Maintenance-Free Moisture Sensor on Dishcloth Substrate

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***Abstract*—** In this study, a passive UHF RFID-based moisture sensor is fabricated and evaluated. The sensor tag can sense the high humidity of the environment and indicate it with a permanent change in its backscattered signal. The sensor tag antenna and antenna-IC interconnections are fabricated on a biodegradable dishcloth material using conductive thread. The sensors are tested in an anechoic chamber and in normal office conditions, when initially dry, after dipped into water for 1 minute, and again after 24 hours of drying in air. These sensor tags initially show read ranges of 6-9 meters throughout the global UHF RFID frequency band. When wet, the read range decreases to 5 meters, while after 24 hours of drying, the read ranges of the tags permanently decrease to around 2-4 meters. The dishcloth material comes thicker when wet, also causing a change to the embroidered antenna structure, finally causing the permanent change in the backscattered signal. In normal office conditions, moisture causes the average backscattered signal an obvious change from around -66 dBm to -69 dBm.

Keywords—Conductive thread; eco-friendliness; moisture sensor; passive UHF RFID.

I. INTRODUCTION

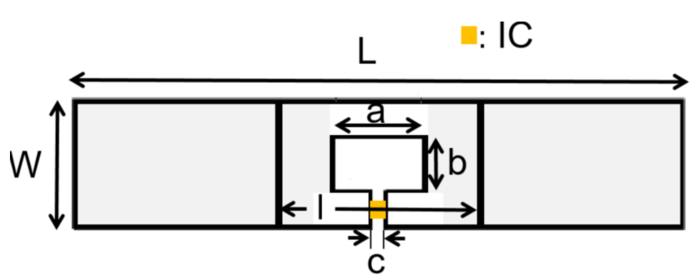
Passive UHF (ultra high frequency) RFID (radio frequency identification) technology is a compelling approach towards energy-autonomous and cost-efficient wireless platforms for versatile sensing solutions. Such sensor tags have already been studied widely and they have showed possibilities for monitoring strain, temperature and humidity [1]-[7], just to name a few application areas. As the technology is passive, no onboard power sources or maintenance are needed. Thus, the cost and weight of the sensor element are extremely low.

Fabrication of cost-effective and environmentally friendly wireless platforms has been an active research area during the recent years. One great example are embroidered structures fabricated from conductive thread. As previously studied, this approach enables seamless integration of antennas and antenna-electronics interconnections into different types of structures [8]-[10]. In our previous work [11], an embroidered moisture sensor on a thin dishcloth substrate was introduced. In this previous version, the increased moisture caused a conductivity improvement of the antenna pattern and increased backscattered power from the tag. Thus, when the tag got dry again, the performance returned close to the initial performance. As a next step, in this paper, we introduce a passive RFID-based embroidered moisture sensor on a dishcloth substrate, which shows a permanent change in the backscattered signal, after exposed to high moisture conditions. This type of moisture sensor can be used for example for detecting moisture exposure during transportation, especially since our sensor works globally throughout the UHF RFID frequency band. After this introduction, we introduce the tag antenna design, as well as the used fabrication method and conductive thread material. Finally, we present the initial measurement results in an anechoic chamber, as well as the practical testing results of the developed moisture sensor in normal office conditions.

II. TAG FABRICATION

The size and structure of the sensor tag is shown in Figure 1. The tag antenna is embroidered on a dishcloth substrate, which is a 100 % biodegradable natural material with 70 % cellulose and 30 % cotton. The used thread is multifilament silver plated thread (Shieldex 110f34 dtex 2-ply HC). The DC linear resistivity of the thread is 500±100 Ω/m, and the diameter is approximately 0.16 mm. The used microchip, which is a passive NXP UCODE G2iL series RFID IC (integrated circuit), is shown in Figure 2. The microchip is connected to the antenna body by embroidering the antenna directly over the microchip strap copper patterns. A ready sensor tag and close looks of the IC and IC-antenna interconnections are also shown in Figure 2.

The dishcloth substrate material was used in two ways: one substrate is the original dishcloth material, while another is the same dishcloth, which was dipped into water and dried before the antenna embroidery process (referred as pre-wet dishcloth). This material will have a little bit structure change after the first-time-wet. It is important to determine if this condition can affect the tag. Thus, by using these two comparison groups, we can confirm if the change in the performance of the sensor tag is actually caused by the antenna body.



L	W	a	b	c	l
100	20	14.3	8.125	2	30

Figure 1. Antenna size (in mm) and structure.

Figure 2. Ready-made embroidered sensor tag (left) and close look of the microchip and antenna-microchip interconnection (right).

III. WIRELESS MEASUREMENT

A. Anechoic chamber measurements

The wireless performance of the sensor tags is firstly evaluated in an anechoic chamber using Voyantic Tagformance RFID measurement system, in order to evaluate their performance without any environmental disturbances. This system contains an RFID reader with an adjustable transmission frequency (800-1000 MHz) and output power (up to 30 dBm) and provides the backscattered signal strength (down to −80 dBm) from the tag.

For sensor tag evaluation, we record the lowest continuous-wave transmission power (threshold power: P_{th}) at which the tag remains responsive. The wireless channel from the reader antenna to the location of the tag under test is firstly characterized using a system reference tag with known properties. This enables the estimation of the attainable read range of the tag (d_{tag}) versus frequency from

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

where λ is the wavelength transmitted from the reader antenna, P_{th} is the measured threshold power of the sensor tag, Λ is a known constant describing the sensitivity of the system reference tag, P_{th^*} 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 regulations.

The tags are tested when initially dry, after dipped into water for 1 minute, and again after 24 hours of drying in air. The read range measurement results (in frequency range of 800-1000 MHz) for both the original dishcloth and for the pre-wet dishcloth are shown in Figure 3. As presented, the tags show read ranges of 6-9 meters throughout the global UHF RFID frequency band on both substrate types. When they get wet, the read range decreases to 5 meters in both cases. After 24 hours of drying, the read ranges of the tags permanently decreases to around 2-4 meters through the global frequency band. The selection of the substrate does not show any influence to the functionality of the sensor tag. As shown in Figure 4, absorbed moisture changes the structure of the dishcloth, which comes thicker when wet. This mechanical change affects the properties of the embroidered tag antenna, which most probably causes the permanent change in the read range.

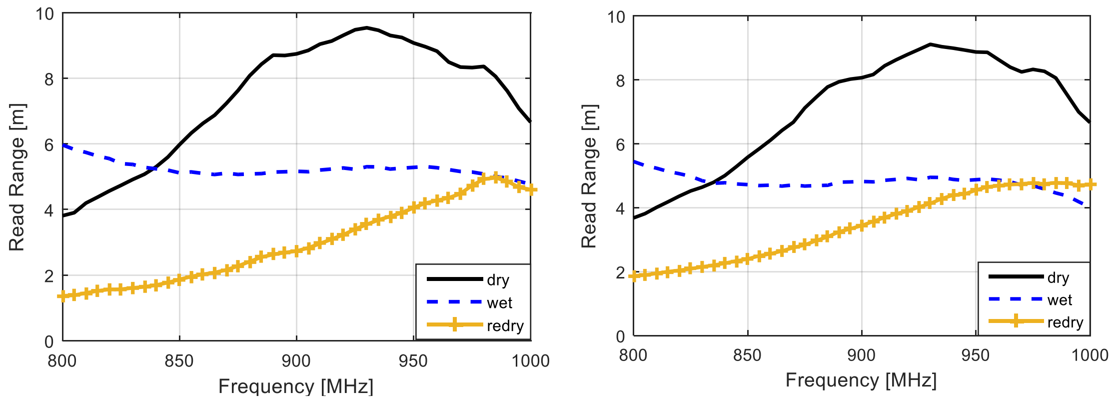


Figure 3. The measurement results of the sensor tag on original dishcloth (left) and on pre-wet dishcloth (right).

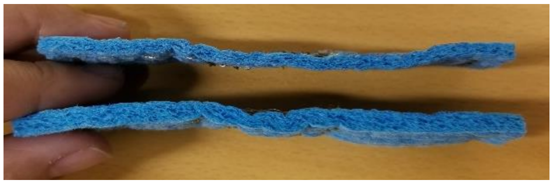


Figure 4. Dry substrate (top) and wet substrate (bottom).

B. Practical measurements in office conditions

The practical performance of the sensor tag is next tested in a normal office environment by recording the backscattered signal using Thing Magic M6 RFID reader. The test is done with a 1.2 meters distance between the reader antenna and the sensor tag. The transmitted power is 28 dBm. The measurement results, as shown in Figure 5, show that the average backscattered power strength before and after the tag gets dry again has an obvious change from around -66 dBm to -69 dBm. Thus, moisture exposure of the platform can be detected easily by checking the wireless performance of the sensor tag.

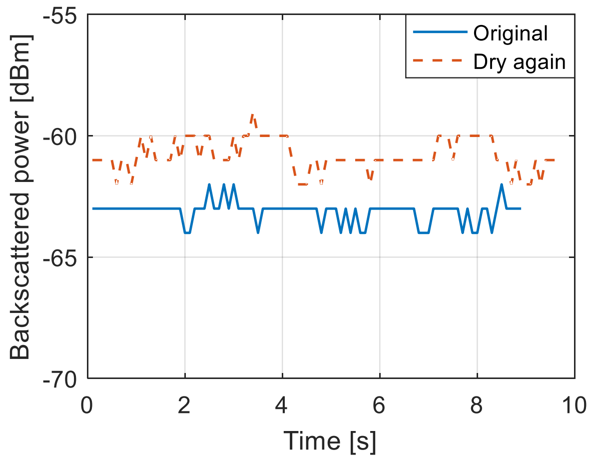


Figure 5. Backscattered signal (backscattered power strength) of the sensor tag in an office environment before and after getting dry again.

IV. CONCLUSION

In this study, we fabricated and tested a passive RFID-based embroidered moisture sensor with an eco-friendly substrate material. The sensor was evaluated in an anechoic chamber and in practical use conditions. Based on the measurement results, the sensor initially showed around of 6-9 meters of read ranges throughout the global UHF RFID frequency band. After the platform exposed to high moisture, the read range of the tag had a permanent decrease in the read range to around 2-4 meters globally. During the practical test, the backscattered power strength of the tag had around 3 dB difference before and after the platform got wet. Thus, this kind of cost-effective and eco-friendly embroidered tag was sensitive to moisture exposure and showed this in its wireless performance. The next steps are a referenced readout for moisture, by integrating a protected reference tag into this sensor platform, and testing of the effects of moisture exposure time on the sensor performance.

V. REFERENCES

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