A Battery-less NFC Sensor Transponder for Cattle Health Monitoring

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***Abstract*—This paper presents the design and assessment of a battery-less NFC sensor transponder to measure biomarkers in the tear fluid of cattle eyes. A battery-less NFC temperature sensor prototype with a diameter of 22 mm is developed for the feasibility analysis of cattle health monitoring. With a measured wireless communication range of 44 mm, the developed NFC sensor prototype is shown to be a potential solution for wireless power and data transfer. In addition, the design method to develop a screen-printed, NFC-enabled smart contact lens for next-generation cattle health monitoring is also presented.**

***Index Terms*—battery-less NFC sensor, cattle health monitoring, flexible, RFID and screen-printed contact lens**

I. Introduction

Health monitoring of cattle is essential to ensure their well-being and to diagnose severe health conditions at an early stage [1]. Currently, health monitoring of cows relies largely on farmers' senses and understanding of the cow's behaviour. When the cow's health deteriorates, veterinary consultations are required to assess the cow's health. This type of health monitoring is time-consuming and expensive. Therefore, a time and cost-efficient approach is required without a veterinarian's involvement, unless treatment is necessary. The health-related parameters (e.g., body temperature and glucose level) of a cow can be extracted by examining the cow's tear fluid [2]. Furthermore, due to associated discomfort and complexity, the integration of a battery in the cow's eye is not a viable solution, and therefore a battery-less, wirelessly powered sensing solution is required.

Near field communication (NFC) is a contactless data transfer technology that uses inductive coupling to enable wireless power and data transfer [3], [4]. At present, the NFC technology not only enables consumers to perform payments, but also enables passive wireless measurement of multiple disparate parameters, including monitoring of soil moisture [5], gases [6], environmental parameter [7], [8], museum artefact [9] and biomedical sensing [10]. Fig. 1 illustrates an overview of the health monitoring system for cattle using NFC technology. It is shown that wireless health monitoring of a cow can be achieved by employing NFC technology [11], [12] in conjunction with Wi-Fi or cellular networks. As shown in Fig. 1 the sensors integrated into the NFC-enabled battery-less contact lens gather physiological parameters, such as body temperature and blood glucose level of the cow. Later, the health-related dataset can be wirelessly read using a handheld NFC reader and forwarded to the data cloud via the internet. Once the measured health parameters are available on the cloud, they can be easily accessed for treatment planning [13].

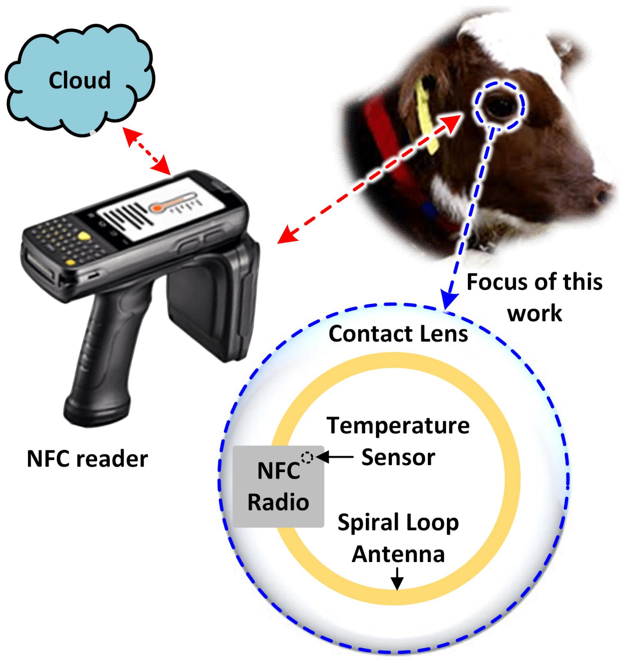

Fig. 1. Illustration of cattle health monitoring using NFC technology.

In this paper, a prototype of the battery-less NFC sensor has been developed for wireless health monitoring of cattle. The obtained results demonstrate that the NFC-enabled contact lens with integrated sensing capabilities can be suitable for monitoring the health or well-being of cattle. The design method of a screen-printed contact lens has also been outlined.

II. Hardware Design

The NFC sensor transponder design was tailored for a low-cost implementation using commercial-off-the-shelf components, which comprises an NFC radio transceiver (NHS3152) with an embedded temperature sensor [14]. Fig. 2 show the hardware prototype of the NFC sensor, which was implemented on a 2-layer FR4 printed circuit board (PCB) with a thickness = 0.8 mm, and diameter = 22 mm that was fabricated by ECS Circuit, Ireland [15].

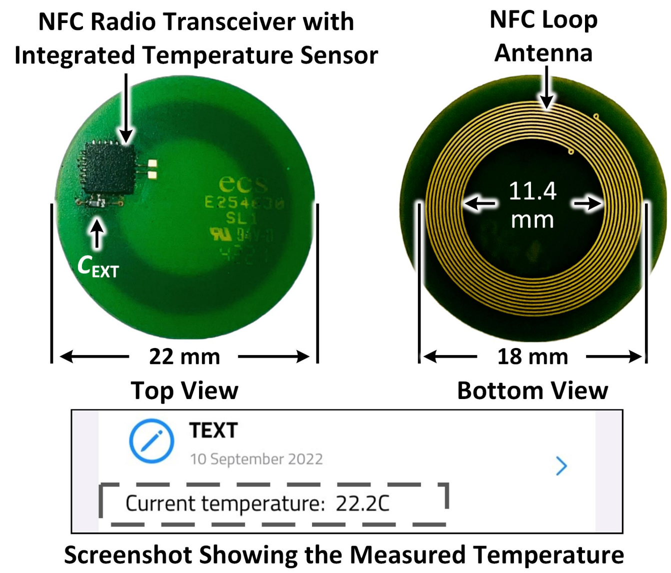

Fig. 2. Developed prototype of the battery-less NFC sensor transponder.

The NHS3152 and external tuning capacitance (C_{EXT}) were placed on the top layer to yield a planar structure. The simulation results of the loop antenna in free space have recently been reported by the authors in [2]. The antenna was fabricated on the bottom side of the PCB, as shown in Fig. 2. The antenna was designed to have 11 turns (N), a trace width (T_{W}) = 0.15 mm, turns spacing (T_{S}) = 0.15 mm, a copper thickness (t_{CU})= 35 μm and diameter = 18 mm that yields an inductance of 2.67 μH at 13.56 MHz. An integrated capacitance (C_{IC} = 50 pF) within the NFC radio transceiver connects in shunt with the antenna to form a parallel LC circuit with a resonant frequency (f_{R}) of 13.78 MHz. In order to tune the f_{R} of the NFC sensor transponder close to the desired frequency of 13.56 MHz, an external tuning capacitance (C_{EXT}) of 1 pF was connected in shunt with the antenna.

III. Result and Discussion

The radio frequency (RF) performance of the developed NFC sensor transponder was characterized using an industry-standard measurement system, i.e., Tagformance Pro from Voyantic Ltd, a shown in Fig. 3 [16]. To evaluate the performance of the transponder, the Tagformance uses dedicated

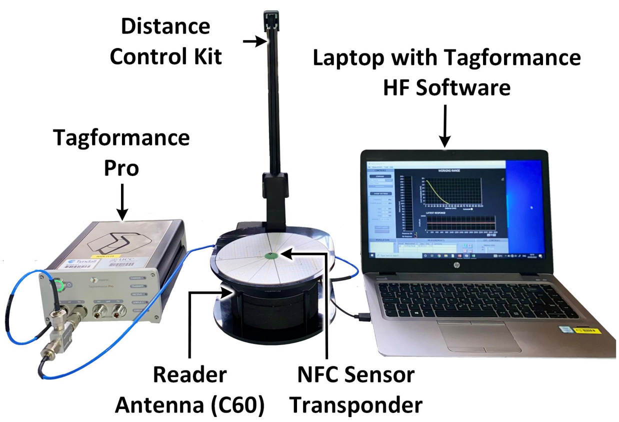

Fig. 3. NFC sensor transponder characterization setup.

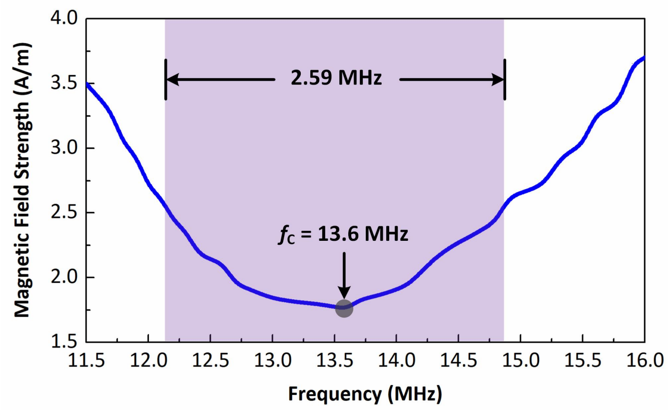

Fig. 4. Measured receiver sensitivity, bandwidth and f_{C}.

commands defined by the ISO/IEC 14443 (Inventory and Read). After sending a command, the Tagformance acts as a time-domain network analyser, which provides a carrier signal for the transponder and records the backscattered response.

A. *RF Receiver Sensitivity Measurement*

The RF receiver sensitivity of the NFC sensor determines the minimum RF power level that is required for the NFC sensor to respond to the command received from the reader. The RF receiver sensitivity of the NFC sensor was measured by performing a transmit power (T_{X}) sweep from -10 dBm to +25 dBm in the frequency range of 11.5 MHz to 16 MHz. It is evident from Fig. 4 that in free space, the NFC sensor requires a minimum magnetic field strength (H_{MIN}) of 1.76 A/m at 13.6 MHz to be able to respond to the read command from the reader and ensures that the NFC sensor is readable. The Tagformance software algorithm then calculates the centre frequency (f_{C}) and -3 dB bandwidth of the transponder with the help of the measured H_{MIN}. As defined in the Tagformance technical manual [16], the threshold value of $\sqrt{2}H_{\mathrm{MIN}}$ is used by Tagformance software algorithm to calculate the minimum frequency (f_{MIN}) and maximum frequency (f_{MAX}). With the help of estimated f_{MIN} and f_{MAX} the Tagformance software algorithm then calculate centre frequency (f_{C}) and bandwidth of the transponder under test. The developed NFC sensor transponder demonstrated resonant frequency (f_{R}) of 13.6 MHz and the bandwidth of 2.59 MHz in free space. The f_{R} of the transponder can be affected by environmental factors such as the proximity of water or metallic object to the transponder which can deviate the H_{MIN} [4], [17].

B. *Wireless Communication Range*

To measure the wireless communication range of the NFC sensor, the Tagformance Pro was configured with the following parameters: (a) Wireless communication range sweep = 7 mm to 48 mm with a resolution of 1 mm, (b) Transmit power level = +25 dBm, (c) Modulation index = 100 %, (d) Command = Read, and (e) resonant frequency (f_{R}) = 13.6 MHz. The received signal strength (RSS) of the NFC sensor was recorded at each defined distance point, as shown in Fig. 5. The RSS is a modulated carrier signal that is returned from the NFC

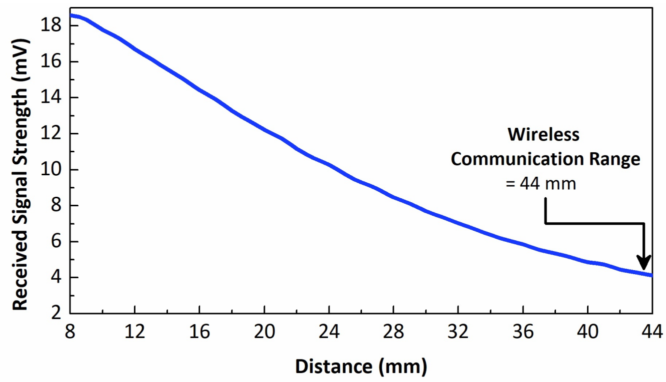

Fig. 5. Wireless communication range of battery-less NFC sensor.

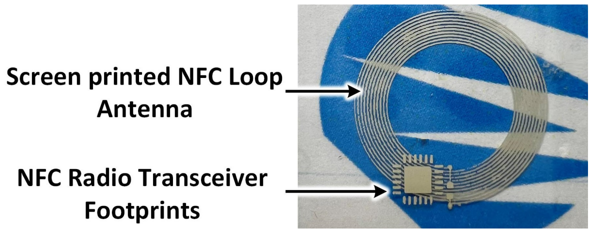

Fig. 6. Early stage transparent and screen-printed contact lens PCB.

sensor transponder in response to the "read command". It is evident from Fig. 5 that the wireless communication range of 44 mm is achieved for an applied transmit power of +25 dBm. The achieved wireless communication range is adequate to measure cattle health-related parameters comfortably using a handheld NFC reader.

IV. Towards Screen-printed Contact-lens

In order to develop contact lenses for health parameter monitoring, numerous technological advances in the manufacturing process, including photolithography, soft lithography, laser ablation, and injection molding, have been reported. Research efforts in the past years have shown that the development of flexible/stretchable electronics has been aided by additive technologies, including screen printing, inkjet printing, and 3D printing, due to their advantages of low cost, high accuracy, speed, and ability to support roll-to-roll production. Investigating the viability of screen-printing technology, possibly the most straightforward additive manufacturing technology, in the development of smart contact lenses is one of the short-term goals of this study. As a starting point, a screen printed and flexible version of the contact lens is developed using Henkel's WIK21285-89A elastic silver ink on different flexible, transparent, and biocompatible substrates, such as DuPont Teijin's Polyethylene naphthalate (Kaladex 2000L) and Polyethylene terephthalate (Melinex ST506). One example of the constructed prototypes on Melinex ST506 film is shown in Fig. 6.

V. Conclusions and Future Works

This paper has presented the development and assessment of a battery-less NFC temperature sensor transponder for cattle health monitoring. The wireless communications range performance of the prototype transponder was tested using a Voyantic Tagformance pro. It was shown that the developed transponder can achieve a maximum wireless communication range of 44 mm for an applied transmit power of +25 dBm. In addition, the RF receiver sensitivity of the transponder was measured to be 1.76 A/m at 13.6 MHz in free space. Finally, the screen-printed design method was presented to develop a smart contact lens. Future work will focus on optimizing the screen printing technique and glucose sensor interfacing with NFC transceiver. In addition, future work will also include the performance analysis of the screen-printed contact lens on a cow eye's phantom for real-world deployment.

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