Wearable Sensing Devices for Human-machine Interaction Systems

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Abstract—Two projects involving wearable sensing devices with antennas are summarized. The first project senses physiological signals; namely, photoplethysmograph (PPG), galvanic skin response (GSR), and skin temperature (SKT), in a design that is low cost, low power, and embedded in a non-intrusive wristband form factor. These wearable sensors are capable of physiological monitoring, which is important when detecting implicit communication cues related to emotions and affective expressions such that affective computing is possible [1]. The device transmits data wirelessly to a PC using Bluetooth Low Energy (BLE) technology. A related computer interaction has been developed to teach words to students, while monitoring their physiological signals to classify engagement. The second project aims to provide occupant-specific energy feedback in real-time. To do so, it is necessary to gather information about how each occupant is using energy (i.e., how much electricity they use on a daily basis). Therefore, a sensor was designed with the capabilities of detecting energy-related events, confirming the energy-related events using a proximity sensing technique, and being small enough to be worn or carried around during day-to-day activities. The printed circuit board (PCB) designs of both projects are summarized.

I. Introduction

Humans are rich signal producers traversing through a world full of signals. However, advancements in communication links and interpretation of signals between them and technology are needed. Human-machine Interaction (HMI) systems that investigate these problems are integrated into every research project in the lead author's research laboratory. This paper summarizes the use of wearable sensors and antennas in two projects. The first describes the in-house designs of small sensor circuits which allow for wearable wireless devices to collect data from humans [2]. These wearable devices could be used in a variety of applications. For example, a closed-loop system could examine human-robot interaction in academic settings while monitoring physiological signals of human students. The second project involves monitoring electricity use through sensors small enough to wear on a person's lanyard [3][4], that enhances the ways humans and technology interact to solve meaningful problems.

II. Wearable Physiological Sensor

The aim of this project is to design a non-intrusive wearable device, which is low cost and low power. Due to the lack of available sensors that can be worn comfortably during normal daily activities and over extensive periods of time, research in the area of physiological monitoring might be limited to laboratory settings or clinical settings [5]. A wristband device we designed consists of a suite of sensors, to collect physiological data on PPG, GSR, and SKT [2].

PPG is an optical measurement technique used to detect blood volume changes in the microvascular bed of tissues. This technique uses a light source to illuminate the blood tissue, and a photo detector to measure variation in the light caused by the blood volume. In our design, we used a reflective configuration of PPG. The analog data collected by the photodiode is passed through two-amplification stages and a band-pass filter is used to remove the noise from the signal. When a person becomes emotionally stressed or physically aroused, his/her skin often increases the conduction of electricity, or GSR. GSR is measured by applying a small voltage to the skin and measuring the skin conductance. We used Ag/AgCl type electrodes for our design. For temperature measurement, we used an off-the-shelf LM35 temperature sensor. We accommodated PPG, GSR, and SKT sensors on a single PCB housed in a wristband form factor, as shown in Fig. 1.

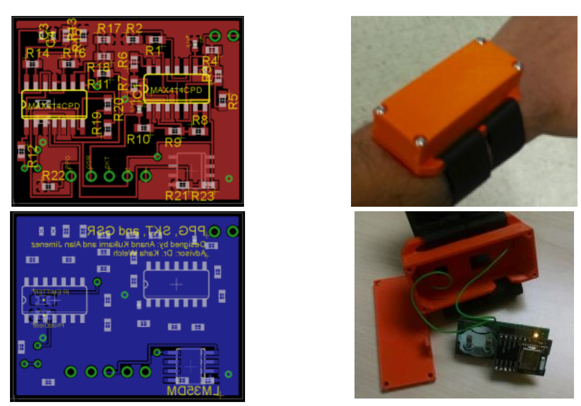

Fig. 1. Wearable physiological sensor images of: EagleCAD top side layout (top left), EagleCAD bottom side layout (bottom left), outside of wristband housing (top right), PCB inside housing (bottom right).

RFDuino, enabled with BLE is used for data acquisition and transmission. The device is powered by a 3.3V, 285 mAh, CR2430 lithium battery. A BLE dongle programmed as a receiver is connected to a PC for data collection. A python script is used to collect the data from the dongle, display the data, and save it for analysis.

An early version of the system for transmitting data used an RFduino and an iPad with techBASIC. Connected to the iPad, the device had a transmission rate of 1 Hz. Although 1 Hz may generate usable SKT, a 1 Hz signal is incapable of capturing a usable PPG signal and does not generate desirable detail for a GSR signal. The iPad system also did not support the live use of data required for a machine to respond in real time to emotional changes. By connecting the system to a BLE dongle on a PC and processing there, significantly better results were achieved. Transmission of a single integer from the RFduino to the PC through the Bluegiga dongle was tested by varying transmission rates to the PC. As the intended rate increased, the actualized rate became increasingly unstable and slower than anticipated. A rate of 120-130 Hz was the maximum that the RFduino could transmit; however, substantial losses were seen at this rate and variability in timing was also noticed. A transmission rate of 50 Hz was more stable and gave results much closer to expected values. During testing, 97.3% of transmissions at 50 Hz took the expected amount of time.

Tests were performed by sending a single integer; however, data packets are capable of containing larger payloads. Although the Bluetooth standard indicates that 37 bytes is the maximum size of a payload, during testing the software would not transmit more than 20 bytes in a single transmission. Each value read from the Arduino requires two bytes to store; thus, allowing a maximum of 10 values to be transmitted in a single payload. Surprisingly, increasing the size of the payload had little to no impact on the transmission speed, stability, or loss of the transmissions. Transmitting three sets of three values simultaneously was tested at 50 Hz. By transmitting three complete readings per payload, and transmitting payloads at 50 Hz, sampling of data from the sensor is effectively performed at 150 Hz for PPG, GSR, and SKT each individually. These results can sufficiently collect data at a rate required for the signals. Data compared to a Biopac MP 150 system yield 0.95 and 0.99 Pearson correlation coefficient for GSR and SKT, respectively. Calculations of mean interbeat intervals from PPG match between Biopac and the wearable physiological sensor.

III. WEARABLE EMF SENSOR

The aim of this project is to provide occupant-specific energy feedback in real-time, by monitoring electromagnetic fields (EMF) [3][4]. The antenna of the sensor perceives radiated EMF and a current is induced in it due to the changing magnetic fields. The current induced in the antenna is given as an input to the transimpedance amplifier, which converts current into voltage. The antenna is a PCB loop antenna and is laid around the transimpedance amplifier and the signal conditioning circuit. The antenna is printed on both sides of the PCB to achieve maximum number of turns, while maintaining the small size of the PCB. Fig. 2 shows the wearable sensor. The size is 54 mm x 72 mm x 12 mm, and weight is around 62 grams. The small form factor of the sensor allows it to be worn during day-to-day activities. As shown in Fig. 2, this wearable sensor consists of two PCBs. The circuit is split into two parts to avoid the interference from high-speed Bluetooth data lines. The PCB at the top collects localization information; whereas, the one at the bottom is the EMF sensor.

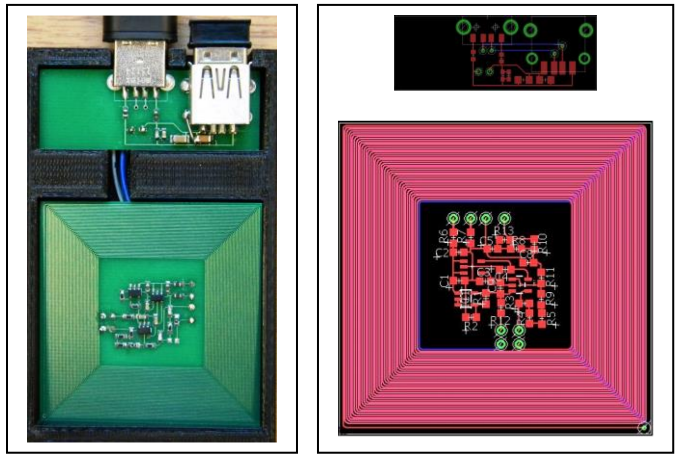

Fig. 2. Localization sensor (top) and EMF sensor (bottom) shown as PCB (left) and in EagleCAD (right).

The EMF sensor was designed and fabricated to collect the EMF radiated by appliances. Proximity sensing, using BLE technology, confirms the energy-related activity. Once confirmed, this activity is attributed to the occupant who initiated it.

IV. CONCLUSIONS

These devices have many future applications. Beyond the academic setting mentioned above, city planners are interested in mapping how physiological signals respond as citizens walk through neighborhoods. Military settings are another possible future application in which monitoring people's body signals could be useful information for when and how to reduce cognitive workload. An HMI system using the wearable EMF sensor would provide a detailed energy consumption report of individual occupants, which would help the occupants understand their energy consumption patterns and in-turn encourage them to undertake energy conservation measures.

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