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Implementation of a Wearable Sensor Vest for the Safety and Well-being of Children

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Abstract

This paper presents a prototype wearable vest for improving the safety and well-being of children in nurseries, daycare centres and primary schools. The safety vest is built around the LilyPad Arduino and Adafruit Flora platforms with Xbee radio module, GPS, temperature and accelerometer sensors. The vest will automatically gather and provide information about the location and well-being of the children. Teachers are able to receive alerts and notifications, e.g., when a child moves across certain restricted outdoor or indoor area. All the information gathered by the vest is made available through the web utilising Sensor Web Enablement (SWE) services to guarantee a standardised way to manage the data coming from multiple sources. The vest is part of a larger framework to provide digital safety applications and services for parents and teachers.

Keywords: wearable computing; safety of children; sensor; LilyPad Arduino; Adafruit Flora; safety vest; Sensor Web Enablement;

1. Introduction

There is an increasing need to have easily deployable and autonomous technical devices to support the safety and well-being of children in nurseries, daycare centres and primary schools. Additionally and not negligibly, these new devices should also ease the burden of the respective teachers in their daily routines. Therefore, carefully designed solutions could provide more resources and time for the actual duties of teachers, instead of spending time on safety issues.

There are already a great variety of sensors and devices deployed in schools, roads and at homes, and more are expected in the near future. However, utilising these multiple sensors and the information that they provide is not straightforward, as often the data is not easily accessible or available. Also difficulties arise, when managing the multi-sensor data in order to make intelligent reasoning, and to be able to draw conclusions about the children's safety and well-being. Our framework scenario in Figure 1 illustrates the different levels from collecting and providing the sensor data to be utilized by the end users' safety applications and services. Context-aware applications offer real-

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time and secured information, with partially dedicated views for, e.g., teachers at school, parents and school nurses, utilising a variety of sensors from the surroundings of the children as presented in Figure 2 .

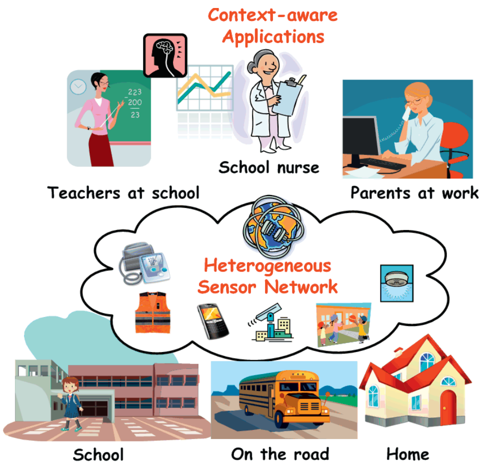

Fig. 1. Children's safety scenario.

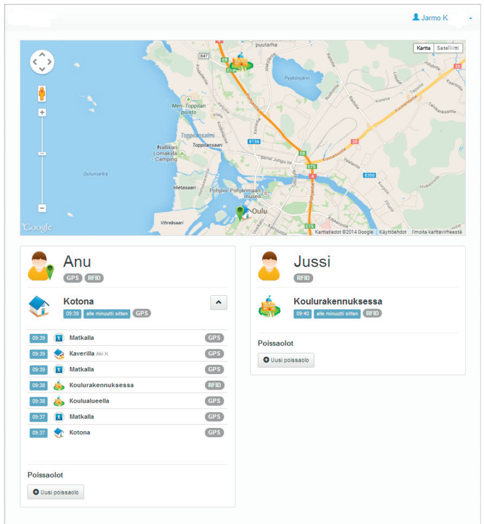

Fig. 2. Application user interface.

In our work a wearable safety vest, which is part of the presented scenario, would automatically provide information about the presence or absence of children from their restricted outdoor or indoor area. In addition, the vest would gather other sensor information about the overall well-being, behaviour and activity of the children, through temperature and accelerometer sensors. There are many things to consider when talking about children's safety and well-being in nurseries and schools. Our research and implementation is providing solutions to some of these issues regarding: children's outdoor activities, going outside the nursery/school premises (trips, sports etc.), children's disappearances from the nursery/school, and guardian's fetching the children from the nursery/school. Our safety vest framework consists of three main building components:

- Two demonstration safety vests equipped with LilyPad Arduino[1] and Adafruit Flora[2] controllers that collect information from sensors and send it wirelessly through the XBee[3] radio module to the Raspberry Pi network[4] gateway.
- Standardised Sensor Web Enablement (SWE) services, in our case Sensor Observation Service (SOS), which makes the multi-sensor data available to different web applications and services.
- Context-aware applications and services providing real-time information to the end users.

At the moment we have equipped the vests with the XBee radio module, GPS, temperature and accelerometer sensors but the platform technicalities do not restrict it from including other sensors and radio modules in the future. Wearable solutions and computing are a growing area of products and markets, such as smart glasses and watches (e.g. Google glasses, Samsung Galaxy Gear and Pebble Smartwatch). Hence, additions to the wearable platforms such as LilyPad and Flora should be expected soon. The structure of our paper is organised as follows. Section 2 depicts a literature review of wearable solutions that consider children's safety and well-being. The system design and architectural components of the safety vests are presented in Section 3. Conclusions and suggestions for future work are discussed in Section 4.

2. Related Work

In recent years, there has been a growing interest in research and development into different wearable and monitoring systems for children. However, most of the developed solutions aim to answer certain dedicated health, activity and/or security issues, but a large scale system, suitable for common use, e.g., for children, teachers, parents and school nurses, is missing.

A description of the trends and potential challenges in developing monitoring systems for ubiquitous care for children is presented in [5]. Their system, UbicKids, focuses on three main aspects, such as children's awareness (e.g. location or any physical information related to the child), assistance (guiding the child on the road, etc.) and advice (umbrella reminder, etc.). In [6] the focus is on the design of a wearable device for kids under six years old. The system gathers biological and physical information such as heart rate, body movements, and it also includes GPS and a camera. Health- and activity-related systems are proposed in [7,8,9]. KiMS is a monitoring system for the early detection of symptoms for various diseases, as well as encouraging children towards healthy habits and activities [7]. Wearable acoustics sensors are used to detect audio signals, such as coughs, sneezes, and crying. In addition, body temperature and pulse rate sensors are combined into the system. In [8] the use of spectral analysis techniques for multiple sensor data for a child's activity recognition is proposed. An accelerometer, air pressure sensor and gyroscope are utilised to detect, e.g., walking, lying down, running, climbing stairs, falling and standing up. In [9] a similar wearable device with a camera, accelerometer, GPS and a heart rate monitor is developed to detect activity modes.

The third popular area in child monitoring, besides the health and activity issues, is safety. The design in [9] also monitors potential emergency situations by searching for a child with a different activity mode from that at other nurseries. A similar design of a system for detecting dangerous situations in children's school routes is described in [10]. The architectural implementation of the system is described in [11]. The work in [12] describes a device to detect isolated children on field trips based on RSSI values. In [13] the focus is on a protocol development of a location-based child safety care service with privacy issues, and an extended description of this system can be found in [14].

There are also applications and devices to monitor children's safety and well-being that are already available on the market. Some of the latest solutions include: RFID tags for school uniforms [15], GPS wristwatches, sensors measuring human emotions (q-Sensor) [16], communication and location devices (e.g. Filip [17]) and school bus and child safety tracking systems (e.g. NorthStar [18]).

3. System Design

The preliminary system design has been an iterative process including many phases, such as analysing the available "off-the-shelf" wearable sensor components, constructing the sensor vests, analysing available middleware solutions and interfacing sensors, implementing the integrated system design and evaluating the design choices. The overall system architecture is presented in Figure 3 which consists of: wireless sensors, sensor gateway, sensor bus implementation, SWE middleware services and the safety service applications for parents, teachers and children. In the next subsections, the main building blocks are explained in detail.

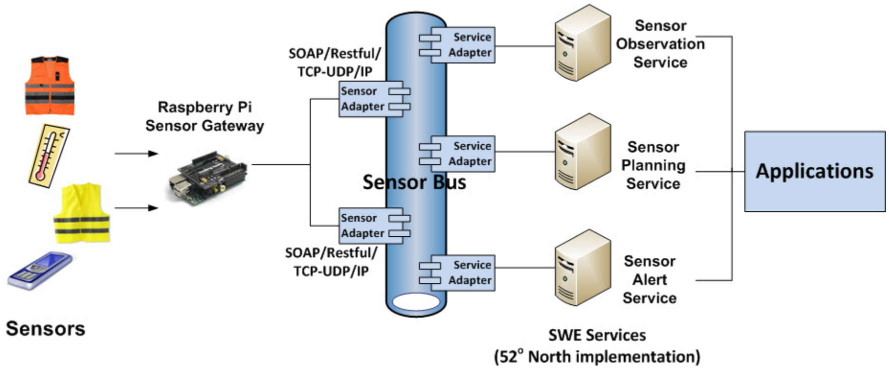

Fig. 3. System architecture.

3.1. Safety Vest Design

For our safety vests, we chose two slightly different platforms: the LilyPad Arduino simple board and Adafruit's Flora board to test and compare the basic functionalities. They are micro-controller boards designed for wearables and e-textiles. The simple board is a reduced version of the original LilyPad main board that also provided the inspiration for Flora. There are some differences between the two boards, as the Flora is slightly smaller than the LilyPad, and outputs a steady voltage of 3.3 volts, whereas the LilyPad outputs its input voltage. The LilyPad simple board however can charge its battery without additional circuitry. The USB serial driver is built-in to the Flora whereas the LilyPad requires an external USB driver. The physical communication between the vests and the gateway is handled by XBee Series 1 and 2 radios, which are based on the IEEE 802.15.4 standard. The maximum range of the Series 1 radio is 100 metres and 1.6 kilometres (1 mile) for Series 2. The micro-controllers are running CoAP (Constrained Application Protocol) servers, which offer temperature, accelerometer and GPS resources depending on the configuration of the vest. Programming was done using Arduino IDE and C++ as the programming language. The sensor data is read from the analogue pins of the microcontroller and appended into a payload to be sent to the gateway.

We designed two vests with different configurations. The first vest, as shown in Figure 4, has a LilyPad simple board with an accelerometer, temperature sensor and an XBee radio. The temperature sensor is used to measure environmental temperature values. The accelerometer can be used to measure acceleration as one-dimensional acceleration or tilt using three dimensions. The other vest is built from the Flora main board, GPS-module and an XBee radio, as shown in Figure 5. The components are connected and sewn together on the fabric with a conductive thread. It turned out to be easier to connect the components to the Flora, because it has more ground and voltage pins than the LilyPad. This allowed us to connect the components to the Flora without any crossings of the thread.

The power consumption of the systems can be greatly reduced by putting the XBee radios to sleep periodically. Without any power-saving techniques with the XBee Series 1 radio (range 100 m) and using a lithium polymer battery with a capacity of 850 mAh at 3.7 volts, the LilyPad vest can be operational for approximately14 hours and the Flora vest for 10 hours. By putting the XBee radio to sleep for every other second, the LilyPad vest can achieve a battery life close to 24 hours. Approximately the same battery life can be achieved with the Flora vest by using the radio for one second every 30 seconds. The GPS module consumes a lot of power. Therefore we have to use a longer sleep time for the radio in order to achieve the same battery life. This also means that the GPS data will be sent less frequently. Further improvements in battery life can be achieved by using sleep modes within the micro-controllers themselves.

Fig. 4. Safety vest with the Arduino LilyPad.

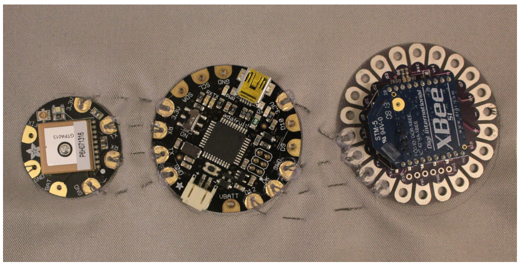

Fig. 5. Other safety vest based on Adafruit Flora.

3.2. Gateway Implementation

The gateway is implemented in a Raspberry Pi, which is a credit-card sized computer. In the gateway we are running a Raspbian operating system, which is a Debian based Linux distribution optimised for Raspberry Pi. We programmed the gateway using C++ to be consistent with the code written for the vests. Raspberry Pi has an Ethernet port to connect to a local area network and an XBee radio shield to communicate with the vests. Detecting whether the child's location is inside the allowed indoor and/or outdoor area can be based on the XBee radio range covered by the gateway(s). In order to support special use cases, when the mobility and portability of the gateway is required but the battery lifetime does not need to be very long, e.g., during sport lessons and nursery/school trips, other radio modules with a wider range (GSM, 3G and Wi-Fi) are also possible to be used in gateway(s) and the vests. Besides having the capabilities of a lightweight computer, Raspberry Pi can also host multiple sensors and implement intelligent reasoning algorithms for decision making.

3.3. Sensor Web Enablement

Nowadays it is possible to gather a great amount of information through multiple sensors but sharing, finding and accessing them across applications and services is not easy. The sensor suppliers utilise various proprietary and non-standardized protocols and communication methods, which make the integration and interoperability of sensors and devices very demanding in order to create a “Sensor Web”.

The Sensor Web Enablement (SWE)[19] initiative of the Open Geospatial Consortium standardises web service interfaces and data encodings that can be used as building blocks for a “Sensor Web”. The suite of SWE standards enables sharing, finding and accessing networked sensors, transducers and sensor data repositories via the web. The main OGC Standards in the SWE framework are: the SWE Common Data Model, providing data models and schema; the Sensor Model Language (SensorML) with models and schema for sensor systems and processes; Observations & Measurements (O&M) with models for packing observation values; the Sensor Observation Service (SOS) with a web interface for accessing observations; the Sensor Planning Service (SPS) for tasking sensor systems and requesting acquisitions; the Sensor Alert Service (SAS) for publishing and subscribing to sensor alerts; the Web Notification Service (WNS) for asynchronous notification and the SWE Service Model.

Our prototype implementation utilises 52 North Initiative for Geospatial Open Source Software[20] implementation of SWE services[21]. In addition to this we used a modified version of their Sensor Bus implementation[22]. The Sensor Bus[23] establishes an intermediary layer between sensor networks and the “Sensor Web” to close the conceptual gap between these two distinct layers resulting from different protocol stacks and data models.

3.4. Sensor Applications

Many different body movements can be recognised based on the accelerometer data[24] in order to provide and gather information about, e.g., a child’s activity level and behaviour to implement numerous applications. The basic identified modes can usually be categorised as walking, running, sitting/staying still or using a form of transportation. Implementation of the vest has some limitations concerning the way the movement data is gathered compared to those wearable systems that have sensors, e.g., in the arms and/or legs. With arm and leg sensors other more specific activities can also be recognised such as eating, using stairs, falling and lying down etc. On the other hand, the components in our other vest are attached to a separate piece of fabric, in order that a suitable place for the sensitive components can more easily be tested to guarantee the best functionality and wearability. Another advantage of using a vest is the usability (safety vests already in use in many nurseries) and extensibility to add other sensors in the future to apply intelligent reasoning, context-awareness and functional accuracy.

The temperature sensor in the vest is used for environmental monitoring purposes. This sensor can assist teachers during extreme weather to control, when and for how long, to stay outdoors during nursery and sport lessons. Also knowing the temperature and its variation is important for the well-being of those children suffering from cardiovascular or pulmonary diseases, e.g., seizures, asthma. Temperature information is also valuable for the parents of children suffering from the aforementioned diseases, e.g., in order to be able to pick them earlier from the nursery and take care of their health condition.

4. Conclusions and Future Work

This work presented wearable safety vests with GPS, an accelerometer and temperature sensors to be used in nurseries and schools. The current vest prototype is designed to mainly provide safety, behaviour and activity-related information, but as a future work, the vest could be made more appealing from the children’s point of view and include some gaming and socialising applications in addition to safety issues. The basic functionalities of the vest have been tested but more concrete real-time measurements and analysis will be done as a future study. The technicalities of the vest do not restrict adding other sensors as well, or having other end users besides children. Hence in the future, one other prominent demonstration case could be constuction workers and their safety and well-being issues. We are also aiming for more intelligent reasoning and context-awareness using the input from many sensors to assist in decision making. The situation-aware application will be based on the earlier work on run-time context management with the context ontology dedicated for the smart applications[25]. The data gathered from one sensor is usually not enough to draw conclusions, but if we are able to do the reasoning based on multi-sensor data, the applications and services around the system will be more valuable.

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