Drowsiness Control Center by Photoplythesmogram

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***Abstract* — Daytime drowsiness and fatigue lead to decreased driving reliability, lower working efficiency and fatal accidents. According to recent research, heart rate variability (HRV) can be robustly calculated from the photoplethysmogram (PPG) to indicate parasympathetic nervous activity and classify drowsiness level. In this paper, a low power wireless PPG sensor has been designed. N-back M-pitch, a working memory cognitive test has been used to correlate HRV, extracted from the new sensor, with mental fatigue, indicated by lower accuracy in the test. Signal processing algorithms have been designed, which are being implemented into real time software running on Intel Tunnel Creek Atom board, to function as the drowsiness control center.**

I. INTRODUCTION

National Transportation Safety Board (NTSB) showed that sleepiness is a significant factor in fatal automobile accidents. Different levels of fatigues would impair the abilities in making crucial decisions in avoiding accidents. Moreover, abnormal sleepiness is common in modern society due to increasing stress. This also impairs motivation, energy and awareness, which decrease reliability of human-involved tasks. It is therefore critical to identify and classify stages of drowsiness from light to deep directly from physiological signals. Drowsiness control center in this paper is doing exactly that.

Autonomic Nervous System (ANS) influences organ activities, including heart rhythms. ANS has two divisions, parasympathetic nervous systems (PSNS) and sympathetic nervous system (SNS). SNS supports intensive physical activity during fight-on-flight, while PSNS supports resting state and thus is more active during drowsiness. It is found that power spectrum density of HRV could represent SNS and PSNS [2]. Specifically, area of high frequency region over low frequency region indicates PSNS, as shown in (1).

PSNS Activity = HF/LF (1) [3][4]

This drowsiness control center delivers with sensors and computation module to execute decisions from signal processing. As the PPG is non-invasive and low cost, it has thus been selected to fetch cardio-physiological data. A wireless low power PPG sensor has first been designed with three stages of filtering and ZigBee communication module. Concurrently, a 48-hour sleep deprivation psycho-physiological experiment -- N-back, M-pitch has been implemented to verity and specify the correlations between mental fatigue and HRV. The collected data were then used to design robust signal processing algorithms to extract HRV power spectrum density to correlate with drowsiness. Together with other correlation algorithms, it is being implemented into real time processing software running on Intel Tunnel Creek Atom board.

II. METHODOLOGIES

A. Biomedical Experiments

In order to improve the control to the drowsiness assessment, IRB-approved N-back M-pitch experiment has been implemented [5]. It directly assesses the working memory as a reliable source of cognitive performances [1]. During the experiment, subjects are requested to report whether the auditory stimulus N steps prior has the same as duration as the current one has, while neglecting the M numbers of pitch differences. N-back M-pitch has been programmed in MATLAB with 4 pitches at 500Hz, 600Hz, 700Hz, and 800Hz [5]. As a result to the preliminary software testing, the two durations were set to 50ms and 100ms, while Inter Stimulus Interval (ISI) to be 2ms. The stimuli with two different durations were programmed with equal probabilities into a random sequence, so does the pitch differences. Accuracy was calculated in (2).

$$Accuracy = \frac{Number\ of\ Correct\ Responses}{Total\ Number\ of\ Trials} \times 100\% \quad (2)$$

In addition, multiple responses to one instance and omissions are recorded by positions, as shown in fig 1 as the performance example.

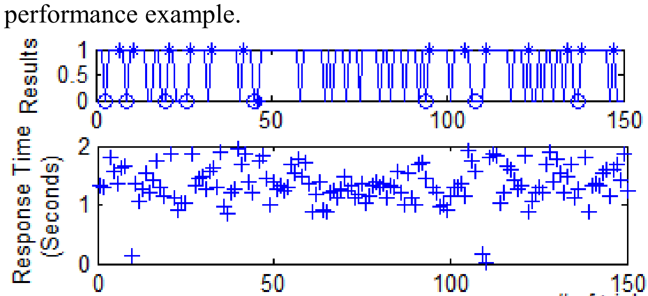

Fig 1. N-back M-pictch Performance Reuslts Example with a 72% Accuracy

Subjects are requested to perform N-back M-pitch test every hour during the 48-hr sleep deprivation. Each one consists with two 10 minutes sessions with a 2-min break in between. During each test, subjects wear the wireless sensors on forehead and superficial temporal artery to monitor PPG. In correlating the results with physiological parameters, we calculate the average accuracy in a 5 minutes window, to compare with the results from HRV power spectrum density and other physiological parameters.

B. Sensor Design

Fig. 2 shows the block diagram of the sensor design. The purchased commercial PPG sensor DCM02 from AMPKorea outputs a current source. It is then converted to voltage through a trans-impedance amplifier. An active band pass filter from 0.53Hz to 7.9Hz then knocks out DC offset and higher frequency noises. The operational amplifier used in this stage is biased to have an offset voltage in order to digitize the signal. A notch filter at 60 hertz is implemented in the last stage to further reduce interferences from indoor lightings.

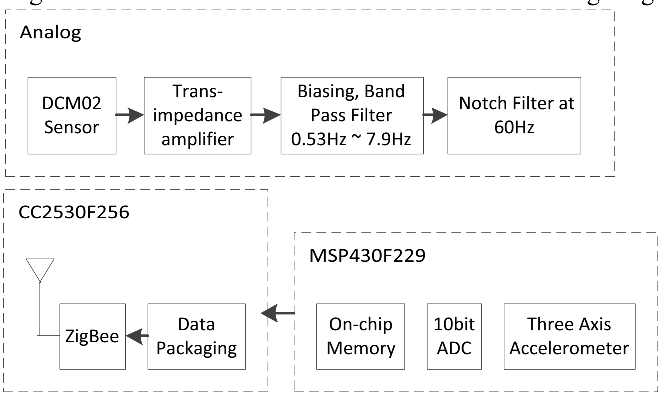

Fig. 2 Block Diagram of Wireless PPG Sensor Design

Two Zigbee CC2530ZNP target boards from Taxes Instrument are used at both the receiving end and the transmitting end. The coordinator acts as the receiving end and would be plugged into a USB port to collect data. The end device acts as the transmitting end and it sends data to the coordinator. Each target board contains two microcontrollers: MSP430F229 on one side and CC2530F256 (Zigbee networking processor) on the other side. PPG signal is digitized using an on-chip, 10-bit ADC by MSP430. XYZ accelerations are also measured by an on-board accelerometer and stored in MSP430 simultaneously. An external serial RAM will be incorporated to increase data buffering abilities.

When the network is powered up and communicating, the end device would continuously send data to the coordinator at 88Hz (100%CPU load) including PPG and accelerations. Current power consumption of our Zigbee module is 24mA. In order to reduce power consumptions, future improvements will be made by sending data in bulk and timer based sampling. Multi-channel communication will also be supported.

C. Signal Processing and Software Implementation

As the low power sensor design compromises quantization levels and sampling rates, a dynamic peak detection algorithm has been designed to solve the threshold setting problems. After the initial peaks have been detected, a dynamic interval for detecting the next peak was determined by the previous p-to-p interval with error prevention conditions. As shown in the block diagram in fig 3, beat to beat interval found after the peak detection was not periodic. Instantaneous heat rate was calculated by setting the values in the entire interval as the calculated heart rate, and down sampled into 4Hz. After low pass Butterworth filtering to reject high frequency noises, the heart rate variability power spectrum density was then calculated by Welch's method. The ratio of HRV HF area from 0.15 to 0.4Hz and LF area from 0.04 to 0.15Hz was then calculated to determine PSNA. This ratio was processed in a window of 5 minutes, and compared to the N-back M-pitch performance.

Additional drowsiness-correlation algorithms are being developed by methods such as extracting respiration patterns. These algorithms are then being implemented into real time software running on Intel Tunnel Creek Atom board provided by Intel Cornell Cup Embedded System Design Competition. User interface of this drowsiness control center are also being designed using GTK+ Graphic User Interfaces (GUI) designing tool kit, based on the size of a purchased 5-inch capacitive touch screen.

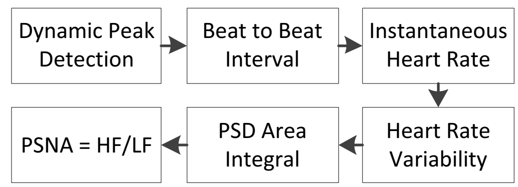

Fig. 3 Block Diagram for HRV Processing from PPG Signals

III. Current Results

The sensor design described in part b has been fabricated on to PCB. As a glitch has been found, an updated version with an external SRAM and on board accelerometer is under way. Fig. 4 shows the output signal measured at superficial temporal artery (on scalp close to ear) from the current version. The sensor could thus be implemented with a pair of glasses. Peak detection algorithms on signals from the designed sensor had an accuracy of 100%.

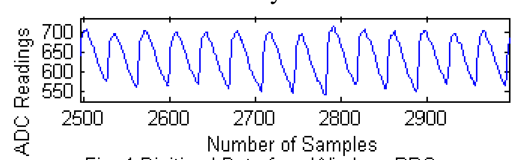

Fig. 4 Digitized Data from Wireless PPG sensor

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