Embroidered and e-textile Conductors Embedded inside 3D-printed Structures

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Abstract— This paper discusses the fabrication and wireless performance evaluation of textile-integrated passive ultra-high frequency (UHF) radiofrequency identification (RFID) tags, which are embedded inside flexible additively manufactured wireless platforms. Two different methods are utilized to fabricate the tag antenna, including embroidery with conductive thread and conductive e-textiles. After antenna fabrication, RFID ICs (integrated circuits) are attached to the antenna patterns, to achieve fully functional RFID tags. These two types of tags are embedded inside flexible 3D-printed platforms, which can protect the tags from mechanical stresses and moisture. Our preliminary results show that the peak read ranges of both types of platforms are higher than 6 meters, which are suitable for versatile wireless applications.

1. INTRODUCTION

Increased bendability and stretchability has already significantly impacted the way electronics can be used. The development of new materials and novel manufacturing methods has resulted in wide-ranging applications of flexible electronics, some of which are bendable displays, wearable biomedical devices and wireless components [1–5]. Further, elasticity of electronics benefits significantly fabrication of clothing-integrated electronics, which need to endure an extremely harsh environment. The challenging unobtrusive implementation of flexible electronics structures into clothing, with low price and high reliability, can be achieved via a structural additive manufacturing, which will be presented in this paper.

In addition to logistics and supply chain management, passive UHF (ultra-high frequency) RFID (radio frequency identification) technology can be utilized in various types of wearable solutions. Possible application areas can be found, e.g., from sports, healthcare and welfare, as well as work safety and efficiency. Thus, wearable RFID solutions have been an active research area during the recent years [5–12]. This paper discusses the fabrication and wireless performance evaluation of textile-integrated passive UHF RFID tags, which are embedded inside flexible additively manufactured wireless platforms. Two different methods are utilized to fabricate the tag antenna, namely embroidery with conductive thread and use of conductive e-textiles. These two types of tags are embedded inside flexible 3D-printed platforms, which can protect the tags from mechanical stresses and moisture.

2. TAG PLATFORM FABRICATION

In this study, platform 3D printing is conducted using Prenta Duo 3D printer and Ninjaflex filament, which is a flexible thermoplastic material. 3D printing has been particularly advantageous in the development process of wireless solutions and RFID components, and Ninjaflex has been especially used as a substrate material [13–17]. Ninjaflex has a measured relative dielectric permittivity of 2.75 to 2.94 and a loss tangent of 0.05 to 0.08 [18]. In this study, the 3D printing processes of

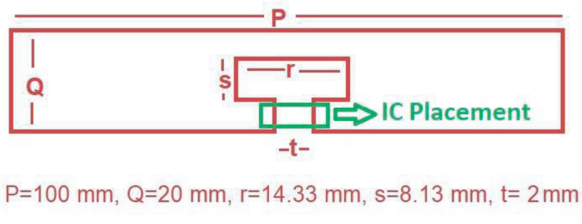


Figure 1: Tag design.

the platform is done using an extruder temperature of 220°C, with a nozzle diameter of 0.42 mm, and the printing speed being maintained at 10 mm/s. The models for the substrates are developed using AutoCAD 2017.

As presented in Figure 2, the substrate model for the embroidered tag comprised of two distinct patterns, i.e., a base pattern and an enclosure pattern. The base pattern is a simple rectangular pattern (140 mm × 35 mm). The enclosure pattern comprised of a cavity pattern (for protection of the IC component) and a boundary pattern. The heights of the base pattern and enclosure patterns are 0.2 mm and 0.7 mm, respectively, making the height of the entire structure 0.9 mm. A hollow of 0.1 mm height is kept at the bottom side of the cavity part, for 3D printing convenience, and for the housing of the RFID IC (integrated circuit) component. The dipole antenna design used for this study is as presented in Figure 1. This antenna design has been previously used, and it is known to exhibit excellent wireless performance [8, 13]. The embroidery of the antenna is conducted using Husqvarna Viking Ruby Royale embroidery machine, and the thread is Shieldex Filament 110f32 2-ply HC, with a DC linear resistivity of $500 \pm 100\,\Omega$/m. After the embroidery process, which includes four rounds of conductive thread, the RFID IC is attached to the embroidered antenna pattern, using conductive silver epoxy. The RFID IC used in this experiment is NXP UCODE 2GiL.

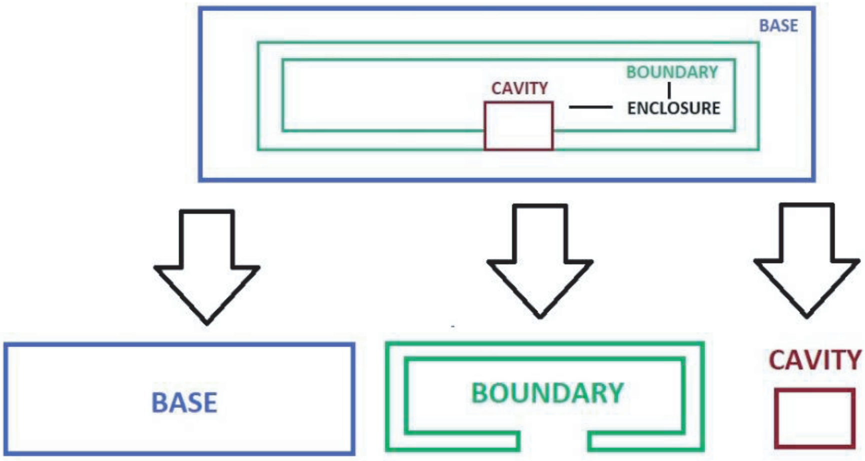
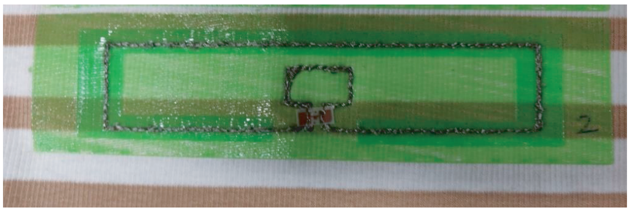


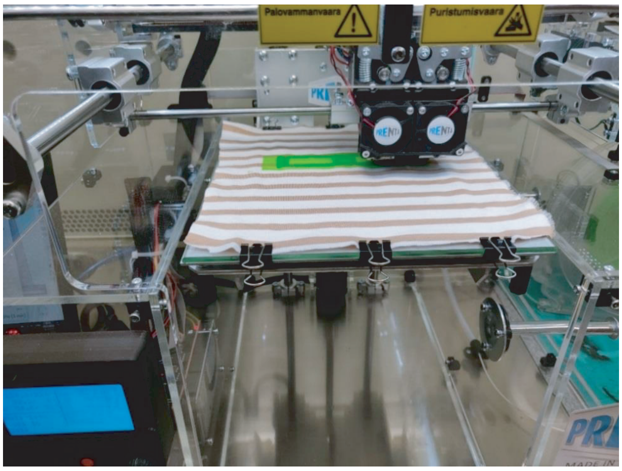
Figure 2: 3D printing parts for the platforms with embroidered tag antennas.

The 3D printing process is conducted in two stages. For the first stage, namely the pre-embroidery stage, the full base pattern and 0.2 mm of the boundary pattern (without the cavity pattern) are printed on the cotton-based textile substrate. The layer height of the print is 0.1 mm, infill pattern is rectilinear, and the infill density is 80%. After this process, the embroidered antenna is fabricated, and the IC is attached. The next stage of the printing process, which is presented in Figure 3, is the post-embroidery process, where the remainder of the enclosure pattern (boundary and cavity patterns) are printed on top of the tag, as well on the opposite side of the textile. The layer height is again 0.1 mm, infill pattern is rectilinear, and infill density is 100%. Ready platforms are shown in Figure 4.

For the e-textile antenna platforms, a base pattern (dimensions 110 mm×30 mm, height 0.75 mm) is first printed on the same cotton-based textile. The used e-textile material is nickel-plated Less EMF Shieldit Super Fabric (Cat. No. A1220), which exhibits a sheet resistance of $0.16\,\Omega/\square$. It has a hot melt glue layer on backside and can thus be easily ironed onto various types of substrates. The antenna (shown in Figure 5) is cut from e-textile using Epilog Fusion Laser Model 13000 laser cutter. The e-textile antenna is ironed onto the substrate, and RFID IC is attached to the antenna pattern, using conductive silver epoxy, as presented in Figure 5. Finally, a cover pattern (dimensions 110 mm × 30 mm, height 0.2 mm) is printed in top of the tag structure. The printing parameters of both the base pattern and the cover pattern are the following: layer height 0.1 mm, rectilinear pattern and 100% infill. Ready e-textile tag platforms are presented in Figure 6.

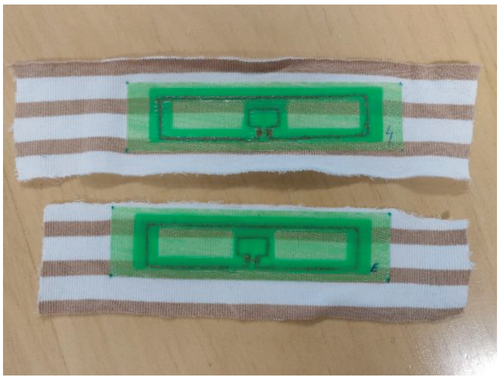


(a)

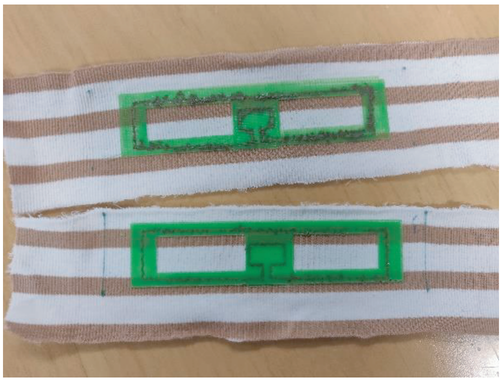


(b)

Figure 3: (a) Embroidered tag antenna and attached IC component on top of base pattern and (b) subsequent 3D printing of the top layer.

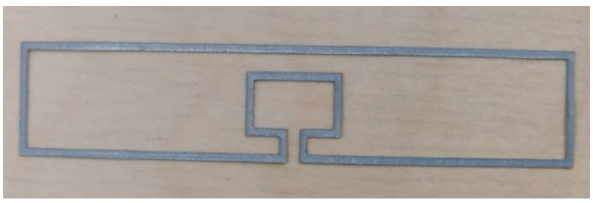


(a)

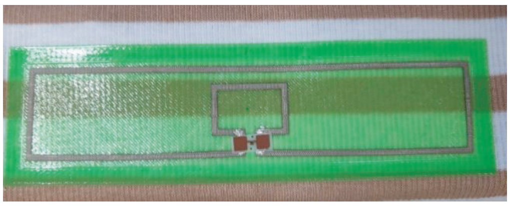


(b)

Figure 4: (a) Top sides and (b) bottom sides of platforms with embroidered tag antennas.



(a)



(b)

Figure 5: (a) Antenna cut from e-textile and (b) RFID tag attached to 3D-printed base pattern.

3. WIRELESS MEASUREMENTS

The manufactured RFID platforms are measured in an anechoic chamber, using Tagformance RFID measurement unit with a capability to power-frequency sweeps. The minimum transmitted power from the reader to activate the tag (i.e., threshold power, Pth) is recorded between 800–1000 MHz. Next, the read ranges of the platforms are computed, in the absence of multipath propagation, which

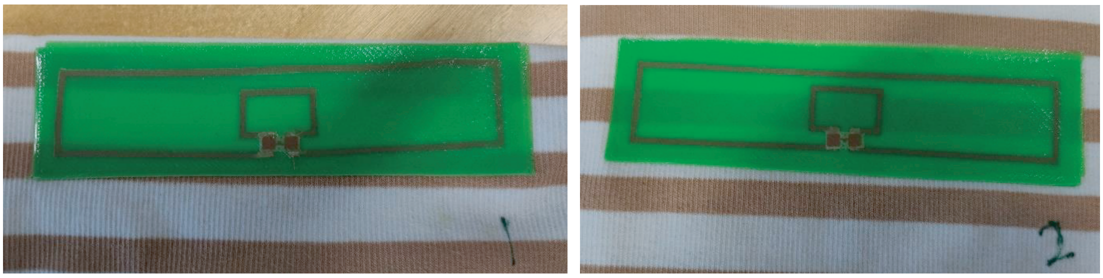


Figure 6: Platforms with e-textile tag antennas.

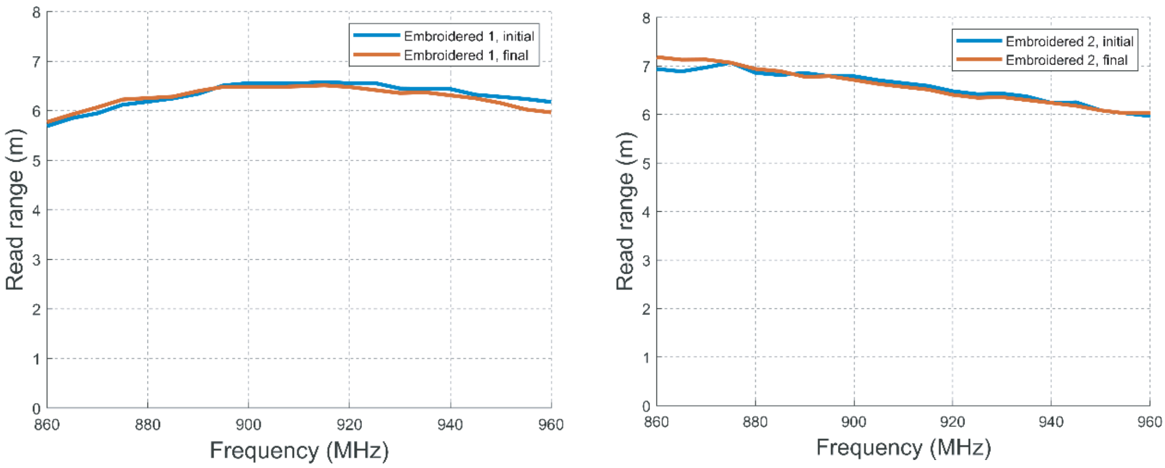
is a widely used tag performance indicator. The reader antenna's wireless channel with respect to the location of the tag antenna is characterized with a reference tag with known properties. The read range of the tag platform can be calculated using the following equation:

$$d_{Tag} = \frac{\lambda}{4\pi}\sqrt{\frac{EIRP}{P_{TS}L_{fwd}}} \tag{1}$$

where λ is the wavelength transmitted from the reader antenna, EIRP is the maximum equivalent isotropically radiated power allowed by European regulations (3.28 W), P_{TS} and L_{fwd} are the measured threshold power and forward losses, respectively.

4. RESULTS AND DISCUSSION

Figure 7 and Figure 8 show the read range measurements of the embroidered and e-textile tags, respectively, right after tag fabrication and after fully finalizing the platforms and covering the tags. The results show that the peak read ranges of both types of platforms are higher than 6 meters, which is suitable for versatile wireless applications. Further, the tags are fully functional throughout the global UHF RFID frequency band. Due to more simple fabrication process, e-textile-based platforms are selected for further studies. The next step is to evaluate the reliability of these platforms under mechanical stresses and machine washing. We also plan to integrate them into T-shirts and test the effects of normal use of clothing on the performance of these wireless platforms.



(a) (b)

Figure 7: Read range measurements of embroidered tags: (a) Tag 1 and (b) Tag 2.

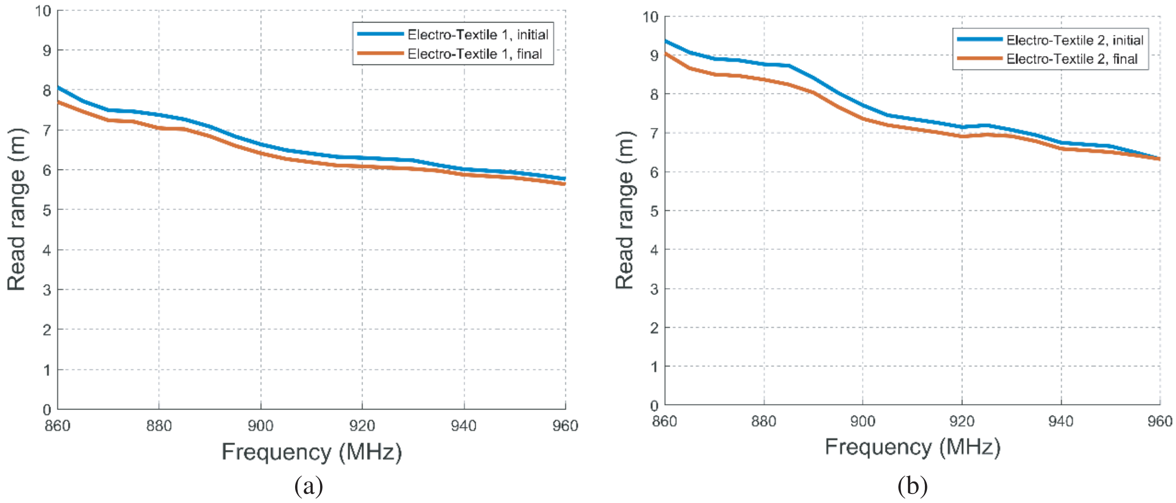


Figure 8: Read range measurements of e-textile tags: (a) Tag 1 and (b) Tag 2.

5. CONCLUSIONS

In this paper, a structural additive manufacturing method was introduced, combining 3D printing and embroidery in addition to 3D printing and e-textiles. This method was tested for fabrication of textile-integrated wireless platforms. The achieved preliminary results show that the peak read ranges of both types of passive UHF RFID-based platforms are higher than 6 meters, which are suitable for versatile wireless applications. The next steps are washing machine and strain reliability testing, and integration of these wireless platforms into regular clothing for daily wearing.

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