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Food spoilage estimation using a sensing RFID tag

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Abstract

To provide more information about the food product and to indicate its freshness status, we propose to add to the package a passive RFID sensor operating in UHF and HF band. It is based on a conventional RFID antenna associated with an interdigitated capacitor. This planar structure has a sensitive layer made of biopolymer. This layer senses variations of environmental parameters, which depend on spoilage of packaged foods. The sensitive layer is made of proteins extracted from the residues of food industry, and it is therefore, intrinsically biocompatible. In this paper, we have demonstrated the proper functioning of the system on several packaged beef samples.

1. Introduction

Because of the nature of some perishable foodstuffs, stock management is crucial in food distribution. Indeed, the consumption limit of a food product essentially depends on the microbial contamination that develops over time and that is a function of the applied environmental conditions. The food spoilage changes the sensory and/or visual aspect of the product and makes it potentially pathogenic [1].

Expiry dates mentioned on food packages help to guarantee consumer safety. However, these dates are not related to the history and/or the state of real packaged products. They are estimated beforehand during ageing tests and according to an arbitrary scenario, legislated or not (microbial load of the raw materials, predictive microbiology, safety margin considering, for example, a temperature overrun over a certain period, ...) [2]. Even today, no indication of expiry date is easily digitized to allow a simple management. Moreover, expiry dates do not consider conditions of transport and storage of food products.

To add value to RFID technology, sensors are being developed to interface with RFID tags. These sensors monitor different aspects of food quality, such as milk freshness, bacterial growth, or fish spoilage, to reduce waste, and inform food logistics actors about product spoilage [2]. In this paper, we propose a low-cost passive UHF RFID-sensor based on the mismatch of the impedance of its antenna. This mismatch is due to the reaction of a biopolymer (wheat gluten), residue of the food industry, applied on a zone of the antenna and whose dielectric properties vary according to the gaseous environment coming from the food degradation. At the end, food degradation is a function of the activation power of the RFID-sensor resulting from the RFID reading.

In the following section, we detail the instrumental chain and the choices that allowed us to design the RFID-sensor to achieve a low manufacturing cost. We describe actions of physical quantities synonymous with food degradation on the biopolymer. Subsequently, we detail the characteristics of the sensor used with the biopolymer as well as its association with the antenna. The design is validated by electromagnetic (EM) simulations. Furthermore, since the measurement is converted to digital format only after its transmission, we explain why our reading system allows a more reliable reading. We conclude by presenting results of our latest experiments under real conditions in which we record the evolution of the RFID signal during the food degradation of meat pieces undergoing a classical logistic cycle.

2. Sensor-RFID design

2.1. Sensing principle of food spoilage

The degradation of a food in a hermetically sealed container leads to changes in gas compositions [3], [4] and the dynamics of this degradation depends on the ambient conditions [1] (temperature, humidity). We choose wheat gluten as a sensitive element for spoilage detection. This biopolymer is biodegradable and inexpensive. The complex permittivity of this element was previously studied as a function of temperature, humidity, and exposure to volatile organic compounds [5]. It senses humidity due to the absorption of water by the biopolymer matrix leading to a variation of effective permittivity [6]. Following the absorption of water, it senses concentrations of volatile organic compounds, including CO_2 [7] and ethanol [8]. By dissolving in the water contained in the biopolymer matrix, CO_2 lowers the mixture pH and increases the ionic conductivity.

2.2. Design of the RFID sensor

Our device consists of an RFID chip (EM Microelectronic EM4423) compatible with two RFID technologies: RAIN (EPC 2nd generation operating in the UHF 860 960 MHz band), and NFC (13.56 MHz). With its far-field operation allowing a longer reading range (> 10 m), RAIN technology allows fast inventories. However, NFC technology, which is widely integrated in today's smartphones, operates in the near field. For the RFID tag, in order to easily use the two frequency bands mentioned above, we connect the chip to two antennas, as described in Figure 1.A.

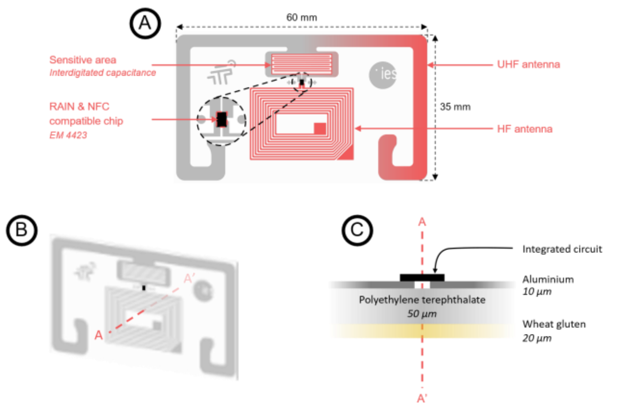

Figure 1. RFID-sensor

The UHF antenna is a classical dipole which can be easily integrated on a flexible laminate. To communicate properly with a reader, the antenna must have an impedance equal to the complex conjugate of the impedance of the chip. To achieve this, a "T-match" matching circuit [9] is placed between the antenna and the RFID chip (read activation power of -18dBm) ($Z = 18{,}1\text{-}j248\ \Omega$).

To reduce the size and to provide a sensing feature adapted to the changes in dielectric properties, we have integrated five pairs of interdigitated electrodes into the T-match. This type of sensor is flat, which facilitates its integration into an RFID tag. The design chosen is as follows: the length of two electrodes facing each other is 13.5 mm, the spacing between common connector and electrodes is 0.25 mm, and the distance between two electrodes is 250 µm. Thanks to the small gap between the electrodes, this design allows the electric field to interact mainly with the thin layer of deposited biopolymer. To achieve an industrial design and thus facilitate its adoption by the actors of the food logistics, we realized the RFID sensor in collaboration with Tageos, a French manufacturer of RFID tags.

The RFID-sensor is simulated using CST Design Studio 2019 in its final configuration (positioned inside a food package in the presence of meat). As shown in Figure 2, a variation of humidity from 30 % to 95 % leads to a variation of dielectric permittivity of the biopolymer, thus a variation of capacitance and modifies the matching impedance from -12dB to -1.5dB. In this study, the estimation of degradation is based on monitoring the activation power of the RFID-sensor.

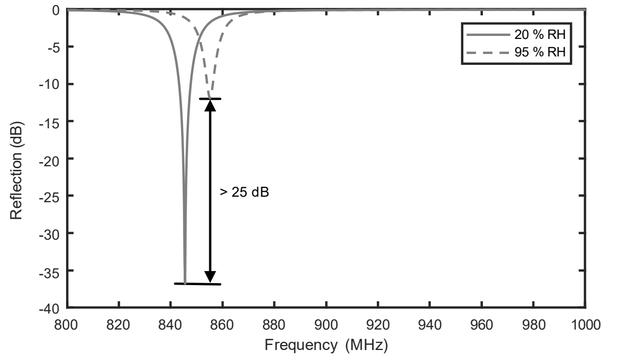

Figure 2. Simulated reflection coefficient between UHF antenna and integrated circuit

2.3. RFID-sensor reading system

$$\boldsymbol{P_C(threshold)} = \boldsymbol{P_{R_{tx}}(threshold) \cdot G_R \cdot \left(\frac{\lambda}{4\pi \cdot d}\right)^2 \cdot PLF \cdot G_T} \quad (1).$$

UHF RFID readers generally have an RF generator that can set power and frequency. For the frequency bands available in Europe (865.7-867.5 and 916.3-918.7 MHz), the regulations remain strict despite the desired standardization with the North American bands (902.75- 927.25 MHz). In this study, we focus on the transmission power required to activate the RFID tag, or “turn-on power”, noted $P_{R_{tx}}(threshold)$ in equation 1. This measurement is quite simple to perform as it concerns only the monitoring of the necessary power sent by the reader for the tag activation. This power depends on the distance between reader and tag, d, the wavelength of the signal, λ, the gains of reader and tag, G_R and G_T, and the threshold power required to activate the chip (or "reading sensitivity") noted $P_C(threshold)$. Furthermore, an additional attenuation noted PLF is present if the reader and tag antennas are not aligned.

3. Results and discussion

For our experiments, we chose beef meat. Pieces of meat are often kept under a protective gas environment consisting of 70 % O_2 and 30 % CO_2. This environment stifles the growth of microorganisms [3], [10] and revives the reddening of the meat [11].

In the two experiments presented in this paper, we use the Voyantic Tagformance Pro solution to measure turn-on power. Climate chambers in which the experiments take place (to maintain stable temperature) are made of metal. To reduce the reflections of EM fields on walls, we use a near field antenna (Voyantic SnoopPro) for the RFID reader.

3.1. Validation in a simulated environment

In this first experiment, RFID-sensors are subject to a protective environment, followed by a gaseous environment simulating significant microbial respiration (50 % O_2 and 50 % CO_2).

An RFID-Sensor is glued on the cover plate of a cylindrical (Ø 10 × 10 cm) hermetic container made of polyoxymethylene. The Voyantic SnoopPro antenna will be attached to the cover and communicate with the RFID-sensor through the lid. Gas concentration monitoring is performed by the wireless and compact PreSens oximetry solution. As our sensor is also sensitive to temperature [6], it is suited to stabilize this condition when the gas sensitivity is studied. For this, a climate chamber is used (Memmert HPP110). The changes in gas composition leads to change in the maximum absolute humidity. To maintain a relative humidity, we place a container of water in the airtight container to saturate the environment with moisture, like a food package.

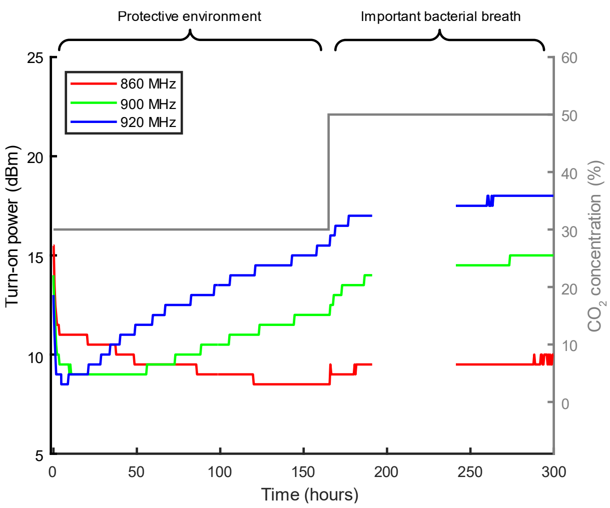

Figure 3. RFID signal as a function of the gas

In Figure 3, we study behaviors of 3 frequencies (860, 900, and 920 MHz) for 2 gaseous environments (protective and important microbial respiration). We observe a stabilization of the signal at the end of the step and change between 2 states is notable. Indeed, for the change between 30 % and 50 % CO_2, the difference between the stabilized states of turn-on power is +3.0 dBm at 900 MHz. Conventional UHF RFID readers could detect these steps because their resolution is 1 dBm typically.

3.2. Validation in real environment

In a real environment, our RFID-Sensor is glued inside the lid of food packages containing 100 g of beef steak. Packages are made of polypropylene with a thickness of 550 µm (70 µm for the lid) and is filled with a protective environment (70 % O_2 and 30 % CO_2).

This experiment is conducted at 5 °C on 17 identical samples. Three were set aside at the end of their preparation to know the contamination generated by this step. Each day, two samples were removed from the measuring device to know the evolution of the contamination (destructive analysis). In Figure 4, analyzed samples on the first day do not reveal any major dispersion. In this figure, the expiration date of the meat samples is represented by a vertical red line. The horizontal red line represents the contamination limit for which the beef meat is not consumable. This line crosses the exponential trend line (increasing dotted red line) 6 days after the expiration date.

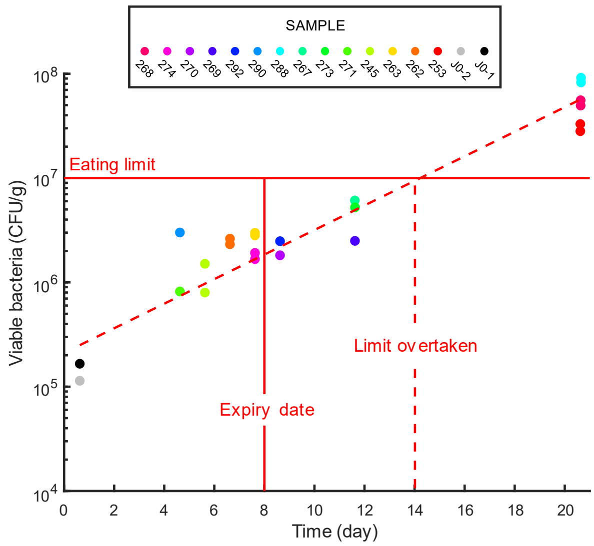

Figure 4. Contamination of meat samples

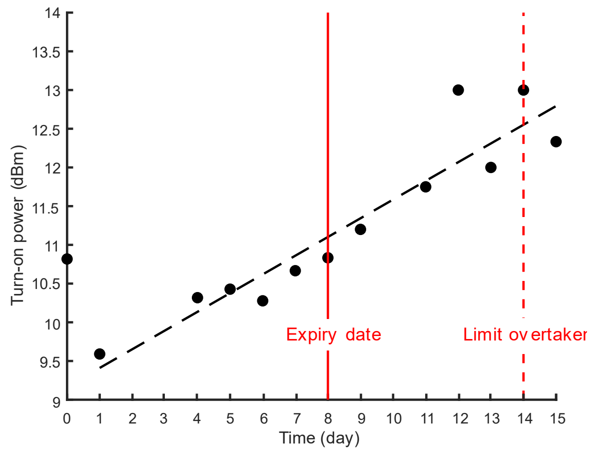

Figure 5. RFID signal of RFID-sensors along meat spoilage

In Figure 6, we observe that RFID-sensors turn-on power fluctuates by more than one decibel between the first 2 days. This relates to a stabilization of the gas environment in the food container. Indeed, during this period, the meat absorbs O_2 and desorbs nitrogen. Subsequently, the turn-on power increases with time of exposure to meat samples, which shows a good correlation with the growth and respiration of bacterial colonies. By applying a linear regression, we obtain a growth rate of 0.24 dBm per day. The measurement of the first day is not considered because it corresponds to the stabilization stage.

4. Conclusion

In this paper, we have demonstrated that it is possible to track food spoilage using an industrial low-cost RFID-sensor positioned inside a food package. A joint design of the UHF antenna and the interdigitated capacitor on which a biopolymer layer was deposited allowed to obtain the necessary sensitivity to determine an expiry date based on microbial contamination.

Through a first experiment, we proved the sensitivity of RFID-sensors to changes in the gas environment. These represent different levels of degradation of a food in a closed package. Conventional RFID readers have sufficient read power sensitivities to distinguish these changes.

Then, we test the RFID-sensors in real conditions. Thus, for a classical food storage we observed a good correlation between the turn-on power of RFID-sensors and the bacterial contamination of the food (+ 0.24 dBm per day).

In a future work, reproducibility measurement will be performed at a larger scale to rate the reliability of this novel RFID sensor.

5. Acknowledgements

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