SleepSmart: Smart Mattress Integrated with e-Textiles and IoT Functions for Sleep Apnea Management

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***Abstract*—Obstructive Sleep Apnea (OSA) is one of the most serious sleep disorders. People who is suffered from OSA may not be aware that their upper airway is blocked and they have difficulty to breathe. For this reason, real-time sleep monitoring in daily life is important. In response to this need, I aim to develop an unobtrusive, wireless sleep monitoring system called SleepSmart. SleepSmart, is a smart mattress topper, which is integrated with textile pressure sensors and allows people to monitor their sleeping habits and respiration rate in real-time in their own bed with its IoT functions. The overall research has three milestones: (1) designing the mattress topper, (2) performing signal analysis on the pressure data to extract respiration rate, and (3) establishing an IoT infrastructure to provide services. This paper demonstrates the promising ongoing research results and the goals for future milestones.**

Keywords—obstructive sleep apnea, e-textiles, smart textiles, IoT, embedded system

I. Introduction

People who have sleep apnea experience shallow breath or even stop breathing during their sleep. When OSA occurs, the upper airway is blocked during sleep and people may not be aware that they have difficulty to breathe [1]. Monitoring of respiratory, sleep and cardiac parameters are used to diagnose OSA [2]. In this project, a research to develop an unobtrusive sleep monitoring system, SleepSmart that is made of smart textile pressure sensors connected to a wireless embedded system with IoT functions, is pursued. The aim of SleepSmart is to develop a fabric mattress topper, which is embedded with textile pressure sensors, which can track sleeping habits and respiration rate to monitor the probability of OSA. SleepSmart topper consists of a fabric sensor grid, resistor networks, and an embedded system with IoT and wireless capabilities. Embedded algorithms will be developed to detect the episodes of OSA during sleep and also monitor the sleep quality. IoT framework will be established to offer person-centered visualization of the sleep quality and OSA data on a tablet app.

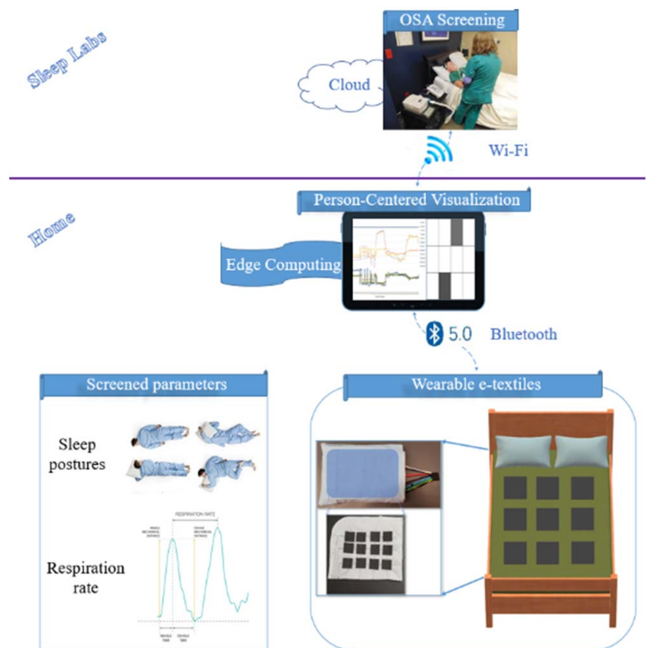

Figure 1: General Diagram of the System

II. Research Goals

The overall system aims three milestones.

a) Research Goal 1: Designing textile pressure sensors embedded into a mattress topper: This milestone aims to fabricate a smart textile mattress topper integrated with piezoelectric conductive materials to monitor the pressure changes.

b) Research Goal 2: e-Textiles data analytics for OSA detection: The signal coming from the pressure sensors will be analyzed and features of sleep stages and OSA will be extracted. Several signal processing methods and machine learning techniques will be applied.

c) Research Goal 3: SleepSmart IoT infrastructure for OSA management: To provide services to individuals with sleep and OSA challenges, a SleepSmart IoT infrastructure will be established. The Sleep Labs in the region will be colloborated with for the pilot study.

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III. Ongoing Research

A. *Designing Textile Pressure Sensors Embedded Into a Mattress Topper*

1) *Cushion Cover Design*

A 4x3 textile pressure sensor grid (equal to 12 sensors) was designed to perform initial testing. The textile pressure sensors were designed with piezoelectric conductive materials responsive to subtle pressure changes such as respiration cycle or changes in sleeping posture. To monitor the pressure changes, the sensor grid was connected to embedded computing unit, MSP432 (TI). While each sensor row was connected to digital pins to power up the sensors; each sensor column was connected to analog pins to collect analog pressure data. An embedded computing code was written with Energia IDE (Wiring and Arduino framework for Texas Instruments MCU boards) to drive the sensors and to collect pressure data. Then the sensor grid was expanded to be built on a cushion cover. The pressure sensors were connected to each other with conductive tape. A conductive thread was used to make connections between sensor array and analog/digital pins. The size of each pressure sensor was 1 sq. inch. As the next step, the conductive tape was changed with the conductive thread and the topper was placed on top of a cushion foam, covered with a bed sheet to simulate the bed. The process is shown in Figure 2.

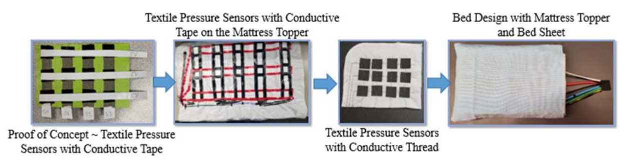

Figure 2: The Design Process of Cushion Cover

B. *Monitoring the Pressure Changes and Sensor Location*

To monitor the pressure changes, the data coming from sensors were stored into a .csv file and was plotted from that .csv file on Matlab. The pressure was applied using bare fingers tapping on to the sensors. Figure 3 shows the pressure changes when the finger was tapped.

Figure 3: Monitoring the pressure changes

The system was also programmed with Processing IDE to show the sensor location on graphical user interface (GUI). According to the pressure changes coming from MSP432, the GUI showed the location of sensor and changed its color from white to black. The results is shown in Figure 4.

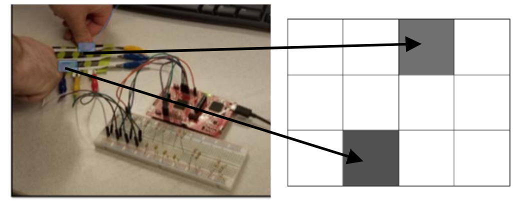

Figure 4: Monitoring Sensor Location and Pressure Changes

C. *Bluetooth Communication*

The data collected from the sensors was sent to a tablet for displaying and further processing via Bluetooth. The sensor grid was connected to Arduino Nano 33 BLE Sense board and its built-in BLE communication protocol was used. The data coming from the sensors were displayed by LightBlue App in an Android tablet.

IV. Discussion and Future Works

Promising results were achieved from initial tests for designing the mattress with textile pressure sensors. However, there are still disadvantages that need to be addressed. The connection between textile sensors and the electronics is the biggest challenge. Also, the repeatability and linearity of the sensors are the big issues. To solve those problems, we are working on designing fully knitted textile pressure sensors. The sensors will be knitted with fabric sensor and conductive thread and/or silver plated knitted jersey, therefore they can be easily sewed onto cushion cover or any other fabric.

For the Research Goal 2, designing a printed circuit board (PCB) which includes all electronics by using their main chips is aimed. Thus, the system can be controlled from a small embedded system and connected to the environment via Bluetooth communication for displaying. In addition, an embedded algorithm will be developed for further signal processing and machine learning.

For wireless communication and real-time monitoring (Research Goal 3), a custom Android app will be developed to show the user interface, collect the data and store it in .csv file. Moreover, to plot the data MQTT communication protocol will be used. A custom Python script will be written and run to take the data from sensors and plot the data in the client computer. Thus, we will be able to monitor the pressure changes in real-time.

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