A Wearable Fabric-Based RFID Skin Temperature Monitoring Patch

Saisai Wen, Hadi Heidari, Anastasios Vilouras, and Ravinder Dahiya
Bendable Electronics and Sensing Technologies (BEST) group, School of Engineering, University of Glasgow, G12 8QQ, UK
Correspondence to - Ravinder.Dahiya@glasgow.ac.uk

***Abstract*— This paper presents a novel design of wearable radio frequency identification (RFID) sensor patch make of conductive fabric and integrated on clothes. The wearable RFID with similar design is also implemented on a Polyimide (PI) substrate to show the effectiveness of the system. We also demonstrate the wearable and washable RFID patch by using conductive fabric coil antenna as well as non-conductive fabric substrate. The conductive fabric offers great flexibility and comfortability as it can be sewed into clothes and connect the components of the patch. As a proof of concept, we developed the conductive fabric based RFID for temperature sensing and demonstrate its use by measuring variations in the skin temperature. We observed that the proposed antenna is strain independent during bending. Further, it has the advantage of simplicity and is relatively free from issues such as degradation of performance.**

Keywords*— RFID, Wearable patch, Conductive Fabric, Strain-independent Antenna, Wearable Electronics, Flexible Electronics

I. Introduction

Wearable devices such as watches, wristbands, and eyewear that can be used for health monitoring are rapidly gaining traction in our lives [1, 2]. Such devices can pick up and transmit signals from the human body and have the potential to transform the health monitoring and human machine interface. For that reason wearability and flexibility of devices are important, since these attributes improve the effectiveness in terms of usage and acceptability in comparison with their rigid and planar counterparts [3, 4]. A vast majority of the devices reported on flexible substrates are unable to maintain intimate and prolonged contact with the soft and curvilinear human body [5, 6]. Furthermore, they are unable to attain simultaneously the high sensitivity and high stretchability, which limits their applications [7]. In this regard, the wearable e-textile based systems can offer interesting solution [8, 9].

One of the key applications of wearable systems is in the area of health monitoring, especially early stage detection and diagnosis [10, 11]. One of the basic parameters for human health is the body temperature. For people performing mentally and physically demanding tasks, such as soldiers or athletes a continuous monitoring of body temperature is essential. Body temperature is homoeothermic and regulated at about 37^{0}C, with small fluctuations from day to day. Human body temperature is influenced by internal or external heat sources, and is a good indication of infection, inflammations, hyperthermia, or hypothermia. Complications such as hypothermia; a condition in which the core temperature of the human body drops below the level where cerebral and muscular function properly, may cause from loss of finger movement to even death. Considering the importance of monitoring body temperature, the wearable technology to measure and transmit body temperature to mobile phones in real time will be very useful. Herein, we present a wearable fabric-based temperature sensing patch as a promising platform for real time continuous temperature monitoring.

The RFID technology employed in this work is a common wireless communication method. RFID tags are either passive (absorb power from electromagnetic field that is transmitted from the RFID reader through antenna), or active (local battery needed). Generally, active patch offers longer range of data transmission than the passive version [11]. Due to the limited size of patch, safety consideration as well as short transmission range, we developed a passive tag on a fabric substrate and present the same for continuous monitoring of skin temperature. There is no need for battery in the patch presented here and this makes the size of sensor patch small and easy to be implemented.

This work is organised as follows: The bendable RFID patch is discussed in Section II. The design and implementation process is presented in Section III. Section IV summarises the experimental results. Finally, Section V conclude and presents directions for future work

II. Bendable RFID Patch

A surface skin temperature monitoring patch with small skin contact area and high bendability is demonstrated to enhance wearing comfort of the patch with clothes. This bendable prototype was designed to be sewed into clothes or to adhere with the skin. For the first concept, the patch is sewed at the position of collar and the washability is the primary consideration. The patch can monitor either surrounding or skin

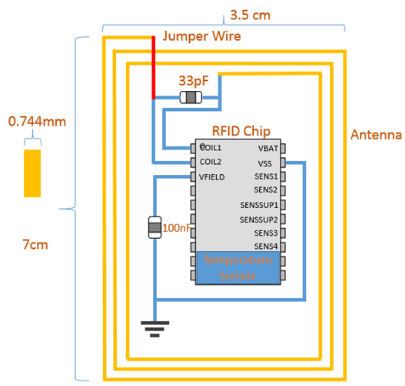


Fig. 1. Schematic with details of antenna coil geometry and electronics placement of RFID Patch.

temperature. For the second case, the patch is more intimate with human skin but additional layers should be attached on the patch to improve its waterproofing. In addition, the stretchability of substrate and circuit has been taken into account.

Fig. 1 shows the prototype of RFID patch. The RFID chip, which has a built-in temperature sensor, is located at the centre of the patch. The measurement range of the temperature sensor is from -40^{0}C to 105^{0}C. The accuracy of the sensors is up to $\pm$ 0.5^{0}C. The whole circuit is surrounded by 3 turns of antenna. The V_{SS} pin/terminal is connected to the ground as given in the data sheet. The capacitor connected to V_{FIELD} terminal temporarily stores the energy from external electromagnetic field. The C_{OIL} 1 and 2 terminals are connected with the start and end of antenna separately.

III. Design and Implementation Process

A. Patch Size and Communication

The size of the patch directly depends on the geometry of the antenna. In this work, two coil antennas were designed and fabricated in different sizes from extracted parameters based on [12]:

$$f_{resonance} = \frac{1}{2\pi\sqrt{C \times L}} \quad (1)$$

$$L = \frac{N^2\mu_0}{\pi}\left[-2(w+h) + 2\sqrt{h^2+w^2} - h\ln\left(\frac{h+\sqrt{h^2+w^2}}{w}\right) - w\ln\left(\frac{w+\sqrt{h^2+w^2}}{h}\right) + h\ln\left(\frac{2h}{a}\right) + w\ln\left(\frac{2w}{a}\right)\right] \quad (2)$$

where $f_{resonance}$ is the resonance frequency set on 13.56 MHz to obtain required performance of the electronics RFID chip. TABLE I summarizes the other parameters.

Accordingly, the total patch size is determined as 80 mm × 40 mm for polyimide substrate (FPC) and 60 mm × 35 mm for fabric one. For the FPC patch, the size is little larger than a standard Band-Aid and all components are placed on the same side of patch. In case more sensors are required, the patch can still offer sufficient area. In the fabric version, the electronics part is hidden under substrate to bring more comfort during gluing the patch on clothes. In this regard, first the electronics and sensors are mounted on a small layer of polyimide and then connected on the backside of the fabric substrate. The cross-section and layers view are shown in Fig. 2(a), where Fig. 2(b) illustrates the exploded view of different layers of the flexible patch.

TABLE I
Antenna Parameters

Parameters	Value (FPC patch)	Value (Fabric patch)
Total Capacitance(C)	75pF (internal) + 33pF (external)	75pF (internal) + 33pF (external)
Total Inductance (L)	1.2756 µH	1.2756 µH
Track Width of antenna Wire (a)	0.744 mm	1.44 mm
Width of Antenna (w)	35 mm	30 mm
Length of Antenna (l)	70 mm	50 mm
Turns (N)	3	4

B. Bendable and Wearable Patch Implementation

The first step towards a fully wearable and bendable patch is to fabricate polyimide version of the patch. This also allows testing of the whole circuit. For optimal covering of the components of sensor patch, and to enable the use of all sensing functionalities, a 150 µm-thick double polyimide layer based FPC was used [13]. The printed circuit board (PCB) schematic and layout was designed in Altium Designer and fabricated using toner transfer method. Finally, all discrete components were carefully soldered and tested.

Further comfortability was improved using 100 µm-thick double metalized nylon conductive fabric in the second stage. The pattern of antenna was created by laser cutting machine which allowed high accuracy in the size and distance between the antennal coil routing. The antenna was then glued onto normal non-conductive fabric substrate. In the end, the circuit made by FPC was linked to the fabric antenna, as shown in Fig. 2(b).

IV. Experimental Results

Experimental works were carried out in terms of electrical and reliability tests, with two versions of the bendable patch without any encapsulation, to validate their effectiveness for wearable application. The electrical measurements further distinguish flexible PCB (FPC) and fabric while the reliability tests were carried out with FPC only.

A. Flexible Fabric Antenna Performance

Conductive fabric is a new material which obtains both the similar mechanical properties as fabric and similar electrical properties as copper PCB. It indicates that this kind of fabric can be not only part of cloth but also part of electrical circuit, which offer much flexibility on wearable products.

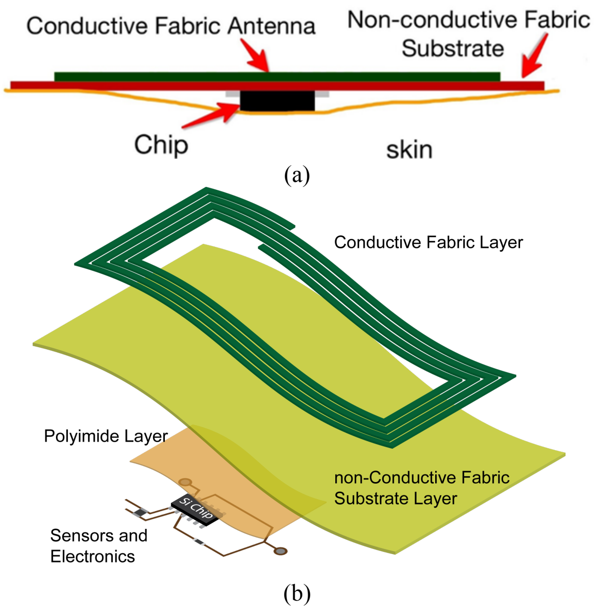
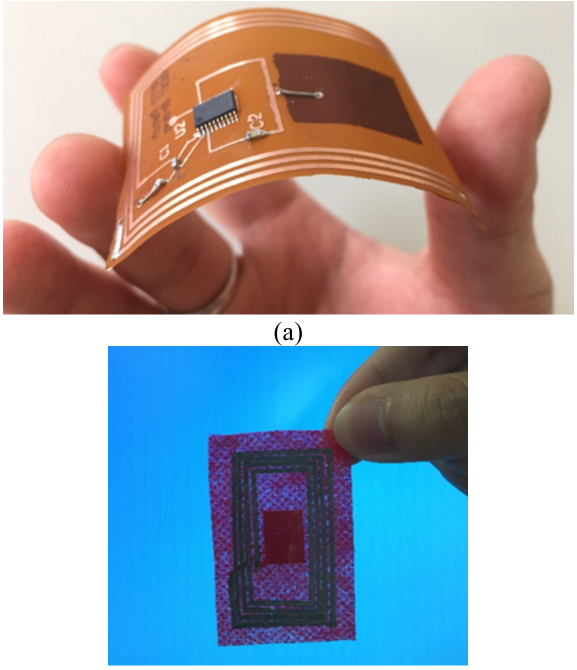


Fig. 2. (a) Patch cross-section view, and (b) device layer integration exploded view (from top to bottom: conductive fabric coil antenna, non-conductive fabric substrate, polyimide (FPC) layer, and sensors and electronics).



(a)

(b)

Fig. 3. Fabricated patches (a) on a bendable polyimide (FPC) substrate, and (b) on flexible non-conductive fabric substrate with conductive fabric antenna.

Fig. 3(a) shows the flexible RFID patch and it can be seen that unlike conventional rigid PCBs, the patch is bendable. A fabric-based prototype is shown in Fig. 3(b). In the beginning, the patch was tested by a computer-based reader called Cherry TC-1200. After that, an android phone was used as a reader and basic information of the chip can be accessed for both FPC and fabric patches. As shown in Fig. 4, the built-in NFC is read information of the chip with the help of a third party application (app), so that the basic design is acceptable.

B. *Sensors and Electronics Performance*

The chip used in this design is MLX90129. The power required for the circuit rely on the energy scavenging system in this chip. Since the patch can successfully read (Fig 4), the scavenging system functions well. All data is accessed by applying custom commands. To achieve this, two methods have been carried out. First, a custom app based on Android system is used to activate the sensor function in RFID chip. Second, the chip is directly programmed with commands using computer-based software and the information can then be read by computer-based RFID reader.

V. CONCLUSION

The primary aim of this work is to fabricate fabric-based wearable and washable RFID sensor patch. This work has good potential for creating low-cost wearable product. The future work will involve accessing information from the patch and improving the fabrication process, washable ability and appearance of fabric version. This will follow by developing a specific Android app, and adding humidity and pH sensors to monitoring more vital signs of human body. In the end, the fabric PCB will be sewed into clothes to validate the effectiveness of a comfortable wearable product.

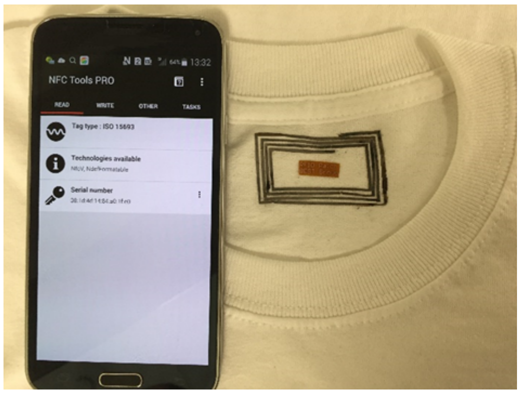


Fig. 4. Fabricated patch glued on T-shirt and the information of patch on Android phone.

ACKNOWLEDGEMENT

This work supported by the Engineering and Physical Sciences Research Council (EPSRC) Engineering Fellowship for Growth (EP/M002527/1) and EPSRC First Grant (EP/M002519/1). We are also thankful from Glasgow Electronics Design Centre for their support in terms of fabrication and device design and characterization.

REFERENCES

[1] W. Gao, S. Emaminejad, H. Y. Y. Nyein, S. Challa, K. Chen, A. Peck, *et al.*, "Fully integrated wearable sensor arrays for multiplexed in situ perspiration analysis," *Nature,* vol. 529, pp. 509-514, 2016.

[2] T. Q. Trung, S. Ramasundaram, B. U. Hwang, and N. E. Lee, "An All‐Elastomeric Transparent and Stretchable Temperature Sensor for Body‐Attachable Wearable Electronics," *Advanced Materials,* vol. 28, pp. 502-509, 2016.

[3] R. S. Dahiya, A. Adami, C. Collini, and L. Lorenzelli, "Bendable ultra-thin silicon chips on foil," in *IEEE Sensors*, 2012, pp. 1-4.

[4] H. Heidari, N. Wacker, S. Roy, and R. Dahiya, "Towards bendable CMOS magnetic sensors," in *Proc. Ph.D. Research in Microelec. Elec. (PRIME)*, 2015, pp. 314-317.

[5] R. S. Dahiya, G. Metta, M. Valle, and G. Sandini, "Tactile sensing—from humans to humanoids," *IEEE Trans. on Robotics,* vol. 26, pp. 1-20, 2010.

[6] N. Yogeswaran, W. Dang, W. T. Navaraj, D. Shakthivel, S. Khan, E. O. Polat, *et al.*, "New materials and advances in making electronic skin for interactive robots," *Advanced Robotics,* vol. 29, pp. 1359-1373, 2015.

[7] C. Wang, X. Li, E. Gao, M. Jian, K. Xia, Q. Wang, *et al.*, "Carbonized Silk Fabric for Ultrastretchable, Highly Sensitive, and Wearable Strain Sensors," *Advanced Materials,* 2016.

[8] H. Kim, Y. Kim, B. Kim, and H.-J. Yoo, "A wearable fabric computer by planar-fashionable circuit board technique," in *Int. Workshop on Wearable and Implantable Body Sensor Networks*, 2009, pp. 282-285.

[9] D. P. Rose, M. E. Ratterman, D. K. Griffin, L. Hou, N. Kelley-Loughnane, R. R. Naik, *et al.*, "Adhesive RFID sensor patch for monitoring of sweat electrolytes," *IEEE Trans. Biomedical Engineering,* vol. 62, pp. 1457-1465, 2015.

[10] S. C. Mukhopadhyay, "Wearable sensors for human activity monitoring: A review," *IEEE Sensors Journal,* vol. 15, pp. 1321-1330, 2015.

[11] Y. Khan, A. E. Ostfeld, C. M. Lochner, A. Pierre, and A. C. Arias, "Monitoring of Vital Signs with Flexible and Wearable Medical Devices," *Advanced Materials,* 2015.

[12] Melexis. Antenna Design for MLX90129 [Online]. Available: http://www.melexis.com/Assets/Antenna-Design-for-MLX90129-5905.aspx

[13] H. Heidari, E. Bonizzoni, U. Gatti, F. Maloberti, and R. Dahiya, "CMOS Vertical Hall Magnetic Sensors on Flexible Substrate," *IEEE Sensors Journal,* vol. PP, pp. 1-1, 2016.