ClothFace: Battery-Free On-body Interface Platform for Future Human-Machine Interaction

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***Abstract*— Smooth communication between people and machines plays an important role in the intelligent environments of the future, where the best sides of both people and machines are to be exploited in the name of efficiency and flexibility. This requires a functional human-machine interface that allows the necessary control actions but does not require any use of robot-specific devices. In this paper, we further introduce a passive ultra-high frequency (UHF) radio frequency identification (RFID)-based platform, which is an attractive solution for on-body interfaces, as it is passive and maintenance-free, does not require a line-of-sight to function, and has reading distances of several meters. The unique aspect of this study is the established fully textile-based battery-free touchpad for writing digits, which can be integrated into everyday clothing and worn on body. Further, the paper presents various use cases for the developed technology.**

***Index Terms*—antennas, ClothFace, human-machine interaction, passive RFID, touchpad.**

I. INTRODUCTION

In intelligent environments, such as factories, hospitals, and shopping centers of the future, smooth communication between people and machines will play a significant role. To utilize the superior efficiency and productivity of robots and other automatic machines, as well as human flexibility and situational awareness in rapidly changing environments, people and machines must be able to communicate as easily and quickly as possible [1]. This requires the development of a new kind of agile communication systems, as well as design of usable, concrete applications.

In this paper, we introduce a passive ultra-high frequency (UHF) radio frequency identification (RFID)-based platform, which is an attractive solution for on-body user interface (UI), as the technology is passive and maintenance-free, does not require a line-of-sight to function, and has reading distances of several meters [2]-[5]. The technology enables identification and tracking of objects and people, achieved with battery-free tags that are wirelessly addressable and composed only of an antenna and an integrated circuit (IC). Each IC has a unique ID. The tag can be read from the distance of several meters, even near the lossy human body [6]. This technology is also cost-effective, as the cost of RFID ICs is only cents.

On-body UI can be integrated into the human clothing / body, freeing the human hands for other tasks, while at the same time allowing control of machines, systems, environments, or robots. The system brings a new perspective and various possibilities for implementation of the human-machine interface. This can be utilized by users who have challenges in using traditional controlling devices, or in such environments, in which the use of traditional controlling devices is challenging if not impossible.

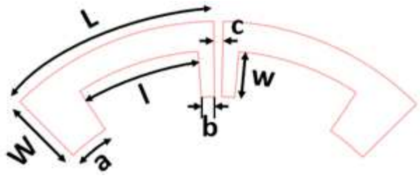
On-body movement and touch recognition has been done by using different technologies, such as skin electronics, different kinds of sensors, and interactive textiles [7]-[10]. However, as these require quite complex electronics systems and/or power sources, their practical use in daily life is limited. Prior studies of passive RFID-based user interfaces have primarily relied on tracking the backscattered signals [3][5]. In that case, when a person touches or moves an RFID tag, it manifests as a traceable change in the backscattered signal, which can be turned into an input for digital actions. However, many factors in the practical use environments, such as electronic devices, wooden and metallic furniture, as well as human bodies, cause the backscattered signals of RFID tags to be noisy and unstable. Recently, RFID-based interfaces utilizing on/off performance of the ICs were studied to track simple expressive gestures [11][12]. In this method, touching the IC will create an electrical connection that allows reading of the specific ID of the touched IC. Thus, instead of changes in the backscattered signal properties, IDs of the ICs are tracked, making the reading more reliable. Recently, He et al. [13] presented the first prototype of a passive RFID-based handwriting platform prototype on a textile, using a 10 x 10 matrix of RFID ICs. This ClothFace platform was demonstrated to recognize handwritten numbers 0–9.

In this paper, the on-body ClothFace UI has a new type of tag antenna array for robust on-body transmission and appropriate size. The unique aspect of this study is the established fully textile-based battery-free touchpad for writing digits, which can be integrated into everyday clothing and worn on body. The paper first presents the design and fabrication of the technology, and then some initial test results. Finally, before conclusions, the paper presents various use cases for the developed system.

II. SIMULATION AND FABRICATION

The on-body UI consists of an IC platform and RFID antennas. To achieve suitable wireless performance on human body, a new type of tag antenna array was designed for the platform by ANSYS HFSS (full-wave EM solver based on the finite element method). The goal of the simulation was to achieve sufficient read range when placed on the human thigh. In simulation, the human body part was simplified to a layered mode for rapid calculation. The model layers from top to bottom were 2 mm thick EPDM (Ethylene-Propylene-Diene-Monomer), 3 mm skin, 100 mm muscle, 100 mm bone, 100 mm muscle, and 3 mm skin. The size of the full model is of 300 mm × 300 mm. The dielectric constant and loss tangent of EPDM are 1.26 and 0.007, respectively, at 915 MHz, and the parameters of the body tissue came from [14]. EPDM was utilized as a substrate to simulate the clothes in practical use. The antenna system was simulated to be fabricated from copper-plated polyester textile (Less EMF Cat. #A1212) with a 0.12 ohm/square sheet resistance.

The antenna is shown in Fig. 1. A small size is a critical parameter in an on-body UI antenna. The simulated realized gain of the designed antenna on body at 860 MHz is shown in Fig. 2. The antenna had highest directivity at the top-up direction (opposite to the direction of lossy human-body). In the RFID target frequency band (860 MHz – 920 MHz), the antenna had the gain around -13 dBi and the gain is stable on UHF RFID frequency band. Based on the simulations, the antenna was suitable for the on-body UI.



L	W	l	w	a	b	c
45.8	19.64	27.5	14.14	7.6	2.8	2

Fig. 1. Antenna structure and size in mm. The platform includes four antennas.

The operation principle of the on-body UI platform is illustrated in Fig. 3. The human finger connects the IC to the antenna, which enables the tag to response to the reader. As the human body strongly influences the wireless performance of the tag antenna; an antenna array was used to increase the backscattered power of the interface, as shown in Fig. 4. It also shows the concept of building the interface platform from individual layers. One pad of each IC is linked to pads of other ICs and connected to an antenna by an electro-textile connector. The top layer electro-textile pattern covers the other pads of ICs, which are isolated from the antenna by the separation material (EPDM) and are thus initially disconnected. When a finger is moved on the platform, it connects a certain IC to the antenna, which is detected by the RFID reader. As presented with details in [13], the raw data collected by the platform is a sequence of IDs from the touched ICs. The system convers the data into bitmaps and their details are increased by interpolating between neighboring samples, using the sequential information of IDs. These images of digits written on the platform can be classified, with enough accuracy for practical use, by deep learning [13].

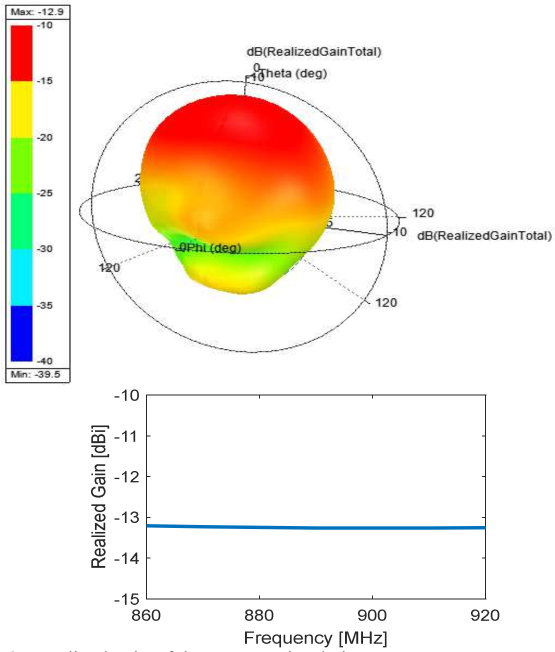


Fig. 2. Realized gain of the antenna simulation.

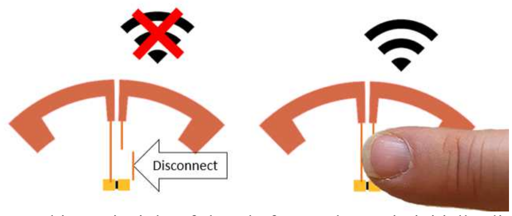


Fig. 3. Working principle of the platform: The IC is initially disconnected and becomes readable when the IC is connected to an antenna by touch.

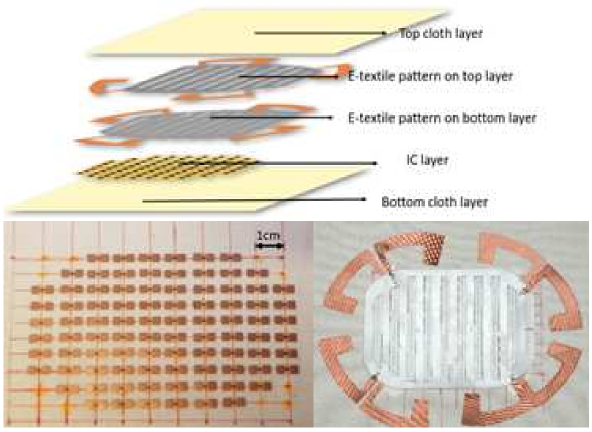


Fig. 4. UI platform fabrication: Individual layers of the platform (top), ICs on the bottom cloth layer (bottom left), platform before the top cloth layer, with four antennas (bottom right).

In UI platform fabrication, the bottom layer is created on a thin cotton-based fabric, with a 10 x 10 array of RFID ICs (NXP UCODE G2iL), as previously in [13], and then cutting three ICs from each corner. In [13], it was noticed that in the corner areas, the ICs had very low press frequency when writing digits. Thus, the ICs are removed from the corners to reduce the total size of the platform. The ICs are attached by the manufacturer on a plastic strap with two copper pad endpoints. These straps are fixed on the cotton substrate using textile glue. The gaps between the ICs are 1 cm and 6 mm at horizontal and vertical direction, respectively.

III. INITIAL PLATFORM TESTING

A. Testing Setup

The wireless performance of the on-body UI platform was evaluated with two measurement setups. The setups included an office environment (without the effect of human body) and on-body, as shown in Fig. 5. The setups consisted of UI platform, a circularly polarized reader antenna, attached to Thingmagic M6 RFID reader through a connecting cable, and a simple testing software. The reader operates at the European standard frequency range (865.6-867.6 MHz) and the used power is 28 dBm.

Fig. 5. Measurement set-up on a chair without human body (left) and on body (right).

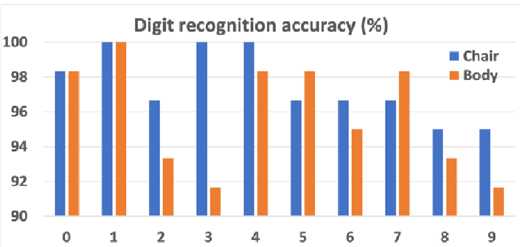


Fig. 6. Digit recognition accuracy on a chair and on body. The horizontal axis shows the digit and the vertical axis its accuracy (%).

The distance from the RFID reader antenna was 1 meter and 1,2 meters on the chair and on body, respectively. Two subjects, a female and a male, draw numbers 0-9 on the interface 30 times on the chair and on body. During testing, the testing software shows a picture of the recognized digit, which was checked and recorded as wrong/right by a researcher. As shown in Fig. 5, in both cases, the handwriting recognition accuracy was over 91 % for all the digits. The average recognition accuracy on chair was 97.5 % and on body 95.8 %.

B. Technical Discussion

In the measurement setups, the reader antenna was placed relatively close to the writing pad (1 meter and 1,2 meters on the chair and on body, respectively) to minimize the effect of noisy environment, as the goal was to validate the system functioning. In the earlier study [13], the performance of the earlier prototype in general was validated without taking into consideration the effects of the proximity of human body on the system operation. The human body has found to significantly affect the operation of UHF RFID technology [15]. Therefore, in this study, the human body proximity was considered in antenna design. In this article, the improved tag antenna array was also validated first without the proximity of human body (on chair measurements). However, especially important finding was that the system was also validated to be performing well on human body. The maximum reading distance is always dependent on the specific environment, as the RFID signal is very unstable, for example due to reflections from metallic objects or presence of people.

In this first measurement setup, the platform was tested only with one reader antenna. In practical use, it would be necessary to have 2-3 reader antennas in the room. Alternatively, a mobile-phone integrated reader could be used. Further research must be done to investigate the radiation pattern of the tag antenna array in different body parts, as the simulations (Fig. 3) were only performed by modeling the writing pad on a thigh. Further measurements are also needed to study the effect of human tissue in different setups, to see how the reading depends on the location of the writing pad in relation to the location of the reader antenna. These measurements will provide valuable information for further system development and real-life implementation. Further, a major limitation of this study was the small number of testers. Thus, the next prototype will be evaluated on a larger amount of people.

IV. PRACTICAL IMPLEMENTATIONS AND USE CASES DISCUSSION

The created on-body ClothFace UI enables various kinds of applications to be developed. The information from the on-body UI platform can be utilized in various systems, as the technology can be powered by an external RFID reader and be connected to any application through WIFI. Also, mobile phone-integrated UHF RFID readers are available.

A. Applications of ClothFace in daily living and care

Possible users of the on-body UI platform include people with declined functional capabilities, such as fine motoric challenges, challenges in speaking, or cognitive impairment. Environmental control devices may be used by such user groups to help them independently operate in daily living environment, such as home, or other essential places, such as rehabilitation clinics or hospitals. ClothFace enables a new user interface for user who may otherwise have trouble to use other kinds of controlling devices, such as remote controllers or voice-controlled systems. The platform is simple to use, and it allows users to transmit messages or control signals with normal daily clothes, thus also making this assistive technology less visible and more acceptable. These messages may be sent for example to control (intelligent) environment, to activate a nurse call, to communicate with others, or update information via online systems practically anywhere, to give some examples.

In this paper, the digits were reliably identified by the system, which is a promising start in further refining the system for different use cases. Passive UHF RFID-based platforms can also be used to identify simpler forms and movements, such as swiping [16], which can also be performed by users with serious motoric challenges that make controlling difficult with for example joystick –type controllers. The created platform could thus be used like a computer mouse, which is integrated into clothing. Even more severely disabled persons may use technologies, such as blow mouse, and ClothFace could be refined to be used with chin movements or with nose tip, thus giving an option to that kind of technology.

In case of users with communication or cognitive challenges, the technology provides a new way of “speaking” and self-expression. With traditional augmented and assistive communication (AAC) devices or software, fine-motoric challenges may cause problems in using them. Therefore, also very simple solutions are available, such as big buttons with pre-defined functionalities, for example to play recorded message. These, on the other hand, have very limited functionalities. In case of ClothFace, various symbols (control movements) could be taught for the system to help the user to “say” certain words and show certain pictures on a screen. As the control symbols and their meanings could be modified according to the needs of the user, this offers customizable and user-centered technology solutions for various users with different needs and abilities.

The on-body UI technology also enables various care work-related applications. It is especially useful in professions, in which additional controlling devices, such as mobile phone is challenging or impossible to use due to dirt, hygiene or other restrictions. To give some examples, in care work, an emergency-call function may be implemented with ClothFace technology. Client groups with challenging behavior may cause dangerous situations for other clients or for care personnel. In these situations, it may be difficult for the nurses to trigger alarms or to call help, if they are for example strangled. ClothFace technology may be placed on various locations in the clothing, which also enables a new way to call help. Additionally, in less acute situations, the technology could provide a silent way of communicating with other professionals without further provoking challenging behavior. As various symbols could be used, short messages could be added to the alarm signal, such as call for certain medication or information, which would indicate the urgency of the call. A completely different example of the technology in the care sector would be environments in which personal protective equipment (PPE) play important role. The ClothFace technology could be integrated to PPE and this provide a new hygienic controlling method for using computers, or to send simple messages. This would be useful for example to surgeons or operation room nurses. Additionally, in less critical care environments, the use of ClothFace could reduce touching to door handles, computers, or other potentially contaminated surfaces.

B. Industrial application of ClothFace

The manufacturing operations in the intelligent factories of the future will be based on flexible, customizable, and versatile production solutions, in which human-machine collaboration and interactions play a very important role. To utilize the superior efficiency and productivity of robots and other automatic machines, as well as human flexibility and situational awareness in rapidly changing environments, the human-machine collaboration, and in the future in particular human-robot collaboration, involves interaction and all kinds of actions to create a direct flow of communication and understanding between the people and robots working towards a common goal [17]. Seamless collaboration requires that humans can communicate with robots without causing process slowdowns or interruptions.

ClothFace allows us to take human-robot collaboration to this required next level. When industrial production wants to combine the productivity of automatic robots with the flexibility of manual work, while at the same time enabling the production of an equally diverse range of products, the design of production involves the design of human-robot collaboration. The goal is to implement various techniques and methods that enable intuitive and seamless interaction between human and robot in unstructured environments and situations [1]. Once ClothFace is attached to the thigh of a person working with a robot, the person can, among other things, help the robot with tasks such as identification, positioning, or orientation selection. In this way, ClothFace combines the superior properties of both workers, i.e., human cognitive competence and the physical strength and speed of the robot. With ClothFace, a human can give advice to a robot very smoothly and quickly without having to take the robot's pendant or the need to interrupt the process, for example.

On the other hand, in warehouse work, a person can use ClothFace to communicate with a mobile robot that handles logistical tasks. Again, the person doing the warehouse work can call the mobile robot by writing any of the numbers and correspondingly send it to the next destination by selecting the item number on ClothFace. In this way, warehousing enables the use of safe mobile robots in working with people and frees the person to carry and lift goods, while at the same time controlling the operation of mobile robots with ClothFace in unplanned logistical tasks and constantly changing environments. The multi-digit ClothFace also allows the person to call and control differently furnished mobile robots. If a mobile robot capable of refrigerated transport is required when emptying the truck, it can be called up from ClothFace with a single number key. If, on the other hand, a mobile robot with a locked transport cabinet is required to transport the batch of medicines, it can also be called to the location with its own number. Again, the person working in the warehouse does not have to dig a mobile phone or other separate device needed for the call, but the call is easily made with one hand via the UI integrated in the workwear.

Müller et al. [18] have presented four different situations, in which a human and a robot work together: 1. coexistence, when humans and robots work in the same space but do not really interact, 2. synchronized, when humans and robot shares their workspace but work at separate times, 3. cooperation, when humans and robots work in the same place at the same time, but basically do different things and 4. collaboration, when humans and robots perform their common shared task(s) at the same time at the same place. ClothFace's flexibility and ease of use allow it to be utilized in a wide variety of human-robot communication situations. In coexistence situations, the worker can use ClothFace for example to set off their own actions or to display their arrivals and departures in the workspace. On the other hand, in a synchronized situation, the worker can use ClothFace to report performed tasks to the robot, tasks that have entered the robot, or even fault situations. In this case, the worker does not have to go to the computer to check in separately. In cooperation situations, the worker can communicate with the robot about the completion of different sections or even a change in the order of work tasks. However, ClothFace certainly brings the most fluidity and flexibility to collaborative situations. When a worker can perform the tasks expected of him but at the same time control the whole situation, he can control the operation of the robot, the work schedule, or even the handling of changing products with ClothFace.

V. Conclusions

The created, fully textile-based on-body platform (ClothFace) enables real-time digit recognition. As the platform is functional without on-board energy sources, it will turn our everyday clothing and textiles around us into passive user interfaces. During preliminary testing, an average success rate of about 95.8 % was achieved in a normal office environment when worn on human body. The on-body UI technology is especially promising for users who have challenges in using traditional controlling devices, or in unpredictable environments, in which the use of traditional controlling devices is challenging if not impossible. The novelty value of the user interface presented in this paper is based on its passive nature, cost-effectiveness, and simple implementation into clothing. The performance of the on-body UI was validated, and several application examples were given.

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