Continuous Monitoring of Heart and Respiration Rate for Neonatal Infants

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I.   Introduction

Health monitoring systems that continuously record respiration rate and heart rate in real time are important to monitoring patients and providing them with an accurate diagnosis. The most common way of measuring this is using an ECG, which requires contact with the patient using a sensor or electrode with a conductive gel that can be harmful, especially for premature babies because of undeveloped skin. Ballistocardiography (BCG) is a measurement of the body's movement from the heart during systole, and both the heart and respiratory rate can be monitored in real time using high precision load sensors without physical contact with the patient [1].

II.   Technical Approach

Four single point high precision load cells will be placed underneath a mattress to sense the signal from a mechanical substitute for a premature baby that's present on top of the mattress. This signal received from each of the load cells will then be amplified and filtered using an analog front end. These signals will be digitized for computer compatibility using an Arduino Mini and sent to the computer program, MATLAB, via USB. In MATLAB, a heart and respiratory rate detection algorithm will be used to determine the heart and respiratory rate as well create an alert for when vitals fall below 80 beats per minute.

A.   Load cells

The four high precision load cells being used will be the CBCL-3L single point load cells. These load cells have a rated output of 1mv/V with a recommended excitation voltage of 10V. These load cells have a rated output of 1mv/V with a recommended excitation voltage of 10V. One solid metal sheet with dampening material underneath will act as the base of the bed where the load cells can be evenly placed. On top of each load cell will be another metal plate which will provide a larger surface area for signal detection. As seen in Figure 1, two load cells will be under each shoulder and two in the middle of the back.
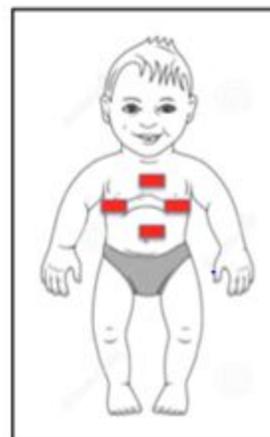

Figure 1. Placement of Load cells from a Top View

B.   Analog Front end

To accurately measure the heart rate from the raw analog signal measured by each load cell, the analog signal must be conditioned before any heart rate detection can be performed. Due to noise created in the load cells themselves and other environmental clutter that will be present, amplifying the signal will be necessary to further separate the signal from any unwanted clutter. The ADS124S08 integrated chip (IC) will make up the analog front end. Once the signal is amplified, any signal amplitude that falls outside the desired range of frequency will have to be removed. In premature babies, the heart rate signal typically falls in the frequency range of about 0.1 Hz to 20 Hz [2]. This IC will both filter out 60 Hz noise

from nearby AC voltage devices as well as perform the bandpass filter. Each analog signal, once amplified and filtered, will then be fed to an Arduino Pro Mini. This allows the data to be processed in real time in MATLAB. The data from each conversion will be transmitted serially to the computer via a USB connection. The Arduino will perform a loop, in which it cycles through each pin, referencing the voltage level at the pin, assigning a 10-bit word corresponding to the sampled voltage level.

C.   MATLAB
To process the digital signals on the computer, MATLAB will be used to read the incoming serial data and process it in real time. A detection algorithm used to detect the QRS complex, known as the Pan-Tompkins algorithm, will be modified slightly to detect the J-peaks of the BCG signal [3]. This can be done since the J peaks of the BCG signal have an almost identical signature to the R peak in the QRS complex. This algorithm will be used to detect the heart rate [4]. Once the Pan-Tompkins algorithm has detected the J-peaks, the respiratory rate can be derived from the BCG signal. The Kurtosis computation algorithm will be used to calculate the kurtosis value for each interval of the two neighboring J-peaks. Once the Kurtosis value is computed between two neighboring J-waves, the respiratory source sample for that specific JJ-interval, known RR-interval for ECG, can be approximated. With the Kurtosis value known for each specific JJ-interval, the impedance from time in between JJ-peaks can be approximated by using spline interpolation to retrieve a derived respiratory signal [5].

D.   Test Baby
A mechanical test baby will be created that will provide a 'beating' heart that will lay on top of a mattress to simulate an infant baby resting on top of the mattress by using a piezoelectric speaker that will output a mechanical vibration consistent with a beating infant heart. A recorded heartbeat signal will be used to create a lookup table of values that correspond to a discrete magnitude of each sample of the heartbeat signal. Because the signals recorded in the MIT-BIH database were recorded with 11-bits of resolution, a conversion must be done in MATLAB to group the samples into 10-bits of resolution. The output will be able to cycle through the different heart rate samples resulting in a changing heart rate. This change in heart rate must be able to be detected in real time by the system and cause an alert if the heart rate falls below or rises above a certain level.

References
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[3] Pan J, Tompkins WJ. A Real-Time QRS Detection Algorithm. IEEE Transactions on Biomedical Engineering. 1985;BME-32(3):230-236. doi:10.1109/tbme.1985.325532.