario, we will show a prototype that uses RFID technology to determine when an employee makes use of a PPE, and that performs mesh network communications using Zigbee. The rest of this paper is structured as follows. Section 2 describes the problem to be solved. Section 3 shows the system architecture. Sections 4 and 5 detail the hardware and software components of

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the system. Section 6 explains the communications protocol and Section 7 shows the results from several performance tests. Finally, Section 8 is devoted to conclusions.

## 2. Problem statement

As we mentioned before, our objective is to design and develop a system to check in real time the use of PPEs in the field of construction. Since this system is going to be included in the topic of wearable computing, and taking into account the environment where it is going to be used, the new system has to cover the following goals:

- Low cost. The system is used in an environment with several workers where each one will wear a device to monitor their PPEs. Thus, the price of each worker's unit should be as cheap as possible.
- Low power consumption. The worker's device is going to be powered by batteries, which have to allow the device to operate autonomously at least for a working day. After each working day, the batteries will be recharged.
- Ease of deployment. Since we are considering an aggressive and changeable environment, we have to consider the deployment of plug-and-play network elements. It is also necessary to create a wireless installation composed of the minimum number of relays to cover the area of interest.
- Non intrusive. The worker's device has to be easy to wear. Note that workers usually require great mobility and comfortable suits. In other case, the worker is going to refuse to wear the device.
- Reliable. Unwanted situations can occur when the worker's device is operating: loss of coverage, device failure or inappropriate handling. All these situations must be considered in the design of the system.
- Scalable. The number of workers, the size of the coverage area or the number of PPEs must be transparent to the system.

In order to analyze possible solutions, we have considered three levels of control ordered by their complexity:

**Level 1** Control points are deployed throughout the building site in order to detect if the workers are carrying their PPEs. The main issue at this level is the deployment of such check points at strategic places. With this idea we could ascertain whether the worker is wearing the PPEs when s/he is crossing each check point, but it is not possible to perform real-time monitoring or to obtain information to know if the PPEs are worn appropriately. This kind of control can be achieved by using standard devices that are able to detect the presence of certain tags as they cross readers (which are usually located at entrances or exits).

**Level 2** Real-time control of the PPEs that are close to a worker. At this level we know which PPEs are next to a worker, but we have no information about their proper use. In order to achieve this level, the density of infrastructure elements has to be very high to cover the whole of the area of interest. This level can be achieved by deploying numerous check points in a similar manner to those required at Level 1. However, this additional hardware increases the complexity and the price of the whole system. Moreover, this approach is likely to be impractical in certain environments.

**Level 3** Real-time control of the use and location of the PPEs. This is the most desirable level, since we can determine, whenever necessary, if the worker is wearing the PPEs and if such elements are properly used. This level includes the lower ones and makes it possible to control the presence and location of the PPEs from the BAN worn by each worker. The information gathered about the BAN is transmitted to a central server where it is processed.

## 3. System architecture

In order to have centralized information of the workers in real time, the system requires two kinds of network: a mesh network and a BAN.

Fig. 1 shows a typical structure of a mesh network where we can see three kinds of devices[1]:

**Coordinator** This device collects the information coming from the worker's device, which is called "End node". The coordinator has the following capabilities:

- Storage: the coordinator collects information from the end nodes. Such information consists basically of timestamps and PPE detection data.
- Node configuration: the behavior of the end nodes (number and kind of PPEs to be monitored, sleep time cycles, etc.) is regulated by several parameters that are stored in this server.
- Synchronization: since the end nodes will work independently, their clocks must be synchronized their clocks with the coordinator in order to obtain proper timestamps for the detection of PPEs.

**Router** In order to achieve a low consumption at the end nodes, it is necessary to optimize the transmission power while guaranteeing that the coverage area is as wide as possible to cover the entire environment. Mesh topology-based networks are appropriate to cover these objectives. Therefore, it is necessary to have router nodes that relay the information in various hops before it reaches the coordinator. These nodes are powered uninterruptedly, providing continuous wireless connection to every end node that needs it.

**End nodes** These devices are the critical part of the system. They are the devices worn by the workers and are responsible for gathering information about the presence of the PPEs. As can be seen in Fig. 2, they are composed of the following elements:

- Central unit microcontroller. It regulates the behavior of the device. It must consider the developed protocol, controlling the sleep cycles and the communications performed through the radio module.
- Radio module. This element will be responsible for transmitting the information through any router of the network. As soon as the end devices awake, it has to look for a nearby router. In the event of being unable to connect to any router, the situation will be reported to the microcontroller, which will store the information locally until the next detection cycle.
- RFID readers. PPEs are associated with RFID tags in order to be detected from readers located throughout the worker's clothing. As can be seen in Fig. 2, the readers are located at strategic points of the clothing, since the technology used only allows them to be read at closed range. Basically, each

[1] The name of the devices follows the Zigbee notation since our prototype was developed by using this network technology.