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Mini-Symposia Title:

Estimation and processing of physiological signals and parameters employing mHealth, wearable and robotic solutions

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Mini-Symposia Speaker Name & Affiliation 3:

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Theme:

- (●) 01. Biomedical Signal Processing
- ( ) 02. Biomedical Imaging and Image Processing
- ( ) 03. Micro/ Nano-bioengineering; Cellular/ Tissue Engineering &
- ( ) 04. Computational Systems & Synthetic Biology; Multiscale modeling
- ( ) 05. Cardiovascular and Respiratory Systems Engineering
- ( ) 06. Neural and Rehabilitation Engineering
- ( ) 07. Biomedical Sensors and Wearable Systems
- ( ) 08. Biorobotics and Biomechanics
- ( ) 09. Therapeutic & Diagnostic Systems and Technologies
- ( ) 10. Biomedical & Health Informatics
- ( ) 11. Biomedical Engineering Education and Society
- ( ) 12. Translational Engineering for Healthcare Innovation and Commercialization

Mini-Symposia Synopsis— Max 2000 Characters

Nowadays, it is recognized that self and remote monitoring of physiological and parameters is relevant to detect health diseases on time. Conventionally, the monitoring and processing of such signals and parameters are performed using specialized biomedical systems. However, those systems are not always available outside clinical and research centers or have prohibitive costs for their daily use by the general population. As alternative solutions, the employment of mobile health, wearable and robotic systems for health care monitoring could help to overcome such limitations given their ubiquitous and mobile characteristics and the current need for monitoring systems that enable a more frequent and earlier monitoring to improve detection of diseases as well as to reduce the burden on health care systems. We aim to discuss recent developments on the employment of mobile health systems for estimating physiological parameters, employing the cost-effective sensors already embedded in mobile devices together with wearable and robotic systems. First, a smartphone-based system for the simultaneous estimation of instantaneous heart and respiratory rates using contact image photoplethysmography (PPG), will be presented. Second, a novel image processing method and an inclusive and affordable screening tool to detect streptococcal pharyngitis using a smartphone, will be presented. Third, the results of a method for central nervous system oxygen toxicity using electrodermal activity, which is intended for being incorporated into a system based on a wearable device and a smartphone application, will be presented. Fourth, a method to reduce the vulnerability to motion and noise artifacts on smartphone-based physiological signals during heart rhythm signal detection, will be presented. Finally, the design of a robot-based device for active and autonomous instantaneous heart rate estimation using remote PPG sensors mounted on a robot, will be presented.

Estimation of Instantaneous Heart and Respiratory Rates using Smartphone-based Contact Image Photopletysmography

Bersain A. Reyes, Universidad Autónoma de San Luis Potosí

***Abstract*— Heart rate (HR) and respiratory rate (RR) are vital signs relevant to understand and evaluate the cardiorespiratory system. We present some results on using a single smartphone device to simultaneously estimate the time series of HR and RR via a contact image plethysmograph approach together with a time-varying spectral estimation method. The proposed system performs the data acquisition, processing and display the HR and RR results directly on the mobile device. The performance of the system was tested considering reference signals from specialized biomedical devices during experimental maneuvers, finding a mean average error below 2 BPM for HR and 1 bpm RR.**

I. Introduction

An alternative for low-cost and ubiquitous heart rate (HR) and respiratory rate (RR) monitoring consists in employing the smartphone camera and an image photoplethysmography (iPPG) method. Several efforts have been made regarding such mobile health solutions, but most of them only focused on a single vital sign or on the average value of both [1]. However, it is well known the influence of the breathing on HR, the respiratory sinus arrhythmia (RSA) [2]. Hence, we exploit the frequency modulation of HR due by RSA to simultaneously estimate the HR and RR time series directly on an Android smartphone using a single camera and performing all the image and signal processing on the device.

II. Methods

We collected data from healthy volunteers during maneuvers that modify HR and RR, e.g., after exercising or experiencing sudden changes in metronome breathing rates. Together with the smartphone-acquired data, signals were recorded using electrocardiogram (ECG) and respiratory band (Resp), as references for HR and RR, respectively. First, the app extracts the iPPG signal by the averaging the pixel intensities of the green video channel (G) over a region of interest of each frame. Then, the iPPG signals are interpolated at 30 Hz and their local peaks are detected. Regarding HR estimation, peak-to-peak intervals of iPPG are used to generate the HR time series at 4 Hz. Estimation of RR time series employs the spectrogram, from which the frequency providing the maximum intensity at each time instant was computed. Finally, the performance of the smartphone-based estimation was analyzed via the mean average error (MAE), correlation index (ρ) and Bland-Altman analysis considering the estimations from references.

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TABLE I. Results for Estimation of HR and RR Time Series

Maneuver	HR time series		RR time series	
	ρ (unitless)	MAE (BPM)	ρ (unitless)	MAE (bpm)
After excercise	0.999 ± 0.001	1.678 ± 0.898	0.998 ± 0.001	0.477 ± 0.129
Changes in breath rate	0.999 ± 0.001	1.187 ± 0.456	0.994 ± 0.002	0.731 ± 0.233

a)

b)

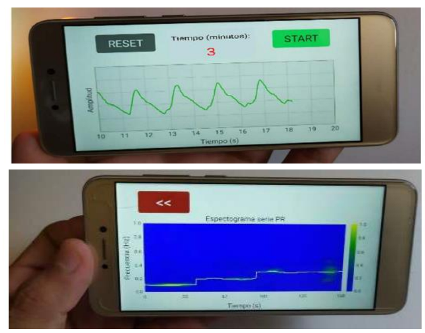

Figure 1. Developed Android smarpthone app. a) Extraction of iPPG signal. b) Example of obtained results for RR time series.

III. Results

Fig. 1 shows the Android app prototype, developed using Processing for Android programming language. Some obtained results for instantaneous HR and RR estimations for a couple of maneuvers are presented in Table I, in terms of the mean value ± standard deviations.

IV. Discussion & Conclusion

The provided results point out to the feasibility of accurately tracking the temporal variation of both HR and RR in different maneuvers employing a single low-cost off-the-shelf smartphone. We consider that this and similar mobile health solutions will contribute to enable the monitoring of vital signs on everyday conditions.

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Strep Throat (Streptococcal Pharyngitis) Detection Using a Smartphone

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***Abstract*— Recently, using smartphones for disease diagnosing and health care applications has become promising due to its convenience. A novel image processing method and an inclusive and affordable screening tool to detect strep throat (streptococcal pharyngitis) using smartphone is proposed. The proposed novel gadget was manufactured using 3D printer and a new color correction method was implemented by utilizing CIE LAB color space components to extract features. For the classification step, we adopted the Support Vector Machine (SVM) algorithm combined with k-fold cross-validation to prevent overfitting. Our method could diagnose diseased throat tissues from healthy throat tissues with a 95.6% accuracy.**

I. INTRODUCTION

Streptococcal Pharyngitis (strep throat) is a type of sore throat caused by bacterial infection and it is the primary diagnosis from visits to the U.S emergency department according to the National Health Statistics Report (NHSR) [1]. Strep throat is an infectious disease that is caused by group A beta-hemolytic streptococcus (GABHS) gram-positive bacteria [2]. Late diagnosis of strep throat may lead to a life-threatening disease known as is rheumatic fever. If rheumatic fever is not treated in time it may cause chronic rheumatic heart disease. Rheumatic heart disease is considered as the cause of 320,000 deaths per year. We propose a throat color analysis method based on images from a smartphone camera to detect strep throat. We first introduce throat color features using CIE LAB color space and by adopting these color features we implement color correction and classify strep throat images from healthy ones.

II. METHODS

Images captured by the smartphone camera are utilized to monitor the conditions of the throat for healthy or strep throat cases. Common symptoms of strep throat include swollen lymph, fever, sore throat, and visual signs as shown in Fig. 1,

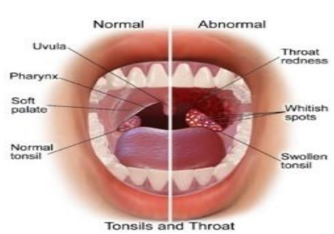

Figure 1. Signs of healthy throat (left) vs strep throat (right).

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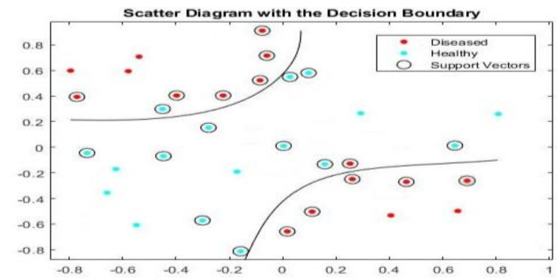

Figure 2. Results of SVM classifier on the color features.

are: inflammations, swollen tonsils, enlarged tonsils, and white and red spots on throat are some of the symptoms of strep throat [14]. A normal throat is also shown in Fig.1 for comparison with the strep throat. Our proposed method to extract these features from the images in four steps are: 1) image acquisition, 2) preprocessing and color correction on images, 3) feature extraction, and 4) classification.

III. RESULTS

We evaluated our proposed method on the smartphone camera images from 17 healthy participants and 17 participants with diagnosed strep throat. The color gamut of the throat has four color features that have been extracted. The average color values of healthy participants and strep throats were derived. The fluctuation in the *b** channel is very low and the differences which differentiate healthy from diseased throat are in the L and *a** color features. Fig.2 shows the results of the SVM classifier on the color features extracted from the throat images. The healthy color data are shown in blue; the diseased throat color data are shown in red and the support vectors are shown with black circles.

IV. DISCUSSION & CONCLUSION

We investigated the feasibility of detecting strep throat using smartphones by adopting a novel image processing method. Our method proposes an accurate, portable, and affordable way to detect strep throat for home care and remote care applications. To improve the efficiency of the proposed method, we made a special 3D gadget to adjust environmental lighting. The accuracy of our modified method for detecting signs of infection and infected tissues from healthy throat tissues has increased from 93% to 95.6%.

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Detection of Central Nervous System Oxygen Toxicity based on Electrodermal Activity collected with a Wearable Device

Hugo F. Posada-Quintero, University of Connecticut

***Abstract*—We are using the electrodermal activity (EDA), specifically the time-varying spectral analysis of electrodermal activity (TVSymp) as a tool for sympathetic tone assessment for the detection and/or prediction the onset of seizures caused by central nervous system oxygen toxicity (CNS-OT) in divers. In the long run, we envision a system based on a wearable device and smartphone application able to collect and transfer the data if required (Fig. 1). This tool will allow the diver to take countermeasures against the consequences of CNS-OT. The preliminary results show large increase in amplitude TVSymp values derived from EDA recordings ~2 minutes prior to expert human adjudication of symptoms related to oxygen toxicity**

I. Introduction

Prolonged and high pressure (deep) diving leads to various physiological challenges including the risk for decompression sickness (DCS) and death. The most effective method to mitigate DCS is hyperbaric oxygen (HBO_2) pre-breathing. However, divers breathing HBO_2 are at risk for developing central nervous system oxygen toxicity (CNS-OT). The electrodermal activity (EDA) is useful for detecting sympathetic nervous system elevation is the measurement of EDA signals [1], [2]. Hence, a pair of electrodes that can continuously measure EDA signals for a prolonged duration in water submersion could potentially detect CNS-OT induced seizures.

II. Methods

We have collected EDA after high-pressure HBO_2 administration to humans following a ketogenic or normal diet (double-blinded). The experiments were carried out in the "foxtrot" chamber pool at the Duke University Hyperbaric Center. The subjects underwent a cognitive stress test based on MATB-II software while being at elevated oxygen partial pressures (2.06 ATA, 35 FSW), for 30 minutes. Due to safety purposes, subjects were seated in water to the shoulders, in a head-out position secured by a harness to prevent head submersion in the event of a convulsion or loss of consciousness.

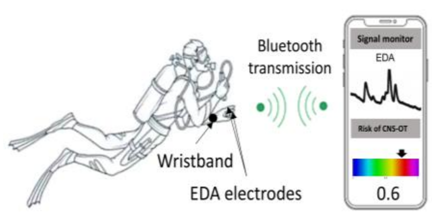

Fig 1. Envisioned system for CNS-OT prediction/detection in divers.

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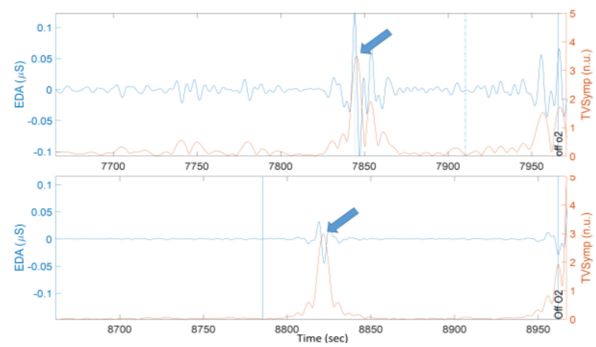

Fig 2. Recordings from the same diver with either ketogenic or conventional diet (unknown) in a hyperbaric chamber. The blue and red lines represent the filtered EDA data and the TVSymp, respectively.

Time-varying spectra of EDA signals was used to quantify the elicited changes of the sympathetic nervous system due to the stimuli [3].

III. Results

In Fig. 2, both figures correspond to the same subject, for one recording the subject is on a ketogenic diet and for the other recording the subject is on a conventional data (unknown). In both cases the TVSymp seems to predict the occurrence of symptoms of CNS-OT. There is a nearly 7-fold increase in TVSymp value (the first red arrow) when compared to its values prior; this increase occurred ~2 min prior to oxygen being turned off due to symptoms of CNS-OT, noted in the vertical text at the end of the recording.

IV. Discussion & Conclusion

Although more data are needed to verify the consistency of these results, this elevation on TVSymp suggest that the subject had profound diaphoresis as his manifestation of CNS-OT. EDA has a potentially better sensitivity to sudden diaphoresis as compared to twitching or visual disturbance, given the nature of collecting the EDA, measured from the skin's conductance which is proportional to sweat secretion [1].

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A Novel Motion and Noise Artifact (MNA) Reduction Method for Smartphone Heart Rhythm Signals Using Diversity Method

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***Abstract*—Smartphone-based physiological signals are more vulnerable to motion and noise artifacts (MNAs) compared to using medical devices, since subjects need to hold the smartphone with proper contact to the smartphone camera and lens stably and tightly for a duration of time without any movement in the hand or finger. The proposed diversity method for smartphone signals reduces the effect of MNAs during heart rhythm signal detection by 1) acquiring two heterogeneous signals from a color intensity signal and a fingertip movement signal, and 2) selecting the less MNA-corrupted signal of the two signals. Experimental results show that our diversity method increases the usable period 19.53% and 6.25% compared to the color intensity or the fingertip movement signals only, respectively.**

I. INTRODUCTION

The heart rate estimated from these smartphone signals is 90% accurate when they are acquired without motion. However, there are different factors that limit accurate measurements of heart rhythm and heart rate variation when using smartphones. Some of these factors are limited sampling rate of smartphones compared to clinical devices, heating problem of the flash light in long term measurement and the experimental artifacts induced during acquisition step [1–2]. We propose a novel diversity method which exploits the diversity gain to obtain reliable heart rate information, i.e. to increase the ratio of the clean usable segment to be used.

II. METHODS

The proposed diversity method exploits the diversity gain to obtain reliable heart rate information, i.e. to increase the ratio of the clean usable segment to be used to calculate heart rate. We consider two different types of heterogeneous smartphone signals obtained from a single smartphone camera recording as show in Fig 1 (see left): 1) color intensity signal, and 2) fingertip movement signal. These two acquired signals are heterogeneous since they extract different information, i.e., the color intensity signal measures blood flow change on a fingertip while the fingertip movement signal measures the subtle movement of fingertip initiated by heart pumping. To exploit the diversity from these two heterogeneous smartphone signals, the proposed method 1) first divides the smartphone signals (color intensity and fingertip movement signals) into segments, and 2) then calculates the SQIs' values of each segment. 3) Then, for each time slot, the proposed method selects the better segment between the two segments (color intensity and fingertip movement segments).

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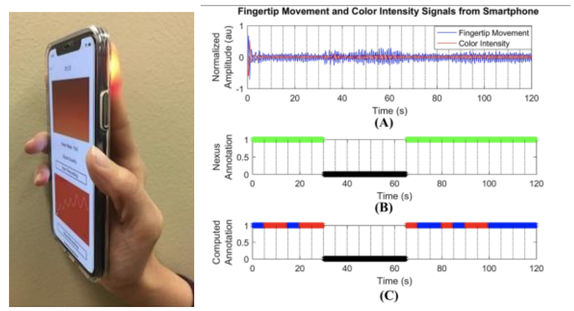

Figure 1. Smartphone signal acquisition procedure (left) and MNA detection decisions made by MNA detection method (right).

III. RESULTS

We evaluate the performance of the proposed diversity method for smartphone signals in terms of MNA detection accuracy as well as the ratio of usable (or clean) period. We compare the proposed diversity method to the non-diversity Usable period ratio (or clean period ratio) of our proposed diversity method is compared to those of the color intensity and the fingertip movement signals as show in Figure 1 (see right). The usable period ratio of the proposed diversity method is shown to be 85.23% while those of the color intensity and fingertip movement signals are shown to be 80.22% and 71.30%, respectively. This result shows that our proposed diversity method increases the portion of usable period by 6.25% and 19.53% compared to the color intensity only and the fingertip movement only signals, respectively.

IV. DISCUSSION & CONCLUSION

The proposed diversity method for two heart rhythm signals - which are respectively obtained by assessing the color intensity and the fingertip movement signals from a single smartphone camera is proposed to reliably and continuously get heart rhythm information in the presence of MNAs. We performed the diversity method on the results of the MNA detection method with the (synthetic minority over-sampling technique) SMOTE approach. The ratio of usable segments after applying the SMOTE technique is 72.71% and without the SMOTE technique is 80.22% for the color intensity. For the fingertip movement signal, the ratio of the usable segments is 67.96% and 71.30% without the SMOTE.

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Robot-based device for active and autonomous instantaneous heart rate estimation using remote photoplethysmography

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Abstract— **Remote photoplethysmography (rPPG) sensors have attracted a significant amount of attention as they enable the remote monitoring of instantaneous heart rates (HRs) and thus do not require any additional devices to be worn on fingers or wrists. However, such convenient remote monitoring has not led to successful commercialization because rPPG sensors are limited by the need for webcams connected to computers. In this study, we describe the design of a robot-based device for active and autonomous instantaneous HR (R-AAIH) estimation using rPPG sensors mounted on a robot.**

I. Introduction

Remote photoplethysmography (rPPG) sensors have attracted much attention because of their capacity to measure instantaneous heart rates (HRs) without any contact with the human skin. The rPPG sensor uses a camera for face detection and records facial skin images representing changes in the arterial blood volume between the systolic and diastolic phases of the cardiac cycle. However, these convenient monitoring capabilities have not led to successful commercialization. This is because the use of rPPG sensors has been limited owing to the use of webcams connected to computers. To extend the use of remote rPPG sensors, we herein present an automated device for active and autonomous instantaneous HR estimation (R-AAIH) using an rPPG sensor mounted on a robot.

II. Methods

Fig. 1 shows our device designed for an active and autonomous instantaneous HR estimation using a robot equipped with a rPPG sensors. The complete system involves six stages of simultaneous localization and mapping (SLAM), robot navigation, face detection, face skin extraction, rPPG signal conversion, and HR estimation. Fig. 1(a) shows our robot developed using a turtlebot2 framework (YUJIN ROBOT, Incheon, Korea). Within the framework, a three-dimensional (3D) camera (ASTRA PRO, ORBBEC, Michigan, USA) is mounted on the device for the SLAM and robot navigation stages, and a web camera (Logitech BRIO, Switzerland) is used for the remaining stages. Both cameras are operated through a laptop computer (TFG175, Hansung, Seoul, Republic of Korea) with AMD Ryzen 5 3400G, 3.70GHz processor. The device is provided with an initial map that indicates the designated start/destination coordinates (Fig. 1(b), left), the robot then performs the SLAM and constructs a map of its surroundings based on data from the 3D camera (Fig. 1(b), right).

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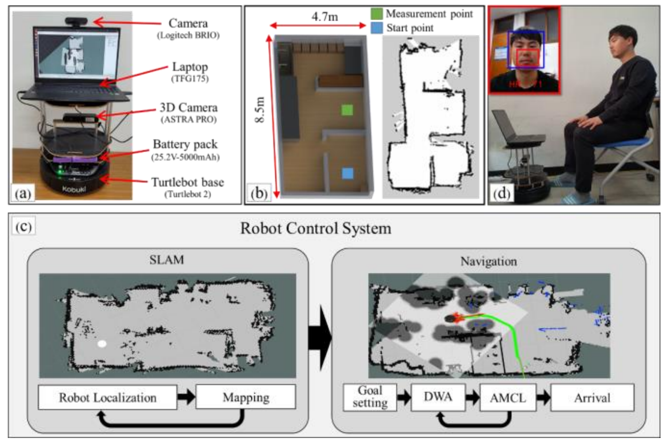

Figure 1. An overview of the proposed system for instantaneous HR estimation using a rPPG mounted on a robot

In addition, the robot localizes its position within the mapped environment [1]. The SLAM iterates the mapping and localization data (Fig. 1(c), left) with respect to the initial map. In this study, we used a factored solution, the FastSLAM, which estimates the robot position using a particle filter and updates the map using an extended Kalman filter.

III. Results

To test our proposed algorithm, we used two datasets, namely the UBFC-RPPG (n = 42) and the ones obtained using our designed robot system, i.e., the BAMI-RPPG (n = 14). Using the UBFC-RPPG dataset, our proposed algorithm was evaluated for a total of 2184 windows corresponding to 42 1-min. video files. The absolute average error was 0.71 bpm. For the BAMI-RPPG, the results showed that our algorithm provided a low AAE of 0.82 bpm

IV. Discussion & Conclusion

For a real-time realizable algorithm, we used relative saturation values, which effectively extracts the facial skin image for the performance enhancement of HR estimation and reduces computational complexity. However, the rPPG acquisition is based on non-contact reflectance; and thus, its SNR is relatively low, especially under ambient light changes and movement artifacts, which is the future work.

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