ClothFace: A Batteryless Glove-Integrated User Interface Solution based on Passive UHF RFID Technology

line 1: 1st Given Name Surname
line 2: *dept. name of organization (of Affiliation)*
line 3: *name of organization (of Affiliation)*
line 4: City, Country
line 5: email address or ORCID

line 1: 2nd Given Name Surname
line 2: *dept. name of organization (of Affiliation)*
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line 5: email address or ORCID

line 1: 3rd Given Name Surname
line 2: *dept. name of organization (of Affiliation)*
line 3: *name of organization (of Affiliation)*
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line 1: 4th Given Name Surname
line 2: *dept. name of organization (of Affiliation)*
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line 5: email address or ORCID

line 1: 5th Given Name Surname
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***Abstract*— Due to their unique advantages, wearable user interface solutions have gained a lot of research and commercial interest. This paper introduces ClothFace technology by presenting a batteryless glove-integrated user interface. The solution is based on passive ultrahigh frequency (UHF) radio frequency identification (RFID) technology. The first prototype of this solution was fabricated from copper tape to a normal cotton-based glove. The user interface on the glove consists of three antenna parts on three different fingers of the glove, each of which has an RFID microchip with a unique ID. Further, an additional antenna part is attached to the thumb of the glove. The antennas are initially separated from each other, and none of the microchips is readable for the RFID reader. When the thumb antenna touches any of the three finger antennas, the touch creates an electrical connection, and the corresponding microchip can be detected by the RFID reader. In this study, the developed glove-integrated user interface was evaluated in an office environment by three test subjects, who all received 100 orders from a specific testing software. The average success rate in this first test was 98 %. These initial results are very encouraging, especially when considering that the glove-integrated user interface, being light, flexible, and cost-effective, promises versatile interesting applications in several fields.**

Keywords—antennas, glove, intelligent clothing, passive UHF RFID, user interface, textile electronics, wearables, wireless systems.

I. Introduction

In recent attractive human-technology interaction solutions, wearable systems have been used as user interfaces through touch or human body movement. The most common ones of such interfaces, for example touchpads and tapping buttons [1]-[4], can be integrated around the arm for detecting hand movements. This type of placement is very convenient for practical use.

Several different types of technology solutions have been developed for wearable touch and gesture recognition systems, such as skin electronics [5], versatile sensors (for example acoustic, ultrasonic, infrared proximity, and reflective marker sensors) [1]-[6], and interactive textiles [7][8]. The main challenge, when considering their daily use and maintenance, is that most of these solutions require complex electronics together with an on-board power source. These requirements significantly increase their cost and limit their flexibility and functionality in practical use.

Further, different vision-based methods have been presented to capture touch traces on surfaces. This is enabled by using several cameras [9]-[11]. As a line-of-sight from the cameras to the user is needed, which means the user must be directly seen by the cameras in these solutions, their usability and especially mobility is quite limited. By using normal WIFI signals, namely by measuring the received signal strength indicator or channel state information, promising early results have been achieved in recognizing different types of gestures and in using them as digital inputs. [12][13]. However, WIFI solutions are challenging to establish into multiple user environments. Further, they are also only useful in a specific use environment [14].

The properties of passive ultra-high frequency (UHF) radio frequency identification (RFID) technology make it an attractive solution for wearable user interfaces. Passive UHF RFID tags communicate wirelessly with RFID readers, and they have a working range of several meters. Each RFID tag has a microchip, i.e., RFID integrated circuit (IC), which has a unique ID. As this technology is fully passive, it does not require any on-board power source. Instead, the tags are powered directly by the reader. The tags respond to the reader by backscattering the received signal with their unique ID. When passive UHF RFID tags are attached to the human body, body movement will cause a variation to the backscattered signal. The variations of the backscattered signal strengths and phases have been successfully tracked in order to recognize specific body positions and movements [15]-[17]. Further, different sensing properties, such as temperature sensing, have been integrated into RFID

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microchips. Finally, as a change in the antenna length or wetting of the antenna substrate both affect the backscattered signal of a passive UHF RFID tag, by tracking the changes in the tags' backscattered signals, passive UHF RFID tags themselves have been also used for example as strain and moisture sensors [18]-[20].

However, despite the successful versatile use of passive UHF RFID technology presented above, passive RFID tag-based gesture tracking and sensor results have revealed, that the backscattered signals of passive UHF RFID tags in normal use environments are noisy and unstable. Thus, a new type of approach is needed in order to fully benefit from this cost-effective and simple technology.

A so called "ClothFace technology" has been developed to solve the above-mentioned challenges. ClothFace enables a simpler readable/non-readable use of RFID microchips, which means the functionality can be simply on/off. The first ClothFace solution, i.e., a clothing-integrated passive UHF RFID human-technology interaction solution, was based on a shirt-integrated antenna, which could be used to activate single RFID microchip components placed around the user [21]. Next, this concept was developed further by fixing a passive RFID-based table platform, consisting of three RFID microchips [22]. Here, several combined passive UHF RFID microchips could be "switched on and off" by touch-created electrical interconnections to antennas. Due to the previously mentioned unique ID of each microchip, they could be then used as specific input buttons.

In this paper, the ClothFace technology is developed further. We are establishing a glove-integrated user interface solution, which comprises of four antenna parts and three RFID microchips (each with a unique ID). A specific microchip, and thus a specific ID, can be activated by single finger movements, and then used as a digital input. Further, swipe controlling to left and right can be achieved easily by only slightly more complex finger movements. As our passive UHF RFID technology-based solution is completely self-energy efficient and draws all the needed power from an external RFID reader, the glove itself is extremely light and flexible.

The used antenna designs are next introduced in the second chapter. The chapter also introduces the design and manufacturing of the glove-integrated interface solution. This developed user interface is tested in the third chapter. The results of the testing are presented in the fourth chapter. The fourth chapter also discusses the practical use of the solution and its potential application areas. Finally, the conclusions of this study are presented in the last chapter.

II. Antenna and Glove-Integrated User Interface Designs

The design of the developed two-part passive UHF RFID antenna is illustrated in Fig. 1. For the glove-integrated user interface, three of such antennas were used. The antennas were integrated into a normal cotton-based glove. As shown in Fig. 1, the antenna was separated into two parts. Part A has an attached UHF RFID microchip. Part A antennas were firstly attached on the index finger, the middle finger, and the little finger on the glove. Part B of the antenna was then attached on the thumb of the glove.

All the antenna parts for this first prototype were cut from a non-stretchable copper tape. All the antennas and the microchip components were attached to the glove using normal textile glue. The microchip used in this work belongs to NXP UCODE G2iL RFID microchips. It has a wake-up power of −18 dBm (15.8 µW). These components were connected to the antennas (to Part A) by conductive epoxy glue (Circuit Works CW2400). A ready-made glove-integrated user interface solution is presented in Fig. 2.

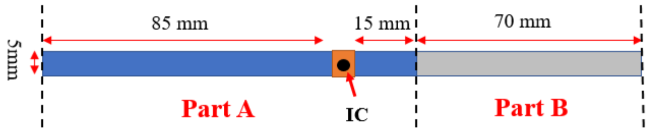

Fig. 1. Glove-integrated user interface antenna design with dimensions.

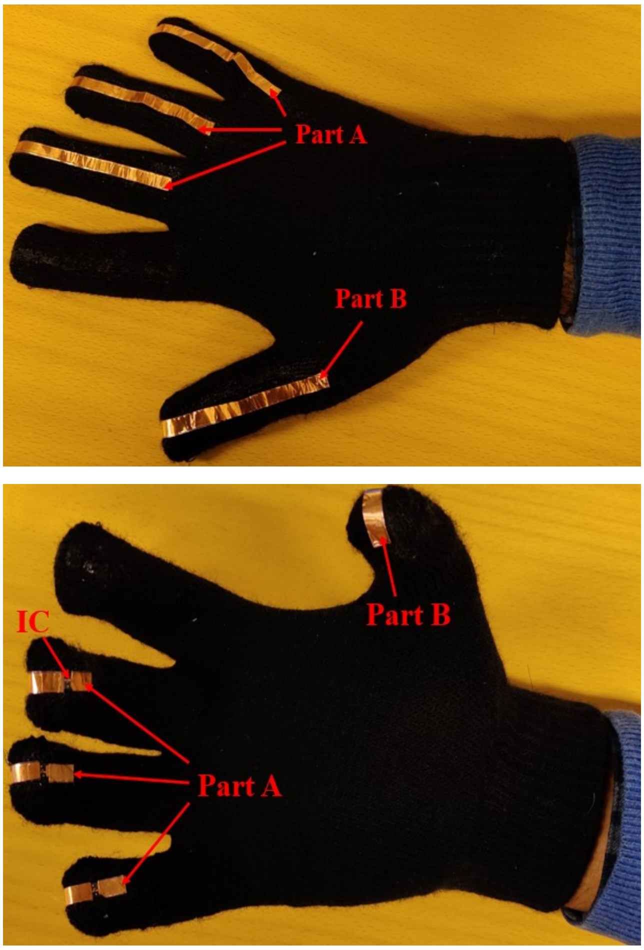

Fig. 2. Top side of the glove (top) and palm side of the glove (bottom).

As presented in Fig. 2, the two parts of the antenna were initially disconnected. Thus, none of the microchips were readable for the external RFID reader. This off-status of the platform is also shown in Fig. 3. When the thumb antenna touches any of the other three antenna parts in fingers, the touch creates an electrical connection between Part A and Part B of the antenna. Thus, the corresponding microchip can be detected by the RFID reader. This microchip activation is shown in Fig. 3.

III. Testing Setup and Testing Software

Fig. 4 shows the testing setup, which included the glove-integrated user interface, a circularly polarized RFID reader antenna, which was attached to Thingmagic M6 RFID reader through a connecting cable, and a specific testing software. The reader operated at the European standard frequency range (865.6-867.6 MHz) and the used power was 28 dBm. All wireless testing was performed at 70 cm from the RFID reader antenna. At this distance, the glove interface was found to have an optimized wireless performance.

As presented in Fig. 4, the testing setup was built to a normal office environment. Thus, the testing environment was very realistic, when considering for example practical use in a home environment, which also has wooden and metallic furniture, as well as people walking around using their mobile phones and WIFI.

The testing software, which is presented in Fig. 5, has been described with more details in a previous study [22]. The testing software uses ThingMagic Mercury API tools to control the M6 RFID reader and filters the received microchip IDs, so that no other RFID tags around will disturb the system performance.

Fig. 3. Off-status (top) and on-status (bottom) of the glove-integrated user interface.

One female and two male test subjects participated in the glove-integrated user interface testing. The testing software asked the users to perform the following actions in a random order: touch finger 1, touch finger 2, touch finger 3, swipe left (done by touching fingers 3 to 1), swipe right (done by touching fingers 1 to 3). Each tester received 100 orders, and the testing software saved the inputs they gave into an excel sheet. The results were saved in a right/wrong format, which was presented as 1/0, respectively. The testing software also stored the asked input and the given input. If there was no input given within 5 seconds, the input was saved as a 0 and thus also counted as an error.

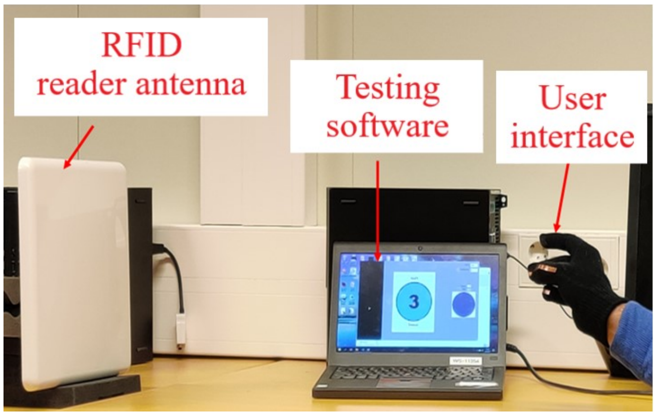

Fig. 4. Testing setup and testing software in an office environment.

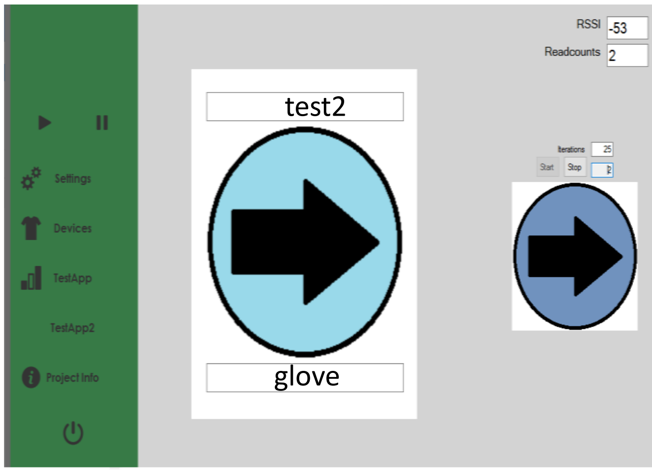

Fig. 5. Testing software screen asking for "swipe right" as an input.

IV. Results and Discussion

Table 1 shows the testing results from three testers, who all received 100 orders from the testing software. As can be seen, the overall success rate in this first test was 98 %. Thus, these preliminary results prove that the glove-integrated user interface can attain a high input accuracy in a normal office environment, which is quite like a home environment.

TABLE I. Success and error rates of the three testers using the glove-integrated user interface in an office environment.

Tester	Success rate	Error rate
1	98%	2%
2	99%	1%
3	98%	2%

These first results about transferring ClothFace technology into gloves can be considered promising. The fundamental strengths of the glove-integrated user interface implemented here lie within its passive nature and cost-effective and simple implementation into clothes. This glove interface uses simple finger movements, which makes it extremely simple to use and thus also convenient for children and elderly people.

This type of intelligent gloves could be used to improve work efficiently and safely, for example in replacing paper and pen by using hand gestures for writing simple notes, or by accessing doors and storages by giving the right password with one's work glove. We also imagine the glove-integrated solutions to be useful in entertaining games as well as in gamification of learning and therapy. A light glove could replace the traditional heavy game controllers, and thus especially support gaming of people who have decreased hand strengths. Further, we imagine this glove to make educational and rehabilitation games more fun, which will greatly support learning and therapy. For example, physiotherapy games could use the glove together with RFID solutions integrated into other parts of one's clothing or into the surroundings. Finally, we imagine this glove to enable more communication possibilities for people with speech and language problems. With the help of our user interface and personally designed software, people could express themselves, for example by writing sentences or by asking for help. This could provide more autonomy and independence.

As a next step, we are optimizing the antenna designs used in the glove. Our goal is to make the user interface functional in the whole office room by using as few reader antennas as possible. Further, we are testing different types of manufacturing methods to integrate the antennas into different types of gloves. Possible methods and materials include for example electro-textiles and embroidery with conductive thread. Further, our goal is to use the glove with a mobile phone-integrated UHF RFID reader. This will make the system fully mobile, as it is powered and controlled through the mobile phone. Further, the glove-integrated user interface will be able to take advantage of any auxiliary or external technology, which can be connected to the system through the mobile phone's Bluetooth connection.

In the future, we want to use the ClothFace technology to build versatile clothing-integrated wireless platforms, which look and feel like normal clothing, and can be comfortably used in the daily life actions. As discussed, such clothing-integrated user interfaces have countless of applications.

V. Conclusion

In this paper, we introduced a new application of the ClothFace technology, a passive UHF RFID-based user interface, integrated into a glove. The presented first prototype was fabricated from copper tape into a normal cotton-based glove. During preliminary testing, an average success rate of 98 % was achieved by three testers in an office environment. These results are very encouraging, especially when considering that the glove-integrated user interface, being cost-effective, light, and flexible, promises versatile applications in several fields.

Next, the glove-integrated user interface solution will be further developed by optimizing the antenna designs for the best possible wireless performance. Further, we will be testing different types of antenna materials and glove types, as well as taking advantage of mobile phone-integrated UHF RFID readers, which will provide a full mobility and more application possibilities for the system.

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