A NEW METHOD FOR THE EVALUATION OF THE SIGNAL ACQUIRED FROM QUANTITATIVE SEISMOCARDIOGRAPH

Hardware and Software Solution for the New Field of Monitoring Heart Activity

Z. Trefny, J. Svacinka, S. Trojan, J. Slavicek, P. Smrcka, K. Hana
Faculty of Biomedical Engineering, Czech Technical University in Prague, Studnickova 7, 2028 Prague 2, Czech Republic

Keywords: Time-domain segmentation of the seismocardiogram, J-wave recognition.

Abstract: The device for quantitative seismocardiography (QSCG) detects cardiac vibrations as they affect the entire body; the measuring sensors (solid-state accelerometers) are usually placed in the plate of the chair – additional instruments applied on the proband's body are not required. The results of the QSCG analysis are usable in various clinical fields. The first and most important step in the process of detection of significant characteristics of measured QSCG curves is to detect pseudo-periods in the signal regardless of the initial pseudo-period position. Other characteristics can be acquired by a relatively simple process over the appointed pseudo-period. We have developed the experimental equipment for the QSCG measuring and analysis. We have also developed special algorithms for preprocessing, segmentation and interactive analysis of the QSCG signal. In this contribution we will introduce technical principles of the quantitative seismocardiography and then we will focus on the original method for the basic segmentation of the QSCG signal in time-domain; the method is easy, robust and is appropriate for real-time QSCG processing.

1 INTRODUCTION

Ballistocardiography (BCG): In 1936, Starr took part in a conference held by the American Society of Physiology which dealt with methods of determining cardiac output. Thus began the era of high-frequency ballistocardiography, which lasted approximately 15 years. Other types of instruments were developed, on which the displacement, velocity or acceleration of a body lying on a bed was measured. Later studies showed that there are difficulties when comparing records registered on different apparatuses. This is mainly caused by two factors: (a) the instrument's natural frequency, (b) the instrument's damping.

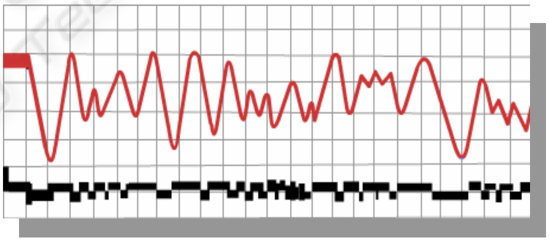

Figure. 1: Records registered using the old BCG instrument with a frequency of 2Hz and critical damping. The lower curve depicts the effect of force applied, which is still of the same intensity but differs in the duration of its effect. The upper curve is a record, from which one cannot determine either size or duration of the acting force.

Quantitative ballistocardiography (QBCG): Following the critical evaluation of all these facts, we began in 1952 our own experiments related to the construction of an apparatus which would lack the aforementioned shortcomings. Thus, over the years, we constructed an apparatus whose advantages lie not only in the simplicity of its design, but also in its important functional qualities. To achieve a minimal distortion caused by the transmission from the origin

Trefny Z., Svacinka J., Trojan S., Slavicek J., Smrcka P. and Hana K. (2006).
A NEW METHOD FOR THE EVALUATION OF THE SIGNAL ACQUIRED FROM QUANTITATIVE SEISMOCARDIOGRAPH - Hardware and Software Solution for the New Field of Monitoring Heart Activity.
In *Proceedings of the Third International Conference on Informatics in Control, Automation and Robotics*, pages 61-66
DOI: 10.5220/0001220000610066

of the force to the recorder it is necessary that the natural frequencies of the transmission systems lie as far as possible from the mentioned frequency range.

The cardiovascular activity is manifested by a force acting on the human body which represents a mechanical vibratory system transmitting the force to the balistocardiographic apparatus.

The basic part of our portable quantitative balistocardiograph is a very rigid piezoelectric force transducer resting on a rigid steel chair. The examined person sits (Figure 2) on the light seat placed on the transducer and the force caused by the cardiovascular activity is measured in this way. The output of the piezoelectric pick-up is fed into an operational amplifier.

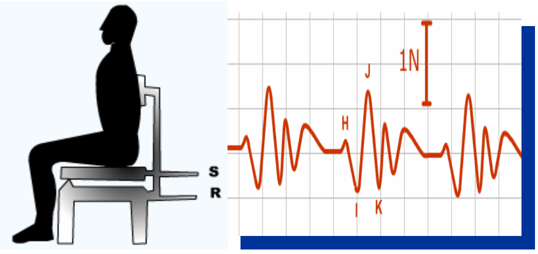

Figure 2: Position of the examined person during the QBCG session.

The advantage of the piezoelectric transducer is in very low compliance together with a very high natural frequency of the apparatus. Another advantage of the rigid pick-up is the fact that it can be preloaded with a substantial static force – the weight of the examined person, and it is still possible to measure the alternating forces of the magnitude of g+ (gram as weight). The simple push button is used to dispose of the static charge caused by the weight of the person. The measured force is registered (REG).

Dynamic calibration of the QBCG apparatus was carried out by an electrodynamic exciter (EXC) acting via a calibrated dynamometer (D), also of a piezoelectric type, on a pick-up (Q) of the QBCG (see Figure 3).

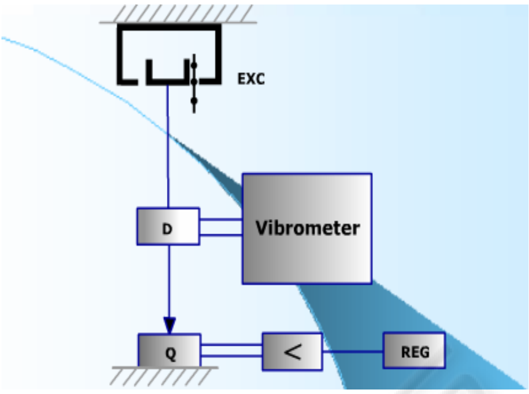

Figure 3: A set-up a dynamic calibration of the quantitative balistocardiographic apparatus.

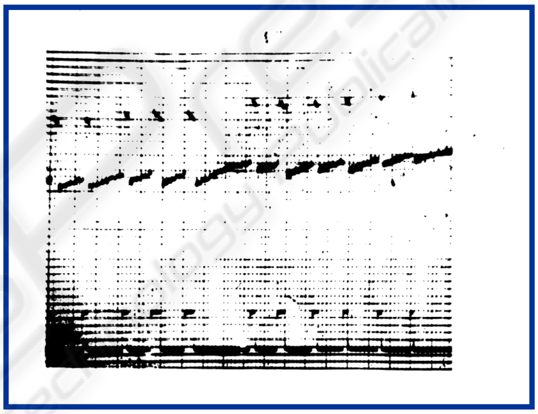

Figure 4: Records registered using the QBCG instrument. The lower curve depicts the effect of force applied. The upper curve is a record, from which we can determine size and duration of the acting force. Compare with BCG record on Figure 1.

Quantitative seismocardiography: (QSCG: This method enables the recording of force applied without phase or time deformation. Thus, heart rate may be monitored and analysed using the method of heart rate variability (statistical and autocorrelation analysis, spectral analysis, total effect of regulation, vegetative homeostasis, activity of subcortical centre, activity of the vasomotor centre and stress index). The method of QSCG was designated by the laboratory employees as an absolutely non-invasive, and the persons examined did not have any electrodes attached to the body surface and were not connected by cables to the registering instrument. This new field of monitoring heart activity, whereby we determine both amplitude-force and time-frequency relationships, is termed quantitative seismocardiography. Thus, one may determine the force-response of the cardiovascular system to changes in external stimuli, as well as the autonomous nervous system regulation of the circulation and the activity of the sympathetic and parasympathetic systems.

2 METHODS OF QSCG MEASUREMENT AND ANALYSIS

2.1 Experimental Equipment

In terms of practical use, a portable telemetric system for the QSCG measuring has been developed. This system allows data to be acquired and assessed using quantitative seismocardiography (QSCG) and triaxial accelerometric measurements on the thorax of a patient. It is composed of the three HW modules that are telemetrically interconnected with the option of interconnecting through a metallic line. These are the seismocardiographic, the accelerometric modules and a module for the data transfer interconnected with the PC through the USB interface. Block scheme of the whole system is on figure 7.

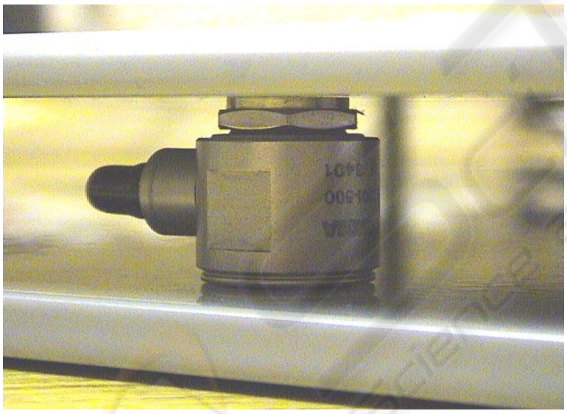

Figure 5: Main sensor of she QSCG measuring equipment - detail of the solid-state accelerometer between measuring metal plates.

Sensing mechanical body reactions, which are induced in response to the cardiovascular dynamics, is provided by the seismocardiographic module, which reads the strain coming from the mechanical deformation of the piezo-electric plate. This sensing module is mounted on a special device, which works by transmitting the mechanical body reactions onto the piezo-electric recorder. The accelerometric module is applied for measuring thorax acceleration as induced by movements from the heart activity, this measurement is made on the three basic orthogonal axes. The core of the module is the sensing device composed of the two biaxial monolithic semiconductor accelerometers. The data transfer module is designed to transmit the data from the radio-module into the PC through the USB interface.

Figure 6: Measuring plates of the proposed QSCG device.

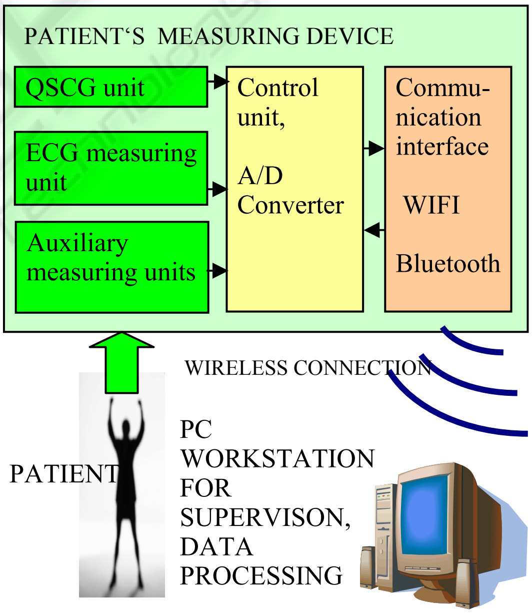

Figure 7: Block scheme of the experimental QSCG device.

2.2 Algorithm for the Time-Domain Segmentation of the QSCG

We have developed algorithms for preprocessing, segmentation and interactive analysis of the QSCG signal. In this contribution we will focuse on the original method for basic segmentation of the QSCG signal in time-domain; this first step is crucial for the successfulness of the whole diagnostic process. Our method is relatively simple and was developed for the detection of QSCG pseudo-periods in real time. The method is derived from a well-known and robust algorithm for QRS complex detection in traditional electrocardiograms (ECG), originally developed by Hamilton et al. The algorithm was based on the first derivative of the input signal and many thresholds and parameters are automatically adapted to individual changes in the input signal using sophisticated empirical rules. The results (position of the dominant – so-called R - wave) are obtained with some detection delay (above 200 ms). For details on the algorithm, see [Hamilton].

For our purposes it is important that the initial values of many parameters are adjustable and by modification of these values the original method was slightly adapted to QSCG's different curve morphology. Namely the following parameters were changed: (1) length of the first derivative from the original 10 ms to 80 ms, (2) length of the high-pass pre-filter from 125 ms to 350 ms, (3) length of moving window integration from 80 ms to 200 ms. Optimal values were selected experimentally in order to achieve the best detection results.

Additionally, we developed a special backward searching process for the precise detection of the position of the I-wave and J-wave in each QSCG pseudo-period.

The function of the whole algorithm is as follows: output of the traditional ECG QRS detector gives the rough position of the systolic complex inside the QSCG - candidate X. Then the specific morphology of the QSCG curve is utilized to backward search the position of the J-wave – we expect the first big negative peak in MTI samples (about 100 ms). If the detection is successful, we assign the position of the peak as the I-wave; see Figure 8.

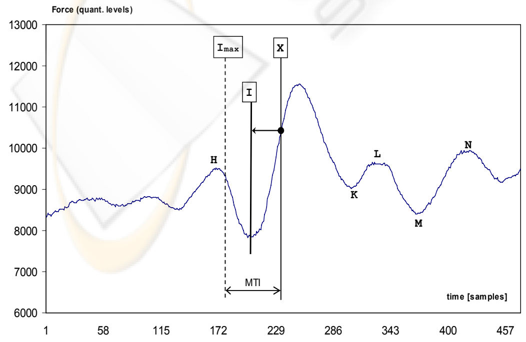

Figure 8: Backward local I-peak searching in the QSCG cycle.

Finally we search forward for the position of the J-wave, which we expect to be the first big positive peak in maximally MTJ samples (about 160 ms), see Figure 9.

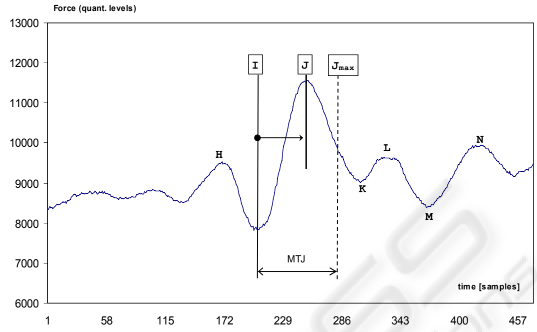

Figure 9: Forward local J-peak searching in the QSCG cycle.

For the peak-detection we used a very simple method based on the first difference (length 15 ms): when the transition from negative to positive value of the difference occurs, then the sequence is marked as a negative peak; the transition from a positive to negative difference means a positive peak. If searching for the J-wave or the I-wave fails, candidate "X" is rejected and the algorithm continues without detection of the QSCG pseudo-period.

The rejection of "candidate X" is very important step and it increases robustness of the whole detection procedure against the artifacts – see demonstration on the Figure 10.

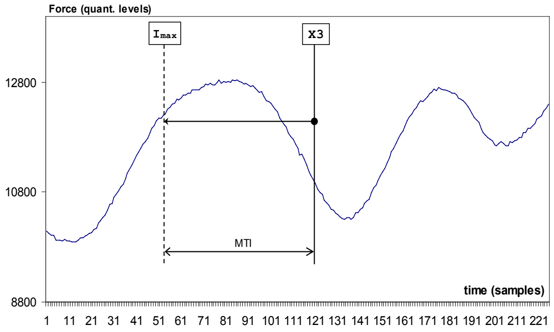

Figure 10: Rejection of the false beat detection. We search backward from "candidate X3" for the first big negative peak. The I-wave must be recognized in MTI samples (about 100 ms), so in this case the detection was not successful.

The false detection of the dominant "candidate X", which is not a true QSCG cycle, was corrected by the proposed simple backward searching algorithm, because the morphology in the nearest neighborhood of the point X3 does not match the detection rules – backward searching for the I-wave in MTI samples was not successful, the false positive detection of the systolic complex was correctly rejected.

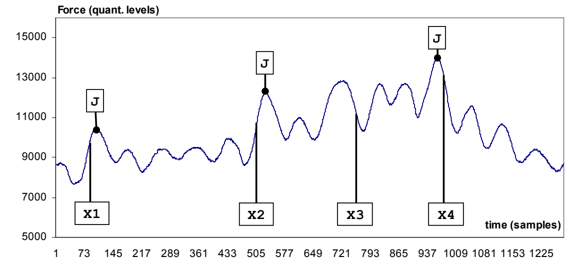

Figure 11: Result of the whole detection: false candidate X3 was correctly rejected.

The whole software system contains additional modules for statistical and autocorrelation analysis, spectral analysis, assessment of the aggregated effect of the regulation of autonomous functions of vegetative homeostasis, activity of the vasomotor centre, activities of the sympathetic cardiovascular centre and the stress index (SI). Our experimental software allows also automatic extraction of classical QSCG hemodynamical parameters, especially so called systolic force (SF). The current version of the system is designed for OS Windows XP and has user-friendly interface. Block scheme of the system is on figure 12:

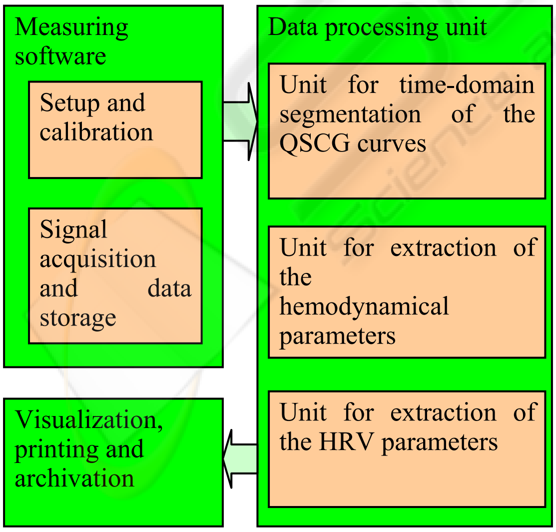

Figure 12: Block scheme of the software system. Presented algorithm is in the box „Unit for time-domain segmentation of the QSCG curves“.

3 CONCLUSION

For high-quality measurements we can obtain good-looking signals for which both methods exhibit excellent results. For disruptive and spurious signals there is still a good chance of obtaining authentic information because we first detect the impairments and remove the particular interval of the signal. It is true that in using this method we also remove certain useful information but simultaneously ensure processing of the remaining signal. We emphasize that we need not process all consecutive pseudo-periods in the signal but only a sufficient amount of pseudo-periods.

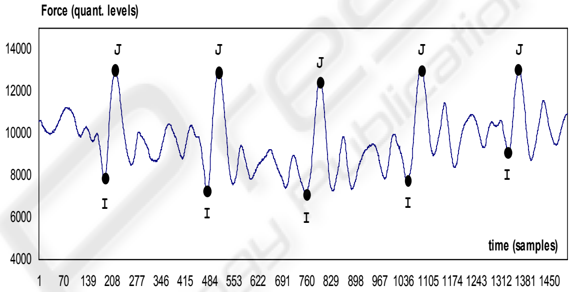

Figure 13: Typical QSCG signal with correctly placed reference points.

For good-looking and typical signals, the methods behave very well, achieving nearly complete success (see Figure 13). The success decreases with deterioration of the signal. On the other way, in such signals it is often difficult even for the human expert to recognize correct pseudo-period time points (see Figure 14).

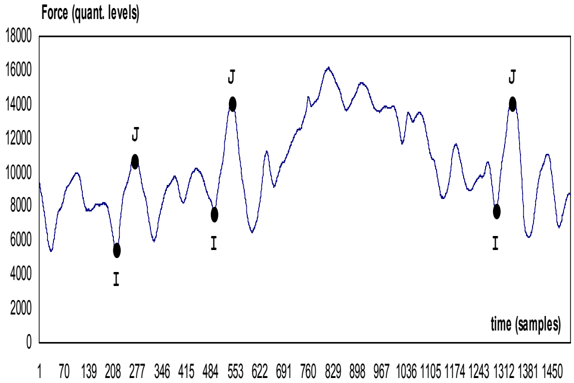

Figure 14: QSCG signal with the motion artifact; it is difficult to recognize correct positions of some reference points.

The QSCG signal offers specific information about functional changes of the cardiovascular system regulation which preceded the structural changes coming later. The equipment is ready for use, algorithms for automatic analysis of the QSCG signal are prepared.

Quantitative seismocardiography probably offers a more complex view of both inotropic and chronotropic heart function. It will be suitable for: examining operators exposed to stress; for assessing the effect of work, fatigue, mental stress; for monitoring persons as part of disease prevention; for determining a person’s ability to carry out their duties both on the ground and in the air.

ACKNOWLEDGEMENTS

This work has been supported by the Ministry of Education of the Czech Republic under project No. MSM6840770012 and by the project UREKA E!3031.

REFERENCES

Jerosch-Herold, M. et al., 1999. The seismocardiogram as magnetic-field-compatible alternative to the electrocardiogram for cardiac stress monitoring, In International Journal of Cardiac Imaging, 15(6), pp. 523-31

Trefny, Z. et al., 1996: Some physical aspects in cardiovascular dynamics, In J. Cardiovasc. Diagnosis and Procedures, 13(2), pp. 141 - 145

Hamilton, P. – Tompkins, W.J. (1987): Quantitative investigation of QRS detection rules using the MIT/BIH arrhythmia database, In IEEE Trans. Biomed.Eng., 33, pp. 1158-65

Trefny Z. – David E. - Bayevsky R.M.: Achievements in Space Medicine into Healt Care Practice and Industry, Development of Space Cardiology metods in the Earth's Health Service, Berlin 2001

Freisen G., Jannet T.: A comparison of the Noise Sensitivity of Nine QRS Detection Algorithms’, IEEE Trans. Biomed. Eng., 1990, 85(1)