Demonstration Abstract: BioWatch – A Wrist Watch based Physiological Signal Acquisition System

Simi Susan Thomas*, Viswam Nathan*, Chengzhi Zong*, Praveen Aroul†, Lijoy Philipose†,
Karthikeyan Soundarapandian†, Xiangrong Shi§, Roozbeh Jafari*
*The University of Texas at Dallas, Richardson, Texas, USA
†Texas Instruments Incorporated, Dallas, Texas, USA
§University of North Texas Health Science Center, Fort Worth, Texas, USA
*{sxt129030, viswamnathan, cxz121430, rjafari}@utdallas.edu
†{praveen.aroul, l-philipose, skarthi}@ti.com
§Xiangrong.Shi@unthsc.edu

***Abstract*— A wrist watch based system, which can measure electrocardiogram (ECG) and photoplethysmogram (PPG), is presented in this work. By using both ECG and PPG we measure pulse transit time (PTT), which is known to correlate well with the blood pressure (BP) [1]. This system, called BioWatch, can potentially facilitate continuous and ubiquitous monitoring of ECG, PPG and BP.**

Keywords— Electrocardiogram; Photoplethysmogram; Pulse transit time; Blood pressure; Dry-contact electrodes; Wrist-based physiological monitoring.

I. INTRODUCTION

Daily monitoring of vital signs outside of a hospital environment can help early diagnosis of chronic ailments as well as promote healthier lifestyle changes. A device built for this purpose should not only provide accurate and reliable readings of physiological phenomena but also be easy to use in a convenient form factor that does not unduly burden the user for daily use. To this end we present BioWatch, a wearable device in the form of a watch, that can monitor the user's heart rate, blood oxygenation and pulse transit time (PTT) non-invasively. PTT has been shown to have correlations with blood pressure (BP) [1]. Fig. 1 shows the relative convenience of a wrist watch based system. On the left is shown a person wearing BioWatch and on the right is a person wearing wet electrocardiogram (ECG) electrodes and a finger based photoplethysmogram (PPG) sensor in a traditional setup.

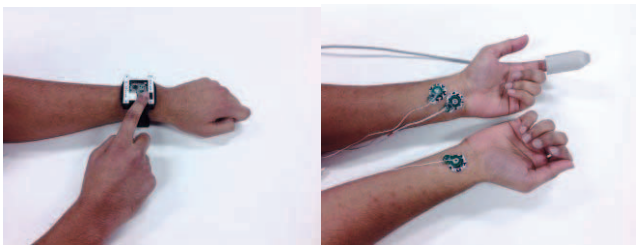

Fig. 1: Wrist watch based system compared to a system with wires

II. HARDWARE

The platform used for BioWatch is designed by our lab, the Embedded Signal Processing Lab (ESP), in partnership with Texas Instruments (TI). BioWatch comes with two analog front ends (AFE): the TI ADS1292 for acquiring ECG signal and the TI AFE4400 for reading PPG. Both of them are controlled by the TI MSP430 microcontroller. The board also contains a nine-axis (Accelerometer + Gyro + Magnetometer) MEMS inertial sensor (MPU-9150 from InvenSense, Inc), which allows to sense body movements. Dual mode Bluetooth from BlueRadios is used for data communication to a PC. The board is battery-powered and can recharge the battery through a micro-USB interface. The ADS1292 also incorporates an active driven right leg (DRL) circuit for better common mode rejection. We designed our own custom dry ECG electrodes which consist of spring loaded gold plated fingers and a flat metal surface soldered on top of it. Two of the ECG electrodes are placed at the bottom of the BioWatch and the third one is on top. The AFE4400 which collects the PPG data is connected to a flat reflective PPG sensor which uses green LEDs and a photo diode. Once worn on the wrist, the user has to touch the top ECG electrode of the BioWatch with the other hand, to measure the ECG signal. PPG signals can be collected without this additional touch.

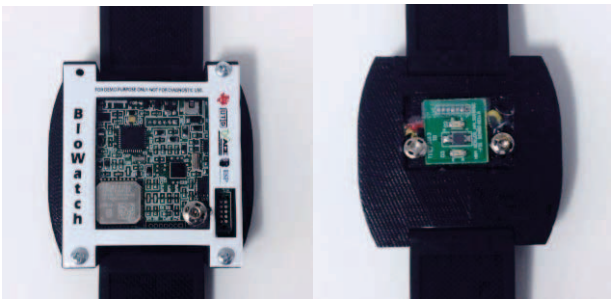

Fig. 2: BioWatch (front and back) designed in our lab

III. MEASURING PULSE TRANSIT TIME

A. Definition of Pulse Transit Time

Pulse Transit Time (PTT) is the time taken for the blood to transit from heart to a specific location for each heartbeat. It can be defined as the time between the ECG R peaks and the corresponding maximum inclination in the PPG [2], as illustrated in Fig. 3.

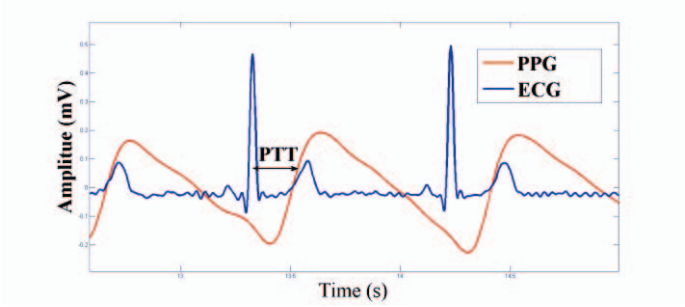

Fig. 3: PTT from ECG & PPG.

B. *Correlations between Blood Pressure and Pulse Transit Time*

According to several recent studies, PTT is highly correlated with BP [3][4]. Estimation of absolute BP needs further calibration and recently a one point calibration is proposed in [5]. As a preliminary analysis we captured both ECG and PPG simultaneously and calculated the PTT. As a reference, the continuous blood pressure was also monitored using Colin Continuous Blood Pressure Monitor, CBM-7000 during the experiment. The data was collected over 3 minutes and we introduced the Valsalva maneuver [6] during that period to introduce sharp changes in the BP. The Valsalva maneuver required the subject to exhale (expire the air) against the closed airway after the maximal inhalation (at the maximal lung volume) to induce the required change. Both systolic BP (in blue) and the calculated PTT (in red) are shown in Fig. 4. In theory the PTT should be inversely proportional to the BP, and this is what we see in Fig. 4. Numerical analysis confirmed a promising -0.7094 anti-correlation between our measured PTT and the actual BP from the reference device. In order to convert measured PTT to BP, we used the first half of the data for training a polynomial fitting function which was applied on the second half and vice versa. The average correlation of both of the calculated BP and the fitted BP is 0.8054. The average root mean square error (RMSE) value is 13.17mmHg. Allowing for an error of +/- 5mmHg between the two devices, the RMSE is 9.3mmHg and allowing an error of +/- 10mmHg, the RMSE is 6.2mmHg. Fig. 5 shows the plot of the fitted BP and measured BP.

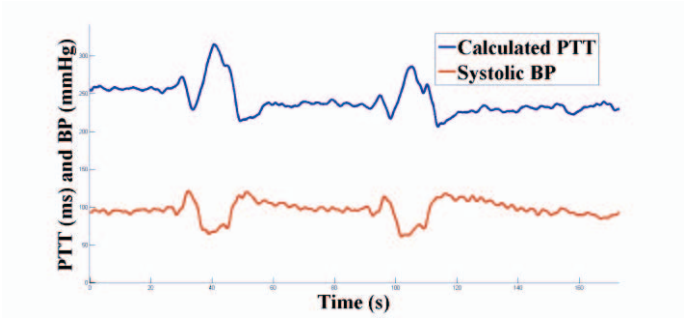

Fig. 4: Calculated PTT (top) vs. measured systolic BP (bottom)

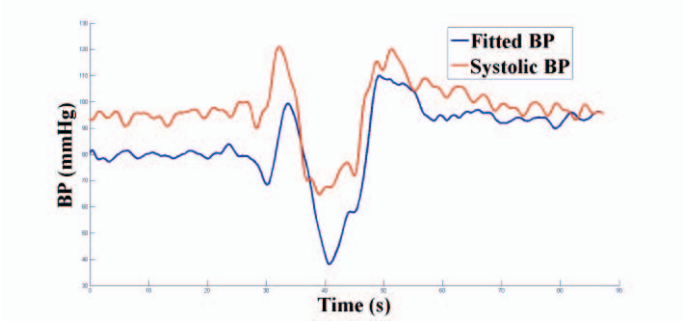

Fig. 5: Fitted BP (bottom blue) vs. measured systolic BP (top red)

IV. CONCLUSION

In this paper, we presented a wrist-based platform for physiological signal acquisition. The platform uses dry ECG electrodes and flat reflective PPG sensors. The Bluetooth provides wireless transfer of data. We are currently in the process of validating BP measurements and developing further signal processing techniques for BP calibration and motion artifact rejection. BioWatch could potentially provide a convenient, wearable solution for daily acquisition of ECG, PPG and BP data.

ACKNOWLEDGMENT

This work was supported in part by TxMRC, the National Science Foundation, under grant CNS-1150079, the Semiconductor Research Corporation, task #1836.103 through the Texas Analog Center of Excellence (TxACE), the TerraSwarm, one of six centers of STARnet, a Semiconductor Research Corporation program sponsored by MARCO and DARPA. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funding organizations.

REFERENCES

[1] A. Hennig and A. Patzak, "Continuous blood pressure measurement using pulse transit time," *Somnologie-Schlafforschung und Schlafmedizin*, pp. 1–7, 2013.

[2] P. Fung, G. Dumont, C. Ries, C. Mott, and M. Ansermino, "Continuous noninvasive blood pressure measurement by pulse transit time," in *Engineering in Medicine and Biology Society, 2004. IEMBS'04. 26th Annual International Conference of the IEEE*, vol. 1, pp. 738–741, IEEE, 2004.

[3] C. Ahlstrom and B. Fredrik Uhlin RN, "Noninvasive investigation of blood pressure changes using the pulse wave transit time: a novel approach in the monitoring of hemodialysis patients," *Journal of Artificial Organs*, vol. 8, no. 3, pp. 192–197, 2005.

[4] C. Poon and Y. Zhang, "Cuff-less and noninvasive measurements of arterial blood pressure by pulse transit time," in *Engineering in Medicine and Biology Society, 2005. IEEE-EMBS 2005. 27th Annual International Conference of the*, pp. 5877–5880, IEEE, 2006.

[5] H. Gesche, D. Grosskurth, G. Küchler, and A. Patzak, "Continuous blood pressure measurement by using the pulse transit time: comparison to a cuff-based method," *European journal of applied physiology*, vol. 112, no. 1, pp. 309–315, 2012.

[6] R. Gorlin, J. H. Knowles, and C. F. Storey, "The valsalva maneuver as a test of cardiac function: pathologic physiology and clinical significance," *The American journal of medicine*, vol. 22, no. 2, pp. 197–212, 1957.