Designing and evaluating an NFC-enabled bio-patch for medical and health & fitness applications

TEXAS INSTRUMENTS

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This paper addresses the design and implementation of a near field communication (NFC)-enabled bio-patch solution. The design serves as a prototype for a flexible solution that would adhere to the skin. The bio-patch design incorporates a combination of sensor solutions which enable on-skin temperature measurements and galvanic skin response (GSR) monitoring. The bio-patch design consists of a single-chip solution based on the RF430FRL152H NFC sensor transponder from Texas Instruments. The device handles the sensor signal conditioning, processes the sensor data, enables data-logging of the sensor data via on-board ferroelectric random access memory (FRAM) and provides the RF communication link through NFC to a gateway, such as an NFC-enabled smartphone or tablet. The bio-patch can operate with or without a battery power source. Without a battery, the bio-patch is functional when in proximity of the gateway, scavenging the RF energy of the radiating element through inductive coupling. As part of the system solution, an Android app was developed to collect the information and provide a link to the Internet of Things (IoT).

Introduction

Bio-patch solutions are sensors worn on the body to enable continuous and semi-continuous monitoring of physiological and psychological parameters without tethering the patient or athlete to a wired hub. Regulation of physiological states can occur both from physical conditions or cognitive functions associated with an individual's state of mind. Electrodermal activity is a sensitivity index of nervous system activity [1]. Nerve endings modulate physiological activity which may result, for example, in the stimulation of sweat glands. This stimulation leads to changes in skin conductivity which can be monitored with a physical sensor. The ability to monitor both the physiological and cognitive functions for an extended period of time outside of a clinical environment allows for innovative health management solutions.

Bio-patch sensor data is transmitted wirelessly to a gateway to enable patients to self-monitor or healthcare professionals to remotely monitor vital information. The disposable nature of the solution also helps meet patient safety requirements in hospitals due to the limitation of bio-patches to one-time-use. This helps prevent exposure to infections associated with reuse of medical equipment at hospitals. Many reusable medical devices, ECG leads as an example, contain antibiotic-resistant pathogens even after completing sanitary cleaning procedures. The bio-patch form factor also enables more direct skin contact providing more accurate data collection compared to other reusable wearable solutions. The bio-patch can also be placed in locations on the body that minimize noise artifacts associated with motion.

A new bio-patch solution based on TI's new RF430FRL152H sensor transponder handles the sensor signal conditioning before processing the data and transmitting it to an adjacent receiver via NFC passive communication. The sensor components consist of a galvanic skin response (GSR) sensor and a thermistor which are in direct

contact with the skin. The GSR signal conditioning is carried out using a non-inverting amplifier design. The onboard power management on the RF430FRL152H transponder senses whether the device is battery-powered or in proximity of an RF field running at the 13.56MHz NFC resonant frequency. The device is able to inductively couple the RF field and run in a passive mode configuration without the use of a battery since the scavenged RF field provides sufficient power to run the entire solution. In this case, the bio-patch collects sensor data only when in proximity of the RF field.

Using sensors on the skin to collect and measure key data

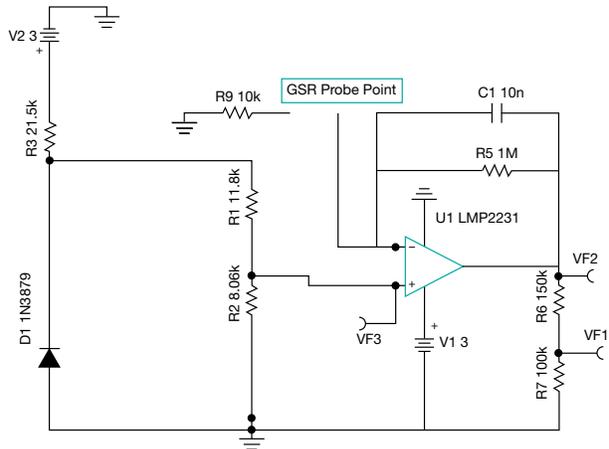The circuit for the GSR sensor is shown in Figure 1. A non-inverting amplifier design is used to monitor the skin impedance during the sense cycle. The output signal is sensed by the 14-bit sigma-delta analog-to-digital converter (ADC) integrated into the RF430FRL152H device. The impedance of dry skin varies from 1,000 – 100,000 ohms [2]. The transfer function characteristic of the circuit is shown in Figure 2 and is tuned to the expected range. The input resistance on the plot in Figure 2 represents the expected skin impedance and VF2 is the output sensor voltage sensed by the 14-bit ADC. The output response can be adjusted by modifying the R5 and R9 resistor values.

The on-skin temperature is obtained via a thermistor and a reference resistor. A small current (2.4µA) is applied on the reference resistor and thermistor. The voltage on both the thermistor and reference resistor is sampled by the sigma-delta ADC. Using the known value of the reference resistor and the exact current being applied allows for an accurate determination of the thermistor value and the correlated temperature value.

Figure 1. A non-inverting amplifier design is used to monitor the skin impedance during the sense cycle. The output signal is sensed by the 14-bit sigma-delta ADC integrated into the RF430FRL152H device.
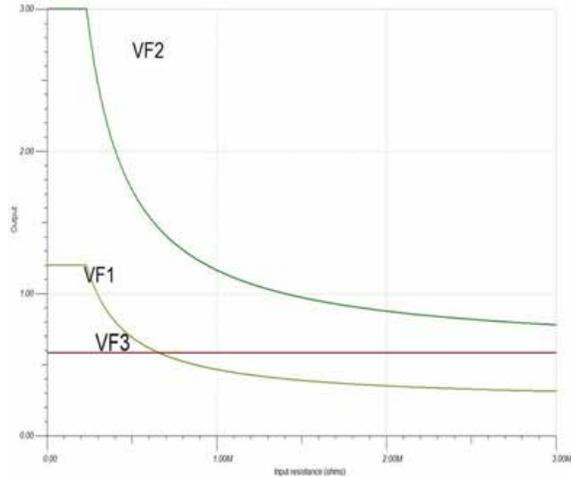

Figure 2. The transfer function characteristic of the circuit. The input resistance on the plot represents the expected skin impedance and VF2 is the output sensor voltage sensed by the 14-bit ADC. The output response can be adjusted by modifying the R5 and R9 resistor values.

Building a bio-patch prototype

The bio-patch prototype illustrated in Figure 3 was designed to adhere to human skin, therefore it had to be both durable and flexible. FR 7013 was used as the base substrate. Unlike FR-4, FR-1, CEM-1 or CEM-3, FR 7013 provides the durability and flexibility needed for the prototype. The input to the GSR circuit is provided by two square gold-platted probes located on the bottom of the patch. The GSR
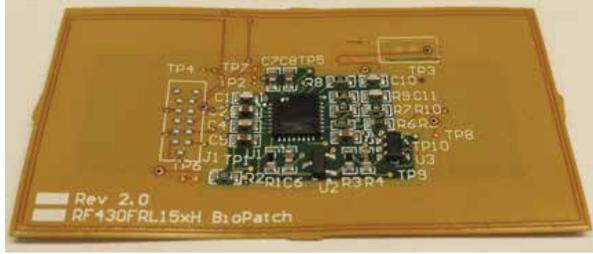
Figure 3: Prototype of the bio-patch.

probes are gold-plated to reduce both oxidation and noise. To further decrease GSR noise, conductive gel should be placed on the GSR probes. The temperature reading is accomplished with the use of a thermistor which is also located on the bottom of the patch.

The RF430FRL152H transponder provides the power to the GSR circuit and the analog GSR value is sensed by the onboard 14-bit ADC. The output swing of the GSR circuit is dependent on its source voltage. Since the GSR is being sourced by 3V, its output can swing anywhere from 0 to 3 volts. This required the addition of a voltage divider on the output of the GSR circuit which is represented by resistors R6 and R7 in Figure 1. The voltage divider guarantees that the output of the GSR circuit is within the range of the onboard ADC.

Testing the bio-patch with the accompanying Android application

The bio-patch prototype was verified on a test subject. The probe points of the GSR circuit were attached to the subject to monitor physiological response while being shown a movie to provoke an emotional reaction. Both an oscilloscope and the bio-patch Android application (app) logged sensor data approximately three minutes before an action scene in the movie and would stop approximately three minutes after the scene concluded. The test subject's GSR response was recorded through

changes in their state of mind – from a relaxed emotional state to a tense emotional state back to a semi-relaxed state of mind. The recorded results are illustrated in Figure 4. The sampling rate for the Android app and the scope is one and 250 samples per second respectively. The top graph in Figure 4 shows the data recorded with the bio-patch Android app and the bottom graph with an oscilloscope.
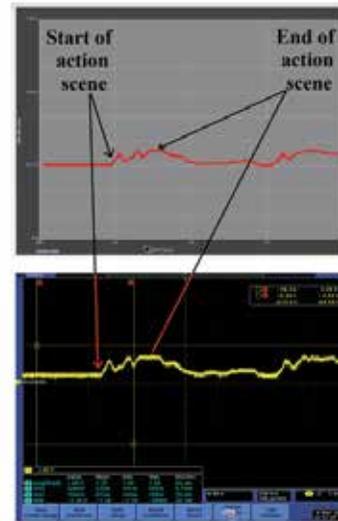

Figure 4: The test subject's GSR response was recorded through changes in their state of mind – from a relaxed emotional state to a tense emotional state back to a semi-relaxed state of mind.

The oscilloscope was connected in the voltage divider circuit right before the analog GSR signal is fed into the ADC.

As seen in Figure 4, the test subject is initially in a relaxed state. As the action scene commences, the subject's skin conductance changes. During the action scene, the skin conductance fluctuates in accordance with the stimulus from the scene. One observation made from Figure 4 is skin resistance does not immediately revert to its pre-relaxed state. Instead, the subject's skin conductance gradually returns to normal. This result can be attributed possibly to the after effects associated with the physiological response to the cognitive stimulation.

Figure 4 also confirms the correct functionality of the Android app. The data logged by the oscilloscope matches the data logged by the Android app.

The Android app is illustrated in Figure 5, which displays the GSR value on the top graph and the temperature value on the bottom graph.

The time it takes to power the bio-patch, sample the data and transfer it to the phone is approximately two seconds. During the sampling process, the handset should remain in close proximity to the bio-patch in order to ensure proper inductive

Figure 5: The Android app running on an Android phone.

coupling. The GSR and temperature reading should be achieved even under clothing. The approximate reading distance for the prototype and the Android handset is approximately two centimeters.

Learn more about the single-chip RF430FRL152H sensor transponder

The RF430FRL152H solution provides an NFC/RFID wireless communication front end that supports the ISO 15693 RF protocol. It has an embedded 16-bit programmable microcontroller,

14-bit sigma-delta ACD with ultra-low input current, low noise and ultra-low offset and 2 KB of non-volatile FRAM. The non-volatile FRAM enables data storage as well as extension and adjustment of the embedded application code in ROM. This manages RF communication and sensor readings to provide the ultimate configuration flexibility. The embedded MSP430™ microcontroller core enables the device to be fully programmed and allows for standalone functionality without the need for a host controller. Multiple sensors can be managed and the arithmetic processing of the sensor data can be customized. The on-board power management allows the bio-patch to operate with power coming from a separate single-cell battery or through scavenged RF energy. The scavenged energy from a handset provides a continuous RF field that can also be used to power an external sensor. The power management also enables the battery to be connected and disconnected via an RF command.

The on-board FRAM memory technology has similar behavior to DRAM [3]. Each individual bit can be accessed, and unlike flash, does not require a special sequence to write data nor does it require a charge pump to achieve the higher programming voltages. FRAM programs at 1.5 V versus the 10-14 V of flash or EEPROM. While flash programming occurs through a tunneling mechanism, FRAM programming relies on polarization in a dipolar molecule. Since the polarization occurs in 1 or 2 nanoseconds, it is what is commonly referred to as universal memory. This means it can function as the data memory or the program memory at any given time in its life. This allows a developer to extend the functionality of a bio-patch based on the required sensor solution.

Conclusion

This bio-patch design is a prototype for future implementation on a flexible substrate to enable adhesion to skin. It was proven that the RF430FRL152H, GSR, temperature and antenna circuit could all be put into one flex PCB. The response of the GSR sensor has been validated and the functionality of a thermistor confirmed to measure the on-skin temperature. An Android app was developed to allow the NFC-enabled handset to wirelessly receive information from the bio-patch and provide a link to other connected devices on the Internet of Things (IoT). Enabling an unobtrusive mechanism to collect physiological data associated with physical stress or cognitive stimuli allows people to monitor vital data on their own and share it securely with their doctor or health providers. Future work will also include development of algorithms that will correlate the sensor data to known physiological states such as hydration and hypertension.

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