Clothing-integrated RFID-based Interface for Human-Technology Interaction

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Abstract—**In this paper, we present a new type of passive UHF RFID-based user interface for human-technology interaction. Our system is controlled with a shirtsleeve-integrated electro-textile antenna. The other part of the system consists of small ID ring antennas, each with a unique ID, embedded into our environment. Each ID ring has an RFID IC and can thus be "activated" by placing the shirtsleeve next to the specific ID ring. The shirtsleeve-integrated antenna has bands going around the wrist, thus increasing the read range even when the ring is behind the wrist. This cost-effective and maintenance-free solution can be seamlessly integrated into our everyday clothing, as well as into furniture, textiles, and items around us. The presented first prototype of this system, which can be used when sitting by a table, allows wireless controlling of technology by simple hand movements. The achieved read ranges are very promising, allowing activation of ID rings from distances of around 0.5-1 meters from a mobile RFID reader placed on a table.**

Keywords—human-computer interaction, natural user interface, passive UHF RFID, textile electronics.

I. INTRODUCTION

Interaction with technology has become extremely important in our daily lives. Due to versatile use environments and disabilities of people, current handheld, screen-based and touch- or voice-operated devices are not suitable for all consumers and all situations [1]-[3]. Currently touchless human-technology interfaces are usually voice- or body movement -based. Voice-controlled interfaces have their own challenges, such as linguistic coverage, conceptual failures, challenges in noisy environments, and un-usefulness in places that require silence. Although there is a lot of research going on around the topic, and there already are notable commercial interfaces using human body movement, the available technology solutions have some drawbacks. The current solutions require a line-of-sight, which means the person needs to be directly seen by the device, or complex electronics with an on-board power source, which makes them costly and inconvenient for daily use.

Thus, there is an urgent need for a human-technology interface, where the required input actions are touchless, simple and instinctive, allowing the whole society to effortlessly interact with the surrounding wireless world. To revolutionize our lifestyle, clothing-integrated and body-movement-based interfaces are an extremely convenient solution. In order to be truly useful in everyday life, clothing-integrated human-technology communication needs to be functional without line-of-sight, passive, and maintenance free. Functionality must be unobtrusively integrated into everyday clothing, which means the technology needs to act invisible and be cost-effective to fabricate.

In this paper, passive UHF (ultra-high frequency) RFID (radio frequency identification) –technology is used in a completely new way, as a body movement-based solution for human-technology interaction. Clothing-integrated passive RFID technology uses battery-free remotely addressable electronic tags composed only of an antenna and a small integrated circuit (IC). The use of propagating electromagnetic waves in the UHF frequency range enables rapid interrogation of RFID tags. Thanks to the energy-efficient mechanism of digitally modulated signal backscattering, utilized in the tag-to-reader wireless communication, tags can be read from distances of several meters, even through various media. Variations of backscattered signal strengths and phases from on-body passive RFID tags have been shown to successfully provide information about body positions and movements, for example in [4]-[7]. However, the backscattered signals of passive RFID tags are noisy and unstable, and strongly affected by the environment, which is a major challenge when implementing the presented solutions into practical use in our everyday environments.

Our clothing-integrated solution for human-technology interaction has two novel features: reliable and natural on/off activation of inputs by simple hand movements and functionality even when the line-of-sight is blocked by the body. Our clothing-integrated system consists of centrally aligned split ring tag antennas, attached on shirtsleeves with antenna bands that go around the wrist. These split ring antenna tags, such as the ones presented in [8]-[9], enable two-layer structures. In one layer, we have a series of small ring antennas, each with own IC and ID, integrated into different parts of our clothing or into furniture, items, and textiles around us. In the other layer, a bigger ring, which will act as a radiating antenna, can be integrated, e.g., into a wrist of a shirt.

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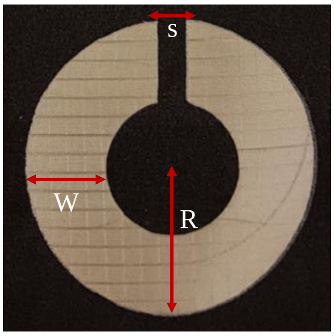
Then, by taking the wrist with the bigger ring next to the desired ID ring, the tag will be “activated” and its ID will be read by an RFID reader. As only the tag ID is read and the ID codes a specific action, this system is more reliable compared to solutions based on measuring noisy backscattered signal strength or phase. The other novel feature in the system is the modification of the bigger ring to include separate radiating elements that go around the wrist. This way we can circumvent possibly blocking body and the read range is increased substantially.

As the RFID reader can be connected to any application through WIFI, these split ring tags will work as wireless input points on body, furniture, and items. By activating a specific ID, an explicit wireless input can be given to any connected device, which will allow a person to interact with the digital environment through clothes. Thus, in our approach, reading the ID of a specific IC is used as shortcuts to desired digital actions, allowing all connected devices to be controlled accurately but effortlessly, which will offer a new level of convenience.

II. ANTENNA DESIGNS AND ANTENNA FABRICATION

A. Antenna Designs

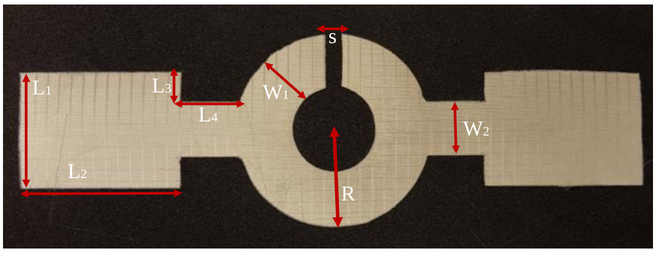
Firstly, we implemented three different types of wrist antennas in order to find an optimal solution to be used to activate the ID rings. The first wrist antenna (presented in Fig. 1) was based on a previously published design [9] and consisted only of a simple ring. While this design is attractive due to its simplicity, the human wrist will cover the whole tag during actual use, which will most probably affect the wireless performance of this antenna design and decrease the read range.



Width (W)	*18 mm*
Radius (R)	*30 mm*
Slot (s)	*6.5 mm*

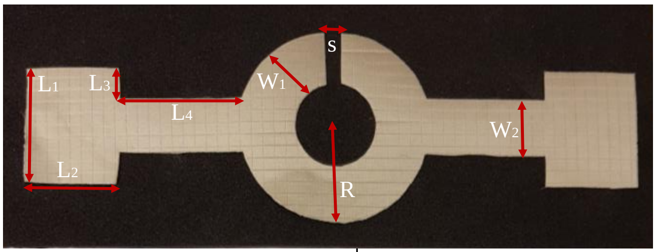
Fig. 1. Wrist antenna 1 with antenna dimensions. This antenna design has only a simple ring.

Next, we implemented two different wrist antennas that also had antenna bands going around the wrist, as presented in Fig 2 and Fig 3. The idea of these antenna band designs is that the human wrist will not fully cover the antenna. Similarly to the first wrist antenna design, the ring element will couple with the smaller ring and thus activate the IC when in close contact. The bands with radiating elements at the ends will go around the wrist and thus will be visible when the rings and the IC are close to each other under the wrist. Thus, we speculate to achieve a better wireless performance and a longer read range. The longer read range will allow us to build a larger user interface area around a single RFID reader, which means a more functional user interface, for example when used sitting by a table.



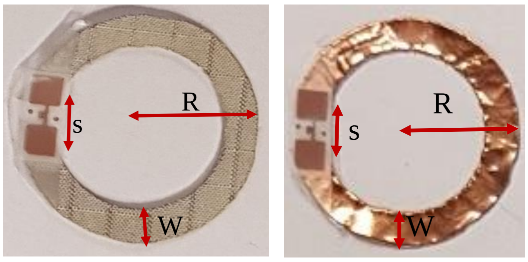
Length (L1)	*36 mm*
Length (L2)	*50 mm*
Length (L3)	*10 mm*
Length (L4)	*19 mm*
Radius (R)	*30 mm*
Width (W1)	*16 mm*
Width (W2)	*16 mm*
Slot (s)	*6.5 mm*

Fig. 2. Wrist antenna 2 with antenna dimensions. This antenna design has also an antenna band going around the wrist.



Length (L1)	*36 mm*
Length (L2)	*30 mm*
Length (L3)	*10 mm*
Length (L4)	*39 mm*
Radius (R)	*30 mm*
Width (W1)	*16 mm*
Width (W2)	*16 mm*
Slot (s)	*6.5 mm*

Fig. 3. Wrist antenna 3 with antenna dimensions. This antenna design has also an antenna band going around the wrist.



Width (W)	*3 mm*
Radius (R)	*16 mm*
Slot (s)	*2 mm*

Fig. 4. ID ring with antenna dimensions fabricated from electro-textile (left) and copper tape (right).

The design of the ID ring is presented in Fig. 4. These ID rings are small enough to be embedded into versatile structures. The ID rings presented in Fig. 4 are fabricated from electro-textile and from copper tape, in order to integrate them into clothing or into furniture and items. In the future, versatile manufacturing solutions can be used to integrate these ID rings into our surroundings, for example ID rings printed from conductive ink or paint, ID rings cut from copper tape, and ID rings embroidered with conductive thread directly into textiles.

B. *Tag Fabrication*

The electro-textile antennas were fabricated with nickel and copper plated Less EMF Shieldit Super Fabric (Cat. #A1220) as the conductor. For initial measurements, they were attached on a 2 mm thick EPDM (Ethylene-Propylene-Diene-Monomer) cell rubber foam. The electro-textile material has hot melt glue on the backside and can be easily ironed into textile substrates, such as clothing. The electro-textile material is light-weight and conformal with the touch and feel of regular clothing. The ID rings were cut from both the electro-textile material and from copper tape. The idea is that different materials can be embedded into different structures in different future use environments. In this study, the electro-textile antennas were integrated into clothing while the copper tape antennas were used on the table and items placed on the table.

The RFID IC used in this study was NXP UCODE G2iL RFID IC, provided in a fixture made of copper on a plastic film with 3×3 mm^2 pads. We attached the pads to the electro-textile and copper tape ID rings using conductive epoxy (Circuit Works CW2400). This chip has a wake-up power of −18 dBm (15.8 µW). The IC component can be seen in Fig. 4, when attached to the ID ring antennas.

III. TESTING AND MEASUREMENTS

Firstly, we measured two samples of each wrist antenna type, with both an electro-textile ID ring and a copper tape ID ring. This initial evaluation was done in an anechoic chamber, in order to get an understanding of the wireless performance of these different types of antenna designs. Then, the actual evaluation measurements were started by first making a comparison of the wireless performance of the three different types of wrist antennas on-body. Next, the best one was selected for further testing, where the selected wrist antenna design was fabricated from the electro-textile material and ironed directly onto a shirtsleeve together with an electro-textile ID ring. This ready-made shirt was then used for practical evaluation of the developed system: A case study was conducted while sitting by a table where we had embedded copper tape-based ID rings.

A. *Initial Measurements*

The initial measurements were performed in an anechoic chamber (shown in Fig. 5) by using a Voyantic Tagformance RFID measurement system. The system is calibrated firstly using a reference tag to characterize the properties of the wireless channel from the reader antenna to the tag. The theoretical read range between the tag and the reader antenna is then based on the measured path loss and threshold power, as given in (1),

$$d_{Tag} = \frac{\lambda}{4\pi}\sqrt{\frac{EIRP}{P_{TS}\,L_{fwd}}} \qquad (1)$$

where EIRP is the emission limit of an RFID reader, given as equivalent isotropic radiated power. In this study, EIRP = 3.28 W, which is the emission limit in European countries. λ is the wavelength transmitted from the reader antenna, P_{TS} and L_{fwd} are the measured threshold power and forward losses, correspondingly.

The results of the initial measurements between 800-1000 MHz are presented in Fig. 6. As can be seen, wrist antenna 1 shows similar read ranges of around 4-5 meters with both types of ID rings (fabricated from copper tape and from electro-textile). In case of wrist antennas 2 and 3, it can be seen that the read ranges are slightly longer when measured with the copper tape ID ring. This result is caused by the higher conductivity of the antenna material in the copper tape ID ring. Based on these initial measurements, the wireless performance of the fabricated wrist antennas is stable and the different wrist antenna types will be next compared on-body, in order to select the best one for practical testing.

Fig. 5. Measurement set-up in an anechoich chamber.

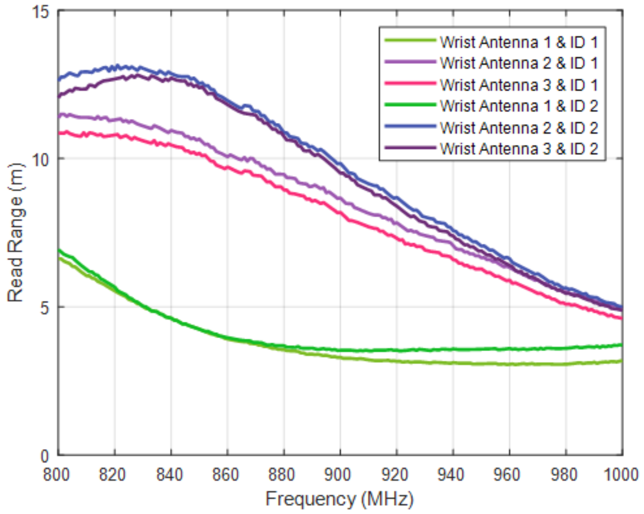


Fig. 6. Initial comparison of the three different wrist antennas and two types of ID rings (ID 1 = ID ring fabricated from electro-textile; ID 2 = ID ring fabricated from copper tape).

B. *Tag Comparison*

Firstly, the wrist antennas (attached on the black EPDM substrate) were simply taped into a shirt, as presented in Fig. 7. The copper ID rings were embedded into two different positions: on a table and on an item placed on the table. This used item was a piece of foam. Further, an electro-textile ID ring was attached into the other wrist of the shirt. This setup is presented in Fig. 8. We placed each of the three wrist antennas next to the three ID rings and manually (by using a measurement tape) measured the reading distance, i.e., the distance where the RFID reader was able to identify the specific ID of the ID ring.

The used mobile reader (Nordic ID Medea, which is designed for quick, accurate, and reliable data collection) measures the tags at 866 MHz, which is the European center frequency for UHF RFID systems, and then communicates with any background system through WIFI. As the reader is handheld and thus mobile, this user interface can be easily transferred together with the person using it.

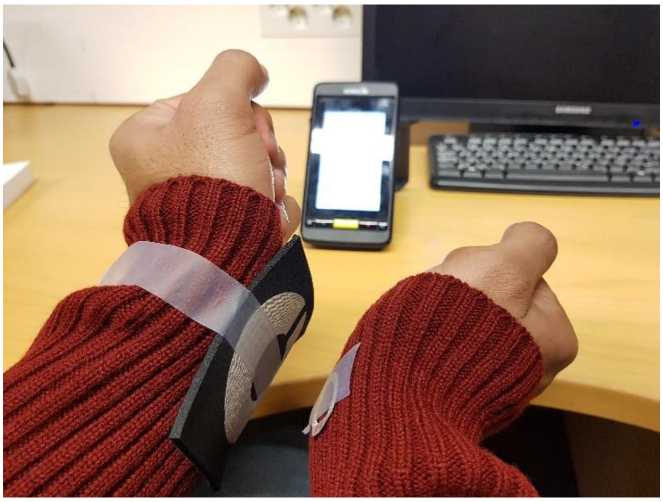


Fig. 7. Initial comparison of the three different wrist antennas: Antenna on a substrate is taped into a shirt wrist and an ID ring is taped into the other wrist of the shirt.

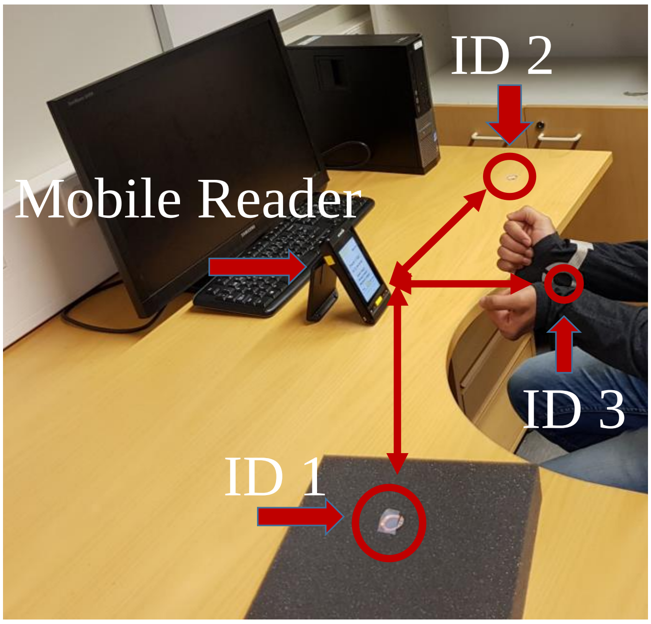


Fig. 8. Testing environment: Three ID rings are embedded into the environmnet (table, item, wrist), activated by the wrist antenna, and read by a mobile RFID reader on the table.

As can be seen from Table 1, while all the wrist antennas were able to activate the ID rings from distances of more than 30 cm, wrist antenna 3 showed significantly longer read ranges than the other two wrist antennas. We were able to detect the ID rings embedded into the table, item, and wrist from distances of 80 cm, 51 cm, and 56 cm, respectively. These results can be considered suitable for a user interface, which would be used when sitting by a table. Each ID ring can be used to activate a specific application or to give a specific input to already activated application. As the read range from the ID ring on a table is 80 cm, these ID rings could be embedded all around a table. By moving the RFID reader, the user interface area can be modified easily.

TABLE I. WRIST ANTENNA COMPARISON: READING DISTANCES OF ID RINGS IN DIFFERENT POSITONS.

ID 1 (Table)	**ID 2 (Item)**	**ID 3 (Wrist)**
Wrist antenna 1 36 cm	Wrist antenna 1 44 cm	Wrist antenna 1 36 cm
Wrist antenna 2 38 cm	Wrist antenna 2 45 cm	Wrist antenna 2 40 cm
Wrist antenna 3 80 cm	Wrist antenna 3 51 cm	Wrist antenna 3 56 cm

C. Case Study

Next, wrist antenna 3 was selected to practical integration into clothing. The wrist antenna was ironed into a sleeve of a thin cotton-based shirt, while the ID ring was ironed into the other sleeve, as presented in Fig. 9. When wearing this shirt, the male test subject tested the ID rings on the table and on the item, as well as on the other sleeve, as presented in Fig. 8 and Fig. 10.

Fig. 9. Practical integration into clothing: Electro-textile wrist antenna and ID ring ironed directly into a shirt.

The clothing-integrated wrist antenna 3 showed excellent performance: We were able to use the setup presented in Fig. 8, while the mobile reader was at distances of 93 cm (ID ring on the table), 48 cm (ID ring on the item), and 58 cm (ID ring on the other shirt wrist). Thus, the performance of the clothing-integrated solution was similar or even better than the prototype solution taped onto the shirtsleeve. Each ID ring was read three times in a row, in order to confirm the wireless performance.

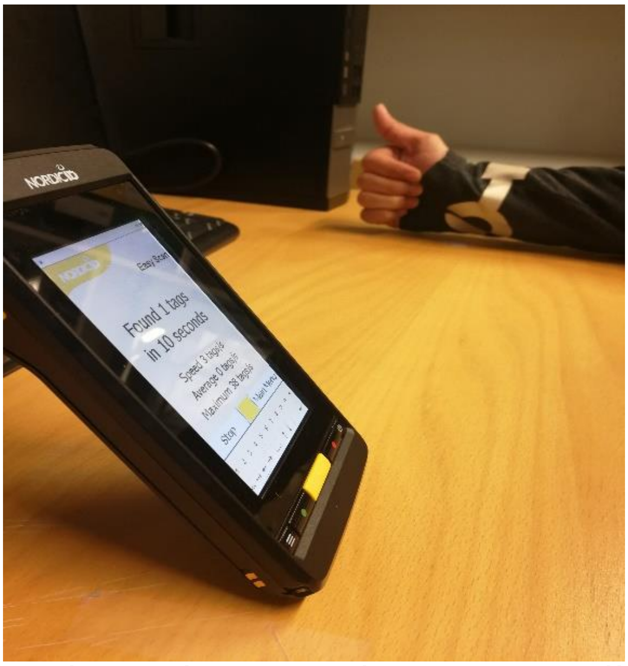


Fig. 10. Shirt-integrated wrist antenna is used to activate an ID ring on a table. This setup showed a read range of 93 cm.

IV. DISCUSSION

These read range results are very promising, especially when considering the requirements of daily use of a clothing-integrated human-technology interface. The read ranges need to be long enough, in order to achieve large enough user interface area, which will enable convenient and seamless use of the solution. Since the mobile reader provides full mobility for the system, the practical applications are endless. As the system is cost-effective, passive, and maintenance-free, it can be seamlessly integrated into different type of clothing. Further, when coated with a protective coating, this user interface can also be washed with the garment.

The developed user interface has various application possibilities especially for special needs users. In addition to environmental controlling (opening doors, switching lights), simple motivation and rehabilitation games could be developed. For patients with physical inabilities in hands, such as spasticity or muscle weakness, the solution enables game controlling without need of holding a controller. It provides also alternative controlling method for patients with challenges in controlling precise movements (for example due tremor) or who has challenges in producing voice. Both of the before-mentioned symptoms occur for example in Parkinson's disease. The on-body user interface controlled games could also be targeted for neurological patients for rehabilitation. To name an example, spatial neglect (a failure to report, respond, or orient to stimuli in contralesional space after brain injury that is not explained by primary sensory or motor deficits) rehabilitation could benefit from a game in which the player must become aware of the affected side by touching it with the healthy side [10]. The development of a game for rehabilitation purposes is part of our future work. Further, we envision that these ID rings and clothing-integrated wrist antennas could be used to transform our daily environments into intelligent user interfaces for human-technology interaction.

V. CONCLUSIONS

There is an urgent need for a human-technology user interface that allows touchless, simple and instinctive input actions into different applications. We presented a cost-effective and maintenance-free passive UHF RFID-based solution, which can be seamlessly integrated into our clothing and into our living environment. Our solution had two novel features: hand movement-based activation and around hand antennas. These features allowed reliable and natural hand movement-based interaction and increased read ranges. Based on this first setup, which was built around a person sitting by a table, the read ranges of our solution are suitable for practical use. It was shown that the system can be integrated into clothing as well as into the table surface and into items on the table. Thus, based on these preliminary results, this system can be considered a promising solution for future human-technology interaction. The next step is practical testing of our solution with home environment applications, such as controlling of music and lights, as well as development of a game for rehabilitation purposes.

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