Glove-integrated Passive UHF RFID Tags – Fabrication, Testing and Applications

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***Abstract*— Passive RFID technology enables versatile energy- and cost-efficient wireless platforms. We present passive UHF RFID tags integrated into normal work gloves for wearable RFID applications. The tags were designed to be functional throughout the global UHF RFID frequency range. The use environments of work gloves are challenging, for example due to moisture and mechanical stresses, which means the glove-integrated solutions have unique reliability issues to consider. We introduce 3D printing of a flexible thermoplastic material directly onto the glove and embed electro-textile antennas and RFID microchip components inside the 3D-printed structure. This manufacturing method solves the above-mentioned reliability challenges and enables the practical use of glove-integrated passive RFID tags. The performance of the fabricated glove-tags is firstly evaluated on a male test subject in an EMC room and in an office environment. Based on the wireless measurement results, the read ranges of the glove-tags are around 2-3 meters throughout the frequency range of 800-1000 MHz. These results meet the requirements of many practical applications of glove-tags. Further, these glove-tags are found to endure extreme moisture and mechanical stresses, which supports their use in versatile use environments. Finally, the developed glove-tags are successfully tested in actual use situations for identification and access control. These results are very promising, especially considering the cost-effectiveness and the easiness of tag integration into different types of gloves.**

***Index Terms*—electro-textile, glove-tag, passive UHF RFID, reliability, wearable antenna, 3D printing.**

I. INTRODUCTION

RADIO-FREQUENCY identification (RFID) technology can be used in versatile ways for efficient automatic identification [1][2]. By using the cost-efficient technology, identification, access control, as well as remote monitoring of movement and physiological parameters of a person or animal can be achieved unobtrusively [3]-[8]. Embedded RFID technology has also become essential in item tracking, supply chain management, and factory automation, just to name a few applications [9]-[12].

Further, in addition to clothes, RFID-based systems have been installed into footwear, as well as into different types of gloves [13]-[16]. Especially passive ultra-high frequency (UHF) RFID technology is among the key technologies of future wearable wireless systems. As the technology is passive, no onboard power sources or complex electronics are needed. Particularly gloves are an interesting choice to integrate simple passive RFID tags into. These “glove-tags” provide versatile possibilities for identification, access control, and possibly for antenna-based sensing. They could be especially useful in safety-critical working environments. This type of applications, however, require the RFID tag to be lightweight, cost-effective, easy to fabricate on different types of glove materials, as well as designed to be placed near the human body. Most of all, these RFID components need to endure mechanical stresses and moisture.

Embroidered and electro-textile-based antennas have been proposed and tested successfully in normal office or laboratory conditions. However, there has been subsequent degradation in the wireless performance of these tags, for example when they have been repeatedly washed in a washing machine. This has occurred for example due to dissolution of the antenna material from the surface [17][18]. Several types of coating materials, such as textile glue, protective encapsulant, textile moisture protectors, and thermoplastic polyurethane have been applied on textile RFID tags [18]-[22]. Although they have improved the tags’ reliability, especially when they were exposed to moisture [22], there were still some degradation in the tags’ performance after several washes [17]-[19], and for example formation of cracks in printed tag antennas when exposed to mechanical stresses [19]. Thermoplastic polyurethane material as a coating protected the antenna performance, despite them being washed several times [20][21]. However, any antenna peripherals not included within the coating’s scope remained exposed, subjecting to several reliability issues [20]. Thus, reliability aspects are critical in development of these new type of glove-tags.

Previously, electro-textiles and copper tape have been used to establish prototype tag antennas attached onto gloves [16]. Further, embroidery has been recently successfully used to fabricate tag antennas onto gloves [23]. Although these glove-tags have showed promising read ranges, they are not suitable for practical use, as they do not endure moisture or mechanical

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This work was supported in part by Academy of Finland and Jane and Aatos Erkko Foundation.

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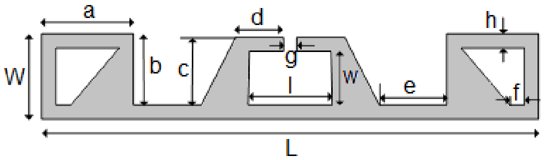
stresses. Thus, now we introduce a new type of manufacturing method to solve the reliability challenges: We are using 3D printing of a flexible thermoplastic material, directly onto the glove surface, and embedding electro-textile antennas and RFID microchip components inside the 3D-printed structure. One of the inherent advantages of 3D printing are the easiness and cost-effectiveness of implementing different types of structures [24]. Thus, when compared for example to spray coating [18], brushing [18] or iron pressing method [22], the advantages are clear: In 3D printing, the thickness and design of the protective coating layer can be quickly controlled and varied according to the need, and also the mechanical and electrical properties of the protective platform can be modified simply by modifying the printing parameters [25], which makes 3D printing a new promising method for fabrication of protective platforms for embedded antennas and electronic components.

The fabricated glove-tags are tested on-body in an office environment, their reliability is evaluated under high moisture and mechanical stress, and their performance is tested in actual use situations.

II. Antenna Design and Simulation

The developed new glove-tag antenna design in presented in Fig. 1. The optimization of the dipole antenna structure is based on electromagnetic modelling in ANSYS High Frequency Structure Simulator. In the glove-tag antenna simulation model (presented in Fig. 2), two cubes (100 × 200 × 30 mm and 600 × 480 × 260 mm) are used to simulate human hand and body with a 170 mm gap between them. The body model is made from muscle with a 2 mm skin layer on top. The hand model has the following layers (top-to-bottom): 3D-printed thermoplastic layer (0.3 mm), electro-textile antenna, 3D-printed thermoplastic layer (0.1 mm), glove (1.5 mm), air (1.9 mm), skin (1 mm), muscle (1 mm), bone (26 mm), muscle (1 mm), skin (1 mm), and glove (1.5 mm). The used materials are given the following relative permittivity and loss tangent (at 915 MHz): bone (20.756 and 0.3215), muscle (54.997 and 0.33866), skin (41.329 and 0.41435) [26], 3D-printed thermoplastic (2.84 and 0.003) [25], and glove (4.3 and 0.004) [27]. The electro-textile antenna is given a sheet resistance of 0.16 ohm/square [28]. The body model used in the simulation is a simplified layered body block model. Based on an earlier study, this model provides comparable results and can thus be used instead of an accurate human body model for rapid evaluation [29].



W	**L**	**w**	**l**	**a**	**b**
13.1	76	8.3	12.9	14	10.9
c	**d**	**e**	**f**	**g**	**h**
12.3	7.4	10.4	2.3	2	2.1

Fig. 1. Glove-tag design with antenna dimensions [mm].

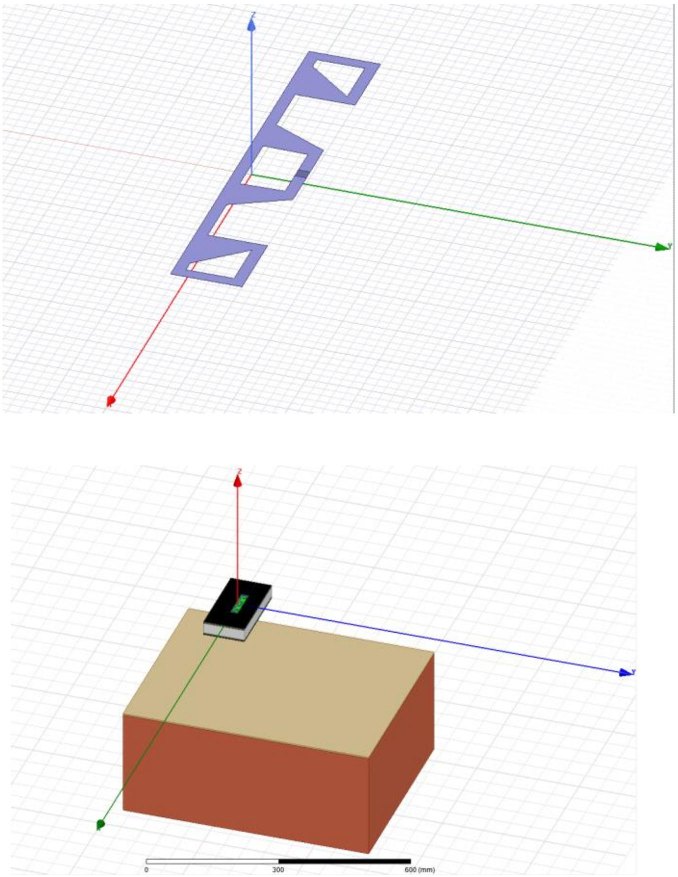


Fig. 2. Glove-tag simulation setup showing the tag antenna only (top) and body part and the hand part (bottom).

III. Tag Fabrication

The used 3D printing material is thermoplastic polyurethane (NinjaFlex). Such materials have recently gained a lot of interest as they are lightweight, yet strong and flexible. They have, for example, been used as substrates for wearable antennas and passive UHF RFID tags [25][30][31]. Now, in this study, NinjaFlex is 3D-printed directly onto working glove surfaces (presented in Fig. 3) and electro-textile antennas and RFID microchip components are embedded inside the 3D-printed structures. The work glove surface is fake leather, which gives a relatively smooth surface for 3D printing.

Fig. 3. Normal working glove used in this study.

The used electro-textile antenna material is nickel-plated Less EMF Shieldit Super Fabric (Cat. #A1220). This electro-textile exhibits sheet resistance of approximately 0.16

ohm/square. It has hot melt glue on the backside and can thus be easily ironed onto versatile textile substrates, such as onto gloves. The electro-textile antennas are cut by a laser cutter (Epilog Fusion Laser Model 13000).

The 3D printing is done using Prenta Duo 3D printer. Using a nozzle temperature of 220 ˚C and a printing speed of 10 mm/s, platforms of 87 mm x 19.1 mm are printed using 100 % rectilinear infill pattern (0 and 90 degree lines) and 0.1 mm layer thickness. For comparison, two types of 3D-printed structures are fabricated: The first version has the electro-textile antennas ironed directly onto the glove surface. The second version has a 0.1 mm thick 3D-printed substrate under the ironed electro-textile antenna.

The RFID microchip used in this study is NXP UCODE G2iL RFID IC (integrated circuit), provided in a strap made of copper on a plastic film with 3×3 mm^2 pads. We attach the pads to the antennas using conductive epoxy (Circuit Works CW2400). After IC attachment, a 0.3 mm thick structure is 3D-printed on top of all tags. The fabrication steps of the glove-tags are presented in Fig. 4.

Fig. 4. Fabrication steps of glove tags: Electro-textile antenna was ironed either directly onto the glove surface (top) or onto a 3D-printed structure that was printed onto the glove surface (middle). After IC attachment, both types of ready glove-tags were coated with 3D-printed structures (bottom).

IV. WIRELESS TESTING

All the wireless measurements are conducted using Voyantic Tagformance RFID measurement system. It contains an RFID reader with an adjustable transmission frequency (800-1000 MHz) and output power (up to 30 dBm) and provides the recording of the backscattered signal strength (down to −80 dBm) from the tag under test. Firstly, the wireless channel from the measurement system reader antenna to the location of the evaluated tag under test is characterized using a system reference tag with known properties.

Firstly, the electro-textile tag was measured in an anechoic chamber, without glove or human body, in order to get an idea of its wireless performance. The results of this measurement and the initial simulation results of the tag are shown in Figure 5. As can be seen, the simulation and measurement results are quite similar, both showing peak read range at frequencies higher than 960 MHz. Both the simulated and measured peak read ranges are around 8 meters.

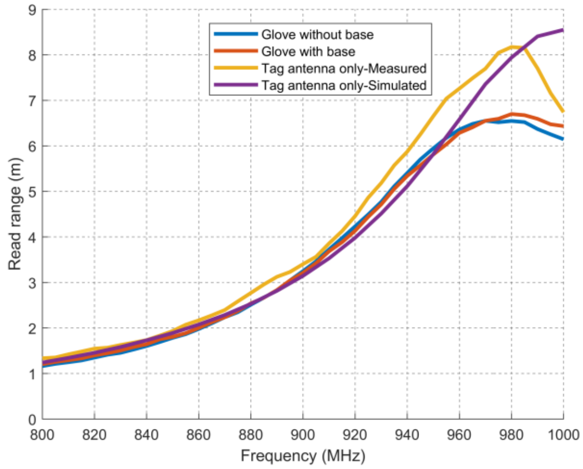


Fig. 5. Simulated and measured read ranges.

The ready-made glove-tags (after 3D printing the protective layer on top of the tag) were first measured inside an anechoic chamber and these results are presented in Fig. 5. The differences in read range values of the tag-only and the prepared glove-tag are probably due to the loss tangent and dielectric relative permittivity of NinjaFlex material, which are 0.05 to 0.08 and 2.75 to 2.79, respectively, and have caused this downward shift in read range values.

The prepared tags were then measured in an EMC room, where on-body measurements can be done within a relatively ideal environment, as shown in Figure 6. Next, the glove tags were measured in the same way in a normal office environment, with wooden and metallic furniture, people, and computers.

Fig. 6. Measurement setup in EMC room.

During actual testing, we record the lowest continuous-wave transmission power (threshold power: Pth) of each tag, i.e., the lowest power at which a valid 16-bit random number from the tag was received as a response to the query command in ISO 18000-6C communication standard. This enables us to estimate the attainable read range of the measured tag (d_{tag}) versus frequency from

$$d_{tag} = \frac{\lambda}{4\pi}\sqrt{\frac{EIRP}{\Lambda}\frac{P_{th*}}{P_{th}}}, \qquad (1)$$

where λ is the wavelength transmitted from the reader antenna, Pth is the measured threshold power of the tag, Λ is a known constant describing the sensitivity of the system reference tag, Pth* is the measured threshold power of the system reference tag, and EIRP is the emission limit of an RFID reader, given as equivalent isotropic radiated power. We present all the results corresponding to EIRP = 3.28 W, which is the emission limit in European countries.

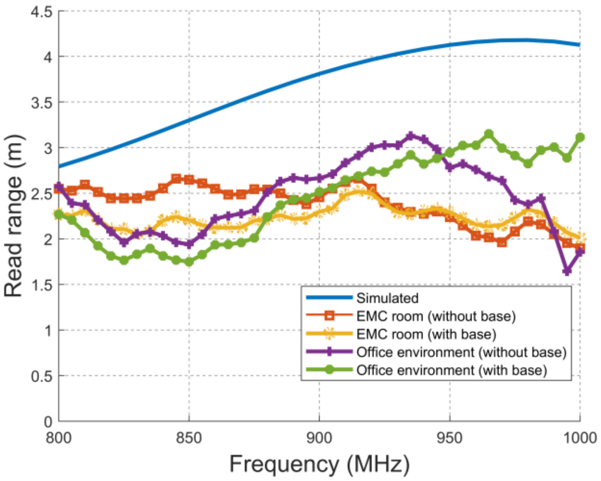


Fig. 7. Simulated and measured read ranges of the glove tags near human body.

Fig. 7 shows the simulated on-body read range of the glove-tag and the measured read ranges, both in the office space and in the EMC chamber, for both types of glove-tags, between 800-1000 MHz. As can be seen, the simulated read range is longer (around 3-4 meters) than the actual measured read ranges (around 2-3 meters). These differences are probably mostly caused by the fact that the distance between the body and the hand was never accurate in real life measurements. However, also the measured read ranges can be considered suitable for many practical applications of glove-tags, such as identification and access control.

V. PERFORMANCE EVALUATION

A. Reliability evaluation

Our goal was to integrate the RFID tags into the gloves in a way that they would be reliable enough for normal use. In our initial tests, placing an electro-textile RFID tag onto the glove without any protective platform was found to be a non-suitable way. Fig. 8 shows the first reliability challenge, which is the antenna and the IC component ripping off from the glove during normal hand movement. As can be seen from Fig. 8, the 3D-printed platforms solve the above-mentioned challenge: None of the fabricated glove-tags were affected by normal hand movements and hand bending during this study.

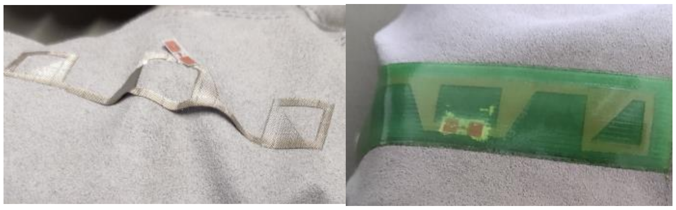


Fig. 8. The most significant reliability challenges of non-protected RFID tags integrated into gloves (left) can be solved with the developed 3D-printed platform (right): The electro-textile antenna and the IC component are protected from mechanical stresses and moisture inside the 3D-printed platform.

Another reliability challenge is moisture: The non-protected RFID tags cannot be used after exposure to a high moisture environment, due to the antenna ripping off and IC being damaged. Thus, the performance of the new type of glove-tags is also tested after exposure to extreme moisture (after 1 minute wash in water). This preliminary reliability test is used to get an initial idea of the practical performance of these glove-tags. The read range measurement results are taken immediately after the wash test and after drying for one day.

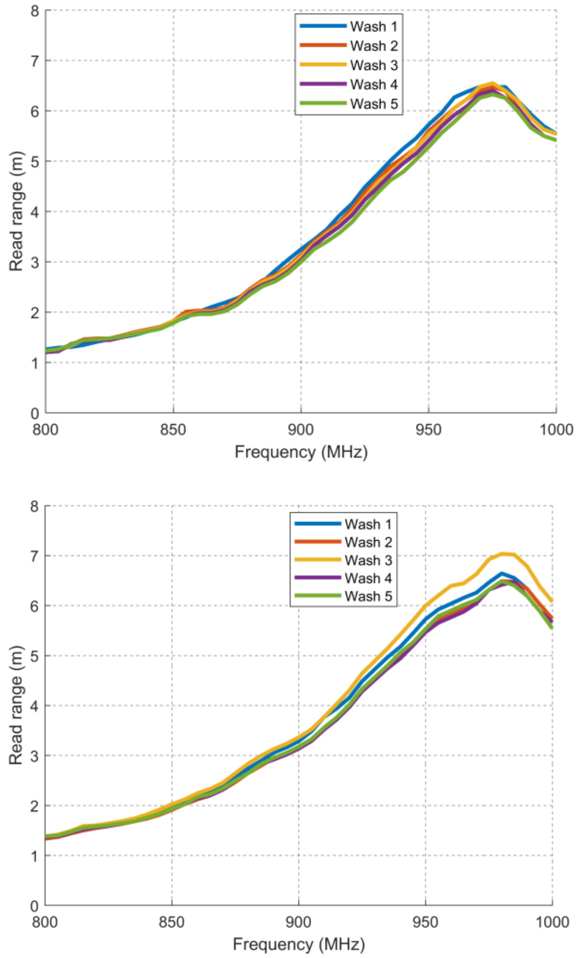


Fig. 9. Read range measurement results of an example glove-integrated tag without a 3D-printed base layer (top) and with a 3D-printed base layer (bottom). These measurements are done after wetting in water for one minute and subsequently after drying for one day.

As can be seen from Fig. 8, the wireless performance of both types of glove-tags is unchanged even after 5 wash cycles. It should be especially noted, that both types of tags remain perfectly functional (throughout the global UHF RFID frequency band) even after one minute in water. Thus, in addition to mechanical stresses, both types of 3D-printed platforms can be considered to protect the tags from moisture.

Our second preliminary reliability test focuses on mechanical stresses that will occur during actual use of the gloves. We study if the tag performance is affected when the gloves are clenched while being worn on the hand. The read range measurements are taken initially (before any clenching is done), after 50 clenches, and after 100 clenches, for both types of gloves, as presented in Fig. 10. From the measurement results, it can be observed that there is no drop in performance after 100 clenches, implying the reliability of the glove-tags is suitable for practical use.

Although promising, these reliability evaluation results are preliminary. Further reliability testing needs to be done to ensure the performance in a high moisture environment and under mechanical stresses.

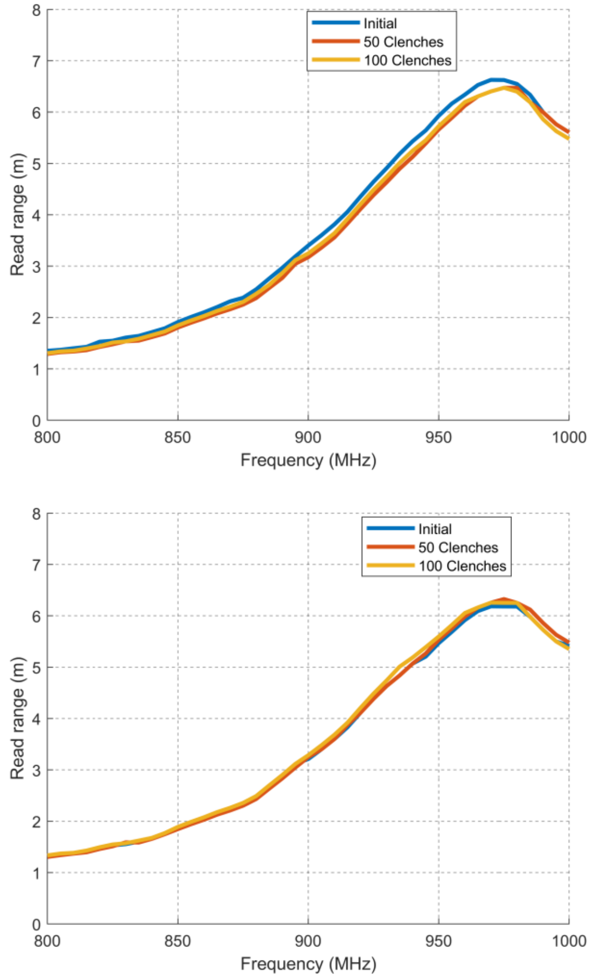


Fig. 10. Read range measurement results of unclenched glove-tags, glove-tags after 50 clenches, and after 100 clenches, for an example glove-integrated tag without a 3D-printed base layer (top) and with a 3D-printed base layer (bottom).

B. *Functionality testing in practical situations*

Next, a commercial mobile reader (Nordic ID Medea, which is designed for quick, accurate, and reliable data collection) is used to test our glove-tags in practical situations. This hand-held reader measures the tags at 866 MHz, which is the European center frequency for UHF RFID systems, and then communicates with any background system though WIFI.

As shown in Fig. 11, the reader is first located next to a shelf in a corridor and the male test subject walks past the reader. The distance from the glove-tag to the reader is about 1 meter and the reader is placed at a height where a person is able to read the reader display in a comfortable way. The reader is able to recognize the glove tags successively. By preinstalling the locations of readers into a background system, the system will identify the person wearing the glove-tag and map the walking path of the person, for example in a factory or in a warehouse. Thus, also indoor tracing can be achieved with this system.

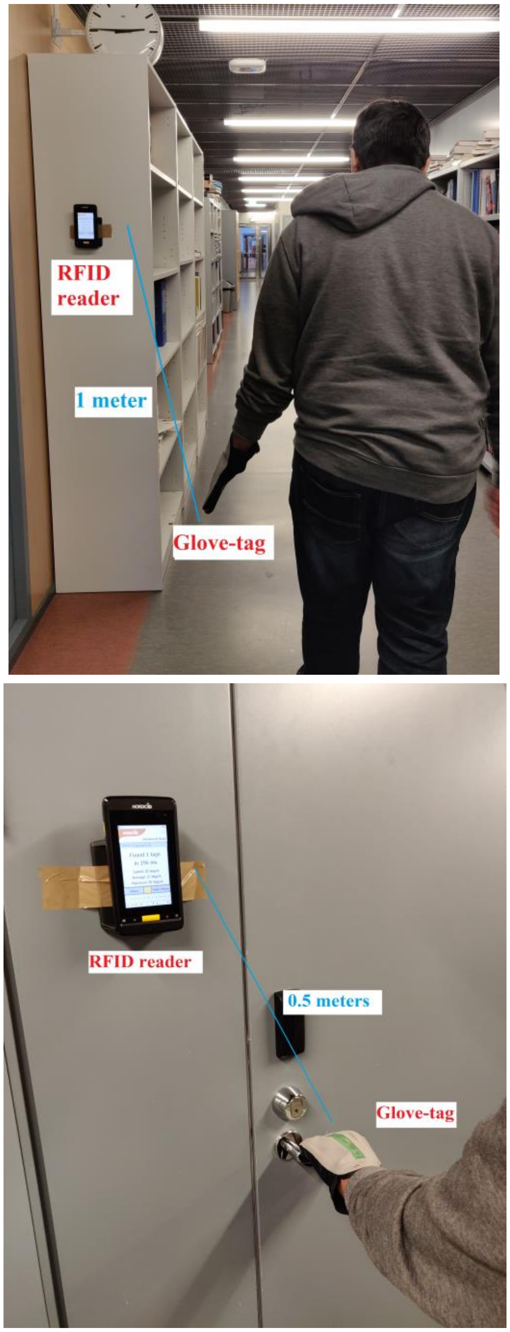


Fig. 11. Practical evaluation of glove-tags: identification (top) and access control (bottom).

Next, as presented in Fig. 11, the reader is placed at a distance of 50 cm from a door handle, in order to test an automatic authentication system for access control. The reader is able to read the glove-tags also in this configuration. Based on these preliminary results, the developed glove-tag could be used for versatile applications moving towards easier and safer working and living environments.

VI. CONCLUSION

We presented passive UHF RFID tags integrated into normal work gloves, introduced 3D printing of a flexible thermoplastic material with embedded RFID microchips and electro-textile antennas as a new efficient fabrication method for glove-integrated tags, as well as carried out preliminary performance evaluation in normal use environments. The performance of the glove-tags was evaluated on-body in an office environment and they were also tested in actual use situations for identification and access control. The read ranges of the fabricated glove-tags were around 2-3 meters, when measured near the human body. Further, the tags did not meet any reliability problems due to the mechanical stresses caused by hand movements or extreme moisture. These results meet the requirements of many practical applications of glove-tags. The achieved results are very promising, particularly when considering the enormous amount of glove-tag applications, the cost-effectiveness of the introduced manufacturing method, and the easiness of their integration onto different types of gloves. The placement of the platform on top of hand was selected to support user comfort. A glove with a 3D-printed platform is very comfortable as the platform is unnoticeable when the glove is worn. The next goal is to integrate RFID tags into different types of gloves and test them in real use environments, such as in a factory and in a warehouse. Also, further moisture and mechanical reliability testing will be carried out, with a larger amount of samples, in order to assure the glove-tag functionality in these challenging use environments.

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