NAPNEA: A Cost Effective Neonatal Apnea Detection System

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***Abstract*—Sleep apnea is a prevalent and life-threatening problem, especially in infants. Napnea is a cost-effective neonatal (sleep) apnea detection system that aims to provide affordable alternative methods for continuous respiration monitoring and apnea detection. For infants diagnosed with sleep apnea, the current monitoring systems rely on sticky electrodes wired to a cardio-respiratory monitor or expensive smart devices Napnea is a compact and affordable solution for apnea monitoring utilizing a soft, smart e-textile chest belt, integrated with a smartphone app.**

***Index Terms*—Neonatal Care, Health Monitoring, Respiration Monitoring, Smart Textiles**

I. Introduction

Sleep apnea is the sudden and repeated cessation of breathing whilst asleep [1]. The breathing has to have paused for a minimum of twenty seconds to be considered apnea, while breaks in the breathing pattern lasting between 5 and 10 seconds are termed periodic breathing [1]. The current percentage of infants affected by sleep apnea is estimated to be between 1 and 5 percent [2], but the precise number is unknown. The wealth disparity is a large indicator of both infantile apnea and the survival rates, studies showed that the children in the most disadvantaged census tract had the highest proportion of obstructive sleep apnea [3], [4]. Current monitoring system options have drawbacks that make them either impractical or inaccessible for the continued care of infants. For traditional cardio-respiratory monitoring, the adhesive used on the electrodes can be extremely harsh and damaging to the underdeveloped skin of babies [5]. Furthermore, the leads and electrodes can easily be pulled or shifted by movement of the infant, and at-home smart monitoring systems have very high price tags which makes it inaccessible in low-income communities. Napnea aims to alleviate these problems by providing a non-invasive, user-friendly, affordable neonatal monitoring system.

II. Materials and Methods

A. Napnea Sensing System

One of the main components in the Napnea system is the e-textile chest belt. The chest belt is made out of a soft, comfortable material that is wrapped around the baby to secure the sensor in the correct position. There is a force sensor attached to the center of the chest belt. The force sensor works by detecting changes in force when physical pressure is applied to it due to chest movements. The force sensor is connected to the second component of our system which is an ESP32-based microcontroller. The microcontroller unit is contained in a small 3D printed box. When a breath is taken, the force sensor value changes, and the microcontroller can read those changes through a 12 bit Analog to Digital Converter. Subsequently, the microcontroller processes the sensor data, and calculates the respiration rate. Also, we have designed an algorithm that monitors periodic breathing and apnea events status. The microcontroller is equipped with wireless communication capabilities. The respiration data and apnea status data is sent through Bluetooth to the third component of our system, a user-friendly smartphone application (discussed below).

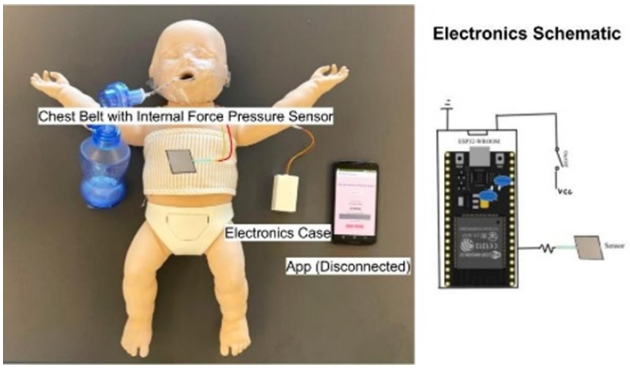

Fig. 1. Napnea System prototype; (a) the baby mannequin, chest belt, microcontroller, and mobile application (left), (b) ESP32 microcontroller connection schematic (right)

B. Apnea Detection with Napnea App

The Napnea app utilizes smartphone Bluetooth to receive the respiration data from the microcontroller. The respiration data is sent once every second, and the ESP32 automatically reads it, and calculates the respiration rate. To begin monitoring the respiration rate, the user simply has to press the connect button on the app, which in turn connects the smartphone app to the microcontroller. The app collects respiration data and apneas status data from the microcontroller. The respiration data is displayed on the app in breaths per minute (BrPM). The apnea status data is the status identifier number related to the apnea event. The status identifier number ranges between 0

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Fig. 2. Napnea Application and Different Levels for Detection

and 3 that sorts the apnea status into four categories, based on the presence of periodic breathing or apnea. Each category has a corresponding color and sound that relays the presence (or lack thereof) of periodic breathing or apnea. Figure 2 shows the Napnea application.

III. Experimental Setup and Results

A. Experimental Setup

To evaluate the Napnea system, the e-textile chest belt was placed on a CPR-training infant mannequin called Stephanie shown in Figure 1 (left) [6]. Stephanie is connected to a respiration pump (Harvard Apparatus Model 607) to simulate breathing. A specific breathing rate can be simulated in a range of 0-50 breaths per minute using this pump. The experimental setup is shown in Fig. 3.

To simulate different breathing types such as normal (30-

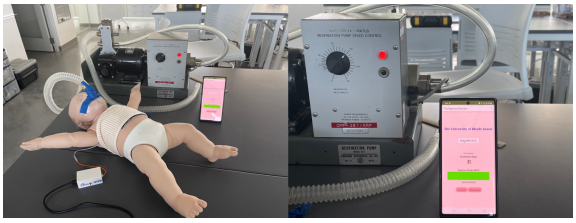

Fig. 3. The experimental setup (left), The respiration pump and corresponding value on the app (right)

40 BrPM), fast (40-60 BrPM), slow breathing (20-30 BrPM) and apnea (0 BrPM), different breathing rates were applied to the respiration pump. The experimental protocol is shown in Table 1.

B. Results

The ESP32 microcontroller board was enabled to collect the raw analog signal coming from the force sensor and calculate the respiration rate from this data.

After collecting the data, respiration rate was extracted from the raw data by using a peak detection algorithm. The calculated respiration rate was also shown on the Napnea app screen. The comparison between the actual respiration rate and the collected respiration rate is shown in Fig. 4 and Table 1.

Since apnea is a time critical event, the time when the system detects the apnea and the recovery time to detect normal breathing was also calculated. Apnea detection time was found as 4.8 seconds for the wired system and ∼5 seconds for Bluetooth-based system. The recovery time to

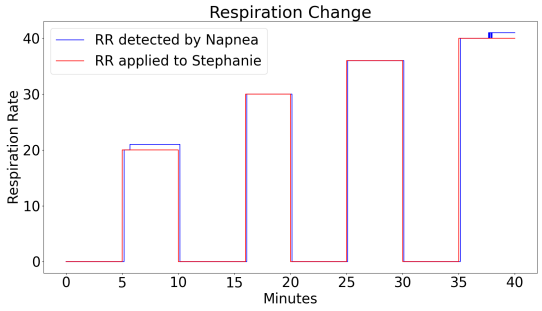

Fig. 4. Respiration rate change detected by Napnea app

TABLE I
Experimental Protocol and Comparison Results

Experiment 1: Wired BrPM		Experiment 2: Bluetooth BrPM			
Provided	**Detected**	**Provided**	**Detected**	**Duration (min)**	**Total (min)**
0	0	0	0	5	40
20	21	20	22	5	
0	0	0	0	6	
30	35	30	31	4	
0	0	0	0	5	
36	37	36	37	5	
0	0	0	0	5	
40	41	40	42	5	

detect normal breathing was found 5.6 seconds and 4.26 seconds for wired and Bluetoth based system respectively.

IV. Conclusion

In our present work, we demonstrated an e-textile based respiration monitoring system called Napnea. Napnea consists of a soft e-textile chest belt integrated with a force sensor and a computing system to monitor respiration, periodic breathing, and apnea. Napnea was evaluated in a simulation environment using a CPR training baby and a respiration pump. Our preliminary results are promising and show that Napnea has a potential to detect respiration changes, periodic breathing, and apnea events. Overall, the Napnea shows the promise to be a cost-effective and user-friendly method to monitor the respiration and apnea effectively.

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