Building unobtrusive wearable devices: an ergonomic cybernetic glove

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Abstract

Usually, experts on wearable technologies decide the physiognomy of the designed devices following their opinion or intuition. In general, no study with real users is conducted to ensure the proposed device is ergonomic. This situation is especially critical when working on cybernetic gloves, since the hand performs high precision movements and has a high sensitivity. Therefore, in this paper we present a novel prototype of cybernetic glove, based on RFID readers and other sensors. Our proposal includes a study about electronic circuit integration in fabrics in order to increase the integration level. Moreover, an experimental validation was conducted in order to analyze which is the best position for the processing device in a cybernetic glove in order to create an ergonomic device by offering four different implementations.

Keywords: RFID, flexible circuits, cybernetic devices, cybernetic glove, ergonomics

1 Introduction

The most remarkable challenges in wearable technologies research, such as creating a friendly user interface or linking the wearable device with the network provider [28], are not typically addressed in scientific works. Either because these challenges are not the object of the research, due to the difficulty of addressing them or because they are more related with an engineering problem than with science, almost any work provides relevant information about, for example, ergonomics in wearable device. In particular, it is common that experts on wearable technologies decide the physiognomy of the designed devices following their opinion or intuition. In general, no study with real users is provided to prove that, in fact, the proposed device is ergonomic. This situation is especially critical when working on cybernetic gloves, since the hand performs high precision movements and has a high sensitivity.

Therefore, the objective of this paper is to design and implement a cybernetic glove based on RFID readers and other sensors such as accelerometers, addressing some of the significant challenges in wearable technologies. In particular, the contribution of this paper includes a study about electronics integration in fabrics.

The motivation of this research is the necessity of proving the society of new and improved wearable devices, where IT infrastructure is seamless integrated into the clothes until it gets disappeared. However, various challenges must be addressed to reach that objective: first, investigating the ergonomics in wearable devices depending on the device configuration, and second looking for new technologies for embedding circuits in fabrics.

The authors also carried out an experimental validation in order to validate the cybernetic glove presented in this paper. Participants performed a special activity with different implementations of the

Journal of Internet Services and Information Security (JISIS), volume: 6, number: 2 (May 2016), pp. 37-52

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cybernetic gloves in order to answer the following research question: *What is the best position of the processing device in the cybernetic glove perceived by users in terms of ergonomics?*

The rest of the paper is organized as follows: Section 2 presents the state of the art in cybernetic gloves and some related research and commercial products. Section 3 describes the contributions of the article. Section 4 explains the experimental validation. Finally, Section 5 shows some results of this experimental validation and Section 6 presents the summary of our work.

2 State of the art. Related works and products

The creation of effective and unobtrusive wearable devices is one of the basic applications of pervasive computing. For example, in works such as [34], it was found, although a formal study was not provided, a wearable glove is the least obstructive way for sensing users. Nevertheless, the prototype designed could not go beyond a sports glove with a plastic package of (approximately) 60x70mm attached to the top. Besides, in an attempt to reduce the weight of the electronic system in the glove, no additional sensors (such as accelerometers) were included. In that way, although these proposals are effective, the unobtrusive and wearable characteristics of the designed device are not fully guaranteed.

The first study about how integrating and RFID into a glove was [36]. Taking this study as precedent, in 2004 the first application for RFID-based gloves appeared. In [24] a ludic application for children is described. In this work, one or more children wear a vest containing RFID-tagged tokens, while one or more pursuers wear gloves with embedded RFID readers. However, the practical implementation of the equipment is pretty similar to the previous case, so it has practically the same limitations mentioned before. Also in 2004, researchers in [34] presented a Proactive Activity Toolkit (PROACT) made of a RFID-based glove for inferring activities given observation from the glove. However, although the pictures shows a more sophisticated glove than the precedents, no electronical description is provided, so it is difficult to evaluate the advances in the state of the art.

One year later, in 2005, a second generation of the RFID-based glove was presented in [17]. Nevertheless, the electronics integration and, overall, the software included into the glove remained still in a low development level.

Also in 2005, the project *wearIT@work* was born [1]. The objective of this project, still active, is contributing on the wearable computing field. In the context of the project several devices for health care, emergency notice applications or production scenarios have been designed and tested. One of the first consisted of a glove with a RFID reader embedded, and a Bluetooth interface to transmit data captured. However, in this case, the prototype included also visualization hardware for presenting the information (instead of the classic computed), which must be located on the user's head. This additional equipment reduced prototype usability and, moreover, the Bluetooth employed at that moment (Bluetooth 2.0) was not prepared for reduced power consumption. In the same year, the 9th IEE international symposium on wearable computers was convened. Many presented works addressed the design of RFID-based devices, among of which [33] described a RFID-based glove including a new miniaturized reader, and [16] a RFID bracelet where the miniaturization of electronic components was priority. Finally, in November 2005, the University of Birmingham presented in [13] a wearable device which joint GPS modules with RFID reader, for being applied in crime scene investigations. As main problem, integration aspects were not appropriately considered.

All these precedents allow the first patent about RFID-based wearable devices to appear in 2006 [29]. The described system includes a RFID-based glove and a RFID-based cap, both connected and powered by means of a wire with a body-area network.

In the following years, [31] presented a solution called Life Pod which tracked activities executed by users by means of a RFID reader integrated in a mobile phone. Other works contributed to sensor discovery when devices are in mobility, supporting device disconnections and reconnections [10], investigating in the correct definition and application of resolution processes [11] and executions in various domains [9]. In 2008, the first evaluation in a real scenario was carried out in the Skoda's car manufacturing installations. As part of the *wearIT@work* project, a new and completed wearable uniform was presented and tested (including a RFID-based glove similar to described in [37]). Also in 2008, a RFID-based glove, including accelerometers for motion analysis, was presented in [29]. In general, this new prototype is very similar to described in [17]. In that year, 2008, a second patent on RFID-based wearable appeared. In [38] a RFID-based glove was presented, including a RFID reader, a small battery, and a connection wire finished into a RS-232 connector to extract data from the device. In this case, no additional sensor was considered.

The subsequent remarkable work on RFID-based gloves appeared in 2009. In [32] one more RFID-based glove was presented. As contribution in the hardware level, this glove included a visualization subsystem, made of a small LCD and a couple of LED. However, integration aspects were not taken into account. Nevertheless, the main contribution of this work is at software level with the incorporation of TinyOS [2], a micro operation system, included into the glove. The glove could receive data from the management system and not only upload the identifications read. Furthermore, the authors integrated the glove with two different desktop applications: an activity recognition application and an inventory application.

Around 2010, the focus of research shifted slightly. From that moment, interest shifts from building advance prototypes to test the utility of RFID-based gloves in different practical scenarios. Thus, in 2011, experiments on the usability of the RFID-gloves in industrial companies [40], interactive therapies with people with neurological damage [18], or picking systems [43] were successfully conducted.

In 2013, the first patent about a RFID-base glove [30] pretty similar to which described in [38] (including a RFID reader, a small battery, and a connection wire finished into a RS-232 connector) is published. More recently, in 2014, articles such as [15] focused on children with learning problems, for which an early diagnosis based on their behavior can be of great importance. In the mentioned article, different smart objects (including a RFID-based glove) were considered to support the discrimination training of children with autism. Also in 2014, a new patent on RFID-based wearable devices appeared. In [41] a new kind of RFID-based bracelet was presented, including this time a wireless communications interface and an improved RFID reader (in order to improve energy efficiency). As final achievement, in February 2014, Fujitsu presented the first commercial product on RFID-based gloves (now called smart gloves) for industrials environments [3]. It included a high-frequency RFID reader, an optical reader for QR codes, various accelerometers and a wireless communication module (specifically Bluetooth). However, the integration is not entirely satisfactory, and the lack of ergonomics in the device is unaffordable outside the industrial environment. Table 1 summarizes and compares all the precedents cited above.

In all precedents, one of the causes of the low integration level is the selected RFID manufacturing technology. The most used solution are high-frequency RFID antennas (also called Near Field Communications -NFC-) [42], which are usually printed coils [4], so its integration is practically impossible in a glove, which must be, overall, flexible and ergonomic. The most typical solution is to create a rigid package placed in the back of the hand [37], where it does not affect the flexion of the fingers. However, as discussed in Section 3, these solutions present problems in practice (such as its negative impact on the natural movement of the hand).

Second, often RFID readers need to incorporate an EMC filter made of capacitors and inductances [5]. The integration level in capacitors can be extremely high, but inductances tend to occupy far more space than any other component [20]. In fact, high integrated circuits try to avoid the use of inductances by means of different techniques [20]. Thus, commercial NFC readers cannot be easily integrated in as much as desired.

Finally, all the works cited above, are focused on solving one particular problem on remote health

Precedent	Connection to the host	Sensorization capabilities	Actuators	Device configuration
Proactive Activity Toolkit [34]	Wireless (WiFi)	No	No	Glove with IT circuits in a plastic case
Tagaboo [24]	Wireless	No	No	Foam glove
Hands-on RFID [17]	Wireless (WiFi)	No	No	Glove with IT circuits in a plastic case or a bracelet
wearIT@work [1]	Wireless (Bluetooth)	Yes	Yes	Configurable, not integrated
Life Pod [31]	Wireless (Bluetooth)	Yes	Yes	Configurable, not integrated
RFIDGlove [32]	Wireless (Bluetooth)	No	Yes	Glove with IT circuits in a plastic case
TinyOS [2]	Wireless (Bluetooth)	No	Yes	Glove with IT circuits in a plastic case

Table 1: Comparison among the relevant precedents

monitoring, implicit interfaces or sensor networks by means of wearable devices. However, none of them addresses the real challenges in wearable technologies.

Therefore, compared with all these precedents, in our proposal a formal study about the glove ergonomics is provided. Usually, researchers decide the physiognomy of the wearable devices following their opinion or intuition. However, in our proposal, a study with real users has been conducted to ensure the proposed glove physiognomy is ergonomic. And second, and finally, the level of integration has been highly improved. Unlike previous works, where the electronic system could easily distinguish from the textile support, in our prototype it is possible to affirm seamless integration has been achieved.

3 An ergonomic cybernetic glove

In this section we technically describe the presented contributions. Mainly, we analyze the integration of an electronic system into an ergonomic cybernetic glove.

3.1 Electronic circuit description

Any cybernetic glove is based on an electronic circuit. In Figure 1, a detailed scheme of the circuit for our cybernetic glove is presented.

Various components make up the circuit:

- Two accelerometers: These sensors are piezoelectric devices, which provide information about the gravity and/or acceleration in the three directions in the space. The information extracted from these sensors will be processed together in order to infer the placement of the fingers and the hand, which helps us understand how the user is performing an action (is a measurement of

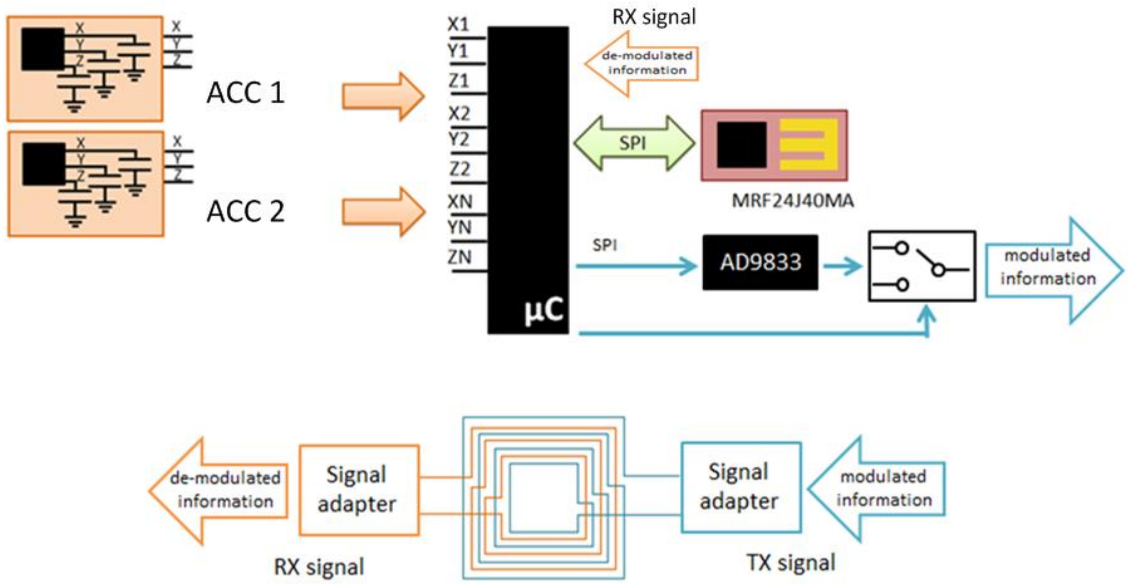

Figure 1: Detailed scheme of the electronic circuit for the cybernetic glove

quality). Phenomena such as tremors, lack of strength, reaction time, or postural deficiencies may be detected by these devices. In the case of in wanting to determine absolute positions of the hand in space, it can be achieved by a prior calibration phase.

- A RFID reader: A miniaturized device, being able to detect objects placed at very short distance (module AD9833 is the digital waveform generator mentioned above). This information will be interpreted at all times as the user is or intends to manipulate the object (grab, drag, press it ....).

- A microcontroller: We have selected a microcontroller from Microchip [6] in QFN package (the smallest possible).

- A 2.4GHz communications module: We used the MRF24J40MA module [7], which allows communication in the band from 2.4 GHz to 2.6 GHz. In particular, we have selected the ZigBee protocol as communication protocol. The main reason for using ZigBee protocol is its ability to greatly reduce the energy consumption of the communication procedure, which is basic to increase the usability of the glove. Both, the MRF24J40MA module and ZigBee protocol allow bidirectional and multipoint communications, however, in the presented prototype, only communications from the glove to the main host have been considered.

The resulting glove may execute several operations, some of which were described in [23]. Once generated the electronic circuit, it is necessary to execute an integration process. Figure 2 presents a conceptual map of the challenges of this process and the contributions made in this paper in each one of them.

3.2 Integration and final design

The integration of an electronic circuit in a garment raises two main questions [22]: how to distribute components along the garment and how to make these components and their connections for being em-

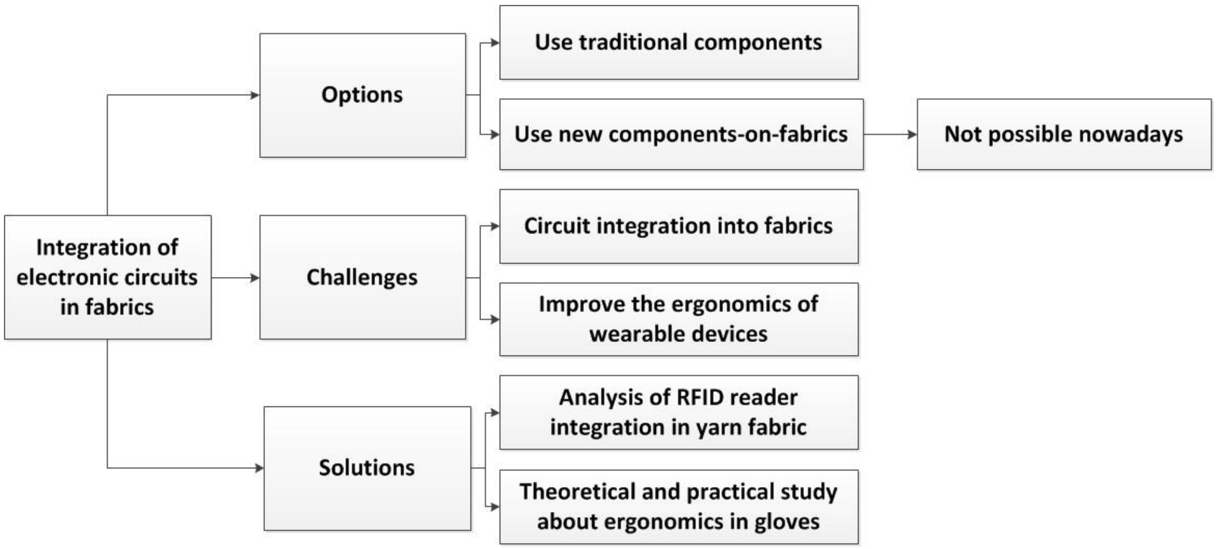

Figure 2: Electronic circuit integration: conceptual map

bedded with fabric. The first question is related with both functional and ergonomic criteria; the second one depends on the solution taken in the first question, the type of fabric and ergonomic criteria.

One possibility is related with removing RFID readers from the glove, and using another technology much more miniaturized. However, many authors have showed the great interest of including RFID readers in gloves [34] [24] [17] [38] [30], as the information about the objects a person interacts with may characterize the user's behavior. Then, we are focusing on how creating an ergonomic RFID-based glove.

The European Standards about ergonomics in gloves [8] propose several requirements which should be taken into account. Table 1 presents the most important requirements, divided into four categories.

Regarding the distribution of the electronic circuit components along the glove, there are two distinct parts. On the one hand, the accelerometers and the RFID reader antenna, which must be positioned so as to provide useful information (functional approach) and do not contravene the criteria of Table 2 (ergonomic criteria). On the other hand, the rest of the elements whose operation is independent of its position on the glove and should only meet ergonomic criteria.

The RFID reader antenna must be positioned so as to ensure a correct reading of the tags placed on objects. Of course, placing the tags on one or more strategic locations is also needed, but since it is not known a priori the way in which a subject performs movements, reader antenna cannot be designed for precision readings. Therefore, and given the way in which hands are articulated, the most appropriate position for the RFID antenna is the palm (it is a large area which always are very close to manipulated objects). Due to the importance of this area it will be very important to make sure that the implementation technology allows the antenna's design to meet the requirements of Table 2.

For its part, the accelerometers must be positioned to provide meaningful information about the movement of the hand. Our proposal is based on one device positioned in the back of the hand, and a second accelerometer on the index finger.

In the hand, index finger is more involved in actions and movements than the others (it is used as clamp to pick up objects, to indicate, for precision tasks such as pressing buttons, etc.). Placing an accelerometer on this finger, and another in the back of the hand, they will be obtained relative values whose variation contains a lot of information about the action that is being developed. The finger accelerometer position also must verify, in particular, the fourth condition of the block ”Adaptation to the

Setting the forms and dimensions of hand	**Adaptation user's activities**	**Thermal comfort**	**Protection**
The glove must fit the shape of the hand	The glove must be sufficiently flexible to allow the natural movement of the hand	The glove must be breathable and avoid the accumulation of sweat	The production of heat in the glove must not cause heat stress or pain on the user
The adjustment to the wrist must be good. It must avoid the loss of the glove without causing pain	The glove must not cause fatigue or decrease the comfort of an activity (or the functionality of an object)	The temperature must not increase more than usual inside the glove	There must not be loose parts to wear out in the glove which cause harmful effects to the user
It must be easy to put and take off the glove	The glove must not get damaged by contact with the objects or substances handled	The glove must have some slack to circulate air without compromising fit hand	Heat dissipating devices must not be in contact with the user
	The glove must keep the finger sensitivity		
	The glove must be light		

Table 2: Ergonomic requirements in gloves

user's activities" ("the glove must keep the finger sensitivity", see Table 2). Since fingers most sensitive area is the yolk, it has opted to place the accelerometer on the back of the finger (on the nail).

In order to place the rest of the components, several proposals have been reviewed. To the antecedents described in Section 2, works about gestures monitoring in Human-Computer Interactions [26] [35] have been added. Thus, in Figure 3 all the possibilities about placing electronic circuits in gloves have been represented.

Among all the showed requirements in Table 2, "allowing the natural movement of the hand" is the most should be respected when designing the placement of the circuit. Thus, in order to select the most adequate placement for the circuit, a specialist on postural health was consulted. He gave us the following tips:

- Implementations A and B are not recommended. The weight of the circuit opposes lot of movements with in these configurations, so it will be necessary to overcome it to perform certain tasks. Users, not having the habit of having that extra weight, lose much control when performing many movements, which impacts negatively in the execution of the tasks.
- Implementation C presents comfort problems to rest your hand on surfaces, as the wrist is curved due to encapsulation. This, for example, can interfere with tasks such as writing.
- In the implementation D weight must be distributed very carefully, in order to build a balanced glove. If not so, similar problems to those described for previous designs may occur.

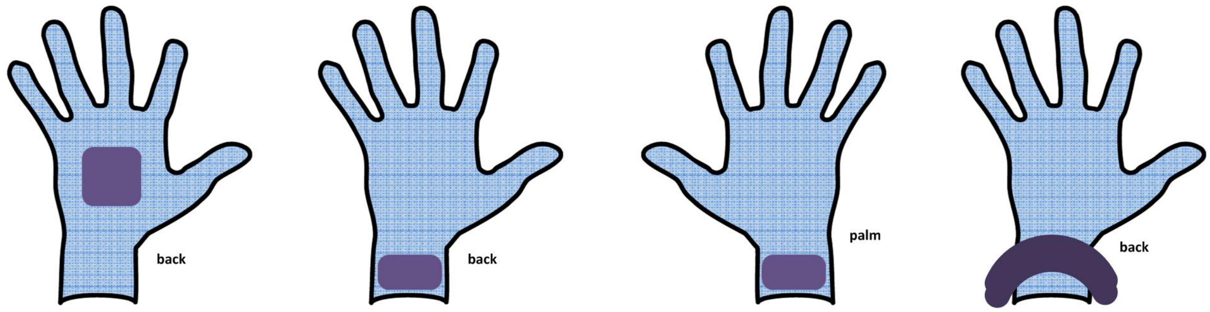

Figure 3: Possible placements of an electronic circuit in gloves

In view of what is described above, the implementation D seems to be the most appropriate. The components distribution should be such that does not bother the support of the hand, but avoiding putting the full weight of the circuit in an area so that users lose control over their movements. Nevertheless, all previous experiences about circuits distributed as bracelets are based on rigid structures [17]. However, the requirements of the category "Setting the forms and dimensions of hand" (Table 2)

shown that the glove, and especially the wrist area should be adjustable at hand, so rigid rings are not a valid solution. Therefore, we decided to make a distribution as an elastic bracelet, so that the glove can be adapted to the contour of the wrist.

Once selected the distribution of the components along the glove, it is necessary an implementation technology, adequate to integrate the circuits into the fabric [39]. Some studies propose the creation of specific fabrics, either based on wires and connectors interwoven with normal yarn [27], or based on several layers of yarn between of which the circuit is enclosed protected, for example, with silicone [21]. These solutions, however, are not necessarily the most adequate. For example, the first proposal does not allow obtaining a circuit as an elastic band over the wrist, and the second one also violates some requirements of ergonomics, for example, "the glove must be breathable and avoid the accumulation of sweat". Thus, for this prototype it has been chosen to use a glove previously woven, on which the circuit is integrated. In this case a crochet glove has been selected as base for the prototype. The glove is woven, to make it more resistant, with three strands of yarn instead of the traditional weaving of one strand. The result is a glove formed by three overlapping layers of crochet.

The first step was integrating the accelerometers. Many works have studied this issue [25] [12]. However, the impossibility of transforming accelerometers in printed circuits or similar technologies, makes all solutions pass through the use of boards as small as possible. Therefore, we also used miniaturized boards where accelerometers are soldered. These boards will be placed over the three layers of fabric of the glove, and covered with an additional layer of yarn, woven with the glove. As the boards were placed in the back of the hand and components properly tined and protected, none of the ergonomic criteria were violated.

The second step is to integrate the RFID antennas in the palm of the glove. Both antennas (receiver and transmitter) are made of coils of copper wire of 0.5mm diameter. The shape of the antennas is almost-square, in order to maximize the covered area without making the manufacturing too much complex. The side of the antenna sizes around 4 cm. Both antennas will be place together, with a little gap between them to avoid the mutual induction (see Figure 5(a)). However, despite of the gap, mutual induction will occur, and the transmission frequency will appear in the reception spectrum and vice versa (Figure 4(a)).

Nevertheless, the RFID signal adapter modules act as extremely narrow passband filters, so also spu-

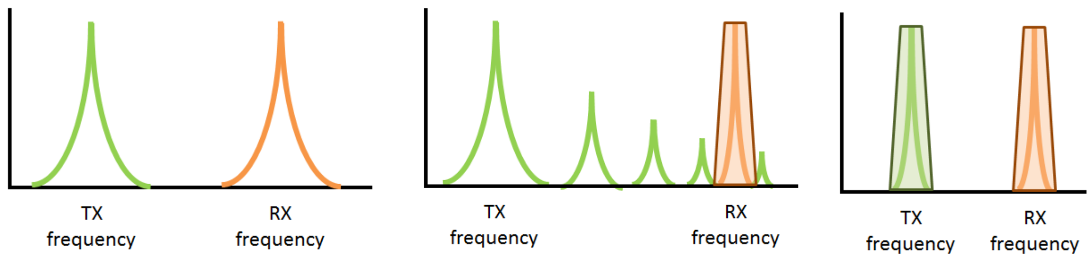

Figure 4: (a) Mixed spectrum due to mutual induction (b) Effect of the filter in the received spectrum (c) Effect of the Signal adapter modules in the spectrum

rious frequencies (including the frequency of the opposite channel and its entire harmonics) are removed (see Figure 4(b) and 4(c)). This situation, however, could not appear in the general case, as it is a particular effect of the selected RFID technology. In order to be able to integrate easily the RFID antenna into the glove, we have selected a technology based on frequency division multiple access (FDMA) which can use copper coils as antennas (see below). This technology, nevertheless, generates a collection of harmonics in various undesired frequencies which usually interferes with the other channel (Figure 4(b)). It is in that situation when signal adapter modules help to limit the interferences (Figure 4(c)).

The copper wire which makes up the RFID antennas is woven in the most superficial layer on the glove, in order to avoid direct contact with the user's hand (along expressed in criteria of Table 2). There are two alternatives for this integration.

The first consists of winding the cable onto the fibers (see Figure 5(b)). However, with this configuration, the magnetic field is parallel to the glove, and RFID reader does not work. In the second option copper wire is woven as any other strand of yarn (Figure 5(c)). In this case, wire is parallel to the glove, so the generated magnetic flow is perpendicular to it. In that way, we can guarantee the correct operation of RFID reader. Finally, coils will be covered with yarn woven with the glove.

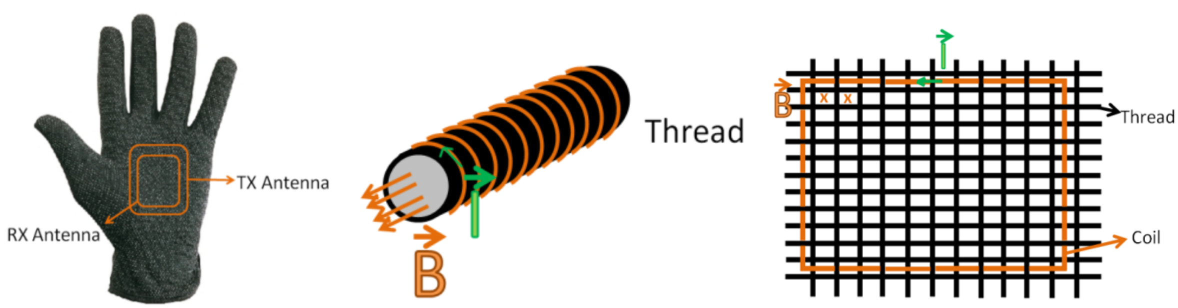

Figure 5: (a) Scheme of the antenna integration in the glove (b) Field scheme in the case of winding wire in the fibers (c) Field scheme in the case of weaving wire in the fibers

The connections between the accelerometers and the circuit in the wrist, and between the RFID and the circuit in the wrist are made with flexible copper wire of 0.5mm diameter, twisted with glove's fibers in the intermediate fabric layer of the glove. An example of this technique can be seen in [23].

Finally, the elastic circuit to be placed in the wrist area is designed. Many solutions about circuit integration in fabric [39] pretend to create flexible circuits; however there isn't any proposal on flexible technology. In part, this is due to the low utility of flexible circuits, where the design would be very complex, because of the existence of transmission lines of varying length (impedance matching, for example, would be impossible). In our proposal we developed a specific circuit implementation.

Algorithm 1: Glove programming

```
input  : Readings and data from RFID and sensors
output: Frame with data integrated
Create an array of bytes FRAME
Create a list of serial ports SP
Create a hash table HT <Integer, Serial port>
Create a serial port object SPC
Function setup ()
    foreach serial port SS in the processor do
        if SS has a device connected then
            Get the information about the connected device
            if connected device is the Bluetooth module then
                SPC is equal to SS
            else
                Create a new entry in HT with the pair (device ID, SS)
            end
        end
    end
    SP is equal to the list of values in HT
    foreach port in SP do
        Configure SP as analog port
        Configure SP as read port
    end
    Configure SPC as digital port
    Configure SPC as write port
    while connection is not stablished do
        Send to SPC a connection establishment message
        Wait for response
        if confirmation message is received then
            Stablish Bluetooth connection
        end
    end
while true do
    foreach entry E in HT do
        if device ID corresponds to RFID reader then
            Active the RFID reader
            Read the serial port stored in E
            Turn off the RFID reader
        else
            Read the serial port stored in E
        end
        Add at the end of FRAME the device ID and the read data
    end
    Write all bytes of FRAME in SPC
end
```

The circuit implementation is based on printed circuits over flexible support (usually called Flex technology). All connections between components of the circuit placed on the wrist will be manufactured with this technique. Once printed circuit is obtained and components are connected, flexible circuit will fold as seen in Figure 6(a). The total length (***l1***) is designed to be will be equal to the contour of the wrist of the glove.

When the wrist of the glove is stretched, flexible circuits will unfold; and the separation between the components will increase (until a length ***l2***). So that the glove can return to its previous state, it must ensure that when the fabric of the glove gets stretched at maximum, the flexible circuits have not been completely unfolded (see Figure 6(a)).

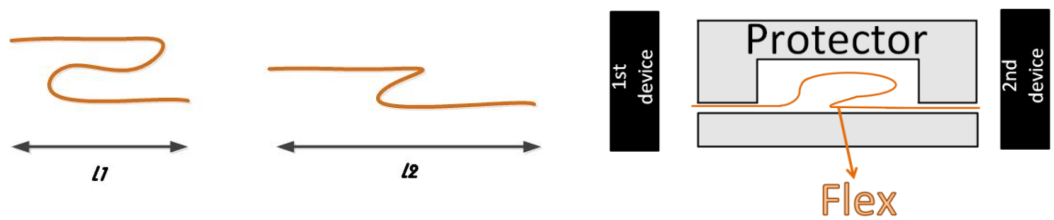

Figure 6: (a) Scheme of the antenna integration in the glove (b) Field scheme in the case of winding wire in the fibers (c) Field scheme in the case of weaving wire in the fibers

Finally, to avoid possible damages and homogenize the surface of the bracelet, the entire set will be covered with a strong and flexible protective substance (previously saving the reserved space for flexible circuits). In our case the protector will be made of silicone (see Figure 6(b)). In the final step the glove was programmed following the Algorithm 1. Figure 7 shows the final prototype.

Figure 7: Final prototype

4 Experimental validation

An experiment was designed in order to analyze and respond the research question that guided this research work: *What is the best position of the processing device in the cybernetic glove perceived by users in terms of ergonomics?*

The aim of this experiment is to determine the best placement of the processing device in the cybernetic glove. For this experiment, four different cybernetic gloves implementations were developed where the distribution of the circuit components changes. The four implementations are described in Figure 3:

- Implementation A: The circuit is encapsulated in the back of the hand. It is most popular solution in research works. An explanation about how to build this implementation can be found in [34] or [19], among others.
- Implementation B: The circuit is encapsulated on the back of the wrist. In [38] the scheme and integration of this solution is described.
- Implementation C: The circuit is encapsulated on the wrist. An example of this architecture can be found in [14].
- Implementation D: The circuit is encapsulated as a flexible bracelet, as described in Section 3.

Experts selected a special exercise routine where all possible hand movements are performed, in order to test with the four physical implementations. Basically, this routine consists of the following exercises: put on the glove, wrist flexion, wrist extension, internal rotation of the hand, external rotation of the hand, finger flexion, grasp an object, rest the hand on a surface and remove the glove. During the experiment the participants tested the four gloves and also a glove with no processing device. Participants never knew which type of glove were using. The information gathered for answering the research question consisted of the subjective perception of the participants about the use of the cybernetic gloves. Using a survey they were asked at the end of each performance if they were able to detect the processing device in the 4 types of gloves and also a fifth glove with no processing device. The available options were five, one for each glove implementation design; and they can also answer “Don’t know”.

5 Results

Several subjects participated in this study evaluating the best position of the processing device in the cybernetic glove. This study is very interesting to improve ergonomics and to make the electronic devices embedded in wearables imperceptible to users. The results are shown in Table 3.

As we can see from Table 3 the more perceptible implementation by the users is the implementation A (where the circuit is encapsulated in the back pf the hand). Almost 80% of participants were able to sense the circuit. We assume that the subjects were able to detect the processing device because although it had little weight, it was easily located in the back of the hand due to its moment of inertia (in the rotations of the hand).

Implementations B and C are quite similar, almost half of the participants were able to sense the processing device. Both encapsulations were on the wrist (back and front) but that extra weight was detected by subjects; because it was not distributed throughout the wrist as in implementation D.

The implementation D was the least detected design by the participants, this was due to two design factors: first, it is encapsulated around the wrist that is where there is less moment of inertia in hand; second, the weight is distributed throughout the wrist, allowing the weight of the processing device to be less sensible.

These results were validated by specialists on postural health, which agreed with the results.

	Implementation A: Circuit encapsulated on the back	**Implementation B: Encap. on the back of the wrist**	**Implementation C: Encapsulated on the wrist**	**Implementation D: Encapsulated as a bracelet**	**No processing device**
(%) Hits	79.17	58.33	41.67	16.67	0
(%) Faults	16.67	8.33	25	29.17	62.5
(%) Don't Know	4.16	33.34	33.33	54.16	37.5

Table 3: Results about processing device position

6 Summary

Wearable technologies are rapidly becoming very important in daily life. Their integration with pervasive computing schemes and cyber-physical systems are the future of consumer electronics. Works about related technologies such as RFID, biometrical sensors or ambient assisted living (AAL) usually propose wearable technologies as experimental prototypes. However, these prototypes rarely address the real challenges in wearable devices, and there is often no progress beyond a very basic first implementation.

In this paper we described a new cybernetic glove which aims to advance both in the level of integration and in the achievement of the objectives for wearable technologies. In this work, we proposed a friendly device for users, where the circuit is integrated paying special attention to ergonomics, and where the included sensors can be easily modified without requiring expert knowledge. We also proposed a new implementation for circuits in gloves, based on flexible bracelets. Finally, we provided also an experimental validation with real users and we found the most ergonomic distribution is in which components are distributed as a flexible bracelet. Some conclusions may be extracted:

- Real seamless integration must be supported by materials engineering. Commercial components can be used in an ergonomic way, but only new fabrication technologies might generate the real wearable devices of the future.

- Despite the first point, commercial components can be used in the design of improved wearable devices, with good results

- New RFID technologies are necessary to advance towards the second generation of wearable devices and, particularly, RFID-based cybernetic gloves.

- Finally, more studies about ergonomics in cybernetic and wearable devices, performed by specialists on postural health are needed, in order to advance in the correct direction towards the next IT revolution

Acknowledgments

The research leading to these results has received funding from the Ministry of Economy and Competitiveness through SEMOLA project (TEC2015-68284-R). We also thank the Autonomous Region of Madrid for the funding of MOSI-AGIL-CM project (grant P2013/ICE-3019, co-funded by EU Structural Funds FSE and FEDER).

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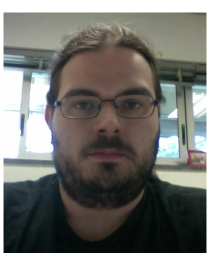

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