Demo Abstract: SEPTIMU – Continuous In-situ Human Wellness Monitoring and Feedback using Sensors Embedded in Earphones

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ABSTRACT
A mobile phone, as a pervasive device, has great potential in human wellness monitoring. In this demo, we first present the design and implementation of our hardware - SEPTIMU. SEPTIMU consists of a small baseboard and a pair of tiny sensor boards embedded inside conventional earphones. The baseboard provides power conversion and data communication through the normal audio jack interface. The embedded sensor board is $1\times1 cm^2$ and integrates 3-axis accelerometer, gyroscope, thermometer, photodiode and microphone. Secondly, we evaluate SEPTIMU using a mobile application that continuously monitors body posture and provides feedback to the user.

Categories and Subject Descriptors
C.3 [SPECIAL-PURPOSE AND APPLICATION-BASED SYSTEMS]: Real-time and embedded systems

General Terms
Measurement, Performance, Design, Experimentation.

Keywords
Mobile Sensing, In-situ Monitoring, HiJack, Earphone.

1. INTRODUCTION
m-Health is gaining attention in both academia and industry in recent years as people become increasingly conscious of their everyday health conditions, and as mobile phones become much more capable than just simple messaging and gaming. The mobile phone is one of the few accessories that many people carry on a daily basis, and provides not only a computing platform, but also a networking interface and a range of sensors. While previous works [2, 3, 4] and commercial products (such as Sony Ericsson's MH907) have taken advantages of these on-device sensors for human-centric sensing applications, we augment the mobile phone with a suite of additional sensors embedded into both sides of the earphone. We utilize the conventional earphone jack for both power and communication to avoid using extra devices. This allows us to provide opportunistic and continuously in-situ human wellness monitoring.

SEPTIMU is a mobile phone accessory, comprised of a pair of sensor boards embedded into conventional earphones and communicates with the phone through the audio jack. We choose to integrate sensors directly inside ear buds because earphones are perhaps the only piece of accessory that every mobile phone user has, and uses on a daily basis. And a set of sensors positioned near the ears can provide additional sensing modalities important for many wellness applications. For instance, the MEMS microphone placed inside the ear canal can act as a stethoscope to detect heartbeat, or placed on other parts of the body for diagnosing other symptoms. This brings convenience to the user and her doctor in remote locations.

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In addition, with two sets of sensors, such as the IMU sensors, that are always positioned at fixed body positions (i.e., ears) SEPTIMU is able to provide more accurate motion detection and more subtle motion discrimination than single devices or ones placed elsewhere on body.

Figure 1. SEPTIMU hardware: the larger board is the baseboard (3.4×1.4 cm^2), and the smaller board is the sensor board embedded in earphones (1×1 cm^2).

2. HARDWARE DESIGN
Figure 1 shows SEPTIMU's sensor board and baseboard enclosed in a small box connected to mobile phone through the standard audio jack interface. The current version of SEPTIMU consists of two parts: two sensor boards and a baseboard. Each sensor board includes an IMU (InvenSense MPU6050, with 6-axis accelerometer and gyroscope), one thermometer (DS18B20), one photodiode (BH1750FVI), one MEMS analog microphone (ADMP401) and a LED. All of these sensors are placed onto a single double-sided board with a dimension of 1×1 cm^2, and integrate into a conventional earphone.

The baseboard design is based on HiJack [1], and contains a TI MSP430F1611 microprocessor and peripheral circuits for harvesting power directly from sound generated by the mobile phone. Similarly, the microprocessor transmits data to the mobile phone via the microphone ring on the audio jack as shown in Figure 2. In our design, the baseboard takes the position of the conventional line-controller.

Figure 2. Audio plug and pin. The pin connections are: (1) left earphone (tip), (2) right earphone (ring), (3) common/ground (ring), and (4) microphone (sleeve).

3. SYSTEM DESIGN

The firmware running on the baseband is based on TinyOS. The microprocessor collects data periodically from the two sensor boards through I^2C and one-wire bus; the majority of data come from the IMU set (with a full scale of ±2g/s for accelerometer and ±250° /s for gyroscope), which comprises 6-axis data with two bytes for each axis. The microprocessor sends data via the microphone ring on the audio jack to the mobile phone using Manchester coding. Data received from the audio jack interface is decoded inside the mobile phone by our driver at a low BER. We found that the average mobile phone at a sample rate of 44.1 kHz can transmit data reliably at a rate of more than 500 bytes/sec, which is enough to support our data communication requirements.

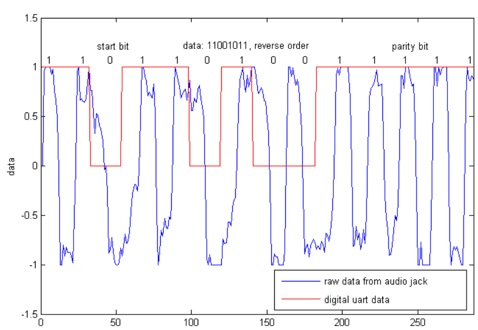
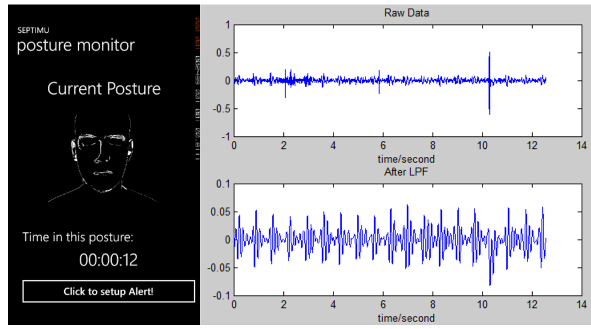


Figure 3. Raw data recovered from the audio jack (blue) and Manchester-decoded data (red).

4. CASE STUDY

We evaluate our system using a specific application to test its usability and accuracy. In this scenario, a user wears a pair of earphones integrated with SEPTIMU to monitor his posture. Combining the output of accelerometer and gyroscope from the user's head, we can determine how long the user remains in the same posture and decide whether he is lacking movement (see Figure 4a). The system can send a notification to the user and alert him to move in the case he has stayed too long in the same posture. At the same time, we are able to monitor the user's heartbeat with the microphone (shown in figure 4b). With this system, we see some opportunities and advantages provided by the pair of SEPTIMU integrated into an average earphone. For example, the combined data from IMU, microphone, thermometer of continuous monitoring can be used to keep a health diary for users.



(a) (b)

Figure 4. (a) Head posture monitoring application on Windows Phone; (b) Heartbeat detection with microphones in SEPTIMU.

5. FUTURE WORK

Current applications only utilize the IMU and microphone to some degree; we plan to develop applications using the other sensors on the board to provide better in-situ human wellness monitoring. In addition, we plan to explore more efficient ways for feedback.

6. DEMO SCRIPT

During the demo, a user will use SEPTIMU with her and exercise different motions as she desires, such as walking or remaining motionless. We will demonstrate that our system is able to detect how long a same posture lasts and gives feedback based on a model of healthy behaviors. We could also track the head movement and user may use it to ensure the correctness of a head exercise.

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