Abstract— There are different experiences in the use of RFID technology for warehouse inventories. However, there is future work to do on the design of advanced reading devices, applying wearable computation techniques and wireless communications. The aim of this work is to allow a natural interaction for the user who performs inventory tasks. In this paper we show the RFIDGlove system, which consists of a glove with an integrated RFID reader, an organic micro display and a communication system. The RFIDGlove system increases the efficiency of the activities in these areas, improving the user's experience and comfort while he/she uses the system.

Keywords-component; RFID; ZigBee; wearable computation; natural integration; glove.

I. INTRODUCTION

The Internet of Things vision may adopt several different development concepts. The most popular one is concerns using RFID tags to link objects from the real world with systems of accessible information through the Internet. In this way, by using RFID reader devices, identifying tagged objects and surfing through the Internet would be possible using these tags as hyperlinks that can be刺激到 obtain the required information, following the physical browsing model [1].

Nowadays, passive RFID tags provide an advantageous alternative, at a competitive cost, compared to other traditional systems like printed bar codes, thanks to their reading capacity without needing line-of-sight, or their writing/modifying capacity for storing data. This was the reason for using them to label products in order to monitor the distribution and storing phase.

At the same time, reader devices have appeared with different form factors (integrated into PDAs, like computer peripherals, autonomous with pencil form, etc.), which enable users and operators to execute monitoring tasks on tagged product distribution. However, these devices generally have great deficiencies that prevent them from providing advanced services for users. Among them, we can emphasize the following:

- Portability restriction: readers connected to the computer as peripherals have limited independent movement due to the wire length preventing their use in many application scenarios. The majority of them do not have wireless mechanisms, so reading events cannot be notified to a monitoring central system in almost real-time.

- Energy inefficiency: those which provide a wireless mechanism generally use IEEE 802.11x (i.e.: Wi-Fi), with the advantage of enabling the communication with Internet systems in a native way, but they suffer from excessive energy consumption, and that fact results in a life time that is limited to a few hours.

- Multimedia feedback into a small form factor: only the RFID readers that are integrated into a PDA can use a high quality screen to show information on the read product. It is a lack of readers with a small form factor that enables connection to the on-line running systems. Furthermore, they cannot provide the user with visual advanced feedback on the tagged product.

- Natural interaction problems: the form factor in which RFID readers are designed normally requires the user to employ one of his/her hands to hold and handle the reader. This causes an uncomfortable utilization. The user has only one free hand to perform other tasks (i.e.: moving the product from one place to other, testing its state by opening the box), and generally, it forces the user to carry a wearable case (on their belt or waistcoat) to temporarily deposit the reader when both hands are needed.

After identifying these limitations of current readers, we decided to design an RFID reader for warehouse and inventory environments that overcomes them. The applied strategy was to design a reader as a wearable component with a glove form. The user’s hand will be completely free for doing any task without inconveniences due to the presence of the reader. The tag reading has to be as transparent as possible for the user: the process of moving the hand next to the tag makes it natural.

In order to connect to the online information systems, IEEE 802.15.4/ZigBee wireless technology was integrated, resulting in enhanced energy efficiency compared to Wi-Fi or other IEEE 802.11x technologies. Moreover, it enables the integration of the glove into a wireless sensor network. Finally, a uOLED organic display was integrated into the back of the glove to provide an advanced visual feedback to the user. The display maintains an average balance between power consumption and graphical resolution, so as to provide
generated instructions, images or graphics about the manipulated object in a very short time for the user.

This paper presents the RFIDGlove, together with the experiences extracted from its evaluation. Section 2 describes the related work. Section 3 is devoted to the RFIDGlove architecture, and section 4 describes applications developed with the RFIDGlove. Finally, section 5 presents the conclusions of the work and future research.

II. STATE OF THE ART

During recent years, an interest in RFID technology has arisen and grown along two connected axes, with the same goals that our research sets out: readers’ mobility as something transparent for users, and their combined integration into wireless communications systems.

The first experience integrating an RFID reader into a glove was [2]. They studied the best form to bridge physical and virtual worlds through RFID technology. They used a low frequency RFID reader and a specific antenna integrated into the clothing. The maximum reading range was 7.6 cm. The reader was integrated into a 6.4 by 10.2 cm housing with a belt clip. The antenna was placed in the glove and it was connected to the reader with a wire. The main inconvenience is that the prototype had to be wired for connection with the host, so the maximum working distance was limited by the length of the wire. Furthermore, the device was more intrusive because not all the hardware was integrated into the glove, nor did it feature any visual feedback system or extended information on the readings.

[3] is another example where RFID technology is integrated into the clothes, but in this case with ludic focus. As in the former case, the RFID antenna is added to the glove and it is joined to the reader through a long wire. Then it is connected to a desktop computer. So it has practically the same limitations previously mentioned, although it does have a feedback system for the readings.

Based on the results in [2], [4] managed to integrate a miniature RFID reader, power supply and wireless unit into surgical gloves and bracelets. They used a high frequency RFID reader which needed an external antenna. Although this reader is quite small, the most up-to-date readers have an integrated antenna, so it is not necessary to design the required impedance adaptation. They selected Crossbow Mica2Dot mote radio for the wireless communication, which has a proprietary communication protocol which works at 916 MHz.

[5] is a project on researching the wearable computing field. In the project context, different prototypes have been designed, tested and evaluated for maintenance, production, health care and emergency notice applications. The tag’s specific information is read by a reader located on the glove, and is transmitted by Bluetooth. The associated information is shown to the user through the visualization device that is located on his/her head. Instead of connecting with a computer, OQQ devices (small-sized computers) can be integrated into clothes. The whole system is a bit bulky, making usability difficult, and using Bluetooth means that communications do not have high enough energy efficiency.

In 2005, the University of Birmingham [6] developed a device which mixed RFID with GPS technology in an application for the police in cases of crime scene investigation. Once all evidence has been tagged, the inventory is made by creating a tie between the evidence bag and content. An RFID reader and a GPS device are connected through serial ports, and some audio and video peripherals are added to it. Thus, each time a reading is done, a detailed description is included in the evidence.

Life[7] is a system which is sensitive to the context and able to recognize workers’ tasks. As part of the wearIT@work project, they are working on the development and testing of a platform which is capable of monitoring industrial world activities, with the Skoda car manufacturer as collaborator. The wearable aid is used to help assembly process learners. To achieve this goal, different types of sensors are combined and installed, both on the body and inside the car. An RFID reader is used again, located on the hand to detect the object that is being handled, but in this case the application adds a Bluetooth interface to obtain communications. To monitor tasks, they have produced a motion jacket that includes the necessary sensors, as well as the Ubisense system, to calculate the worker’s location in the car.

Other experiments, like in [11], have included some aspects on reasoning, contextualization and daily interaction, depending on each environment. They have obtained information through an RFID reader fitted to a glove, which communicates with a data base. The testing application was a kitchen with more than 50 RFID tags. These tags were assigned to certain products, allowing a specific recognition that permitted the identification of what kind of food was being cooked, for example. Results were satisfactory, identifying as many as 11 different activities during testing time.

The MIT Media Lab from Cambridge has developed “ReachMedia” [12], a system which offers instantaneous information on daily aspects enabling transparent interaction through an RFID reader that is located in a bracelet. This operation frees the user’s hands and eyesight, thus allowing maximum transparency for the user. Furthermore, this wristband includes an audio outlet and some accelerometers to obtain an approximation of the possible position of the user’s hand. In ReachMedia project, the miniaturization of all
electronic devices became a priority, to achieve the mentioned transparency.

In all these projects, there are some deficiencies in relation to our research goals, which have been aimed at the specific scenario of a inventory system for department stores. That is the reason why we intend to obtain maximum energy efficiency and to adapt dimensions to the glove size (it requires the maximum miniaturization of the prototype form factor). Interaction requirements must be advanced too (including audible alarm, images, feedback to receive text messages from the base station and so on), and in a few words, general transparency for the user.

Looking at communications that have been commonly used in local applications, Wi-Fi and Bluetooth involve a higher latency for establishing and managing connections, and substantial energy consumption [13]. However, ZigBee is a more suitable and efficient type of communication technology. In addition, we pursue certain information processing in the RFIDGlove, so as to obtain a distributed computing node which connects with other network elements in order to implement the expected service, not a simple peripheral. In the next section we briefly describe the architecture of the RFIDGlove.

III. RFIDGLOVE ARCHITECTURE

A. Concept

As mentioned above, the main goal of the project was to design a natural interaction system capable of obtaining updated information on the products. It is based on RFID tags used to carry out inventory work in stores. The system should be made up of:

- a wearable element in a glove form. Therefore, after a short training period, the user will not consciously perceive wearing the device, it being transparent;
- an energy-efficient wireless communications system to send data on the read tags to a nearby information server and tolerant of mistakes to recover from coverage loss;
- an advanced visual feedback system, based on the display integrated in the glove, which assists the user by showing images of the handled products and allowing the information server to send instructions to the user indicating how he/she can do the possible activities.
- a monitoring system that centralizes the indoor location of all RFIDGloves and the information gathered by the devices, providing an administration tool for the store controller.

The following sections describe various design aspects of the system.

B. Software design

The computing and communication MicaZ platform, which is integrated into the RFIDGlove has to execute different functions. It must communicate with the ID-12 RFID reader to capture what it has read. Then it sends the packet with the information to the base station that is connected to the information service. Furthermore, it works depending on the response that the base sends back. The included uOLED screen displays the results of the reading, for example, an object photograph and the text notifications that the base station sends.

The code which has been implemented in the MicaZ mote is programmed in nesC over TinyOS. The different modules involved in the RFIDGlove program are shown in Fig. 2.

There may be situations where the RFIDGlove cannot communicate with the base mote, for example, due to the lack of coverage. If communication cannot be established, the glove has to be able to enqueue the information to transmit it later, losing as little information as possible. For this purpose a circular transmission queue of 97 positions has been implemented. The queue's maximum size is limited by the hardware. The MicaZ motes have a 4KB RAM memory. It has been decided that when the queue is full, it is not possible to store more data.
power than other platforms. The RFID reader has to be continuously powered during normal operation because it must be able to read passive tags at any moment. The micro-display can be turned off when not needed. The intUOLEDController interface has been implemented to control this micro-display.

As regards communication between the RFIDGlove and the base station, the latter receives messages from the RFIDGlove and is connected to the computer where the local application is running. The Tags’ associated information is taken from the XML file and then a reply message is sent to the RFIDGlove to display it. In addition, the base station can send text messages to the glove, e.g. alarm texts.

As can be seen in the diagram, the first step is to read a tag (1). Almost immediately, the RFIDGlove provides feedback through the visual and audio interfaces and sends the information obtained through the mesh network to the base station (2). The communication between the RFIDGlove device and the base station was developed with the MicaZ wireless module. The information server processes the message with the code of the read tag (3) and replies to the glove sending information to be displayed on the display (5). Furthermore, the server can automatically or manually send a text message to the glove to notify the user about performing a specific action.

The integration of all these devices involves conflicts and disputes which must be resolved, apart from physical changes. For example, the first version of the plates had a copper layer which reduced the RFID reading rank, so the coverage was inefficient. To solve this problem, we hollowed out the unnecessary copper, leaving just the copper paths on the plate. In addition, the final version has an extra insulating layer. A wrong choice of capacitance values can modify the correct operation, reducing its global reading ability. Besides, the integration of all devices generated an increase in temperature for the equipment, but this problem was solved by introducing a resistor in the RFID data pin, whose voltage level is higher than the mote working voltage level. This resistor reduces the voltage level without reducing the current level. Finally, this has simply been a brief summary of problematic situations which were solved step by step.

C. Prototype

The physical result of the hardware implementation can be seen in Fig. 4. The elements’ layout is justified by the intention of obtaining as much handling flexibility as possible for the user. As a consequence, the prototype has been divided into two boards, which are interconnected with the 10 lines bus.

The upper plate (A) only has the user interface elements: screen, buzzer, leds and button. The plate dimension is going to be delimited by the uOLED screen. In addition, the RFID reader is under the screen, on the other side of the plate; on the back of the hand to read tags from objects which will be handled with the palm. The RFID signals are transmitted through the user’s hand. If the reader was at the palm, it would not allow clenching the hand completely and natural handling would not be real.

The second plate (B) has the processing elements, which includes the MicaZ mote, the feeding and regulating system (with the necessary capacitors) and others, like resistors. The global feeding is obtained from an additional battery, which is connected to this plate. Figure 4 shows a 9 V and 260 mAh battery. This second plate is located on the glove wristband.

The smallest elements are hidden below the mote.

IV. RFIDGLOVE APPLICATIONS

We have developed and deployed different applications to prove the functionality of our device.

One of the applications uses the RFIDGlove for activity recognition, Fig. 5. Users can do their routine work without being aware that all the activities are being logged. The workflows can be analyzed in order to improve the efficiency.
Another example is an inventory application, Fig. 6. While the user moves different boxes to their corresponding shelves, the RFIDGlove communicates the movements through the network to the base station, which is connected to the central computer.

The application records the different movements that the operator has made, where each object was placed and in which moment. Therefore, the application can be used to control the existing stock. A possible extension to this application is to connect the system to the Internet through the base station, in order to analyze the stock, and depending on the result of the query, proceed to purchasing more products on-line. Additionally, the base station can connect to the Internet informing the user about extended product information downloaded from the website.

Finally, an indoor location and remote management tool enables monitoring all the RFIDGloves working in the store. The indoor location of each worker wearing an RFIDGlove is shown on the map and the information interchanged between the glove and the central computer can be controlled. Different alarms can be defined for each glove, so that urgent operations can be notified to the workers located closest to the operation area.

V. OTHER POSSIBLE RFIDGLOVE APPLICATIONS

The possibility of automatically recording all manipulations performed by workers in their everyday activities can be extremely efficient in domains where complete traceability is needed.

Some procedures at hospitals, such as medicine or special food distribution to patients, need to be checked and traced to avoid fatal mistakes. Even school menu dispatching to children with allergy problems can be dangerous if correct identification of children and food trays cannot be performed by workers in real time.

Any application needing traceability and location of items manipulated by people can take advantage of this system, such as libraries, internal courier systems, etc.
The added functionality of wearable display and central location, monitoring and alarms setting offers a more reliable and flexible solution for a distribution system where workloads can be changed and assigned on demand.

VI. EVALUATION

The distance ranges in which the RFIDGlove is able to make readings depends on the tag type used. We have measured reading distances from 0.8 cm to 3.5 cm depending on the tag type. By placing the RFID reader on the back of the glove, the signal is reduced when it goes through the glove (a glove for hard work, with resistant materials and reinforced areas) and the hand. The reading distance is also reduced, but the reader is more transparent for the user. In fact, on the back of the glove, where the signal only crosses the display, it is not a problem to read tags between 3 cm and 11.8 cm. The importance of these issues is relative because, depending on the application that the glove is designed for, it is acceptable to require physical contact with the objects in the warehouse.

In addition, it is very important to extend the battery life, to perform as many readings as possible without changing the battery. Although the battery used for tests was a rechargeable battery of 9 V and 260 mAh, the information is generalized for a 1500 mAh battery, similar to those available in cellular phones and digital cameras. The working frequency selected for the calculations is a read operation every 2 minutes and the average will be calculated with the corresponding percentages. The battery is intended to have an energy efficiency of 90%. The results of the theoretical calculations of the consumption of the various main components are presented in Table I.

Therefore, the battery will provide practically 24 hours of continuous usage of the glove and around 720 readings. It can be extended with small optimizations, depending on the usage pattern of the RFIDGlove.

<table>
<thead>
<tr>
<th>Device</th>
<th>Average consumption (mAh)</th>
<th>Life of a 1500 mAh (h) battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFID reader</td>
<td>6.625</td>
<td>-</td>
</tr>
<tr>
<td>uOLE display</td>
<td>36.875</td>
<td>-</td>
</tr>
<tr>
<td>MicaZ mote</td>
<td>3.574</td>
<td>-</td>
</tr>
<tr>
<td>3 Leds</td>
<td>9.225</td>
<td>-</td>
</tr>
<tr>
<td>Buzzer</td>
<td>0.500</td>
<td>-</td>
</tr>
<tr>
<td>TOTAL</td>
<td>56.799</td>
<td>23.76</td>
</tr>
</tbody>
</table>

VII. CONCLUSION

In this paper we have described the design of a wearable RFID reading system with efficient wireless communications and visual feedback as the principal differential factors with regard to previous experiences. The RFIDGlove allows the speeding up of the inventory process. The user has his hands free, as he/she does not have to carry any reading devices. The glove implements a mechanism of natural interaction based on the proximity of the hand to the RFID tags of the products involved in the inventory. The process is faster and more pleasant for the workers.

The integration of a visual element in the glove improves interactivity and it allows a broader understanding of what is happening at each moment. Furthermore, with an appropriate hardware selection and its layout on the glove, a non-intrusive product for users has been designed.

Among the future applications of the system, we plan to add a voice synthesizer to the RFIDGlove. Apart from the visualization of the objects, the user will be able to hear the associated information, thus improving the efficiency of the inventory process. Finally, the integration of the RFIDGlove into an indoor location system based on ZigBee will make it possible to provide location information on each user at any time, thus opening the way for additional location-aware services.

REFERENCES