Save the Babies: Use of Sensors to Increase Survival Rate of Sudden Cardiac or Respiratory Failure in Infants

Monday Group 1
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Introduction

Sleep can be a particularly concerning time for parents with babies. While a baby sleeps, parents are unable to constantly monitor them, which leads to concern that the baby could die of sudden infant death syndrome (SIDS) or one of the other major sudden unexplained infant deaths (SUIDs), such as accidental suffocation or strangulation, especially if the baby suffers from sleep apnea. Sudden infant death syndrome is an issue that has been prevalent for years; however, due to more parental education and new crib designs, the rate of SIDS has been decreasing over the past decade. Still, it remains the leading cause of death among healthy babies, killing over 2000 babies in the United States every year (Murphy, Xu, & Kochanek, 2013).

In addition to the risk of SIDS, there is a high risk of accidental suffocation during sleep, due to improper bedding or movement and subsequent entrapment between pieces of the crib. The chances of this occurring only increase with first-time or extremely tired new parents who may overlook a potential hazard. Even though the overall chances of either of these issues occurring are small, they are enough to concern many parents, especially those who have just had their first child.

The goal of this project is to develop both a cardiac and a respiratory sensor to monitor a baby's heart rate and breathing, particularly during sleep. These sensors will be configured to send an alert to the baby monitor or other interface, like a phone app, when the heart rate or breathing rate reaches below a certain threshold, and allow the parent to monitor these rates in real time. As different physiological conditions could change these threshold rates among different babies, these sensors will be able to be programmed by physicians to be specific to a particular baby. Although these sensors will be unable to prevent SUID or treat any disease, they will be able to give parents a better idea of their child's health, allow parents to be more proactive in case of emergency, and give parents peace of mind while their child sleeps.

Specific Aim 1: To determine how to best monitor respiration in the baby. Low-cost, easy-to-use sensors as well as accelerometers will be examined. However, accuracy should not be given up in order to produce a cheaper alternative.

Specific Aim 2: To determine a low cost and easy to use heart rate sensor that can detect small changes in the infant's heartbeat. This sensor should be able to filter out enough of the surrounding noise so that the reading will be relatively accurate. It should thus be able to filter out some of the noise that will result from movement.

Specific Aim 3: To integrate the sensors into a comfortable system to allow parents to easily place the sensors on the baby. The sensors should not cause interference that will affect their capacity to measure respiration and heart rate. Both sensors should be able to transmit their information to the user interface, and should be able to create an alarm if there is an issue with either heart or breathing rate.

Specific Aim 4: To create a user interface that allows for alerts to be given if the infant is in trouble. The interface should store the data so that it can be shown to a physician if needed. The interface should also allow physicians to program the specifications that will cause an alert.

Background

Sudden unexplained infant deaths – most commonly, apnea, accidental suffocation, and sudden infant death syndrome – are three of the biggest causes of death in babies (Center for Disease Contol, 2015). These problems have persisted for some time, and are always a source of concern for parents, especially if their baby has another respiratory or cardiac condition. Premature babies suffer from these issues almost more than other babies due to their physical immaturity – most of the infantile apnea cases are in premature babies. There are many different monitoring systems that have already been created and are in use, but they can be bulky or expensive, and many are designed for only premature babies. There is a need to create a cheaper, more user-friendly device to help parents monitor their baby's heart rate and respiration while sleeping, even though this will not prevent death or other issues associated with cardiac or respiratory events.

According to the American Academy of Pediatrics, infant sleep apnea is the unexplained cessation of breathing for 20 seconds or longer (Rocker, Israel, & Bechtel, 2015). Small intervals of not breathing happen occasionally, and will not harm the baby. However, the longer the baby goes without oxygen, the more damage can be done, which is why it is essential to monitor a baby who could be prone to apnea and respond immediately in case of an alarm. There are three types of sleep apnea – central apnea, obstructive apnea, and mixed apnea. Central apnea occurs when there is a cessation of output from central respiratory centers, as well as the inability of the brain to effectively communicate with efferent peripheral nerves and respiratory muscles necessary for oxygenation. Obstructive apnea is due to an occluded airway, and mixed apnea has characteristics of both other types. The exact incidence of life-threatening events related to apnea is unknown, but the incidence of obstructive apnea is now around 5-10% of the pediatric population in the United States. This increase is largely due to the increasing incidence of obesity, as obese patients are at a high risk for obstructive apnea (Rocker et al., 2015). When the apneic episode is beginning, the heart rapidly enters into tachycardia. However, it quickly slows to bradycardia after about 20 seconds of this episode (Daily, Klaus, & Meyer, 1969). This timing is critical, as the longer that the baby is not breathing, the longer he / she is not getting oxygen to the brain, increasing the risk for neurological damage and death.

Accidental asphyxiation is another major SUID, and is often due to parental negligence. It can occur in many ways while babies sleep, most often due to babies getting themselves caught between a mattress and the bedframe, tangled in blankets in the bed, covering their faces while they sleep, or co-sleeping with a parent (Byard, Beal, & Bourne, 1994). Like apnea, time is critical, as the longer the baby is not breathing, the less oxygen his / her brain is getting, which only increases the chances for permanent neurological damage or death.

Sudden infant death syndrome (SIDS) is also a major cause of death for babies. It relates to any death of an otherwise healthy child. Many times, deaths due to things like accidental asphyxiation and apnea can be ruled as SIDS, due to the uncertainty and similarity that some cases bring. Although there is **no** direct link between sleep apnea and SIDS, 4-13% of infants that have died from SIDS have had a history of apnea (Rocker et al., 2015). Apnea has also been seen to increase the risk of accidental asphyxiation deaths (Jeffery, Rahilly, & Read, 1983).

There are many devices that have been invented to try to prevent SIDS from happening, by monitoring breathing (whether that be rate or number of breaths in a particular time frame) and / or heart rate. There are many different respiratory monitors that have been used, from pulse oximetry to resistive sensors to metabolic monitors. This project's device is not designed to be completely radical and different from the present devices or to prevent SIDS, but is designed to be used with babies suffering from conditions that would give them a higher risk of SIDS, such as sleep apnea. Ideally, this would make parents more aware of their child's condition, and allow them to be more proactive in case of an emergency. Although this would not prevent any death, it would allow a better chance of survival due to quick notification of the issue.

There is currently a similar device on the market called the Owlet. It uses pulse oximetry to monitor a baby's heart rate and oxygen level, and sounds an alarm through the wireless base station, as well as to an app, much like this project is trying to do (WORKMAN et al., 2014). This device is quite expensive, however, and would be difficult for many families to purchase. There is no cheap and easy-to-use device that measures cardiac rate and respiration and allows such immediate feedback for at-home use.

Research Methods and Design

This project will involve the measurement of respiration and heart rate, analysis of the measurements, and transmission of a signal to a wireless, Bluetooth monitor when the values are below certain, adjustable thresholds. A block diagram depicting the overall design of the user interface for our project can be found in **Figure 1**. The following parameters and methods will be used to complete this project.

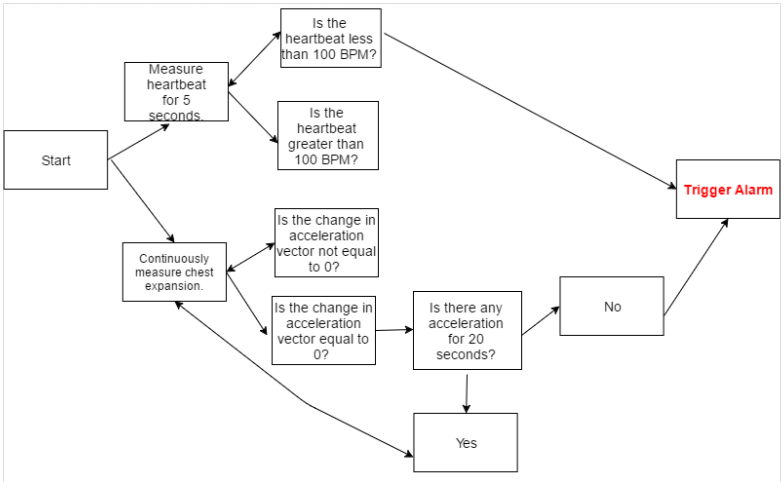

Figure 1: Block diagram representing the program that the system will run to measure heart rate and respiration.

Aim 1: Determine a way to measure respiration

The first step of this project is to research the different types of respiratory sensors and determine which one will work best for the scope of this project. There are several different ways to measure respiration, such as pulse oximetry, resistive or inductive sensors, or metabolic monitors. Since we would like to incorporate the device into clothing, a sensor that could move with the expansion of the thoracic cavity, or an accelerometer that would measure the acceleration vector as the baby moved, would be ideal. Whichever device chosen should be low

cost and easy to use, so that the overall product will be affordable and user-friendly. The accelerometer allows us to simply measure whether the change in the acceleration vector is zero or not. If the change is not equal to zero, then the baby is moving, and thus breathing. When breathing stops, movement will stop and the baby will turn limp. We know then that if the change in the acceleration vector is zero, then the baby is not moving and not breathing. Thus, other motion of the baby will not affect these readings. Alternatively, we could use a resistive fabric band or a resistive sensor. This would require us to calculate the average change in circumference that will occur when the baby breathes, so that the needed specifications of the sensor can be obtained and the breathing rate can be calculated.

Aim 2: Determine heart rate sensor

We also need to research different heart rate sensors to determine the easiest method of reading heart rate. Like the respiratory sensor, this heart rate sensor should be cheap and easy to use so that the product will be affordable and simple for parents. This sensor should be able to detect small changes in the heartbeat so that it can be determined if something is wrong. The heart rate ranges for babies should be determined to ensure that the heart rate sensor chosen will be able to actually measure the full range. Instead of the light-sensitive photodiode that many cheaper sensors use, a pulse oximeter could be used, but those are very expensive and would not be as conducive to our project.

Aim 3: Integrate the sensors into a comfortable system

Once the type of sensors that will be used is determined, the sensors will be integrated into a comfortable system. Ideally the sensors will be integrated into an onesie, as it is all connected and will allow us to integrate both sensors into one piece of clothing. We would like the material to be 100% cotton, as this is soft and will not irritate the baby's skin. If this material doesn't work well with the sensors, there are many other materials that we could try. We will test different methods of integration into the fabric, like a sewn-in pocket or as a part of an elastic band. We would like to place the respiratory sensor about an inch above the belly button and the cardiac sensor at the ankle or foot. Once this sensor is integrated, we will test it to make sure that the sensors will not move excessively when the baby moves, as well as to make sure that the sensors are not in a location that will cause the baby irritation. There are several variations of this system, as we can vary the fabric, the method of integration, and location of the sensor. We will test the different variations to come up with the best combination of parameters.

Aim 4: Design a user interface

To actually allow the device to send an alarm when there is an issue, we must configure an interface to allow the signals to be read and analyzed to determine if they are within the appropriate bounds. We would like to use Bluetooth to send the alarm to an external device, so we must first learn how to send information via Bluetooth. An external device must also be designed that will be able to receive the signal and sound the alarm. We will connect a Bluetooth module in the circuit with our heart rate and respiration monitors, and write code to allow an Arduino chip to read and interpret the data. A schematic of this circuit can be seen in **Figure 2a**.

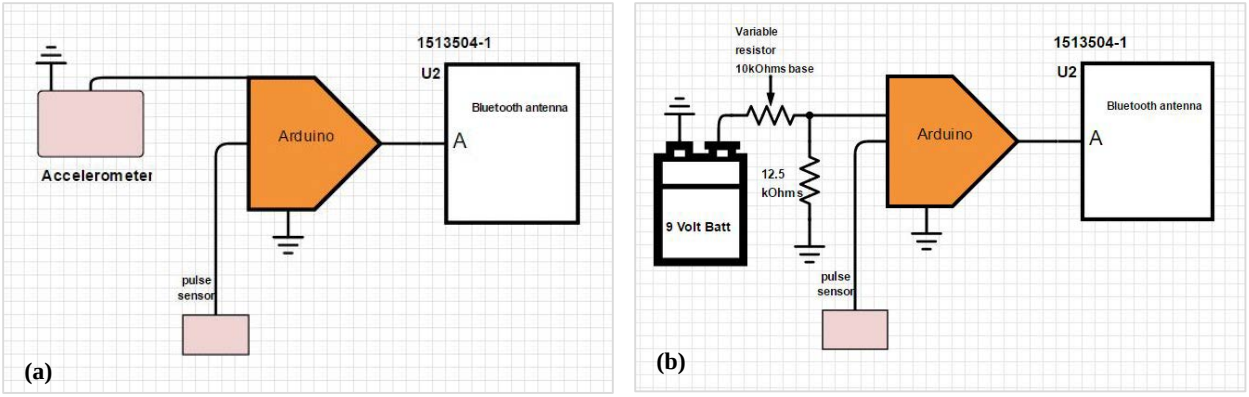

Figure 2: **(a)** Circuit diagram for the planned project, using a pulse sensor and an accelerometer. **(b)** An alternative circuit using a pulse sensor and a flex (resistive) sensor.

We must ensure that this interface will allow the acceptable ranges of heart rate and time without breathing to be set by a doctor, as these values will vary patient to patient. This function might be incorporated into the external device to which the alarm will be sent. Allowing the interface to be customizable will give the device more specificity and allow it to be used by more people. In the future, we would like to change this interface to allow the heart rate and respiration to be displayed in real time.

Discussion

With the completion of this project, we hope to have created a functioning monitoring device to be used on babies, especially those prone to apnea or other respiratory or cardiac issues. The pulse sensor, located on the foot or ankle, will use light-sensitive photodiodes to measure the baby's heart rate. The respiratory monitor, an accelerometer, will be located around the bottom of the ribs and will measure whether or not the baby is moving, and thus whether or not it is breathing. These two devices should transmit their signals to a chip to allow them to be read and analyzed. Ideally, the chip will send a signal via Bluetooth if either of the measurements are outside of the specified range.

We hope to have the ranges integrated into the user interface, allowing a doctor to change these ranges depending on the baby's needs. This specific interface should be concentrated in an external device that the parents can keep with them like a baby monitor, so that they will always be able to hear if there is an alarm. The device should be tested enough to make sure that there will not be a significant number of false positive or false negatives, as this device should be accurate so that it will be a reliable resource for parents.

Eventually, we would like to have the user interface incorporated into a phone app so that parents can use either the external interface or the phone app to monitor their baby. In addition, we would like to have the real-time heart rate and respiration data to be available via the user interface so that the parent can even more effectively monitor their baby. This data should store in the system so that it can be shown to a doctor in case an emergency arises, or in case it is being used to monitor a child who already has health issues. This product will never be able to treat any disease, or prevent any disease from affecting the baby, especially death due to SIDS or asphyxiation. However, it will be a helpful device for monitoring a baby with health issues and will allow parents to be more proactive in case of an emergency.

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