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Statistical validation of magnetic blood pulse as a viable alternative to electrocardiogram for heart rate measurements

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Abstract. Heart rate (HR) is an important human physiological marker commonly used for the understanding of the individual physical health. This paper adopts the magnetic method of non-invasive acquisition of blood pulse using the disturbance created by blood flowing through a localized magnetic field (MMSB). Using concurrent signal acquisition on human subjects for MMSB and a gold standard instrumentation, Electrocardiogram (ECG), 40 resting HR measurements were collected from 20 healthy subjects (aged 18-22). Three statistical tests were applied to validate the HR obtained from MMSB with respect to the ECG. The Pearson Correlation and Coefficient of Determination shows that the HR measured from both methods are positively correlated (R=0.99) with perfectly linear relationship (< 1% scores in the data due to error). The Paired Student's t-test shows no significant difference for the HR measured from the two methods, suggesting the difference between the two sets of measurements is not meaningful statistically. The Bland and Altman Test shows $\pm$ 2SD of 0.48bpm, which is not significant for measurement of resting HR, suggesting MMSB is a suitable alternative for ECG system for HR measurements. These statistical tests support the use of MMSB as a viable alternative to ECG for measuring resting HR for healthy individuals.

Keywords: Magnetic blood pulse, Electrocardiogram, Heart Rate, Bland and Altman Test

1. Introduction

With the advancement of bioelectronics, portable health monitoring devices are able to provide continuous monitoring of an individual's health. One such parameter is the heart rate (HR), whichis a used bythe hospitals and elderly care centres to monitor the health conditions of their patients.

Current methods of heart or pulse rate acquisition can be classified into electrical [1], optical [2], microwave [3], acoustic [4], mechanical [5] or magnetic [6-7] means. Amongst these methods, the electrocardiogram (ECG),which records the electrical conductivity of the heart, serves as the gold standard for the non-invasive HR measurement [8] and diagnosis of arrhythmias and conduction disturbances.

The recent work on magnetic blood pulse sensing [7] measures the magnetic disturbance created by blood (i.e. Modulated magnetic signature of blood - MMSB) in a constant magnetic flux. As such, MMSB supports the acquisition of blood pulse without the need for a good electrical or optical contact.

In this paper, the HR obtained using MMSB will be statistically validated with respect to ECG, a gold standard instrumentation. In clinical measurement, comparison of a new measurement technique (MMSB) with an established one (ECG) is often needed to see whether they agree sufficiently for the new (MMSB) to replace or supplement the old one (ECG).

Three statistical tools used to validate such comparisons will be presented and discussed. These statistical tools are Pearson Correlation and Coefficient of Determination [9], Paired Student's t-test[10] and Bland and Altman Test [11-12].The results obtained from these statistical tests shall aim to support the use of MMSB as a viable alternative for measuring HR in resting condition for healthy individuals.

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2. Trial setup with data acquisition

The trial setup for the concurrent HR acquisition using ECG and MMSB is shown in Fig. 1. Data is acquired at a sampling rate of 1 KHz with resolution of 24 bits over ±250mV. Using this setup, a trial on 20 healthy subjects(aged 18-22) was conducted with 40 resting HR measurements collected.

HR is manually extracted from the time corresponding to two consecutive R peaks of ECG waveforms as illustrated in Fig. 2(a). Using the MMSB waveforms, HR is manually extracted by locating the corresponding peaks (w.r.t. ECG R peaks) of two consecutive MMSB waveforms as shown in Fig. 2(b). The HR obtained from ECG and MMSB pulses (as illustrated in Fig. 2) are tabulated as shown in Table 1.

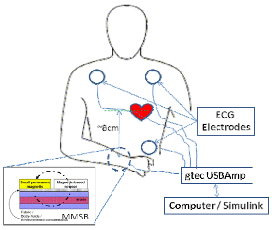

Fig. 1: Concurrent HR acquisition using ECG and MMSB

(a) Instantaneous HR from ECG signal (b) Instantaneous HR from MMSB signal

Fig. 2: Extraction of instantaneous HR from ECG and MMSB waveforms

Table 1: Heart Rate data collected for 40 measurements

Measurement	Gold Standard (ECG)	MMSB Sensor	% w.r.t. ECG	Measurement	Gold Standard (ECG)	MMSB Sensor	% w.r.t. ECG
1	78.174	78.271	-0.12	21	80.170	80.674	-0.63
2	77.857	77.994	-0.18	22	88.417	88.113	0.34
3	78.174	78.694	-0.67	23	87.264	87.363	-0.11
4	75.084	74.912	0.23	24	92.918	92.838	0.09
5	78.976	79.033	-0.07	25	84.998	84.783	0.25
6	78.094	78.311	-0.28	26	100.553	100.160	0.39
7	89.238	89.706	-0.52	27	75.047	74.966	0.11
8	95.557	95.654	-0.10	28	80.911	80.911	0.00
9	70.475	70.734	-0.37	29	80.488	80.488	0.00
10	76.540	76.747	-0.27	30	71.390	71.390	0.00
11	58.945	58.712	0.40	31	91.888	92.215	-0.36
12	56.148	56.659	-0.91	32	97.680	97.583	0.10
13	83.160	82.810	0.42	33	57.107	57.128	-0.04
14	93.071	92.973	0.11	34	57.982	58.055	-0.13
15	77.426	77.251	0.23	35	99.738	100.063	-0.33
16	73.121	73.253	-0.18	36	93.809	94.038	-0.24
17	80.003	79.906	0.12	37	94.268	94.096	0.18
18	80.802	80.619	0.23	38	88.367	88.774	-0.46
19	80.548	80.548	0.00	39	65.746	65.793	-0.07
20	89.759	89.445	0.35	40	69.851	69.930	-0.11

3. Statistical validation for assessing agreement between two methods of clinical measurement

3.1. Person Correlation and Coefficient of Determination

Pearson correlation coefficient (direction of relationship) and the Coefficient of Determination tests (strength of relationship) is used in the validation of the measurement outputs of an alternative instrument (MMSB) against a “gold standard” (ECG)to ascertain the nature of relationship between two sets of scores.

HR was concurrently measured using MMSB and an ECG system (g.USBamp,g.tec Medical Engineering GMBH, Austria).The instantaneous HR for MMSB and ECG measurements are plotted as shown in Fig. 3. To understand the direction of relationship, a linear regression is approximated based on the HR results from the two measurements as illustrated in Fig. 3.

In addition, from the results on correlation analysis of the HR measured (Table 2) using both devices, it can be concluded that the HR data is positively correlated (R = 0.9998).The corresponding coefficient of determination (R^2) is 0.9996 (Fig. 3 and Table 2). These results (i.e. r and r^2) indicate that the relationship between the HR measured by both the MMSB and ECG methods is almost perfectly linear, and that < 1% of scores in the data is due to error. As such, the reproducibility of the HR measurement between the 2 devices is almost 1:1.Such reproducibility assessment is found to be repeatable for any instantaneous HR extractedfrom the measured waveforms, demonstrating the reliability of this study.

Regression Statistics	
Multiple R	0.9998
R Square	0.9996
Standard Error (SD)	0.2440
2xSD	0.4880

Table 2: Correlation test between Gold Reference and MMSB Sensor

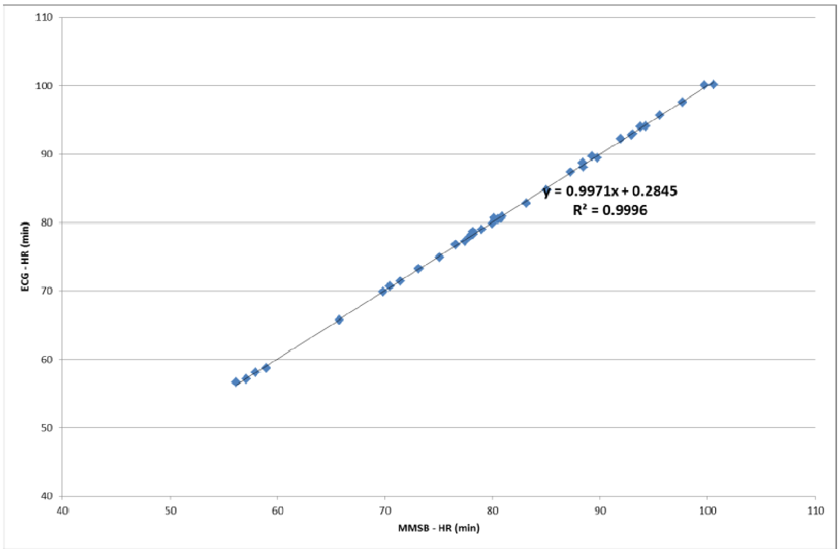

Fig. 3: Plot of Correlation of HR obtained from MMSB and ECG waveforms

3.2. Paired Student’s t-test

The paired t-test is used in scientific validation on the measurement outputs of an alternative instrument (MMSB) against a “gold standard” (ECG)to establish the statistical significance of the differences in the means between the two sets of scores ($P < 0.05$).

Based on the HR obtained in Table 1, the mean and standard deviation is obtained and plotted as shown in Fig. 4. Using the Paired Student t-test, there is no significant difference ($P = 0.24$) between the means of the heart rate measured by both devices (Fig.4). This result suggests that the difference between the two sets of measurement is not meaningful statistically. As such, MMSB can be used as a viable alternative to ECG as the differences in the measured HR have no significant difference.

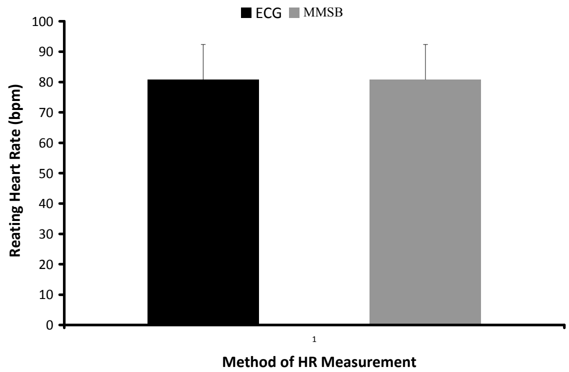

Fig. 4:Mean and standard deviation of HR measured with the ECG and MMSBsensors (P = 0.24)

3.3. Bland and Altman Test

The Bland and Altman test (a.k.a. Limits of Agreement) is used in scientific validation on the measurement outputs of an alternative instrument (MMSB) against a “gold standard” (ECG)to determine the limits of agreement for the errors between the two sets of data. This analysis is recommended [11-12] when comparing the data between a “gold standard” and an alternative biomedical instrument.

The Bland and Altman analysis is obtained and plotted as shown in Fig. 5. This analysis plots the difference (error) between the two HR measurements with respect to the means between the two scores. Most of the errors should fall between ± 2SD of the mean difference between the two HR measurement systems. Such a plot allows the assessment for systematic bias in the scores between the two systems. More importantly, the magnitude of the error at ± 2 SD is used to determine the clinical and practical significance of the measurement errors between the two systems. The magnitude of error should not be clinically or practically significant before the alternative device is accepted as a possible replacement for the gold standard measurement device.

In the current analysis, the mean and SD of the difference in HR measured between the ECG and the MMSB systems is −0.05 ± 0.24 bpm i.e. ± 0.48bpm for ± 2SD. The error data points are also evenly distributed across the range of heart rate measured, suggesting that there is no systematic error in the measurement. The ± 2SD of 0.48bpm is practically not significant for measurement of resting HR, suggesting that the MMSB is a suitable alternative for the ECG system for HR measurement. For example, a resting HR of 70 bpm measured with the ECG system, would range between 69 bpm and 71 bpm in the HR measured by the MMSB system. Such a variation (± 1 bpm) is within the normal range of variation in HR measured in healthy individuals.

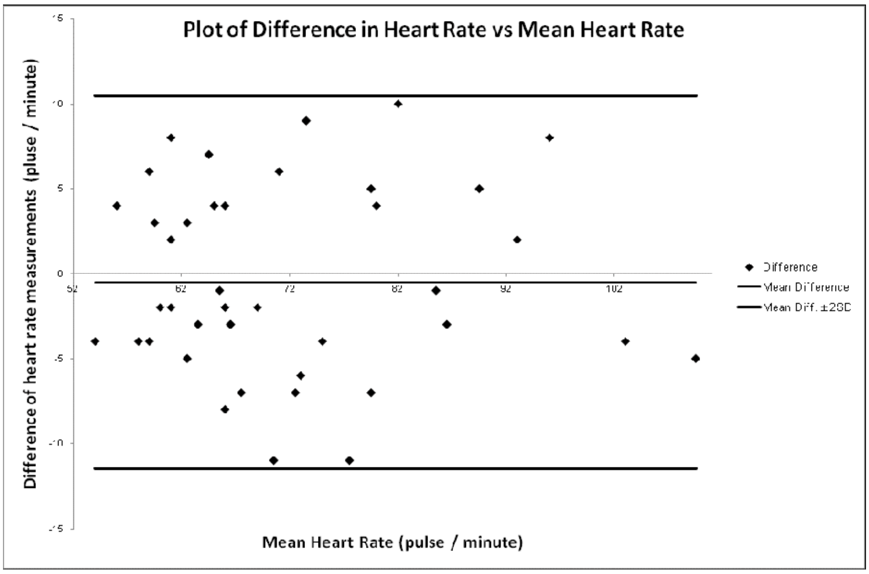

Fig. 5: Plot of Bland and Altman test on HR obtained from MMSB and ECG waveforms

4. Conclusion

From this study, the concurrent acquisition of HR using a gold standard (ECG) and MMSB on 20 subjects had been successfully completed with statistical analyses done on the measured HR. The results of the statistical analyses shows that HR measured by the MMSB is almost perfectly correlated with HR measured with the ECG.There is also very good agreement in accuracy between HR measured by the two devices. As such, these data support the use of the MMSB as a viable alternative to ECG in measuring HR of healthy individuals under resting condition.

5. Future work

With the scientific validation of HR completed for MMSB with a gold standard instrumentation, the research work will continue to focus on the similar validation of blood flow using a gold standard instrumentation.

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7. References

[1] S. Bowbrick, A. N. Borg. Edinburgh (2006) ECG complete, New York, Churchill Livingstone.

[2] S. M. Burns (2006) AACN protocols for practice: noninvasive monitoring, Jones and Bartlett Publishers.

[3] Shuhei Yamada, Mingqi Chen, Victor Lubecke (2006) Sub-uW Signal Power Doppler Radar Heart Rate Detection, Proceedings of Asia-Pacific Microwave Conference

[4] G. Amit et al, (2005) Automatic extraction of physiological features from vibro-acoustic heart signals: correlation with echo-doppler, Computers in Cardiology, Issue September 25-28, pp 299-302.

[5] J.L. Jacobs, P. Embree, M. Glei, S. Christensen, P.K. Sullivan (2004) Characterization of a Novel Heart and Respiratory Rate Sensor, Proceedings of the 26th Annual International Conference of the IEEE EMBS

[6] J.Malmivuo, R. Plonsey (1995) Bioelectromagnetism – Principles and Applications of Bioelectric and Biomagnetic Fields, New-York, Oxford University Press.

[7] Chee Teck Phua, Gaëlle Lissorgues, Bruno Mercier, "Noninvasive acquisition of Blood Pulse using magnetic disturbance technique", International Conference on BioMedical Engineering (ICBME2008)

[8] D.C. McKenzie MD, RESEARCH REPORT - MIO™ LIFESTYLE WATCH, http://www.mioglobal.com/files/file/Research%20Report%20on%20MIO%20Accuracy.pdf

[9] Kelly H. Zou, Kemal Tuncali, Stuart G. Silverman, Correlation and Simple Linear Regression, Radiology 2003; 227:617–628

[10] Elise Whitley, Jonathan Ball, Statistics review 6: Nonparametric methods, Critical Care 2002, 6:509-513 (DOI 10.1186/cc1820)

[11] J. Martin Bland, Douglas G. Altman,Statistical methods for assessing agreement between two methods ofclinical measurement,International Journal of Nursing Studies, 47 (2010) pp931–936

[12] Altman, D.G., Bland, J.M., 1983. Measurement in medicine: the analysis of method comparison studies. Statistician 32, 307–317