Flexible pH Sensor for Wireless Monitoring of the Human Skin from the Medimun Distances

S. Nappi, IEEE Student Member, V. Mazzaracchio, L. Fiore, F. Arduini and G. Marrocco, IEEE Member
University of Roma Tor Vergata, Via del Politecnico,1, 00133, Roma (ITALY)
gaetano.marrocco@uniroma2.it

Abstract—Sweat monitoring is an effective procedure to detect early signs or precursors of some psychophysical diseases. A compact wireless flexible on-skin pH sensor is here proposed for integration with Radiofrequency Identification in the UHF band. The peculiarity is its simplicity and minimal amount of required electronic components. The device comprises a printed multilayer pH sensor and an energy harvesting antenna optimized for application onto the human skin. Preliminary experiments demonstrated that the device is capable to capture a pH range compatible with physiologic data and to exchange data up to 1m without need of battery.

Index Terms—Radio Frequency Identification, Wearable Sensors, Flexible Electronics, Electronic Skin.

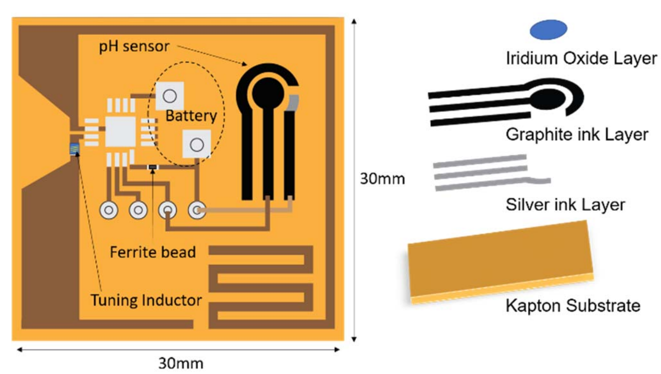
I. INTRODUCTION

Epidermal sensors [1] is a particular class of flexible electronics [2], [3] suitable to a conformal integration with the curved skin to collect the biophysical data with a high comfort for the wearer in daily use. Non-invasive health monitoring of biophysical parameters, such as temperature and sweat, could support Precise Medicine. In particular, the sweat monitoring is an effective procedure to detect early signs or precursors of diseases [4] thanks to the correlation of the pH index with the presence of some electrolytes. For instance, the skin pH of healthy people falls in the 4.5 - 6.5 range, but in case of cystic fibrosis it might be greater than 7 [5]. The pH monitoring is moreover useful in wellness to evaluate the effectiveness of physical workout. State of the art wireless epidermal pH sensors mainly relay on Near Field Communication (NFC frequency 13,56 MHz) architecture for data exchange. The sensing module is energized from remote through a coil harvesting energy from a smartphone or similar NFC-equipped device [6], [7], [8], [9]. The advantage of this architecture is the potential mass application thanks to the growing diffusion of general-purpose high-performance smartphones. However, only a few centimetres read distance is enabled, due to the intrinsic limitation of the NFC protocol. Retrieving pH data will accordingly require an operator to put the reading device in the nearly touch of the sensor. This kind of reading modality is hence *collaborative* and does not allow an automatic data retrieval when the user freely walks inside his house or is making sport activity. Longer read distances (up to 10 m) have been achieved resorting to Bluetooth Low Energy (BLE) modules (2400 MHz) as in [10] and in [11] so that a *non collaborative* data exchange is possible in moderately large environments. However, the required electronics layout is more complex (tents of components) than bare NFC devices and a battery or a flexible solar panel is required to source the device. Accordingly, this architecture is not suitable to low-cost application where an epidermal device should be disposable to comply with sanitary requirements especially for a hospital-grade usage.

This contribution introduces an in-between architecture where a printed pH sensor is integrated into a flexible RFID antenna working in the UHF band (868-960 MHz) that is suitable to low-cost fabrication, since it minimizes the amount of required electronic components, and simultaneously enables a remote interrogation up to 1-2 m, depending on the local configuration.

II. WIRELESS pH SENSOR

The proposed architecture of the UHF-pH sensor (Fig.1) is based on a sensor-oriented RFID transponder (AMS-SL900A IC [12]) that embeds a 10-bit ADC and an internal temperature sensor. The chip can be used in fully battery-free mode (power sensitivity -6.9 dBm) as well as in Battery Assisted Passive (BAP) mode (-15 dBm) that allows a longer read distance and even data logging modality (up to 841 data samples) in the absence of an external reader, with more than two years autonomy. A 3 cm x 3 cm open-loop antenna works as energy harvester and its layout is such to maximize the harvesting efficiency when the sensor is directly attached onto the human skin. The antenna is tuned by a lumped inductor and a ferrite bead is used for RF isolation of the eventual battery port.



a) b)

Figure 1. *a*) Layout of the UHF pH sensor including a thin Kapton substrate, an open coil harvester, a microchip providing ADC and modulation capability and *b*) a printed multi-layer chemical sensor.

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The pH sensor is a chemical multi-layer comprising three electrodes that are screen-printed on a Kapton substrate: a modified graphite working electrode, a graphite counter electrode and a silver reference electrode. Prior to use, the working electrode was electrochemically modified by means of an iridium oxide solution, in order to create a pH sensing film. The response of the electrodes to the pH changing is given by both the H^+ activity and the iridium oxides deposited onto the working electrode surface according to the reaction: $2[IrO_2(OH)_2 \cdot 2H_2O]^{2-} + 3H^+ + 2e^- \leftrightarrow [Ir_2O_3(OH)_3 \cdot 3H_2O]^{3-} + 3H_2O$, with the related Nernst equation equal to [13]: $E = E^0 - 2.3RT/2F \log[Ir_2O_3]/[IrO_2]^2[H^+]^3$.

Electrodes are connected to the external port of the RFID IC and the pH value is measured through potentiometric method as the potential difference generated at the solution/electrode interface. Upon remote interrogation, data are stored in a local memory and then transmitted back. By using a calibration curve, this arrangement can measure a pH index between 4 and 7 with no additional conditioning circuit. The overall number of required electronic components is therefore just three.

III. PROTOTYPE AND PRELIMINARY TESTS

A prototype (Fig.2a) of the wireless pH sensor was fabricated starting from 50 μm thick copper-laminated Kapton substrate, where the antenna layout was obtained by etching. The pH sensor was screen-printed on the Kapton substrate itself by a 245 DEK (Weymouth, UK) screen-printing machine. Graphite-based ink (Electrodag 423 SS) from Acheson (Milan, Italy) was used to print both the active and auxiliary electrodes. The pseudo-reference electrode was instead fabricated by silver/silver chloride ink (Electrodag 6038 SS). The overall diameter of the working electrode was 0.4 cm with a geometric area of 0.13 cm^2. The maximum read distance of the resulting radio-sensor, when attached onto the arm of a volunteer (Fig.2b), was measured (Fig. 2c) by a reader emitting an EIRP of 3.2 W in case of battery-free (max distance at 900 MHz: 0.8 m) and BAP mode (1.9 m).

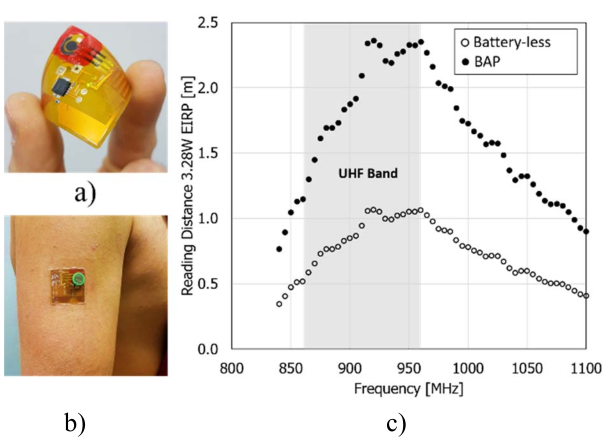

Figure 2. a) Prototype of the UHF pH sensor; b) on-arm placement by Tegaderm™ film; c) read distance measurement for 3.2 W EIRP interrogating power.

The calibration curve of the pH sensor, obtained by using reference liquids, shows a linear response (Fig.3.a). The sensor was then experimented in the measurement of temperature and pH of a runner, during 30 minutes of jogging. The device was encapsulated in a breathable 22 μm-thin polyurethane membrane to isolate the electronic components from the skin sweat. The electrode area was put in direct contact with skin to maximize the absorption of the sweat. After the sport activity, the collected data (Fig.3) was automatically downloaded when the runner passed across a gate equipped with a ThingMagic M6e reader.

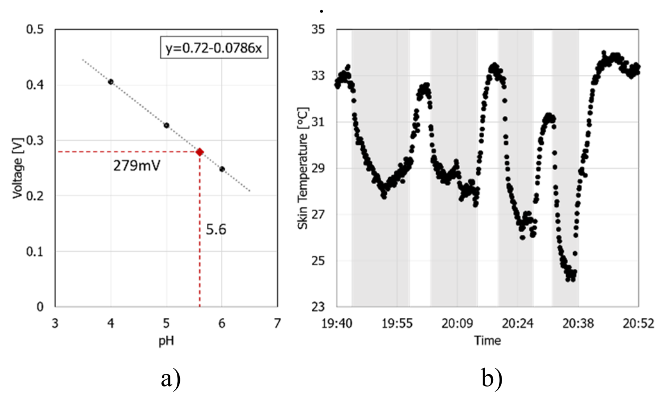

Figure 3. a) calibration curve of the pH sensor; b) temperature data during a 30 min jogging task (grey areas) outside (average temperature 13 °C), alternating rest periods.

The skin temperature shows an oscillating behaviour: during running (grey areas), the temperature decreased due to the cooling effect of the external air flow (environmental temperature between 12°C and 14°C). The skin temperature rapidly increased when the volunteer stopped. The average measured pH value of the sweat monitored during the sport activity was 5.6 that is in line with the expected value of a healthy person.

IV. CONCLUSIONS

A medium-range access pH sensor, closely integrated with RFID-UHF board, has been developed with just three electronic components. The device is flexible, optimized to work onto the human skin and suitable to be read up to 1 m and 2 m in battery-free and battery-assisted mode, respectively. In BAP mode, the device can collect biophysical parameters (temperature and pH) even in mobility. The achieved red distance are fully compatible with an automatic data exchange by means of a fixed reader integrated in a door, a bed or at the side wall of a small room or in an outdoor finish lines in sport activities.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

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