Smart Packaging with Microfluidic-Antenna System for Monitoring Meat Degradation

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Abstract

In this paper, we report the design and prototyping of an RFID-based smart packaging equipped with a microfluidic-antenna system. The recently introduced joint design technique for such antenna systems is exploited, and a preliminary real-time monitoring of meat degradation is completed. Over little more than four hours, the veal loin under monitoring lost significant liquid due to thaw drip loss, and the corresponding meat degradation yielded an average decrease of the sensing metric of 0.65 units every 100 seconds. Meat preservation along the food processing chain can be continuously monitored by such a smart packaging to improve food quality and safety while reducing plastic and food waste.

1 Introduction

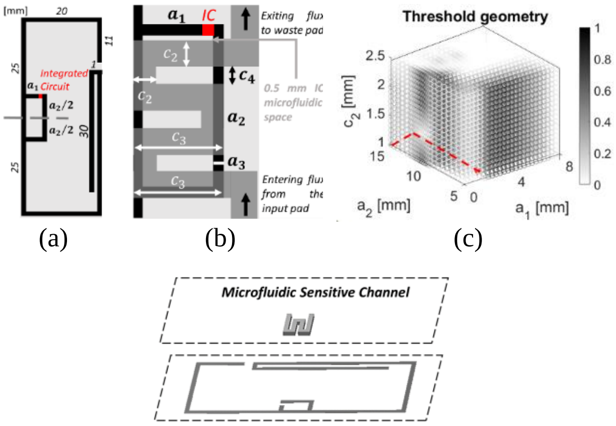
Food safety and quality remain fundamental priorities in the context of modern food production. For instance, a crucial objective is the reduction of microbial load in food without compromising its nutritional and sensory qualities [1]. Among emerging technologies that can contribute to food safety and preservation, RFID (Radio-Frequency Identification) stands out as a prominent solution within Food Industry 4.0 [2].

To quantify meat quality and degradation, two crucial measurands to prevent foodborn illnesses, food scientists usually analyze the drip loss, viz., the liquid lost by the meat during its degradation [3], [4]. The increasing liquid quantity can be effectively monitored by an RFID microfluidic-antenna system by applying a joint design technique [5]. Then, by integrating such sensors in a smart packaging for food [2], it is possible to reduce the food and plastic waste significantly.

In this context, the present study focuses on the feasibility study of this technology by monitoring moisture loss due to the thawing process. This moisture loss is named thaw drip loss and is markedly faster than aging drip loss even if the nature of the liquid is the same [6]. Since the liquid quantification is independent from the causes of the drip loss, the smart packaging could monitor meat quality regardless from the cause of the liquid loss.

2 Joint Design of the Microfluidic-Antenna System

The same starting system layout and joint technique procedure detailed in [5] are considered here. The flexible RFID sensor has a compact 50 mm × 20 mm surface. The microfluidic has a thickness of $c_1 = 1$ mm and comprises two identical ellipses (neglected in electromagnetic simulations) as collecting and waste pads sections, along with a serpentine passing over the antenna's impedance adapter. The antenna geometry is a partially folded Γ-match dipole on a thin layer of Kapton. The antenna is made of a copper trace (thickness 35 µm) and can accommodate the entire microfluidic within its area. The dipole length is such to match the conductance of the chosen self-tuning Magnus S3 IC by Axzon. The system parametrization is reported in Fig. 1(a,b).



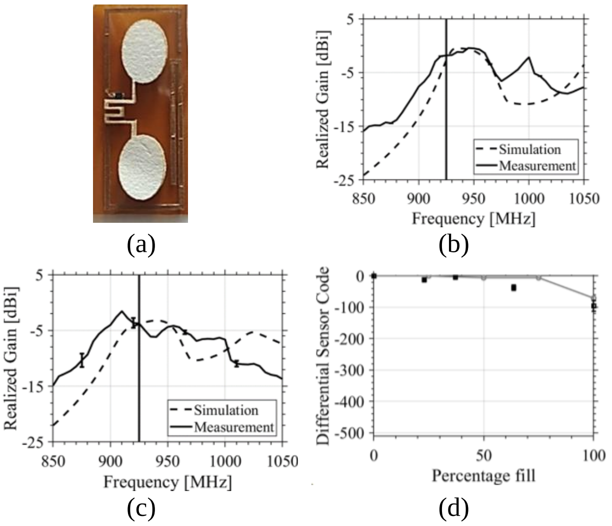
(a) (b) (c)

(d)

Figure 1. Joint design of the microfluidic-antenna system. (a, b) System parametrization; parameter $\boldsymbol{c_1}$, the microfluidics' thickness, is not reported for easiness of visualization. (c) Numerically computed value of the fitness function with the best solution highlighted in red. (d) The exploded numerical model of the jointly designed system.

The numerical design was performed through CST Microwave Studio Suite 2023 (single-frequency simulations) and MATLAB R2022b as in [5]. The design weights (w_1, upper saturation range; w_2 sensitivity; w_3 communications) were set to $\{w_1 = 5, w_2 = 0, w_3 = 1\}$to test a threshold-like behavior of the sensor not investigated in [5]. Fig. 1(c,d) reports the simulated results of the joint design procedure.

The microfluidic-antenna system was prototyped by using a milling machine (4MILL300ATC by Mipec) and a laser cutting machine (40W USB CO2 Laser Engraving Machine Cutter by Vevor). Fig. 2(a) shows the system prototype. The realized gain of the system was tested by



(a) (b)

(c) (d)

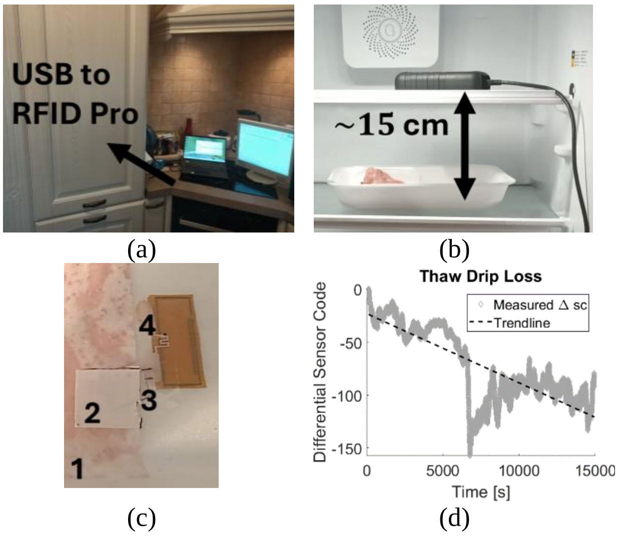
Figure 2. System prototype and test. (a) System prototype. Simulation-measurement comparison in (b) unloaded and (c) loaded conditions. (d) Comparison between simulated (grey line) and measured SC values during bench testing.

using the Tagformance Station (by Voyantic) observing good simulation-measurement agreement (Fig. 2(b,c)). Finally, the system was tested with a USB Pro reader distant 15 cm from the tag and a milligram digital scale (setup from [7]). Even though the simulations returned a threshold response of the sensing metric (the sensor code, SC, [5]), measurements do not agree for filling percentages higher than 50% (Fig. 2(d)), a limitation of the electromagnetic modeling we already observed in a more nuanced way in [5] when testing the “communication” geometry.

3 Smart Packaging Prototype Experimentation

The jointly designed system was hence integrated into a commercial food packaging to monitor in real time thaw drip loss. Pieces of veal loin and the corresponding packaging were bought at a supermarket. Then, 100 g of loin without any bone and with minimal flat were cut apart and frozen for one day. At this point, the system was fixed onto the cleaned food packaging by tape. The day after, the loin was thawed by microwave. The RFID tag was continuously interrogated by an RFID Pro (internal antenna; interrogation power: 27 dBm). The returned Differential SC [5] was visualized and saved on a portable computer.

Fig. 3(a,b) depict the measurement setup employed for the four-hours-long monitoring of the thaw drip loss. The fridge was at 4 ºC for the whole time. Since meat residues can block the fluid progression in the thigh sensitive channel, a plasma separator membrane was interposed between the meat and the filter papers (Fig. 3(c)). Over the four hours, the SC decreased of about 120 units, coherently with Fig. 2(d). However, severe fluctuations affected the measurements. To reduce noise, only data with power-on-chip lower than 22 were considered and a moving average of 100 seconds was employed, leading to Fig. 3(d). A sudden increment of fluid probably also caused the instability of the system resulting in the downward peak at 6000 seconds.



(a) (b)

(c) (d)

Figure 3. Real time monitoring of the meat thaw drip loss. (a, b) RFID arrangement inside the domestic fridge. (c) The smart packaging prototype at the end of the measurement campaign. The red thaw drip loss is clearly visible. The layers of absorbing paper are numbered as the drip loss passes through them: 1) commercial meat pad (model AMP-200 by Gialtek); 2) VividTM plasma separator membrane (by Cytiva); 3) Whatman paper Grade 2 (by ZENPORE); 4) Whatman CF4 (by Citiva) microfluidic channel. (d) Thaw drip loss monitored by the microfluidic-antenna system through the SC metric.

4 Conclusion

In this contribution, we tested the first smart packaging prototype incorporating an RFID microfluidic-antenna system to monitor thaw drip loss of meat. During four hours of continuous monitoring in an actual fridge, the sensing metric decreased of about 0.65 units every 100 seconds. Even though the increasing moisture quantity was successfully monitored, the sensory response fluctuated significantly, highlighting a phenomenon not accounted for in the design stage yet. This research line will continue investigating the drip loss monitoring to quantitatively assess meat quality.

6 Acknowledgements

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7 References

1. A. B. Jadaw and P. Choudhary, “Emerging Techniques for the Processing of Food to Ensure Higher Food Safety with Enhanced Food Quality: A Review,” *Discover Food*, **4**, January 2024, pp. 1-29.

2. A. Mostaccio, G. M. Bianco, G. Marrocco, and C. Occhiuzzi, “RFID Technology for Food Industry 4.0: A Review of Solutions and Applications,” *IEEE J. Radio Frequency Identification*, **7**, May 2023, pp. 145-157.

3. K. Fischer, “Drip Loss in Pork: Influencing Factors and Relation to further Meat Quality Traits,” *J. Anim. Breed. Genet*,, **124**, February 2007, pp. 12-18.

4. K. O. Honikel, “How to Measure the Water-Holding Capacity of Meat? Recommendation of Standardized Methods,” *Evaluation and Control of Meat Quality in Pigs: Current Topics in Veterinary Medicine and Animal Science*, Springer, 1987.

5. G. M. Bianco and G. Marrocco, “Joint Design of Self-Tuning UHF RFID Antenna and Microfluidic Channel for Liquid Sensing,” *IEEE J. Radio Frequency Identification*, **8**, April 2024, pp. 58-67.

6. J. S. Eastridge and B. C. Bowker, “Effect of Rapid Thawing on the Meat Quality Attributes of USDA Select Beef Strip Loin Steaks,” *J. Food Sci.*, **76**, 2, March 2011, pp. S156-S162.

7. G. M. Bianco and G. Marrocco, “Flexible Antenna with Microfluidics for the Quantification of Liquid Micro-Volumes,” *18th European Conference on Antennas and Propagation (EuCAP 2024)*, March 2024, pp. 2299-2303.