

The Feasibility of Using A Forehead Reflectance Pulse Oximeter for Automated Remote Triage

Suzanne Wendelken*, Susan McGrath*, George Blike**, Metin Akay*

*Dartmouth College/Thayer School of Engineering, Hanover, NH, USA

**Dartmouth Hitchcock Medical Center/Anesthesiology, Hanover, NH, USA

***Abstract-** The extreme conditions of combat and multi-casualty rescue often make field triage difficult and put the medic or first responder at risk. In an effort to improve field triage, we have developed an automated remote triage system called ARTEMIS for use in the battlefield or disaster zone. This preliminary research seeks to empirically demonstrate that the Nonin forehead reflectance pulse oximeter is a viable sensor for measuring essential physiological parameters used in automated field triage systems such as ARTEMIS.*

I. INTRODUCTION

Increasing patient survivability by moving information and resources closer to casualties in the field is a major objective of casualty care research. The goal of the Automated Remote Triage and Emergency Management Information System (ARTEMIS) project is to integrate advances in communications and analysis technologies into a remote triage system that can expedite and improve care of the wounded. This approach can be used to monitor soldiers, first responders, and casualties in the military and civilian domain.

ARTEMIS aims to enhance field triage by combining individual computing devices, a mobile agent information management network, a sensor capable of collecting pertinent physiological data, an assessment and alert system that analyzes sensor data [7], a wireless routing system that transports and distributes data among computers in the network, and a user interface that allows field and command personnel to access a person's health status remotely as well as issue treatment protocols. ARTEMIS uses an algorithm based on a triage protocol called START (Simple Triage And Rapid Treatment) which was shown to be effective in multi-casualty incident triage [2,3].

We chose to use the pulse oximeter as our key sensor because it is a simple, noninvasive, and widely utilized device that contains a wealth of information [6]. A forehead reflectance pulse oximeter is ideal because it can be placed beneath a headband, helmet, or facemask, and not be a hindrance to a soldier or first responder.

Pulse oximetry uses the different light absorption properties of oxygenated hemoglobin (HbO₂) and reduced hemoglobin (Hb) to measure heart rate and oxygen saturation (SpO₂). Standard pulse oximeters use red and infrared LEDs to probe arterial pulsations. The waveform, known as the photoplethysmogram (PPG), resembles a pulse pressure waveform. Recent studies have shown that variations in the PPG amplitude strongly correlate with respiration rate and changes in systolic blood pressure and vascular (sympathetic) tone [1,5,8,9].

Physiological parameters such as heart rate, respiration rate, blood pressure, oxygen saturation, and airway obstruction can be

used to automate field triage. Respiration rate and airway obstruction are of particular interest as they have been shown to be key predictors of injury severity and death [4] and thus extremely useful in automated remote triage.

This preliminary research seeks to empirically demonstrate that a forehead reflectance pulse oximeter is a viable sensor, capable of measuring essential physiological parameters used in automated field triage systems such as ARTEMIS.

II. METHODS

In this preliminary research, we test the Nonin forehead reflectance pulse oximeter for its ability to measure standard parameters of heart rate, SpO₂, and PPG in the presence of noise; to see if amplitude variations in the PPG are consistent with respiratory frequencies; and to see if the sensor is sensitive to changes in sympathetic tone. In these experiments, the PPG collected by the Nonin sensor was preprocessed using the Nonin DSP hardware attached to the sensor and logged on a PC. The resulting PPG data was analyzed using Matlab™ software.

In one experiment, we placed the forehead probe on two subjects (one male age 21, one female age 24) using Nonin adhesive, athletic tape, and an athletic headband. While the subject was standing on a treadmill, one minute of baseline data was collected. The treadmill speed was then increased by 1 mph, starting at 3 mph, every minute until a high level of exertion was attained (7-9 mph and heart rate > 160 bpm) while PPG data was continually recorded. After the treadmill was stopped, approximately two minutes of PPG data were recorded during recovery. This experiment simulates PPG data collection during noise caused by exertion similar to that of soldiers or first responders.

In another experiment the forehead probe was placed on a subject (female age 24) and PPG data was recorded continuously for two minutes. For the first minute, the subject was lying down. At one minute, the subject stood up, temporarily increasing sympathetic tone. For the second minute, the subject remained stationary while standing. This process was repeated three times. This experiment simulates a sudden change in vascular tone which can arise from hypovolemia (which can be caused hemorrhage or dehydration—both are important factors in triage) and often occurs in conjunction with an increase in blood pressure [8].

III. RESULTS

For the treadmill experiment, a high quality PPG waveform was obtained even during exercised induced noise and physiological stress (figure 2). The average SNR of the two trials was 67.6 demonstrating that the PPG recorded by the

Nonin forehead reflectance probe is adequate for ARTEMIS applications. PPG data was analyzed with short-time FFTs using a sliding Kaiser window (figure 1). Frequencies between 1 and 3 Hz are from the heart rate. Frequency components from 3 to 5 Hz are most likely result from the step rate of running. Individual pulses were extracted from the PPG data and normalized pulse height was calculated and resampled in order to perform frequency analysis (figure 2). Respiratory induced variations (RIV) in PPG amplitude appear to be present. Respiratory rates were calculated from the frequency of the RIV in PPG amplitude. Normal respiratory rates range from 12 to 25 breaths per minute (0.1-0.3 Hz). The frequency of the RIV was consistently in this range.

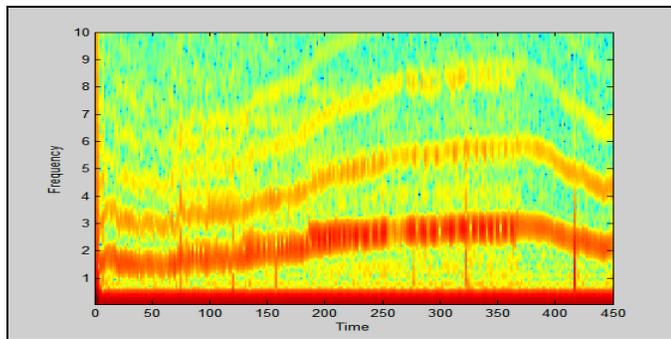


Figure 1: short-time FFT of PPG during treadmill experiment.

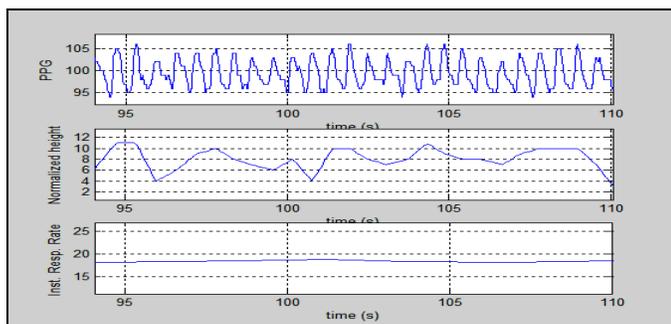


Figure 2: RIV of PPG signal during treadmill experiment.

In the second experiment, the same frequency analysis methods were used. RIV amplitude variations of the PPG were present (figure 3). In addition, there was a distinctive decrease in the PPG amplitude 5 to 10 seconds after the subject stood up (figure 3). This is consistent with findings which show that the amplitude of the PPG will decrease with an increase in systolic pressure and sympathetic tone [1,8]. The sharp decrease in PPG amplitude was present in all three trials. This indicates that the Nonin forehead pulse oximeter is sensitive to sudden changes in sympathetic tone.

IV. FUTURE WORK

We are currently doing a clinical trial in which we study the PPG of post-operative patients. The physiological effects of anesthesia are similar to that of a head injury (depressed respiratory function, lack of or low level of consciousness, and non-responsiveness to pain). We are studying the evolution of the PPG signal as the patient wakes up from surgery to see if there is any predictive statistic of head injury or airway obstruction.

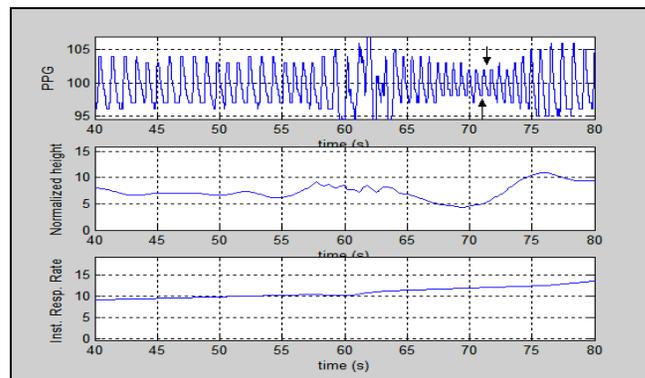


Figure 3: PPG analysis during sudden systolic blood pressure increase.

In addition we are studying the PPG of sleep apnea patients to see if airway obstruction can be detected in the PPG and how fast S_pO_2 decreases during apnic episodes. We are also analyzing other parameters calculated from the PPG including S_pO_2 , beat to beat interval, pulse width, and the height to width ratio to see if there is any correlation with events such as respiration, blood pressure change, and airway obstruction.

V. CONCLUSION

In this preliminary study, the Nonin forehead reflectance pulse oximeter performed well even in the presence of noise. RIV in the PPG amplitude was present in all samples and the frequency of this amplitude variation was consistently within normal respiratory frequency bounds. In addition, the sensor responded predictably to a sudden change in sympathetic tone. These results indicate that this sensor is suitable for use in ARTEMIS applications.

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