Nature-Inspired Electro-Textile Antennas for Passive UHF RFID

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Abstract— Antennas are usually hidden from sight. However, it is possible to design antennas that look visually appealing and socially accepted, while also have the same wireless performance as traditional antenna designs. Literature shows versatile nature-inspired antennas that have leaves and plants as design models. Most of such antennas are used in wideband, broadband, ultra-wideband, wireless local area networks, as well as 4G and 5G networks. The existing implementations do not employ ultra-high frequency (UHF) radio frequency identification (RFID), which, however, is a versatile technology that has taken a growing role for example in the areas of the Internet of Things, wearables, and e-health. Passive UHF RFID-based communication is challenging due to noisy and unstable signals, which sets high requirements on antenna designs. This paper aims to design and fabricate (from electro-textiles) nature-inspired passive UHF RFID tag antennas and evaluate their wireless performance. Each antenna is made in two sizes, a small and a big version. In wireless evaluation, all the nature-inspired antennas show read ranges and radiation patterns suitable for practical use, while the bigger size antennas perform better than the smaller counterparts in terms of read range. In addition to their traditional wireless functionality, these antennas can also have an ornamental function in clothing and can be designed in such a way that enhances the aesthetics and fashionability of wearables or smart clothing.

1. INTRODUCTION

Textile antennas distinguish greatly from conventional antennas, which are made minimized or completely disappear from sight [1]. They generate novel design alternatives, for example by exposing textile antennas in a visible, expressive, or even performative way, further propelling cutting-edge applications on the Internet of Thing (IoT), smart wearables, and fashion technology domains. As a result, the design and development of textile antennas not only emphasize the functional performance and electromagnetic parameters, but also entail well-balanced technical and aesthetical affordances. Previously, we have witnessed a few successful precedents of nature-inspired antenna design in different fields, as their shape with great perimeter makes them compact in size and enables them to resonate at multiple frequencies [2], [3]. To name a few examples, when compared to a planar monopole antenna, the perimeter of the Jasmin flower shape antenna was larger, and by altering the petal length around 7 mm, the resonance frequency changed between 8 and 12 GHz [4]. In [5], the shape of a three-leaf clover was utilized for a coplanar waveguide antenna, and the results demonstrated that it radiates omnidirectionally in H-plane and approximately bidirectionally in E-plane. A miniaturized monopole leaf-shaped antenna with a combination of notching techniques was proposed [6] to obtain an omnidirectional radiation pattern with filtering properties and low cross-polarization, especially at higher frequencies. Palmate leaf-shaped antenna's results revealed that it can achieve a wide bandwidth from 3.08 to 14 GHz [7]. When considering the design aspects, increasing the number of branches to 21 in a sneezewort plant-shaped antenna and modifying the ground with a T-shaped slot showed significant radiation performance improvement compared to 13 branches [8]. Further, a tree-shaped antenna's measurements illustrated good far-field radiation and gain characteristics [9] while a monopole antenna resembling a sunflower was found suitable for satellite communication. [10] Finally, a Papaya leaf antenna demonstrated its application in global system for mobile communication (GSM 1900), Universal Mobile Telecommunication System, Wireless Local Area Network, Long Term Evolution (LTE) 2300, LTE 2600, Worldwide Interoperability for Microwave Access, C-band, X-band, and sub6 GHz 5G band [11]. These examples demonstrate that the research around nature-inspired antennas is versatile and active, and the achieved results have been promising. Some other nature-inspired antenna examples are a spiral seashell [12], a four-leaf clover [13], an Oxalis triangularis plant's leaf [14], a maple leaf [15], a rose leaf [16], and a Koch snowflake [17].

Although there has been a strong interest in the design of antennas that are inspired by plants, expanding the portfolio of antennas to other shapes and figures, such as animals, would greatly widen the possibilities of such decorative antennas. Furthermore, nature-inspired antennas have not been implemented for ultra-high frequency (UHF) radio frequency identification (RFID). Passive UHF RFID is a versatile technology that has countless applications in logistics, toll collection, IoT, e-health, and wearables, just to name a few examples. Due to noisy and unstable signals, passive UHF RFID communication is challenging, causing high demands on antenna designs. The purpose of this paper is to design and fabricate nature-inspired UHF RFID antennas from electro-textiles and confirm their performance through wireless evaluation and practical testing.

2. ANTENNA DESIGNS & TAG FABRICATION

Passive UHF RFID tags with bird-shaped, butterfly-shaped, and leaf-shaped antennas were designed. All the antennas were fabricated from commercial electro-textile material, nickel-plated Less EMF Shieldit Super Fabric. Each type of antenna shape had two sizes, and the bigger antenna shape was 1.2 to 1.5 times the size of the smaller antenna. NXP UCODE G2iL series RFID microchips (with a wake-up power of −18 dBm, 15.8 µW) were used in the fabrication of the RFID tags. Each microchip is attached to a strap that has two copper pads (each 3×3 mm^2) for easy attachment. The antenna designs and ready-made tags are shown in Figure 1.

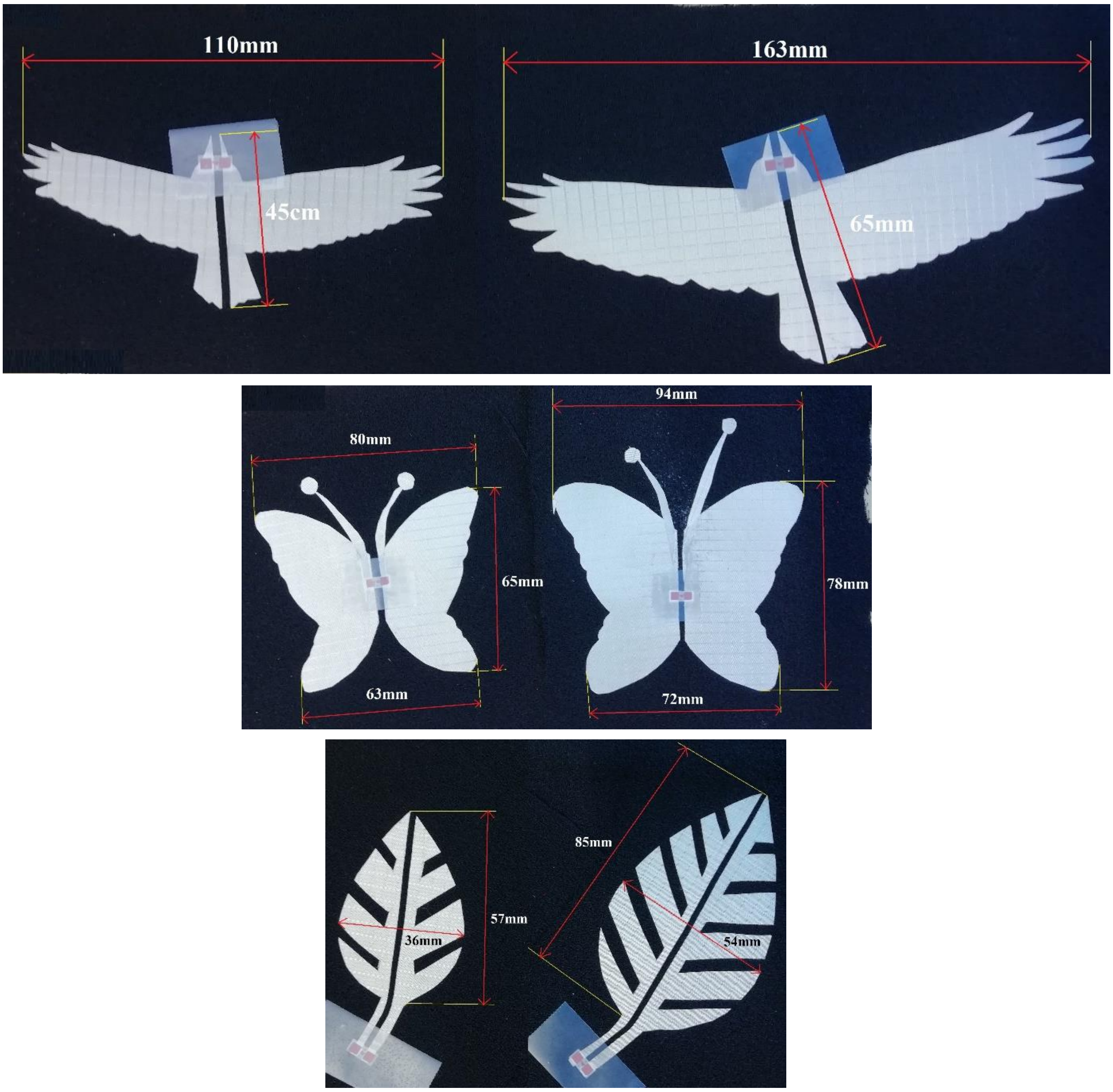


Figure 1. Passive UHF RFID tags with bird-shaped (top), butterfly-shaped (middle), and leaf-shaped (bottom) electro-textile antennas.

3. MEASUREMENTS

3.1 Wireless evaluation

Voyantic Tagformance RFID measurement system was used to evaluate the wireless performance of the created tags. The system includes an RFID reader with a configurable transmission frequency (800-1000 MHz) and output power (up to 31.5 dBm). The read range as well as E-plane and H-plane were measured for each tag shape type, with the exception that in the E-plane and H-plane measurements, only the bigger antenna versions of each shape were used.

To calibrate the system and characterize the properties of the wireless channel from the reader antenna to the measured tag, a reference tag was used. The read range results were based on the measured threshold power (P_{th}). The threshold power of an RFID reader is the minimum output power required to activate the tag under test at a given distance. The measured path loss (Λ/P_{th*}) and threshold power (P_{th}) are then used to calculate the theoretical read range between the tag and the reader antenna, as given in (1),

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

where λ is wavelength transmitted from the reader antenna. EIRP stands for effective isotropic radiated power, which is the emission limit of an RFID reader. The emission limit in European countries is EIRP = 3.28 W, which was used in this study. P_{th*} is the measured threshold power of the reference tag and Λ is a parameter in watts describing the sensitivity of the reference tag of the measurement system. The measured tag was placed on a foam fixture inside an anechoic chamber, as presented in Figure 2.

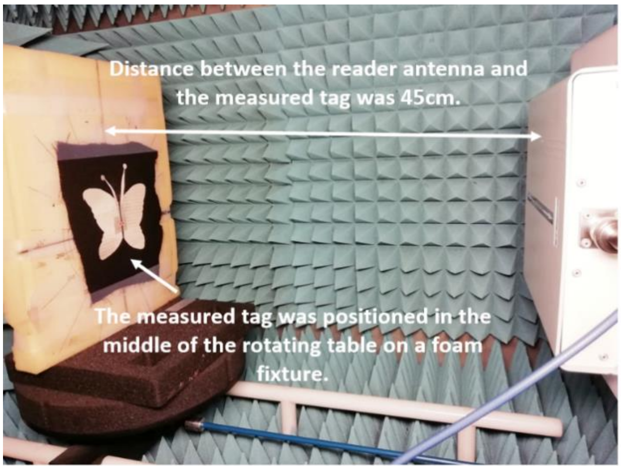


Figure 2. Wireless evaluation setup in an anechoic chamber, a tag with a butterfly-shaped antenna attached to a foam fixture.

3.2 Practical testing

Practical measurements were taken in a normal office environment. The measurement setup can be seen in Figure 3. A circularly polarized reader antenna connected to a Thingmagic M6 RFID reader via a connecting cable was used for the evaluation. The reader operated at the European frequency range (865.6–867.6 MHz) with a 28 dBm power. The read range was obtained by putting the tag in front of the RFID reader and moving it back until it was no longer detectable.

Figure 3. Practical testing setup in an office environment, a tag with a leaf-shaped antenna attached to a foam fixture.

4. RESULTS

4.1 Results of wireless evaluation

Figure 4 shows the read range results of all the tag types at a frequency range of 800-1000 MHz, which covers the global UHF RFID frequency band. The tags with the smaller and bigger butterfly-shaped antennas showed peak read ranges of 1.5 and 1.8 meters, respectively. The peak read ranges for the tags with the smaller and bigger bird-shaped antennas were 2.1 and 4.6 meters, respectively. The tags demonstrated peak read ranges of 0.7 and 2.3 meters, respectively, using the smaller and bigger leaf-shaped antennas. It can also be seen that all the bigger antennas performed better than smaller ones.

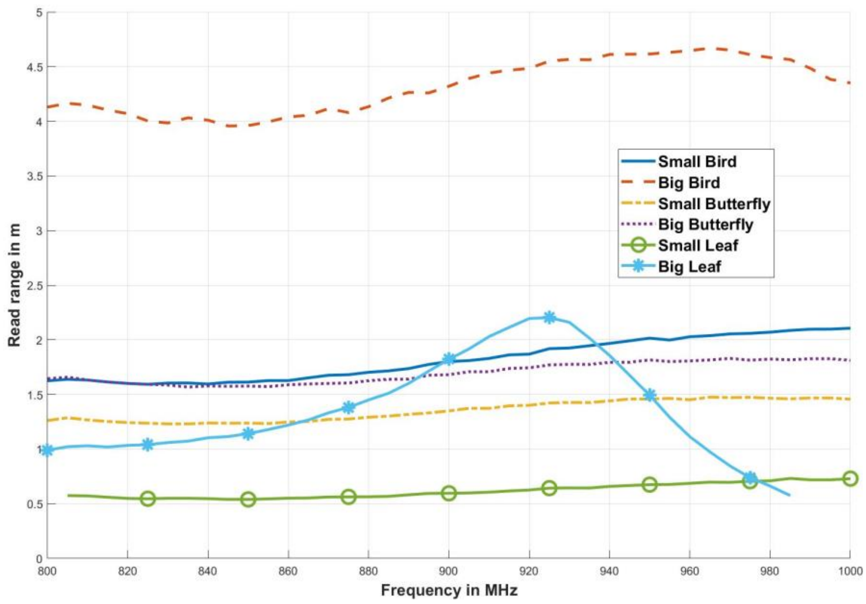
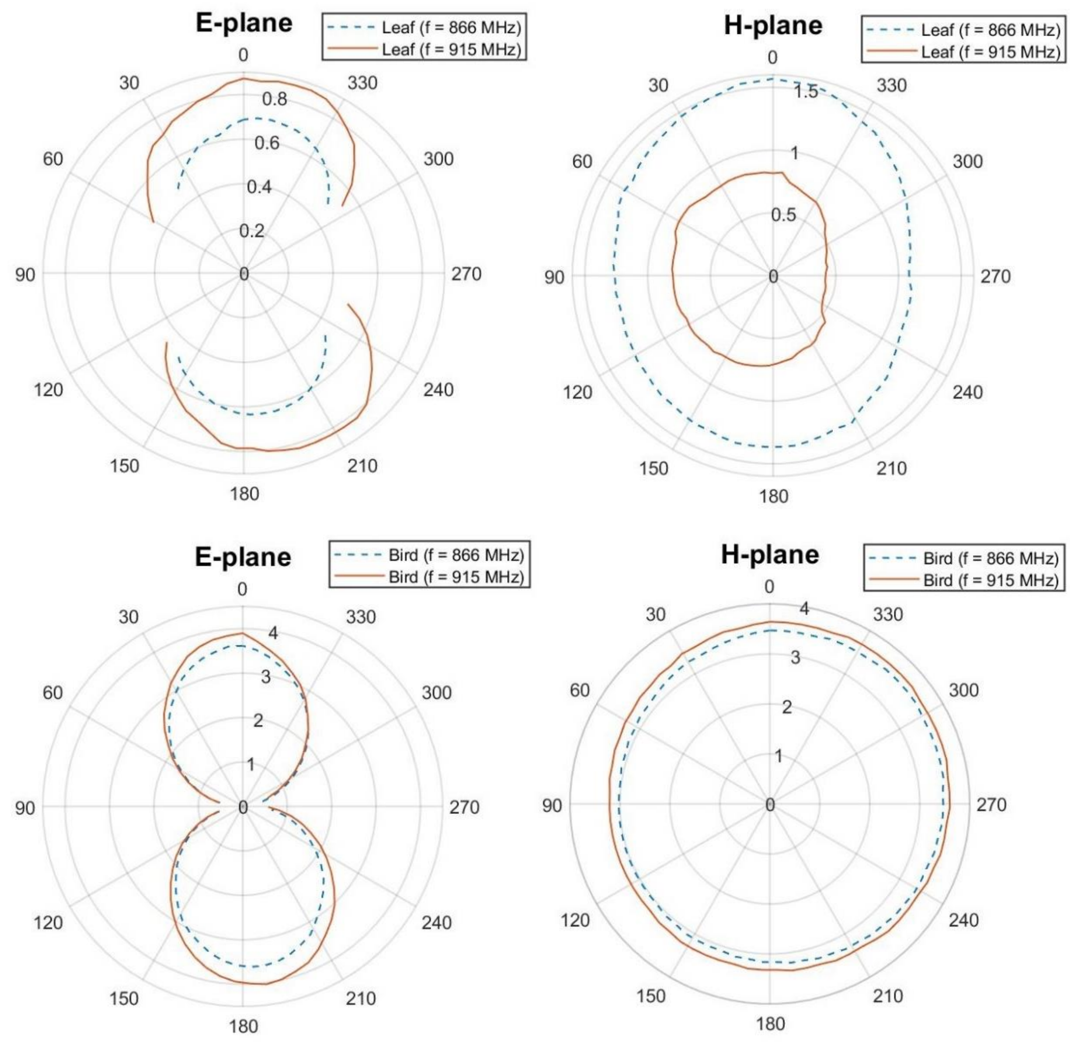


Figure 4. Results from wireless evaluation in an anechoic chamber.

The UHF RFID frequency band ranges from 865.6 to 867.6 MHz in Europe and 902 to 928 MHz in the United States. Because of this, two frequencies were selected for the E-plane and H-plane tests: 866 and 915 MHz, which are around the central frequencies of the frequency ranges. Figure 5 shows the radiation patterns in meters for the leaf-shaped, bird-shaped, and butterfly-shaped tags. All tags are omnidirectional in H-plane.



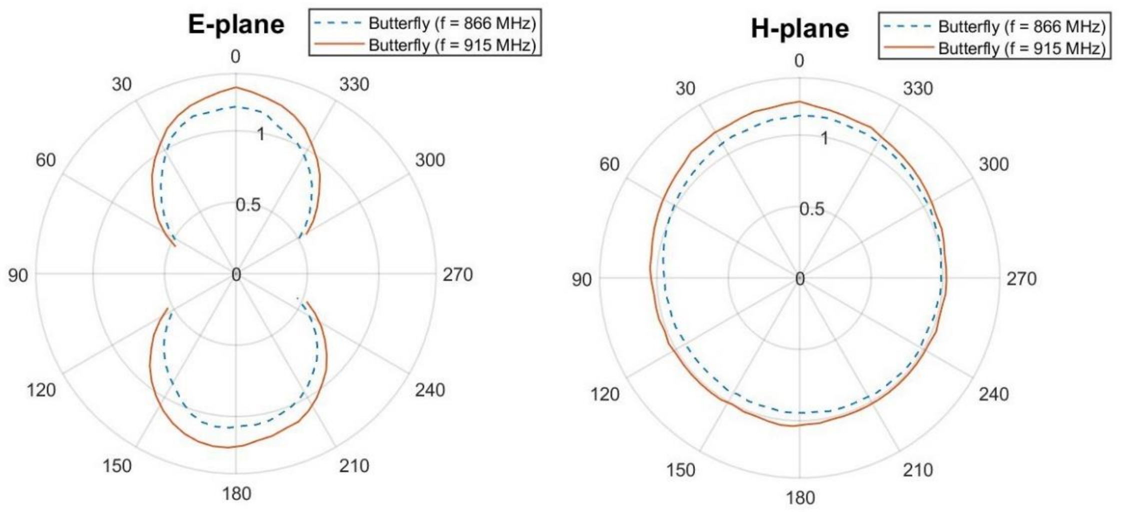


Figure 5. E-plane and H-plane results of the tags with leaf-shaped (top), bird-shaped (middle), and butterfly-shaped (bottom) antennas.

4.2 Results of practical evaluation

The results achieved from the office environment (Table 1) show that the read ranges of the tags with the bigger bird-shaped antennas are slightly less than 4 meters, which can be considered suitable for practical use of passive UHF RFID technology. Also, the read ranges of the bigger leaf and butterfly are well over one meter. The results also show that a bigger antenna performs better than a smaller one, which was expected. The read ranges are slightly shorter than in the anechoic chamber, due to the noisy and unstable signals caused by the environment.

Table 1. Tag read ranges in the office environment.

Antenna	Read Range (m)	Antenna	Read Range (m)
Small Bird	1.66	Big Bird	3.90
Small Leaf	0.30	Big Leaf	1.36
Small Butterfly	1.06	Big Butterfly	1.18

The reason behind the variation between antennas and the superior performance of the big bird might be caused by its shape, which looks like a dipole antenna. Next, to clearly understand the underlying reasons between the geometrical shape and the performance of antennas, further studies that iteratively test small modifications in antenna design will be simulated and conducted.

5. CONCLUSIONS

In this paper, we presented nature-inspired passive UHF RFID tag antennas that resembled a bird, a leaf, and a butterfly. The achieved preliminary results, especially the results of the bird-shaped tags, showed read ranges comparable to tags with more traditional antenna designs. Further, all the tags showed read ranges of more than one meter. The next step is to parametrize the antenna design and discover how geometric modifications affect the antenna performance. Another goal is to optimize the performance of the nature-inspired RFID tag antennas near the human body, which will open the door for playful clothing designs and antennas' ornamental function in clothing. Further, the antennas can be designed in such a way that enhances the aesthetics and fashionability of wearables or smart clothing.

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