Design and Implementation of a Wearable Safety Suit

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Abstract

Wearable computing promises gaining efficiency improvements in industrial applications due to augmentation of sensing and computational devices, thus improving the interaction between the user and the machine interface. Devices such as head mounted displays (HMDs) or wrist-mounted computers help delivering tailored information to the user while enabling hands-free operations. Sensors sewn into clothing increase the safety of maintenance and service staff by collecting information related to environmental conditions such as gas levels or temperature as well as health conditions of the wearer.

In this paper, we present a wearable safety suit which integrates various sensors and is operated via a mobile device. In our prototype, we use different types of sensors for monitoring environmental and health conditions like temperature, carbon monoxide (CO) gas levels, relative humidity, body temperature, and heartbeat. The wearable safety suit is controlled via a mobile application. The latter monitors the sensor data, identifies environmental changes, and provides alerts to the user and/or a remote control center. Keeping the usage of wearable safety suit in mind, the system is designed in a user friendly manner.

Keywords: Wearable computing, mobile computing, service science

1 Introduction

The increasing complexity of industrial plants makes not only their engineering more difficult but is also related to more extensive service activities. In industrial working environments, field service engineers may face different types of hazards. For example, when they perform service activities in rural areas aside frequently used traffic routes. In case of emergencies, it might be a challenge promptly to identify that a field service engineer is in trouble. Here, a wearable computing system could automatically detect that a service engineer needs support. Moreover, it would be able to contact a remote control center self-acting, i.e., without any additional user interaction.

Additionally, service engineers may perform service tasks in confined spaces which are not intended for human occupancy and may have an atmosphere that contains harmful levels of contaminant. Thus, a wearable system which collects information related to environmental conditions such as gas levels or temperature as well as the health of the wearer would increase the safety of maintenance and service staff.

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2 Case Study

Our case study was carried out in a pulp and paper mill located in a rural area. The mill is serviced by more than 100 service engineers and trades.

In the first phase of our project, we interviewed domain experts such as service engineers, technicians, and occupational health and safety (OHS) officers to collect details about the service processes. The interviews were carried out as semi-structured interviews according to [13] and complemented by personal face-to-face interviews as proposed by Frey and Oishi [6].

That way, possible misunderstandings during the information gathering process were reduced. Additionally, workshops with participants from several service departments and domain experts were organized. They aimed to verify and validate the collected service process information. This approach resulted in a broad understanding of the requirements, challenges, and optimization opportunities. In total, 39 use cases related to the improvement of work processes, safety & quality processes, supply chain management, and reliability were identified. The use case "Safety assurance" was selected to be among the highly prioritized application areas for wearable computing. Additional safety-related use cases for wearable computing in industrial service, such as plant isolation can be found in [2].

In the following sections, we describe the design and implementation of a wearable safety suit which provides a possible solution to the "Safety assurance" use case. We decided to integrate our approach into existing safety-related equipment instead of developing a new type of a safety tool. The reason for our decision was to follow a minimal intervention approach. Nowadays, service staff is already wearing various safety-related equipment, such as safety-glasses, high-visibility vests, safety shoes etc. Therefore, we analyzed which of them might be suitable to incorporate our ideas, such as the possible integration of sensors and actuators. Finally, we decided to utilize the high-visibility vest as a starting point for our approach. This is due to the fact, that this equipment have to be worn by service personnel all the time while being present on the plant. The vest is complemented by a mobile phone. Thus, incorporating our sensors and actuators into the high-visibility vest and operating it via a mobile phone reduces the related overhead significantly, since no additional tools were needed.

3 System Overview

The wearable system consists of two major components. The first one is the automated safety suit. It integrates several sensors and actuators, such as a body temperature sensor, a carbon monoxide sensor, an environmental temperature & humidity sensor and a heart beat sensor. All the components are connected via a body area network (BAN) to the central processing unit (CPU) by using conductive material. The BAN protocol is used for collecting the data from the sensors. A Bluetooth module is used for transmitting the data to the second component - a mobile device. The latter is used to organize the sensor data and take the decision according to the user specifications. To be able to do so, a supervising application was developed. The mobile application can be initially set up with predefined sensor thresholds, emergency contact number, and e-mail address of the supervisor. These parameters can be adjusted by the worker before going to execute the work order on the site. The mobile application stores the sensor data in XML format into a local database. The retrieved information can be used for further processing, such as analysis of the working conditions. Therefore, the mobile application can automatically send messages with GPS coordinates of the user location to a supervisor or/and a control central whenever the dangerous sensor levels are detected. The overall system architecture is depicted in Figure 1.

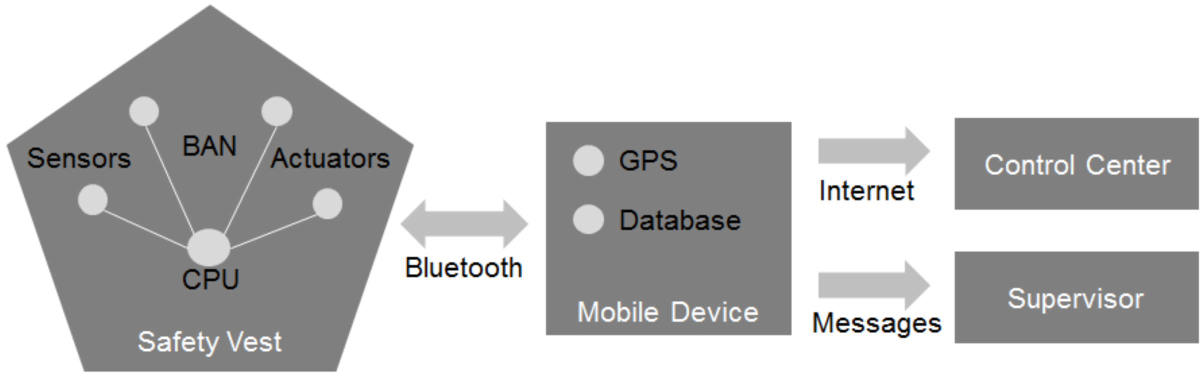

Figure 1: Architecture of the wearable automated safety suit monitoring system

4 Safety Suit

The automated safety suit contains different sensors for monitoring user's and environmental conditions. Additionally, the suit is equipped with actuators, such as speaker and vibrator to provide the vital alerts when undesirable or dangerous sensor thresholds are detected. In this prototype, e-textile technology is used for integrating the sensor and micro-controller inside the safety suit. E-textile is an electronic textile that has electronic components embedded within the clothing. It is used for both complex and protective sensing. The Arduino LilyPad [3] micro-controller is used for collecting the data from the sensors. Inside the safety suit all these sensors are connected using a silver plated nylon 234/34*4ply thread [9]. This material is conductive and has low resistance. It has low resistance, which is about 14 ohms per 30 cm of the thread. The thread carries the current and power signals. We used the Firefly Bluetooth device for communication between the LilyPad micro-controller and the mobile device. It transmits all the sensor data from the suit to mobile phone.

4.1 Sensors

Sensors play a critical role in developing the automated safety suit for monitoring the field service engineers health and environmental conditions. In the following sections, we will describe the sensors utilized in our wearable safety suit.

4.1.1 Heartbeat sensor

The heartbeat sensor is used for finding the heart rate of the users. It is the biggest factor in the ability of the medical officials see the signs of distress. Low and high heart rates for a long period of time cause cardiovascular problems. Photo-plethysmography is one of the methods used to measure pulse, from which one can determine the heartbeat rate [5]. A pulse sensor is used for calculating the heart rate. An ear clip sensor is attached to the lobe and it is connected to the micro-controller. This sensor consumes low power and calculates the heart rate in beats per second which transmits the values to service engineer mobile via serial interface.

4.1.2 Body temperature

A sudden change in the body temperature indicates the infection [5] and the stress. Human body temperature is rather different especially within the outer and inner parts of the body. A general body temperature is measured in the anus which is about 37.1 C. Temperatures are almost invariable for a healthy person and it varies depending upon the age and deviate about 0.4 C to the general body temperature. It serves as an indicator of the impeding infections and general stability of the field service engineers. Body temperature is measured by using the electrical and optical devices. In this work, we have chosen to employ TMP36 temperature sensor [10] to measure the body temperature, since it is compact and easy to integrate within the safety suit. The temperature sensor is located on the chest and it is interfaced to the micro-controller.

4.1.3 Carbon monoxide

Carbon monoxide (CO) is one of the primary toxic gases in industrial environments. CO is colorless, odorless and tasteless gas and also it is not significantly detected by human senses. In some cases, people are exposed to extreme risk when working in industrial environments such as in confined spaces, mines, and at high altitudes. It is extremely dangerous when people don't realize its existence and may suffer with dizziness and headache. One of the gas sensors FAGARO TGS 370 is used for detecting the CO gas levels. It consumes low power and gives more reliable, accurate data. The CO sensor reads the gas levels which is measured in parts per million (PPM) and transmits the data to the service engineer mobile using Bluetooth via micro-controller. The sensor is located to service engineer suit near to the chest location.

4.1.4 Environment temperature and humidity sensor

Temperature is one of the complex issues in industrial working area as it will create thermal discomfort to the field service engineer. A hot working environment creates discomfort to the workers health, efficiency, and performance and also it will affect the field service engineer's heart rate, lower body temperature, and high sweat rate. High humidity with a longer period of time makes the problem worse under these conditions. Therefore, it is hard to perform work orders in these nasty working environments. Several types of sensors are available for measuring the environmental temperature and humidity values. In this work, SHT15 sensor [8] is used since it is fully calibrated and also the quality and accuracy of the sensor is high. The sensor is integrated into the workers safety suit and connected via micro-controller by using conductive thread.

4.2 Feedback devices

Feedback devices are playing major role in wearable applications. They provide the physical alerts to the field service engineer when abnormal conditions are detected. In our prototype, we have used speaker and vibrator for giving the vital signs to the field service engineer. The speaker is located on the chest and the vibrator is located on the hip.

4.3 Emergency panic button

The additional feature in this prototype is an emergency panic button. It is integrated into an advanced safety vest and located in right hand shoulder position. The functionality of the emergency panic button is to send an alert signal to the workers mobile phone by pressing the button when the worker is in danger situation or any minor health problems. The mobile application will make a phone call and / or send an email or SMS to the supervisor of the field worker. Moreover, the mobile application is responsible for sending sensor data and updating the control center.

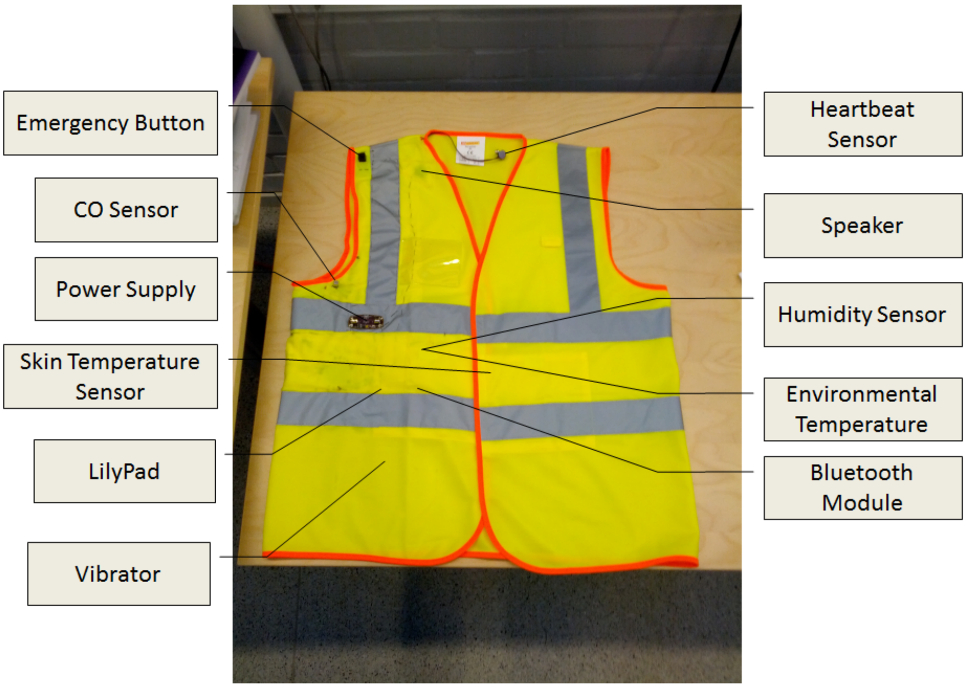

Figure 2: Safety suit

4.4 Electronics integration into automated safety suit

Ardunio LilyPad is used for integrating sensors inside the worker garment. Arduino LilyPad is a cost effective micro-controller and can easily be integrated inside the clothes. It is specially designed for wearable applications where it is responsible for monitoring the sensors inside the worker garment and collecting their data. Arduino LilyPad hardware contains Atmega 328 micro-controller. Arduino LilyPad controls the sensors used for the automated safety suit and it uses serial communication to transfer the data to the mobile phone with baud rate of 115200. It contains a multitude of analog and digital inputs and outputs.

The Lily Pad micro-controller is placed on the worker's safety vest near to the hip. The program for LilyPad is written in C programming language. The micro-controller uses 5V power supply and the battery holder is connected to the micro-controller via conductive thread. Battery holder uses single 1.2 AAA batteries to power up the micro-controller. The battery holder has an inbuilt regulator to regulate the power supply. Sensors and actuators are connected to micro-controller utilizing the conductive thread. The design of the automated safety suit is shown in Figure 2.

In our prototype, BAN protocol is used for connecting the sensors inside the safety suit. BAN is a body area network which is divided into the two categories: Wired and wireless. Wired BAN transfers the data between the sensors and micro-controller using the plastic wires or conductive threads and the power is distributed in the same thread. Bluetooth radio is one of the important components in automated safety suit design which will transmit the data from the suit to the mobile device. The firefly Bluetooth device is used in this prototype and it is connected to the micro-controller via serial interface. The Amarino tool kit [7] is used for transferring data between the suit and the mobile phone via Bluetooth. For this purpose, the tool kit creates a communication channel between the mobile device and the micro-controller. Amarino consists of two primary components, namely an Android application and an Arduino library. The Android application includes a set of modules related to Bluetooth device management,

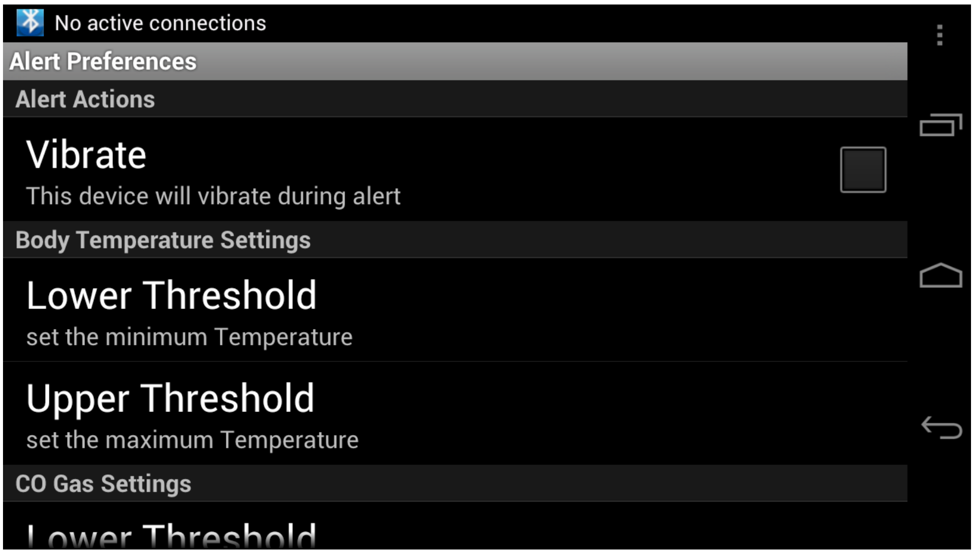

Figure 3: Configuration settings

event management, and monitoring. The Arduino library provides a callback mechanism for processing incoming events. The developer can register a callback function for each expected event type and the Arduino library will call the registered function once an event has been received.

5 Mobile application

The purpose of the mobile application is to collect sensor data, display alerts and notifications on the device when abnormal conditions are detected. It is based on the Android operating system. We decided to utilize an Android-based system due to the fact that it provides a comfortable application programming interface (API) in comparison to previous technologies such as Java 2 Micro Edition (J2ME). According to [11], the average time taken to master Android is about 50% compared to the time needed to master J2ME. Furthermore, many devices are based on the Android operating system. Even ruggedized devices which are specifically designed to reliably operate in harsh environments are available on the market. Finally, it is related to less obstacles than other platforms such as iOS [12], thus basically supporting rapid prototyping [1].

First of all, some user preferences have to be specified beforehand to ensure that the wearable safety suit will perform the right actions in case of abnormal situations. The alert preferences include time-out specification, alert actions, and information related to contact data, such as e-mail address, phone number etc. Additionally, thresholds for utilized sensors have to be set up. Figure 3 presents the corresponding activity.

The main screen of the application presents real time data transferred from the safety suit via Bluetooth. It allows the user to monitor his vital signs and sensor data in a graphical manner (cf. Figure 4). Additionally, the application allows the supervisor of the work field or control center to view the vital signs of the field service engineer engaged in action. This application will automatically send SMS and/or e-mails to the supervisor of the work field including information of the field service engineer location and type of alert is raised in that situation. When the conditions are critical the application will make a phone call to the supervisor so that they could be alerted.

The following pseudo-code presents the algorithm how sensor data is processed and corresponding

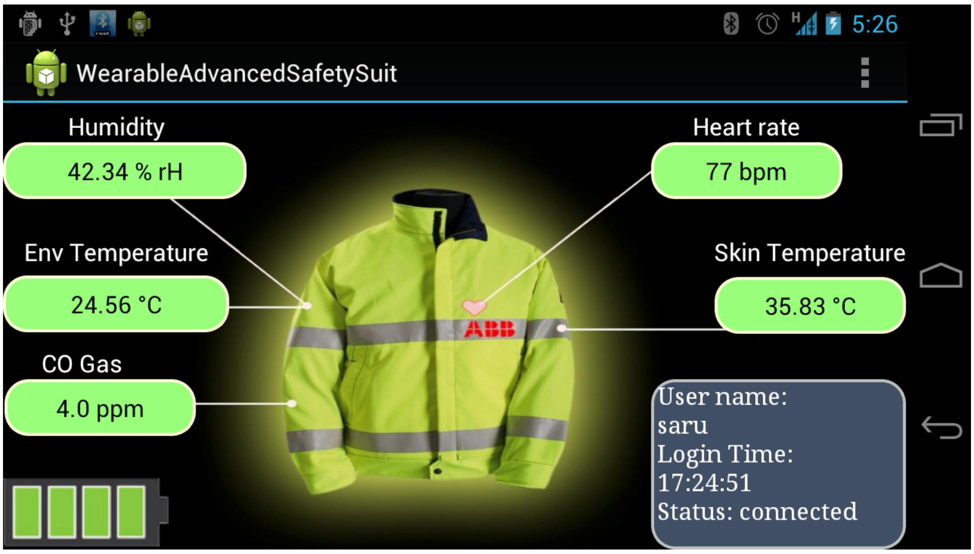

Figure 4: Mobile application running on Android OS

actions are executed.

```
// Pseudo code
for each sensor {
  if(sensor.value < sensor.lowerThreshold ||
     sensor.value > sensor.upperThreshold) {
    if(settings.sendSMS)
      sendSMS();
    if(settings.sendEMail)
      sendEMail();
  }
  monitorSensorData();
}
```

6 Conclusions

The convergence of wearable sensors, networking and communication technologies, and mobile devices simplifies the development of wearable computing applications from off-the-shelf components. General purpose small computing platforms such as Arduino LilyPad supports collecting the data from sensors sewn into the suit whereas a Android-based mobile device is used to control the system as well as monitoring, visualizing, and transferring the sensor data to a remote control center and/or a supervisor. Both subsystems are interconnected via Bluetooth - another standard technology. That way, we were able to develop a wearable system from off-the-shelf components.

Hence, the utilized technologies are still gaining increased popularity, it can be expected that the number of sensors, devices, and development environments will be improved in the future. That way, creating new and advanced wearable computing systems based on standardized components will benefit from this development.

Nevertheless, some challenges still remain. From technical perspective, integrated development environments are still missing, thus a considerable amount of effort making a large scale system functional is still required. Furthermore, the economics of wearable computing requires further investigations. Besides a few case studies and articles such as [4] that report efficiency improvements, little is known about the real long term impact of wearable computing on industrial working environment, thus making further research necessary.

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