Engineering World Health: Infant Apnea Monitor

Caleb Durante, Drew Birrenkott, Douglas Ciha, Priya Pathak
Client: Amit Nimunkar, EWH Advisor: Paul Thompson
Department of Biomedical Engineering, UW-Madison

Abstract

Infant death in the developing world due to SIDS is of immediate and major concern. We hope to further the Engineering World Health legacy design project to reduce SIDS in the developing world by monitoring for apnea as a possible preventative measure for SIDS. Our prototype implements transthoracic impedance to monitor the rhythmic breathing pattern of an infant and trigger an audiovisual alarm in the event of apnea lasting longer than 20 seconds so that caregivers will be altered to the presence of a possible SIDS episode and be able to take preventative measures.

Background and Motivation

Sudden Infant Death Syndrome (SIDS)
- Sudden and medically unexplained death of an infant <1 year
- Leading cause of infant death since 1980s [1]
- Current hypotheses
  - Infant Apnea
    - Cessation of breathing >20 seconds
    - Caused by underdeveloped respiratory muscles
  - Critical diaphragm failure
    - Lungs unable to inspire

SIDs in Developing Countries
- Neonatal mortality rate highest in developing countries (Figure 1)

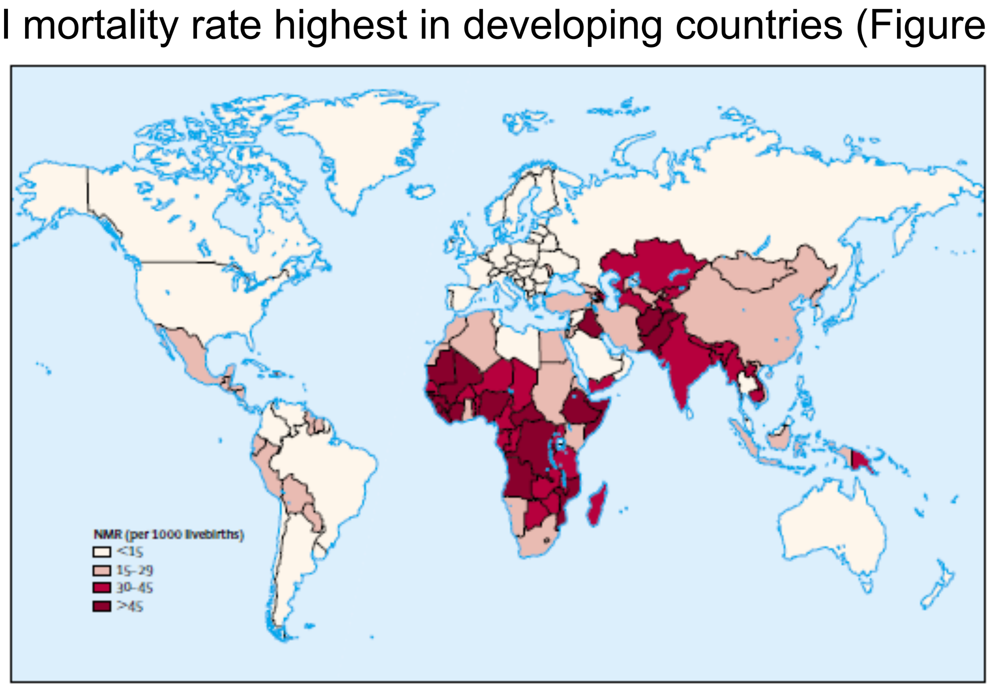


Figure 1: Neonatal Mortality Rate across the globe [2]

- Eight times more asphyxia infant deaths in developing world due to lack of:
  - Cost effective preventative methods [2]
  - Knowledge on causes for infant death [2]

Engineering World Health
- Two previous designs conducted

Design Goal
- Design a cost effective, reliable, and easily operable and maintainable infant respiratory monitor for developing countries that alerts caregiver 20 seconds after cessation of infant respiration

Design Criteria

- Intended for use in impoverished regions with distribution through non-profit organization (EWH)
- Kit Assembly
  - Small & portable
  - 10 cm x 10 cm x 10 cm circuitry housing
- Theft concerns for expensive/rare components
  - Must be low cost ($10-$20)
- Use for infants 0-8 months
- No additional risk of harm to the infant
  - Power may be unreliable- battery powered optimal
- Human element may be untrained or unskilled
- Straightforward assembly, operation, and repair
  - Training/instructions to be included
- Must have ~12 hours uninterrupted operation
- Audiovisual alert after 20 seconds of respiratory arrest

Preliminary Research

- Wide variety of methods available to detect respiration
- Standard U.S. methods:
  - Advanced visual output system
  - Multi-method monitoring for hospital and home
  - Not feasible for the developing world
- Four design options researched and considered (Table 1)

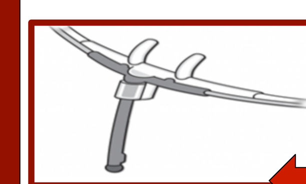


Figure 2: Nasal cannula for thermistor sensing [3]

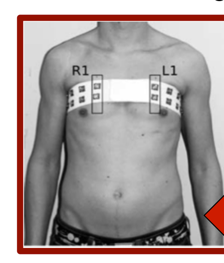


Figure 3: Impedance Pneumography, electrode placement [5]

Table 1: Design options overview)

Method/Device	Measuring Parameter	Sensor type and placement
Thermistor (change in temp)	Breath temperature	Nasal cannula
Chest Force Sensor Resistor (FSR)	Force produced by chest movement	Large plate resistor attached to chest
Impedance Pneumograph (IP) ★	Transthoracic impedance	Skin electrodes on chest
Pulse Oximetry (PO)	$\%O_2$ saturation in blood	Attached to wrist, ankle, or toe

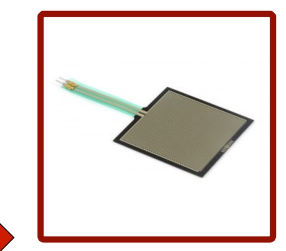


Figure 4: Standard Force Sensory Resistor [4]

Figure 5: Pulse Oximetry apparatus for infants [6]

- Optimal design: Impedance pneumography
  - Most reliable design option→ accepted U.S standard, strive for same quality everywhere else
  - Cheaper than other options

Final Design

Leads → Circuit → Microcontroller → Output

Lead Design (Figure 6)
- Four electrode system
  - Small sections of tin electrodes
  - Dorsal/ventral pairs on 5th intercostal space [7]
- Electrodes held in place by elastic band
  - Adjustable for infants from 0 to 8 months
- Water based lotion applied as electrolyte

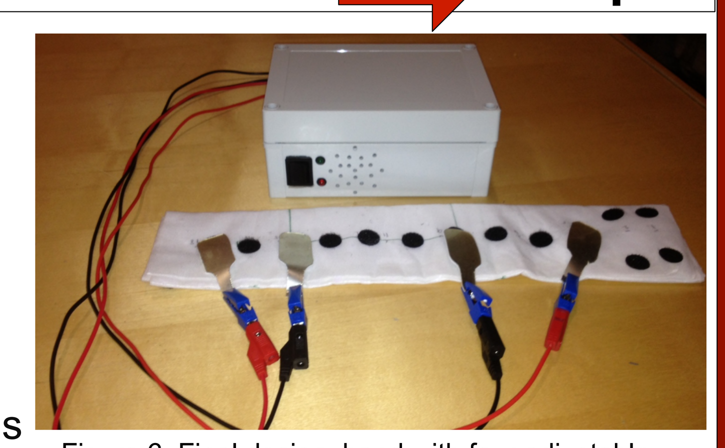
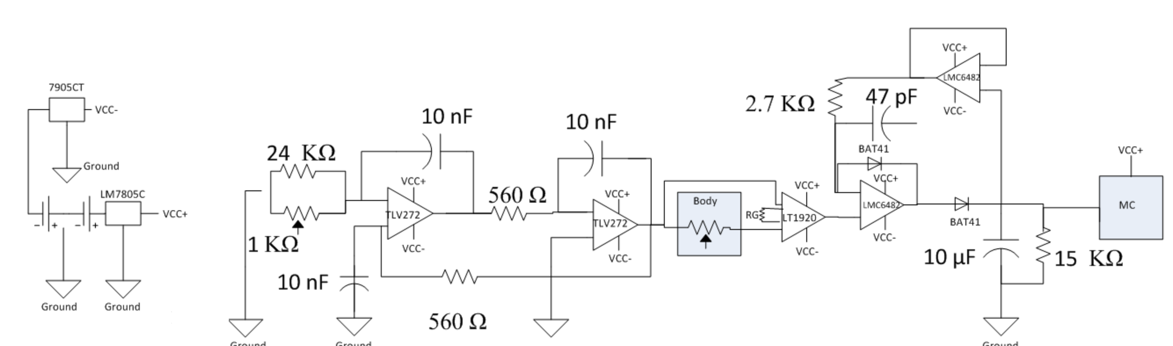


Figure 6: Final design, band with four adjustable electrodes in front and box containing circuit, microcontroller, and output

Circuit Design (Figure 7)
- Oscillating carrier signal injected into body
  - 30 KHz sine at 3 mA
- Chest impedance changes with lung volume
  - Applies amplitude modulation to carrier signal
- Difference between signals is amplified then rectified

Figure 7: Circuit diagram showing three major circuit blocks, sine wave oscillator, full wave rectifier, and instrumentation amplifier



Microcontroller (Figure 8)
- Inputs slowly oscillating voltage signal
- Compares the peak to peak voltage difference
- Checks reasonable, noise free readings
- Good values are compared
  - Alarm triggered if voltage change is too shallow for too long

Output
- 2.86 kHz square wave signal sent to speaker to alarm care taker

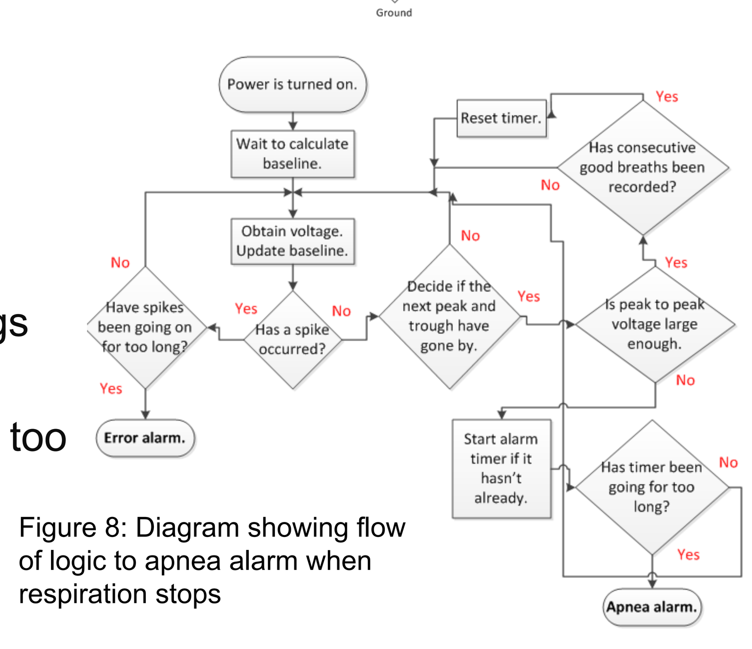


Figure 8: Diagram showing flow of logic to apnea alarm when respiration stops

Testing

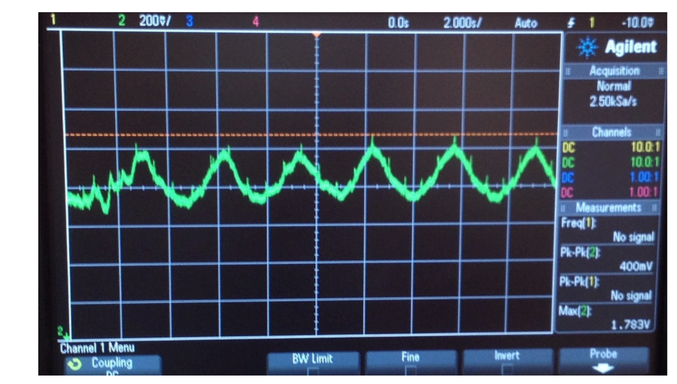


Figure 9: Waveform showing the oscillating respiration waveform with minimized cardiogenic artifact.

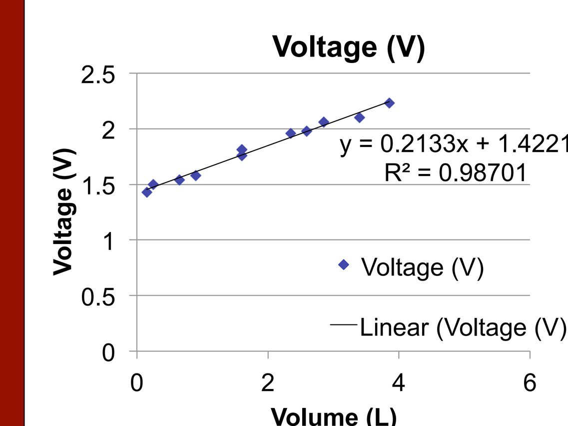


Figure 10: Voltage varies in a direct linear manner with lung capacity, as measured with a spirometer, corresponding to a linear change in impedance

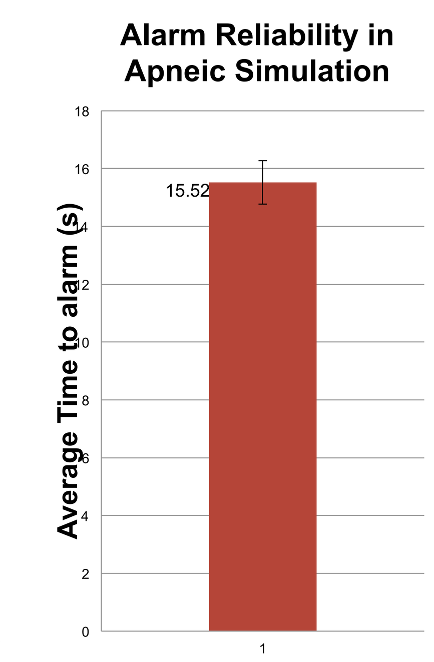


Figure 11: Time taken for alarm to sound when set to sound after 15 seconds of breathing cessation . Apnea was simulated by normal breathing for 7 seconds, followed by holding breath until alarm was activated. There were no instances of false negatives in the 15 trials conducted

Future Work

Leads
- More elasticity and durability of band
- Protocol to determine placement based on infant size

Circuit
- Eliminate cardiogenic artifact from signal
- Phase sensitive demodulation (Figure 12)

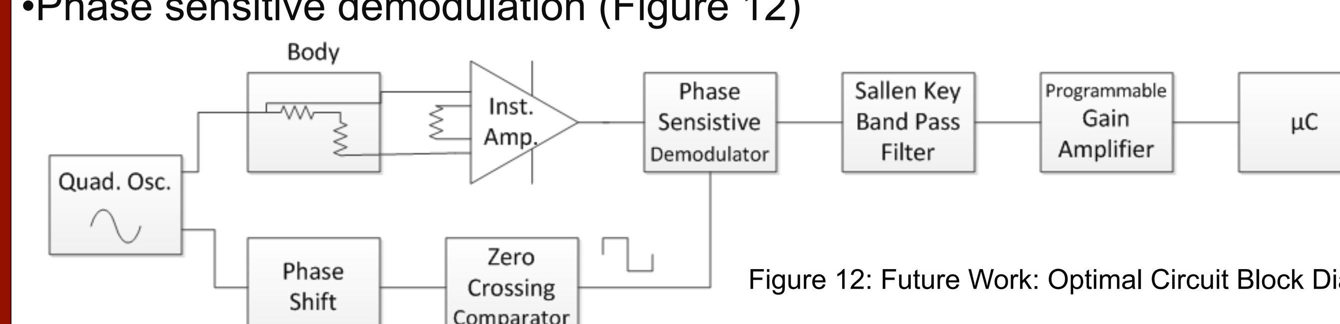


Figure 12: Future Work: Optimal Circuit Block Diagram

Client Requirements
- Cost
  - Prototype cost $235, far exceeded budget (Table 2)
  - Bulk purchasing expected to reduce costs considerably
  - Microcontroller will not be prototyping kit→19% cost decrease
- Power
  - Total circuit draw is 180 mA
  - Expected battery life 8.3 hours
  - Current draw greatly reduced with different microcontroller and more efficient voltage regulation
- Recaliberate voltages for smaller bodies
- Testing on infants
- Visual alarm aspect - LED

TABLE 2: PROTOTYPE COSTS

Item	Price
Banana plugs	$7.00
Electrode strap	$6.00
Voltage regulators(2)	$5.00
Operational amplifier Ics (4)	$3.00
Passive components (R,C)	$7.00
mbed microcontroller	$50.00
Circuitry housing	$20.00
On/Off switch	$6.00
Speaker	$2.00
LEDs	$4.00
9-Volt batteries	$10.00
Breadboard	$15.00
Assembly (10 hours@ $10/hr)	$100.00
TOTAL	**$235.00**

*lab parts - cost estimated

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References:

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[2] Lawn, J.E., Cousens, S., Zupan, J. 2005. 4 million neonatal deaths: When? Where? Why? Lancet 365: 891-900.
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