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Sub-dermal battery-less wireless sensor for the automatic monitoring of cattle fever

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Abstract

Fever detection in cattle is today a time-consuming manual procedure. Isolating infected animals to avoid the spread of the diseases is therefore not straightforward with the consequence of massive dose of antibiotics delivered to the whole cattle. This work proposes a subdermal implantable flexible battery-less wireless sensor for un-cooperative monitoring of core temperature in pigs. The sensor consists in a shaped loop antenna sewed into a textile scaffold, as anti-migration support, for a natural integration with the animal fatty tissue. By resorting to the UHF-RFID communication protocol, the device can be interrogated from a distance of up to 1.7 m that is compatible with the automatic temperature reading when the animal approaches the cattle feeder.

1 Introduction

The fever monitoring in farm cattle is an open issue due to the uncooperative nature of animals. The golden standard is the rectal detection, which is however impracticable for application to several animals, multiple times at day. Therefore, a prompt identification of the origin of the infection and the placement of those animals in quarantine to prevent the spread of the disease and avoid the antibiotic therapy on the whole cattle, is currently unfeasible. To reduce the workload of operators and facilitate the continuous monitoring of fever, a wireless and automatic system detection is therefore requested.

Nowadays, the adoption in farms of implanted transponders for the identification of animals is a standard procedure, but only few commercial devices integrate a sensor for core temperature monitoring [1]. Most of them involve a battery-less system, through the inductive coupling between an internal and an external coil. Unfortunately, the read distance is few centimetres at most, so that a manual intervention is still required by an operator approaching the animal.

To overcome this limitation, and also to get rid of the possible misalignment between coils, implantable devices working accordingly to Radio-Frequency Identification (RFID) protocol in Ultra-High Frequency (UHF – 860-960 MHz) band have been recently proposed. For instance, the small implantable Hilbert-PIFA in [2] provided a read range up to 2-3 meters. However, despite the reduced size of the antenna (25 mm × 25 mm × 7.6 mm), a large box of silicone is required to isolate it from the biological tissues, thus resulting in a larger and uncomfortable overall size. The cylindrical implantable antenna in [3] (length 55 mm, diameter 10 mm) is experimentally read from a distance of up to 1-2 meters, for implantation depths of 1 cm. More recently, novel conductive materials and inkjet printing have been proposed in [4] for the manufacturing of thinner implantable antennas.

Anyway, none of the above RFID-UHF devices includes a temperature sensing capability.

This work proposes a sub-dermal UHF-RFID implantable temperature-sensor having a 2D flexible structure. The device comprises a sewed shaped loop antenna deployed on a meshed scaffold to ease the integration with the animal tissues. In particular, this contribution resumes the optimization of the antenna shape, to achieve the most convenient trade-off between size and communication performance. A first manufactured prototype is then experimented within a piece of pig tissue.

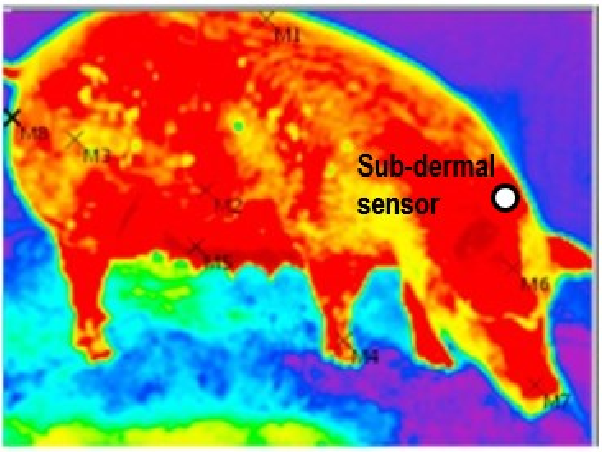


Figure 1. Internal temperature distribution in a pig and possible position of a sub-dermal wireless temperature sensor.

2 Antenna layout and simulations

The dorsal region (Fig. 1) of the pig neck is selected as site of implantation, as the temperature is here closer to the reference rectal one [5].

The considered antenna layout is a square loop, typically used for epidermal applications [6] on humans.
The RFID IC is the Magnus®-S3 [7] by Axzon, capable of temperature sensing. It also includes an internal variable capacitor [8] aiming at maximizing the power delivered to the IC by keeping the antenna-IC matching unchanged over frequency. The chip is mounted on an exciter loop [6] that is inductively coupled to the larger square loop radiator (inset in Fig. 2). The exciter loop is insulated by means of 1 mm thick bio-compatible silicone coating.
For the sake of simplicity, a reference central value of chip impedance (Z_{IC}=2.8-j75.7 Ω) is assumed [7] for the antenna design at 870 MHz.

The pig neck is modelled as a planar layering (200 × 200 mm^2), whose thicknesses (*t*) and electromagnetic parameters (permittivity and conductivity) referred to an animal of almost 250 kg [9] are: *t*=3.75 mm, ε_r=37.1, σ=0.59 S/m for the skin; *t*=26 mm, ε_r=5.8, σ=0.06 S/m for the fat and *t*=40 mm, ε_r=55.1, σ=0.93 S/m for the muscle.

2.1 Antenna Design

Three possible implant placements are preliminary considered for the antenna: *i*) at the skin-fat interface, *ii*) at 1/4 and *iii*) 1/2 of the fat layer. For each configuration, the optimal antenna size (external side a_{opt}) was determined by simulations with Dessault Microwave Studio 2019 (Tab. I). Resulting maximum gains and read distances are independent from the depth of insertions. The selected implant placement is the one at ¼ inside fat layer as it is both minimally invasive for the animal but also far enough from the skin, where the high vascularization could provoke infections.

Table 1. Optimal size and performance of sub-dermal antennas for different implant depths.

Depth of implant	a_{opt} [mm]	*G* [dBi]	*d* [m]	*η* [%]
Skin-fat interface	56	-9.8	2.4	6.7
¼ of fat	65	-9.3	2.6	6.0
½ of fat	60	-10.2	2.3	4.9

After matching the antenna to the microchip, by varying the parameter *h*, the optimal realized gain is -12.7 dBi at 870 MHz, which corresponds to a read range up to 1.7 m.

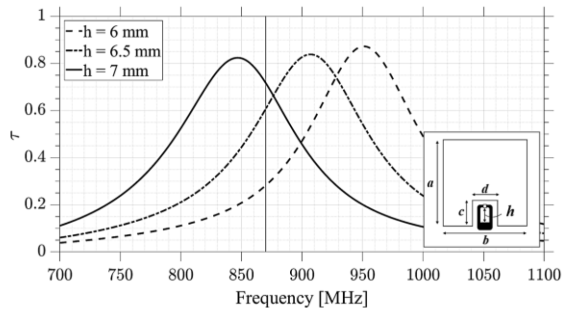


Figure 2. Power transmission coefficient of the antenna, by varying the tuning parameter *h* of the loop exciter. Inset: antenna layout, including the loop exciter and the square loop radiator. Size [mm]: *a*=*b*=40, *c*=15, *d*=13, *h*=7.

3 Prototypes and experimental evaluations

The prototype is fabricated by sewing a conducting yarn on a meshed textile emulating a scaffold for tissue reconstruction used in abdominal surgery (Fig. 3). Indeed, the mesh facilitates the adhesion and proliferation of fatty cells over it, so that the antenna remains in position once implanted into the animal (anti-migration effect). The resulting device is soft and flexible and allows a subdermal implantation, by means of a small cut in the skin.

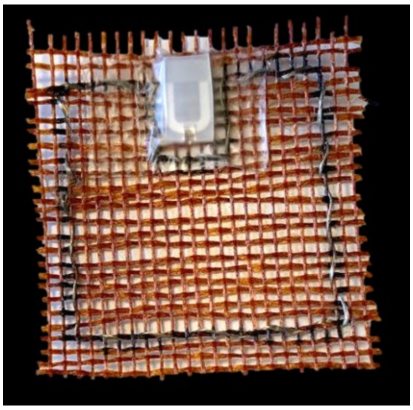
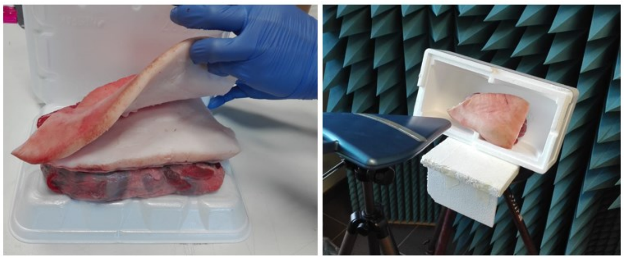


Figure 3. Prototype of the flexible implantable antenna, with the loop radiator fabricated with a conductive yarn sewn on a mesh grid having an anti-migration effect.

A real piece of pork neck (Fig. 4a) is used as a phantom for the electromagnetic test of the antenna. The realized gain is derived from turn-on power measurements using the Voyantic Tagformance station (Fig. 4b).
Measurements are performed along the antenna broadside and along angles θ={45, 60, 80}° w.r.t. the frontal orientation, to investigate the effect of cattle movements during temperature detection.
Apart from a small frequency shift (Fig. 5), probably due to the approximated electromagnetic parameters of the tissues and the imprecise fabrication of the antenna, measurements are in reasonable agreement with simulations.



a) b)

Figure 4. Portion of pork neck used as phantom: a) Site of implantation and b) measurement set up.

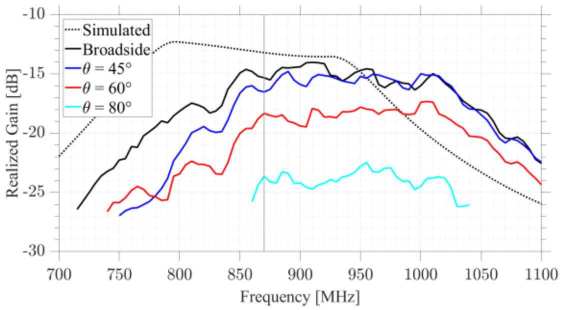


Figure 5. Comparison among measured and simulated realized gain of the subdermal antenna in broadside and by varying its orientation w.r.t. the reader's antenna.

4 Conclusions

The feasibility of a UHF-RFID telemetry system for the detection of core temperature in cattle was demonstrated by the design and prototyping of an ultra-thin square loop, deployed onto a scaffold-like textile substrate, working as anti-migration support. The core temperature can be read up to a distance of 1.5 - 1.7 m that is compatible with an automatic fever monitoring when the animal approaches a cattle feeder (Fig. 6).

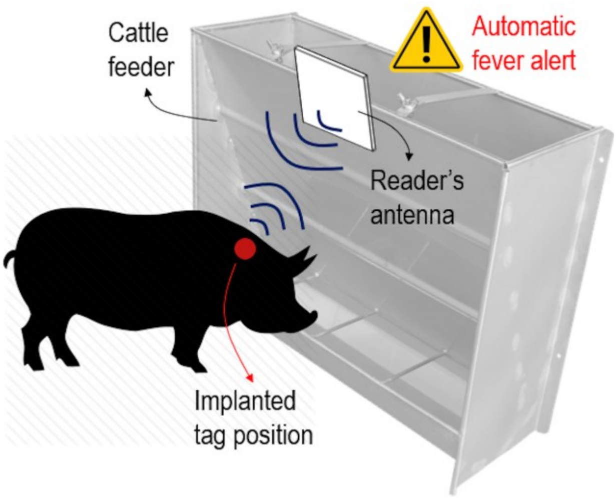


Figure 6. Possible automatic fever measurement setup inside the cattle feeder.

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