T4AI: A system for monitoring people based on improved wearable devices

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Abstract

Monitoring people is central to many applications. Some works from the literature prove that information about that the sequence of objects a person uses while performing an activity robustly characterizes both, the activity and the quality of its execution. In this paper we present a novel system called "Toolkit for activities Inference" (T4AI) for inferring the activities executed by people from the interactions with objects. The system includes as main element a cybernetic glove based on wearable RFID readers and sensors. Our proposal includes an improved RFID technology being able to be used in metallic environments (such as industry scenarios). Moreover, an experimental validation was conducted in order to determine the performance of the proposed system.

Keywords: cybernetic devices, cybernetic glove, RFID, T4AI, Toolkit for activities Inference

1 Introduction

From the beginning, human-activity tracking techniques have focused on direct observation of people and their behavior with cameras, accelerometers, or contact switches [27]. Nevertheless, around ten years ago, a new approach was born [22] [29]. It consisted of complementing direct observation with an indirect study, deducting people's actions from their effect on the environment, especially on the objects with they interact. Thus, many works (such as [25] and [14]) have explored ways to obtain and use knowledge of person-object interactions.

Knowing which physical objects a person touches is central to many applications [27]. Logs of objects touched during a day may be, for example, the basis of "experience sampling" [7] programs whose objective is reconstructing user's behavior.

Basically, three main techniques have been applied in human-activity tracking [27]: computer vision, active sensor beacons and passive RFID. Among all these, computer vision is the least mature technology, remaining many challenges unresolved. Active sensor beacons allow us to know, very precisely, the interactions human-objects, but require the use of batteries (which hinders their long term use). On the contrary, RFID is a mature technology which provides the same accuracy as active sensor beacons, but with the advantage of not requiring the use of batteries. In return, RFID tags are unable to detect motion. Despite this inconvenience, RFID technology has been widely used for tracking human activity, especially by means of its integration in wearable devices [27] [12].

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However, most of the proposed devices based on wearable RFID readers are really similar (they often resembles to some kind of "smart glove"), and remain in a pretty low development level.

Therefore, the objective of this paper is to design and implement a new system for human-activity tracking based on a cybernetic glove built with a new generation of wearable RFID readers and wearable sensors. We call this new system "Toolkit for activities Inference" (T4AI). In particular, the contribution of this paper includes the description of an improved RFID technology being able to be used in metallic environments.

The authors carried out an experimental validation in order to validate the presented T4AI in this paper. The statistical evidences and findings obtained during the experimental validation are very remarkable and indicate the presented system in this paper is a reliable solution for tracking the execution of the human activities.

The rest of the paper is organized as follows: Section 2 presents the state of the art in human-activities tracking systems and wearable. Section 3 presents the contributions of the article. Section 4 describes the experimental validation. Finally, Section 5 and 6 explain some results of this experimental validation and the conclusions of our work.

2 State of the art

RFID technology is considered in many fields (such as sales or logistic processes) as the future way in which information will be introduced in information systems (as replacement, among other solutions, of the barcode). Actually, nowadays, RFID tags are more extensively used than, for example, barcodes in many areas.

In research, since 1999, papers such as [32] have discussed how RFID tags can be used to bridge physical and virtual worlds. One year later, Albrecht Schmidt defined the "Implicit Human-Computer Interactions" as actions performed by the user that are not primarily aimed to interact with a computerized system, but which such a system understands as input [25]. Merging both ideas, concepts such as the RFID-based glove [27] or the iBracelet [12] for human monitoring were immediately developed.

The first study about an RFID-glove was [26]. This prototype is based on a low-frequency RFID technology, so the maximum range reached is quite large. However, the connection between the glove and the main host is wired, so the working distance is limited to the length of the wire. Moreover, the design of the glove it is not very ergonomic, as the hardware is not completely integrated with it.

In 2005, this research field suffered a real revolution. First a second generation of the RFID-based glove was presented in [12]. In this work, a miniaturized NFC reader was employed, instead of the low-frequency RFID reader, so the electronics integration improved substantially. Moreover, a wireless communication module was also included, removing the wire which connected the glove with the main host; thus, the working distance strongly increased. The obtained prototype (called iGlove) was also complemented with a smart bracelet (called iBracelet) for applications where it was not possible to integrate the electronics in the glove (such as in sanitary scenarios). Second, a new RFID technology including sensing capabilities was described. As we said in the introduction, around 2004 a new approach for human-activity tracking was described in [22] and [29] (among others). This technique consisted of complementing direct observation with an indirect study. However, all the described prototypes do not merge direct and indirect observation, but replace traditional instrument by RFID technology. Then, a research group from the Intel Research Seattle presented in [23] a new project (called Wireless identification and sensing platform –WISP-) merging both sensing capabilities and RFID technology. These devices (passive, programmable and provided with a microcontroller unit) interact with RFID readers and WISP readers. If a traditional RFID reader is used, only identification number is obtained. If a WISP reader is used, both the identification and data from sensors included are obtained. However, the

WISP project presented in [23] (called alpha-WISP) is not enough, as sensing capabilities are limited to one-axis accelerometer. Thus, some months later, an improved pi-WISP project is presented in [28]. In this new article, sensing capabilities had grown for supporting three-axis sensors, so most sophisticated application can be considered. With this new pi-WISP technology available, a new iGlove and iBracelet provided with accelerometers were described in [27]. Although this was the first prototype in including both sensing and RFID capabilities, the rate reached for data collection from sensors was rather poor, so critical real-time applications were not covered in this approach.

Finally, after a period when no works about smart gloves were published, in very recent years (since 2013) various prototypes and research works have been reported [8]. In 2013, the first RFID-based glove was patented [19]. It included a RS-232 connector, a small battery and a RFID reader. In 2014, systems based on smart gloves for monitoring the children behavior were described [11]. Also in 2014, Fujitsu presented a system [1] being able to control the operators in industries, using a RFID-enabled smart glove also provided with a QR reader. In 2015 three important prototypes were implemented. First, the Italian company IDROGENET SRL deployed a system called GloReha [2], based on a computerized glove which infers the hand movements (and corrects them) in the context of neurological rehabilitation. Second, the German startup ProGlove [5] developed a wearable tool targeted at professional production processes. The wearable is basically an ergonomic smart glove being able to detect certain patterns. Finally, at the Massachusetts Institute of Technology (MIT) a smart glove based on Arduino platform and some accelerometers was successfully employed to translate the sign language into an English speech. The proposed glove, named as SignAloud [6], is based on a powerful pattern recognition engine and a voice synthesizer. Table 1 summarizes and compares the described relevant previous works.

In all cited precedents, one of the causes of the low development level of the wearable devices is the selected RFID technology. In most RFID technologies the reading range is too high [31], and it cannot be said the glove detects the touched objects when all objects in a meter radius are detected. Furthermore, the reading range in NFC (Near Field Communications, the most used solution) is between five and ten centimeters, and it may become too large depending on the application scenario. On the other hand, all the gloves cited above present a great problem: they cannot be used in metallic environments. This limitation is due to the use of passive RFID tags, which cannot obtain energy from the reader when placed on metallic surfaces (as metals “reflect” the energy). In the last five years various proposals addressing this issue have appeared [13] [10]. However, all are focused in Ultra-high frequency RFID technology, which presents a reading range around 1.5 meters [10] (a too high value) and operates in the band of 850-950 MHz (a band legally regulated in many countries, so that the UHF RFID technology cannot be used freely, for example, in most of Europe) [31]. There also exist some commercial products for “on-metal NFC tags”. Nonetheless, they are based on the creation of a gap between the surface and the tag circuit, by including several layers of different materials [4]. The result is a tag of a much larger size than usual, and that can hardly be placed on small objects which need to be precisely manipulated.

Therefore, compared with all these precedents, our proposal presents a great improvement. An improved and miniaturized RFID technology, capable of working in metallic environments, is developed. It is really important to note that many objects in all scenarios are metallic, and, as we saw, none of them could be tagged by using traditional RFID tags, as none commercial technology is totally suitable for application to a cybernetic glove. This problem, which has only been partially addressed in the literature, is resolved with the proposed technology.

3 Toolkit for activities Inference

We technically describe the presented contributions. In the first subsection, the application scenario is defined. In the next subsection the improved RFID technology is described. Later, in Section 3.3 the

Precedent	Characteristics	Problems
First RFID-glove [26]	Very large maximum range.	The electronic circuit is not completely integrated. Wired solution.
iGlove [12] Children monitoring system [11]	RFID readers are miniaturized. Wireless solution.	Does not include any direct observation technology (accelerometers, sensors, etc.).
WISP [23] Pi-WISP [28] New iGlove [27]	RFID readers are miniaturized. Wireless solution, includes accelerometers.	The data rate is very poor. Critical real-time applications cannot be developed.
First patented RFID-based glove [19]	RFID readers are miniaturized.	Does not include any direct observation technology (accelerometers, sensors, etc.). Wired solution.
Fujitsu smart glove [1]	Includes accelerometers and a QR reader. Wireless solution.	The electronic circuit is not completely integrated.
GloReha [2]	Includes accelerometers and a pattern recognition system.	Does not include RFID readers. Wired solution.
SignAloud [6] ProGlove [5]	Includes accelerometers and a pattern recognition system. Wireless solution.	Does not include RFID readers.

Table 1: Comparison among the relevant precedents

final electronic system is presented.

3.1 Application scenario

From the beginning, wearable technologies and pervasive computing [20] were developed together. In fact, Mark Weiser explained in 1991 [33] [24], talking about pervasive computing, "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it." Furthermore, one of the basic applications of pervasive computing is using computers and sensors to infer users' behavior in their environment. In applications performed in controlled scenarios (such as living labs or training houses), cameras and artificial vision are the proper technologies, as they are the least obtrusive and there is almost no problem associated with their deployment and operation (as conflicts with privacy or improper handlings of equipment by users). However, some applications require to evaluate the users' behavior in uncontrolled environments (such as the workplace or the user's home), which are more aggressive scenarios and deployments may not provide the precision needed by the cameras (which, for example, must be properly focused). Besides, in the second case, it is necessary to consider factors such as privacy, the space configuration (that probably will not be as open as in controlled scenarios) or the available space in the user's home. In that scenario, wearable technologies seem to be the response.

Among all the applications which fit with the second described case, the study of people with cognitive disorders in first stage is a priority (especially in an increasingly aging world) [15]. However, it remains being a difficult application area to infer whether and how people are performing activities [16]. Causes are various [22]. First, people can perform a same activity in different ways, so models adapted to these requirements are needed. Second, the aggressiveness of the uncontrolled environments causes the underlying hardware of ubiquitous computing system and wearable devices should be tolerant to high levels of noise, light, vibration, etc. And, third, the number of activities is too huge for modeling each activity separately; so automatic instruments to create these models are necessary.

In [22], researchers from Intel Research Seattle (closed in 2011) partially solved these problems. They proposed a system (called Proactive Activity Toolkit –PROACT-) which represented activities as a probabilistic sequence of objects used (which allowed addressing the first challenge in human-activities tracking). Moreover, they created probabilistic models of activity use from plain English descriptions of activities such as recipes; solving in that way the third challenge. To address the second challenge, they found RFID as a robust technology to sense the objects being used in several contexts. Nevertheless, due to the technology limitations, a huge list of objects could not be detected, such as those made of metallic materials.

Therefore, the aim of this article is building a new system (called T4AI) addressing the shortcomings of earlier prototypes. For this purpose, an improved RFID technology that detects interactions with metal objects was developed. In the background, we also worked to solve another of the basic challenges in the design of wearable devices: the communication between the glove and other hosts (for which it was made use of modern low-energy technologies).

In scenarios related to people with cognitive disorders in first stage, motion analysis is a very important complementary information source, for evaluating the quality with which activities are being performed. So, the most proper additional sensors for our application scenario are three-axial accelerometers [31].

The proposed system:

- Includes the cybernetic glove, a processing application and an analysis engine to infer the executed activities using both RFID and accelerometers data.
- Represents activities as a probabilistic sequence of objects used.
- Describes probabilistic models as TXT files, written in plain text.

With this system, authors conducted an experimental validation where various people were monitored, allowing us to determine the correct performance of the proposed solution.

3.2 An improved RFID technology

RFID-based wearable devices [9] have received great attention in the last 15 years (see Section 2). Furthermore, in the last five years, many miniaturized new RFID technologies for wearable devices have been proposed. However, most works [21] [17] propose including UHF RFID tags in fabrics, in order to maintain clothes "passive" (without independent power supply). The objective of these wearable devices is to monitor users' position by means of, for example, various antennas strategically placed to make a triangulation [30]. The main reason to include passive tags in fabrics, instead of active readers, is the difficulty of miniaturizing RFID readers and making them energy efficient (see Section 2). However, in our application, we are detecting objects used by the users, so passive tags must be placed in objects and the user have to be provided with and active reader (in our case, integrated in the cybernetic glove).

Two additional problems have to be taken into account in the use of traditional RFID technologies in a wearable glove. First, the minimum distance at which a tag can be read (using high frequency RFID solution [31]) is around 5 centimeters. This value is too high in our application, as we are only interested in the object touched by the users. In a typical daily living situation, various objects are placed together, and we need distinguish which particular object has been picked up. None other tag must be read. And, second, RFID tags cannot be placed in metallic surfaces [31]. On the one hand, traditional RFID tags cannot be read if placed in metallic surfaces, which may be found every day in our lives (in kitchen items, clothing, containers, furniture, etc.). Any case, a real monitoring of the activities of daily life cannot impose constraints on the objects used.

Therefore, to create our cybernetic glove we designed an improved RFID technology based on miniaturized active readers, being able to read tags placed on metallic surfaces and whose minimum reading distance tends to zero (direct contact). As limitation, this technology does not allow the use of commercial solutions, making it difficult to perform large deployments at low cost.

In order to be energy efficient and be able to reuse tags for different applications (which lowers system cost) the proposed technology comprises both a miniaturized, active reader with reading and writing capabilities; and rewritable passive tags. Thus, both the reader and the tags are formed by two different transponders: a transmitter module and a receiver module. The objective of this scheme is to be able to establish a full-duplex communication between reader and tags by means of the use of two different radio channels (Figure 1).

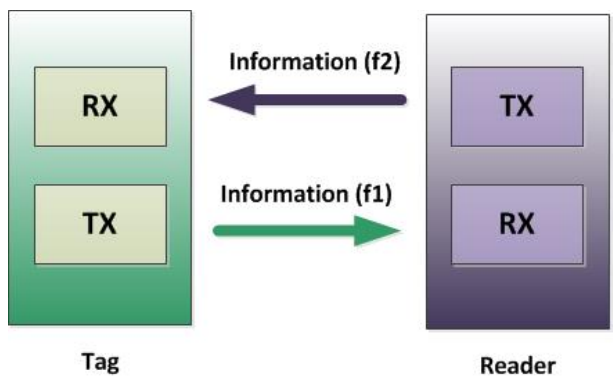

Figure 1: Communication scheme for the RFID technology

If both radio channels are sufficiently separated in the frequency domain, any relevant interference between both frequencies will occur. Over these two channels, data packets containing the identification of the tag and the reader will be sent.

The general design for the transmitter module in the reader and in the tag is the same (Figure 2(a)). The information to be transmitted modules a carrier frequency in amplitude (using ASK modulation), which is adapted to be radiated by means of an antenna tuned at the carrier frequency. The signal adapter module is an extremely narrow passband filter that only allows passage of the carrier frequency, eliminating any other component of the spectrum.

Although the general design is the same in both elements (reader and tags), the transmitter implementation is different depending on the device. The reader must be, overall, robust. It is going to be placed in a glove, so it will be subject to changes of position, shock, friction, etc., in this scenario it is important that its operation is not affected significantly in these situations. The tags, meanwhile, must be inexpensive (as it is important to have a lot to place tags in all objects of daily life). Therefore, to implement the transmitter in the reader, it has been chosen a much more complex and expensive technology, but very robust. Meanwhile, for the tag, it has been sought the most cost effective solution.

In the case of the reader, the amplitude modulation is made by means of an analog switch, selecting between the carrier signal and ground (Figure 3(a)) following a TTL signal which codifies the informa-

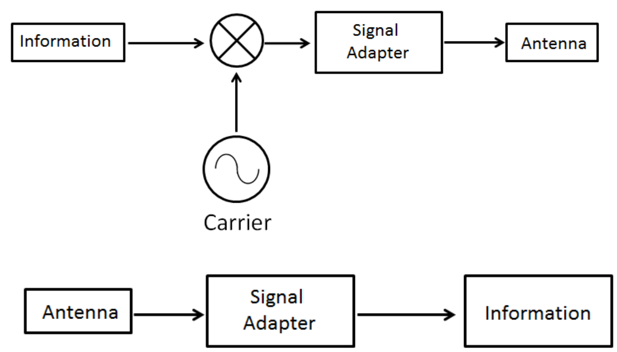

Figure 2: (a) General design for RFID transmitter (b) General design for RFID receiver

tion to be transmitted. Both, the carrier signal and the information signal are generated by the same high integrated microprocessor (to which a digital waveform generator is added). Using a software simulated oscillator reduces the size of the reader, its price, increases its robustness and allows an easy selection of the carrier frequency.

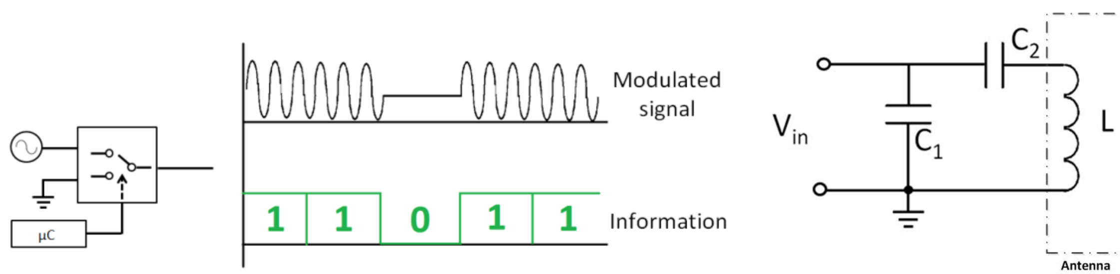

Figure 3: (a) ASK modulator in the RFID reader (b) Signal adapter circuit in the reader

This scheme for the transmitter, although it cannot generate large-signal (more than 3V in amplitude) it is sufficient if the reading distance between reader and tag is very small (as in our case).

Moreover, the use of an analog switch and software oscillator (instead of the traditional analog crystal oscillators) greatly simplifies the signal adapter module. Usually [3] adaptation stages need an EMC filter and an impedance adapter circuit made of six capacitors and two inductances (which are especially problematic in high integration). In comparison, in our technology, signal adapter module only needs one passband filter made of two capacitors. To achieve this, the circuit uses the inductive impedance viewed from the end of the adaptation stage towards the antenna (when it is in transmission). Figure 6(b) presents the resultant circuit. The transference function of that circuit is similar to which showed by a second order passband filter. The advantage of that design is that, at carrier frequency, C_1 capacitor supplies current to the antenna, so the signal is amplified, and the radiated field maximum. Furthermore, at the carrier frequency and due to the fact that the circuit is resonant, the impedance of the set is minimal and negligible the energy dissipation (which greatly reduces power consumption).

In the case of the tag, the amplitude modulation is made by means of only one high integrated microprocessor. The microprocessor will generate a TTL function codifying the information to be transmitted. Then, that signal passes through the adapter signal module described above, so all components in the spectrum are cancelled, except carrier frequency, and TTL signal is "rounded" (the final result is similar to an ASK modulated carrier). This procedure is much cheaper, but is weaker and requires certain degree of stability to operate.

The receiver module is the same in both tags and reader (a global scheme is presented in Figure 2(b)). The signal is received by means a tuned antenna, and it passes through a signal adapter module (which removes all signals in the spectrum except the modulated carrier). Later, the filtered signal passes through a demodulator, capable of extracting the information coded in the carrier.

The signal adapter module is formally the same as described above, except in this case the inductance associated with the antenna is viewed as if it were a signal source (Figure 4(a)). The received signal, therefore, is also amplified in that resonant circuit. The demodulator is made of half-wave rectifier, which transforms any period of non-zero signal at a high level of continuous voltage. Said continuous signal fed to a digital to analog converter (ADC) integrated in the microprocessor. When the ADC accumulates several values much greater than zero, it is decided, then, that has been received a *'1'*. In opposite case, it is assumed transmitted a *'0'* (Figure 4(b)). Thus, sample speed is a critical parameter of the design.

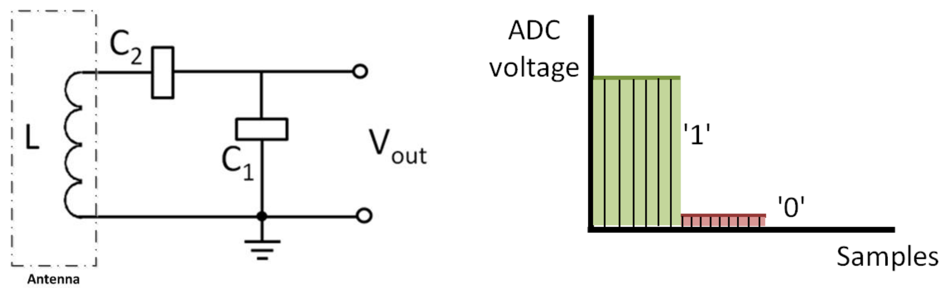

Figure 4: (a) Signal adapter circuit in the reader (b) Output of the demodulator

The physical phenomenon that allows communication between tag and reader is the mutual inductance between two coils. When by a coil of copper wire is circulating a variable current, the coil generates a magnetic field (Figure 5(a)). This field is not too intense, but at very short distance there is indeed a magnetic flux perpendicular to the coil (Figure 5(b)). When a second coil enough approaches the first, the field generated crosses the second coil and induces a current that varies as does the flow (Figure 5(c)). This mechanism (much like how transformers work) permits the use of low power signals, and ensure that only those tags located close enough can be read (ideally those with whom the reader has contact).

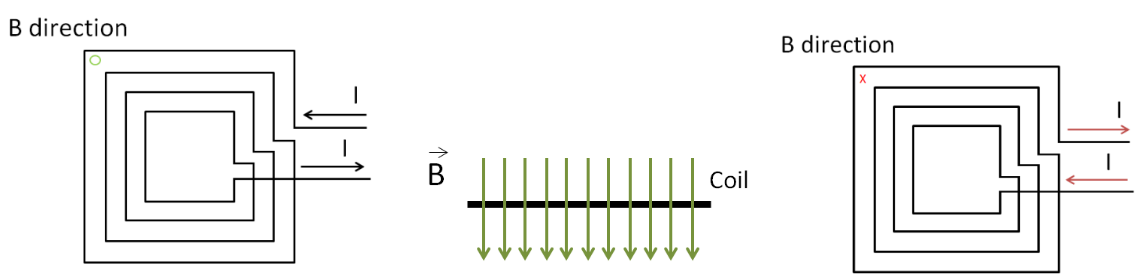

Figure 5: (a) Magnetic field generated in a coil (b) Perpendicular magnetic flux (c) Induced current in a coil by a magnetic field

In traditional RFID technologies [31] there are various ways in which the RFID reader-writer can communicate with the RFID tag. Basically, three physical processes are used: backscatter coupling, capacitive coupling and inductive coupling (which it is used in the glove). With the traditional design of RFID readers and tags, capacitive coupling are used for close range links (within 1 centimeter), inductive coupling for remote links (between 1 cm and 1 meter) and RFID backscatter coupling for long range links (more than 1 meter). However, capacitive coupling requires including rigid electrodes, acting as the plates of the capacitor, which extremely difficult to integrate into a flexible fabric. Thus, the inductive coupling is most suitable procedure (as copper coils can be very flexible), although the read range in the traditional technologies is too large. With the proposed technology, this problem disappears and close range links with inductive coupling are reachable.

Working with very low power signals and very short range links, removes all legal limitations on the use of frequency spectrum. Therefore, it has been chosen to work in the band of tens of kilohertz (up to 1000 times below the NFC band). This allows reducing the power consumption of the system for the same transmitted power, lowering the components' price and getting a greater level of integration. Furthermore, the spurious modulation effects are located far away from the passband at these frequencies, so a more robust operation is achieved.

Nevertheless, the main advantage of using inductive coupling at very short ranges is the possibility of using our technology in metallic environments. Tags can be placed over metallic surfaces, and communications may continue taking place robustly.

Finally, it is important to note that, apart from the reduction in the number of components achieved with our technology (which already greatly reduces the system size), the area occupied by the coils in our solution may be significantly less than that used in commercial solutions. In addition, for all the components mentioned above there are a highly integrated version, and even microprocessors can be developed in printed technology if the algorithm to be run in that microcontroller is prepared.

3.3 Complete electronic system

Once presented all the contributions in the electronic field, in this section we are describing the final electronic system on which the cybernetic glove will be based.

Figure 6 shows the global scheme of the system.

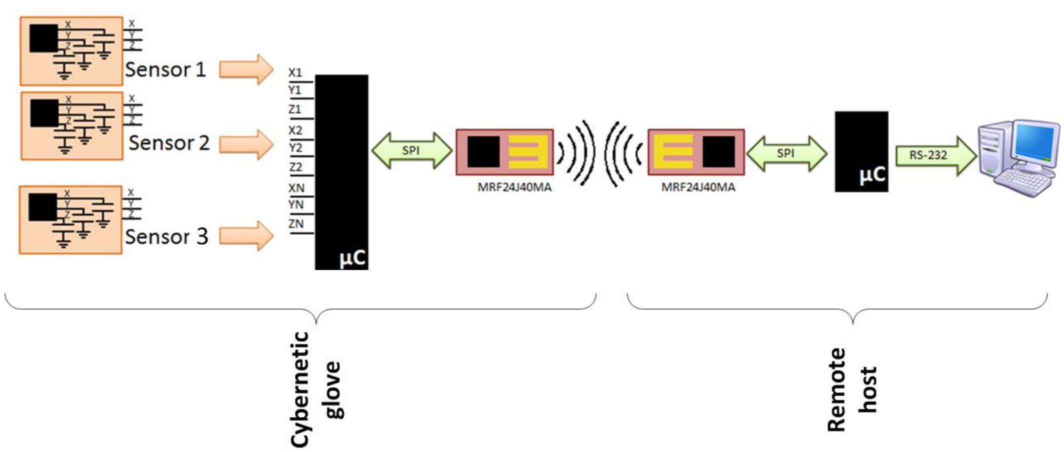

Figure 6: Global scheme of the electronic system

In the cybernetic glove, a sort of sensors is connected to a main microcontroller. Being more specific, the glove is provided with three sensors: two accelerometers and one RFID reader (see Section 3.2). The microcontroller, with the data collected, builds a data frame to be transmitted toward the remote host where processing takes place. That frame is transmitted by a traditional SPI port to a 2.4GHz communications module, which implements ZigBee protocol. The remote host is connected through a RS-232 port to a ZigBee receptor made of a microcontroller and a 2.4GHz communications module (equal to which is included in the glove). In that host, a MATLAB application receives, processes [18] and presents data and results.

Then, the sum of all information provided by the accelerometers and the RFID reader (transmitted by means of the processor and the communications module) enables a MATLAB application to calculate and determine the users' behavior in the remote host.

3.4 Final prototype and system operation

The electronic system described above was integrated in a woven glove, being able to communicate with the analysis engine and the data processing application, both implemented in MATLAB code. The resulting wearable device can be seen in Figure 7.

Figure 7: Final integrated smart glove

Both the analysis engine and the data processing application were implemented using MATLAB code and some of the pattern recognition functions available in that environment. In particular, the data processing application filters the received data and removes the frequency components due to electronic noise, interferences, etc. Once the important information has been extracted, it is sent to the analysis engine where a Hidden Markov Model (HMM) allows the identification of the executed activity. Figure 8 represents the graphic application used as interface between the pattern analysis engine and the users.

Finally, the system operation is described in the flowchart showed in Figure 9.

4 Experimental validation

Table 2 shows the activities selected for this experimentation.

The experiment was split in three different phases:

- *Training phase:* Participants received some training about the activities they had to perform with the cybernetic glove, the activities they have to perform and how to perform it. The participants attended a lecture where they were trained and they saw the gloves for the first time, while experts presented them and performed some examples.

- *Activities performing phase:* Each participant was interviewed in this phase. The participant was asked to execute the 6 activities being monitored with the proposed T4AI.

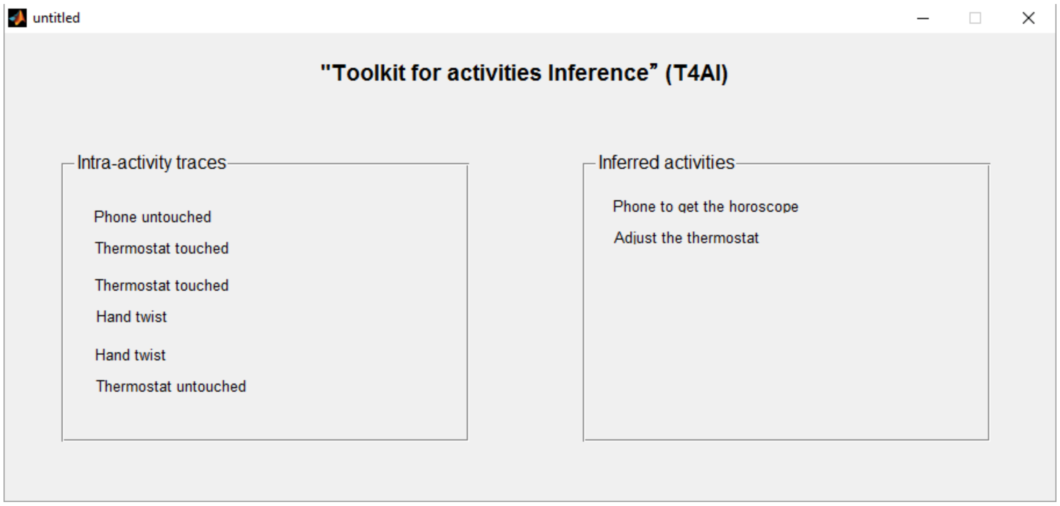

Figure 8: Graphic application in the analysis engine

Activity number	**Activity description**
1	Use a microwave
2	Adjust the thermostat
3	Turn on TV, watch it for a few minutes, turn it off
4	Take some pills
5	Phone to get the horoscope
6	Make yourself a cup of coffee

Table 2: Tested activities

- *Evaluation phase:* In this phase, experts evaluated the records obtained by the system for each participant.

The experiment was performed in a laboratory at the Technical University of Madrid (UPM). The "Toolkit for activities Inference" (T4AI) was deployed in the laboratory, in order to collect and process all data from the cybernetic glove, and for inferring the activities being performed by users. T4IA reported automatically the result of the activity at the end of each performance; experts took note about all the results. When a performance was correctly classified, it scored a true positive (TP); an incorrect it scored a false positive (FP); but when an activity occurred and was not reported by our system, it scored as a false negative (FN).

5 Results

In this section we present the results obtained in the experimental validation. The analysis about the activities inferred by T4IA is shown in Table 3.

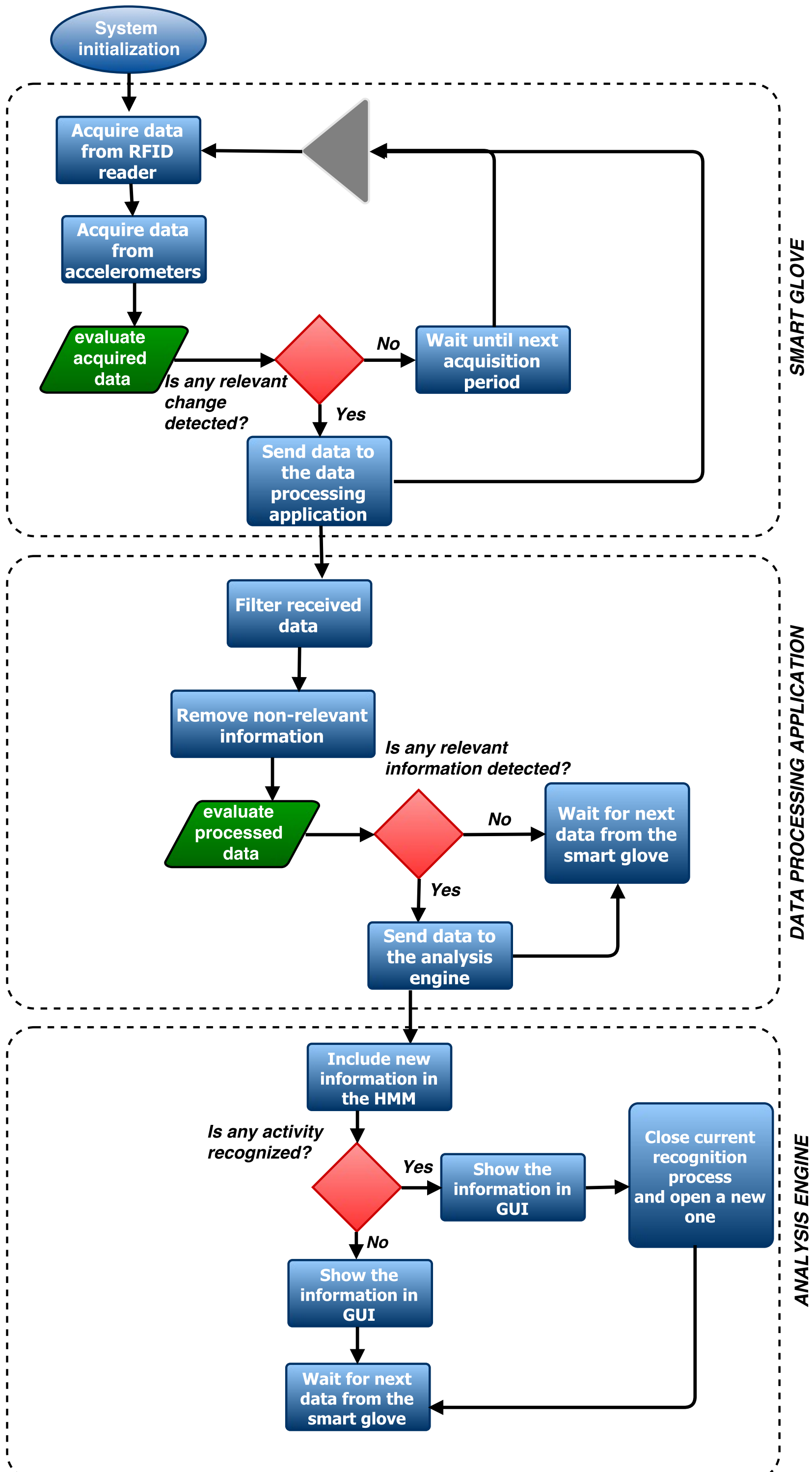

Figure 9: Flowchart of the proposed T4AI

A Mann-Whitney U test was conducted in order to test if the precision and recall obtained in our experiment are significantly different from the results obtained by Philipose and Fishkin [22]; we could not find any statistical evidence confirming the difference between the two samples.

Activity no.	True Positives	False Positives	False Negatives
1	12	3	6
2	15	0	3
3	15	1	3
4	13	2	6
5	20	0	4
6	10	3	5
Total	85	9	27

Table 3: Experiment result for the RQ1 validation

Therefore, we can assert that T4IA (Toolkit for Activities Inference) used in the validation behaves the same way as system presented by Philipose and Fishkin [22]. Then, it can be said that activities performed by user can be inferred with the proposed system as with the precedent, so in the proposed T4AI no functionality is lost compared to the previous prototypes (Section 2). However, our system presents various advantages such as the possibility of considering metallic objects in the application scenarios.

6 Conclusions

With our proposed T4AI and its cybernetic glove, the limitations about the objects which can be manipulated by users being monitored are reduced thanks to an improved RFID technology being able to read tags placed over metallic surfaces.

We provided also an experimental validation with real users. In order to probe the correct performance of the proposed system, we investigated if the TP, FP and FN obtained using our system are significantly different from the results obtained by Philipose and Fishkin [22]. We did not find any statistical evidence confirming the difference between the two proposals.

Acknowledgments

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