Research of Real Time and Wearable Blood Pressure Monitoring System

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Abstract. In this paper, a wearable medical device for blood pressure monitoring is presented. Its basis is a validated and certified existent medical device. This device was evolved in order to allow new physiological signal monitoring and real time assessment of blood pressure levels by adding a photoplethismography (PPG) probe and the incorporation of new algorithms in an online interface. The device presents accuracies of 94.6% for systolic blood pressure and 92.3% for systolic blood pressure when compared with reference values obtained from a commercial electronic sphygmomanometer.

1. Introduction

Wearable technology has seen substantial advances in recent years, mainly triggered by the need for non-invasive, non-obtrusive ways to monitor physiological signals over long periods of time. Monitoring and recording of vital signs is an important part of medical equipment market that has been moving from hospitals to the patient's home. In this domain, intelligent wearable garments are emerging as a promising technology [1]. These advances are partly possible due to the miniaturization of electronic devices and the development of new ways of mobile computing. Some approaches such as Sensatex's "Smart Shirt" and Vivometrics "Lifeshirt" have already been discussed and developed. Both examples integrate vital signs monitoring, a high level of mobility and comfort [2]. These systems are able to record biophysiological signals from subjects for days and weeks in a noninvasive way either for real time feedback or for offline analysis. Among the physiological parameters with clinical relevance we find blood pressure (BP) and photoplethysmography (PPG).

BP is a continuous physiological variable, with considerable changes from beat to beat and minute to minute caused by numerous external and internal influences. BP can be measured by both invasive and non-invasive methods. The invasive BP measurement method is generally used in hospitals and intensive care units via intra-arterial catheterization and provides more accurate data. Non-Invasive BP devices have become increasingly common in the last decade [3], these are less accurate but allow a higher degree of freedom and easiness of use without the need for complicated medical procedures. One of the most commonly used is the method. A combination of all the parameters referred above can be relevant in stress assessment as it is well known that specific cardiac pathologies can be associated with different stress levels. E.g.: high stress levels induce vagal tone and other autonomic nervous system activity with a tendency to cause lethal arrhythmias [4].

PPG is known to provide valuable information about the cardiovascular system such as heart rate, oxygen saturation, blood pressure, cardiac output and autonomic function .Although this electro-optic technique is extremely attractive, its susceptibility to movement artifacts, is presented as its major drawback [5].

Having a wearable device that acquires PPG signals, is able to indirectly estimate arterial blood pressure levels and depict these on the fly is of immeasurable value for continuous monitoring of subjects. The interpretation of this data will allow the correct evaluation of an users' physiological well being, thus enabling a fast response in case of emergency, and preventing any expensive treatment or in worst-case, loss of life. In this paper we present a novel wearable medical device for PPG and blood pressure real time monitoring system. This new device allows monitoring of subjects, online calculation of their arterial blood pressure recurring to an algorithm based on the arterial pulse-wave transit time derived from PPG data. Validation of the developed system was preformed and presented in order to assess the accuracy of the vital parameters extracted from this innovative system.

2. Materials and methods

2.1. Experimental Setup

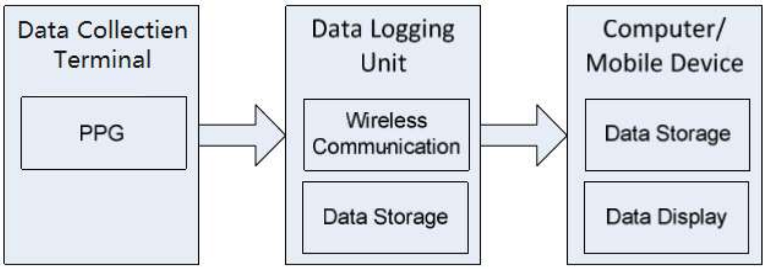

Figure 1. Block diagram of the overall system architecture.

The physiological signals acquired using wearable device are gathered through a custom build data logging unit that simultaneously allows either storing the data on a Micro SD card or its wireless transmission to a Computer or a mobile device. Data acquisition/display software allows real time displaying of biosignals and blood pressure levels as well as their storage on the computers hard drive.

An online interface was developed and estimated BP levels were validated recurring to an offline analysis in order to address the accuracy of this novel solution. This study was performed on a group of 5 subjects of both genders (4 males) between the ages of 22 to 28 (24 ±1.6). The subjects all had blood pressure levels considered normal for their age. For each group, 60 minutes of PPG data were recorded with periodic measurements (each 5 minutes) of BP using a commercial oscillometric device (OMRON M6 Comfort). In order not to compromise the quality of the PPG signal the probe was placed on the upper left arm. Calibration of the algorithm is done for each measure individually at the start of the acquisition.

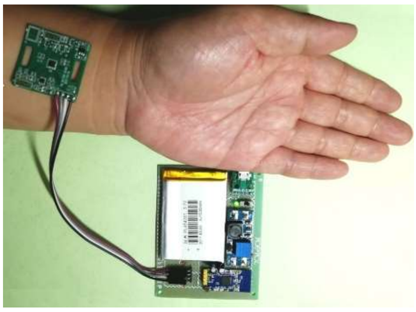

Figure 2. Data Collectien Terminal + Data Logging Unit

2.2. *Principle of operation*

The arterial pulse-wave transit time can be measured between the ECG R-wave and the finger pulse, and has been shown previously to have a correlation with blood pressure; given this an approach based on ECG and PPG data will be explored in order to obtain estimations for BP.

Blood pressure is calculated according to the method first described here. This method recurs to an algorithm that uses pulse wave velocity and wave shape characteristics from continuous PPG signals.

Blood pressure is related to the inverse of the pulse arrival time squared and the fractional change in pulse volume for each passing pulse [6]. Having synchronous acquired PPG data, the systolic (P_{sys}) and diastolic blood pressure (P_{dia}) values for the i_{th} pulse are the estimated using the two following equations:

$$P_{sys} = \left\lfloor K_s \times \left(C_{dx}\right)_i^2 \right\rfloor + K_{sys\_cal} \tag{1}$$

$$P_{dia} = \left\lfloor K_d \times \left(C_{dx}\right)_i^2 \right\rfloor + \left[K_{IHR} \times IHR_i\right] + K_{dia\_cal} \tag{2}$$

IHRi is the instantaneous heart rate for the ith pulse, Ks, and Kd are the fixed constants; Ksys_cal and Kdia_cal are the systolic and diastolic calibration constants, KIHR is the constant related to the IHR. These equations are known to be the most accurate for calculation of systolic and diastolic blood pressure. The introduction of the IHR factor becomes important since the BP of an individual for a particular heart beat is related to the duration of decay and is inversely proportional to that pulse duration, thus Diastolic BP depends in a direct manner of the IHR[7] .

2.3. *Signal Processing*

Regarding PPG slope detection, a simple but effective algorithm was developed. The algorithm first applies a moving average to smooth PPG signal, then squares it and detects maximum PPG points analyzing sample by sample if the values to its left and right are lower by a fixed threshold. With this procedure max points are found. For 50% slope calculations, the algorithm then searches back from each max(i) for the first point that corresponds to a change in the first derivative signal: min(i). 50% slope exact time is then calculated by searching the sample in which PPG = (max(i)-min(i))/2 (Fig.3) .

In order to correctly calculate BP levels, constants Ks, Kd, KIHR, Ksys_cal, and Kdia_cal need to be determined. These constants are obtained by using 3 measurements of Systolic and Diastolic BP obtained through an oscillometric device. The measured values will substitute the terms Psys and Pdia in the equations as well as means of 30 computed values for IHR obtained. These values make possible estimate the referred constants in an empirically manner.

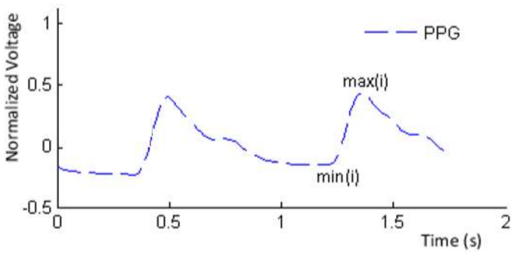

Figure 3. PPG signals.

2.4. *Online interface*

The software interface created for BP estimation (Figure 4) depicts the PPG waves, as well as the blood pressure values, estimated in real time, after calibration.

The interface was designed in a minimalistic manner in order to be graphically appellative and effective, allowing a simple and easy access to all the information and options. It allows connection management calibration setting and resetting and depicts PPG signals in real time as well as BP estimations both numerically and graphically through a plot designed for that purpose. All the gathered and calculated data can be recorded to text files thus allowing future analysis.

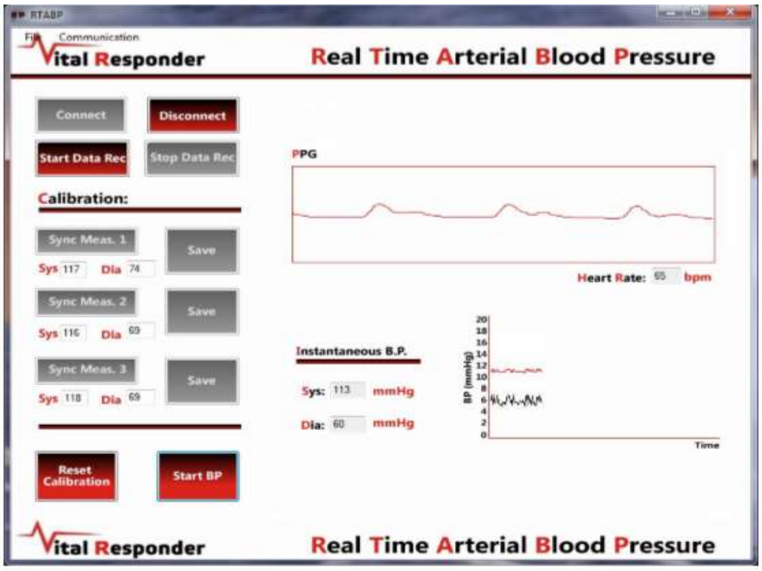

Figure 4. Systems Interface.

3. Results

The data gathered using the developed software was recorded to text files and validated in an offline manner recurring to the periodic measurements (each 5 minutes) made with the oscillometric device. The first three measurements were used for calibration while the others were used for validation. For a 1000 beat analysis (signals obtained with the developed device) by a health professional, sensibility and specificity of the implemented PPG slope calculation algorithm, were of 100% and 98%.

Table 1. Constant values and mean IHR values for all the individuals.

Numble	Mean(IHR)	K_s	K_d	K_{IHR}	$K_{sys\text{-}cal}$	$K_{dia\text{-}cal}$
1	68	-8.52	-4.13	-0.17	208.1	124.2
2	75	3.69	42.9	0.52	389.1	229.2
3	66	213	654	-3.86	68.6	-131
4	77	107.3	19.15	0.43	-881	-145
5	57	-23.9	3.72	-1.69	336.2	124.8

The calculated constant values and mean values of IHR for each individual are presented in Table 1. These personalized constants, obtained through the calibration procedure, were used to estimate each individual subject BP using the method previously described. In Fig.5 the values obtained using the oscillometric device is compared to the ones estimated by the software (for one of the 5 subjects).

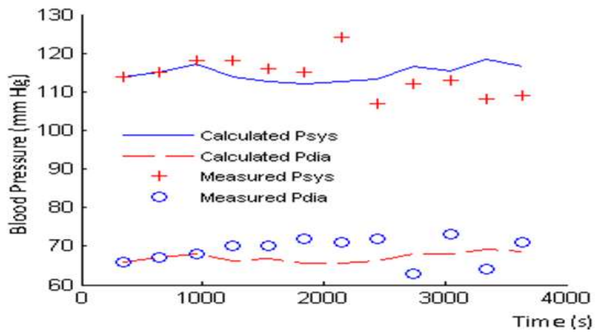

Figure 5. Measured and calculated values for systolic and diastolic blood pressures for one of the 5 subjects.

In Table 2, relative deviations and monotony analysis of the estimated blood pressure values for all the subjects. Measured values used in the constant estimation were discarded from the analysis and only estimated BP was considered for this analysis.

Table 2. Constant values and mean CDX and IHR values for all the individuals

Numble	Mean Sys. Deviation (%)	Mean Dia. Deviation (%)	Diastolic Monotonicity Agreement(%)	Systolic Monotonicity Agreement(%)
1	3.9	5.1	56	56
2	1.8	9.5	33	56
3	3.27	9.6	77	67
4	12.3	7.9	56	56
5	5.7	6.5	67	44

4. Conclusion

From the obtained results we can conclude that this method provides good estimations for BP levels needing only a prior calibration before the start of the session. Mean error in BP estimation for the tested subjects are of 5.4% for Systolic and 7.7% for the Diastolic, which can be considered accurate for this type of application. In what monotony concerns we obtain mean agreement values of 58% for diastolic and 55.8% for systolic relatively. The PPG probe were considered comfortable by all the subjects and that can be considered a good indicator for future tests that aim for prolonged monitoring periods.

Acknowledgments

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References

[1] M. H. S. Vogel, D. Starke, and S. Leonhardt, "A system for assessing motion artifacts in the signal of a micro-optic in-ear vital signs sensor," Proc. 30th Annu. Int. Conf. IEEE Engineering in Medicine and Biology Society, pp. 510-513, 2008.
[2] P. Pandian, et al., "Smart Vest: Wearable multi-parameter remote physiological monitoring system," Medical engineering & physics, vol. 30, pp. 466-477, 2008.
[3] J. A. et al, "Photoplethysmography and its application in clinical physiological measurement," Physiol Meas, vol. 28, pp. R1-39, 2007.
[4] S. M. Ming-Zher Poh, IEEE, Nicholas C. Swenson, and Rosalind W. Picard, Fellow, IEEE, "Motion Tolerant Magnetic Earring Sensor and Wireless Earpiece for Wearable

Photoplethysmography," IEEE Transactions on Information Technology in Biomedicine (TITB-00242-2009.R1).

[5] D'Angelo L.T., Tarita E., Zywietz T.K., Lüth T.C. (2010) : A System for Intelligent Home Care ECG Upload and Priorisation, in 32nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Medline, U.S. National Library of Medicine, pp. 2188-2191.

[6] Boqiang Liu, Yanyan Zhang, Zhongguo Liu, “Wearable monitoring system with multiple physiological parameters” in Medical Devices and Biosensors, 2008. ISSSMDBS 2008. 5th International Summer School and Symposium on, 2008 June 1-3:268-271

[7] D'Angelo L.T., Parlow J., Spiessl W., Hoch S., Lüth T.C. (2010) : A System for Unobtrusive In Car Vital Parameter Acquisition and Processing, in Pervasive Computing Technologies for Healthcare, 2010. PervasiveHealth 2010. Fourth International Conference on, pp. 1-7.