A System for Detection of Three-Dimensional Precordial Vibrations

Mikko Paukkunen, Aalto University, Finland
Matti Linnavuo, Aalto University, Finland
Helena Haukilehto, Aalto University, & Emergency & Medical Assistance Group, Finland
Raimo Sepponen, Aalto University, Finland

ABSTRACT

Accelerometer-based seismocardiography and sternal acceleration ballistocardiography are promising approaches to the noninvasive detection of precordial vibrations. However, in order to be widely accepted as diagnostic or even prognostic tools, clinical validation and standardization of these methods are necessary. In precordial vibration studies, using all three axes instead of one in cardiac vibration analysis is anticipated to enable more accurate cardiac event detection. Simultaneously acquired electrocardiography, photoplethysmography, and respiration information are considered as promising ways to enhance seismocardiogram analysis. In this article, an easy-to-use system that combines three-dimensional seismocardiography, electrocardiography, photoplethysmography, and respiration measurements is described, and its performance is demonstrated. In the test measurements, the system demonstrated its capability to capture accurate cardiovascular data.

Keywords: Ballistocardiography (BCG), Electrocardiography, Photoplethysmography, Precordial Vibrations, Respiration, Seismocardiography

1. INTRODUCTION

Ballistocardiography (BCG) measures the vibration of the human body due to cardiac and circulatory function. The existence of BCG signals was first reported by Gordon in 1877 (Gordon, 1877). In the mid 19th century, BCG was extensively researched especially by Isaac Starr, who published some of the first scientific papers on it (Starr, Rawson, Schroeder, & Joseph, 1939). Due to its noninvasiveness, BCG measurement sensors can be imperceptibly embedded into different everyday objects. In fact, there have been reports of embedding measurement equipment of the BCG signal in different modified scales (Gonzalez-Landaeta, Casas, & Pallas-Areny, 2008; Inan, Etemadi, Wiard, Giovangrandi, & Kovacs, 2009), a chair (Junnila, Akhbardeh, Barna, Defee, & Varri, 2006), a wheelchair (Han, Kim, Cha, & Lee, 2008; Postolache, Girao, Mendes, & Postolache,
new approaches to the measurement of BCG signals have emerged and contributed to the research of BCG. Three of these are accelerometer-based seismocardiography (SCG) (Zanetti, 1990) and sternal acceleration BCG (SAB) (McKay, Gregson, McKay, & Militzer, 1999), and radar-based mechanocardiography (MCG or R-BCG) (Postolache, Madeira, Girão, & Postolache, 2010; Tavakolian, Zadeh, Chuo, Vaseghi, & Kaminska, 2008).

It has been proposed that the different approaches to BCG measurement can be further divided into precordial vibration recordings, such as SCG, and circulatory reaction recordings, such as the conventional BCG (Tavakolian, Ngai, Blaber, & Kaminska, 2011). Precordial vibration recording has also been proposed to be a feasible tool in cardiac time interval detection whereas circulatory reaction recording could be more useful in deriving cardiac output or stroke volume (Tavakolian et al., 2011). Conventional BCG and its newer variants have been combined with other noninvasive measurements such as ECG, photoplethysmography (PPG), and respiration measurements in different devices and test setups (Chuo, Tavakolian, & Kaminska, 2011; Han et al., 2008; He, Winokur, & Sodini, 2011; Junnila et al., 2006; McKay et al., 1999; Pinheiro, Postolache, & Girão, 2009; Shin, Hwang, Chang, & Park, 2011; Tavakolian, Vaseghi, & Kaminska, 2008). Combining precordial vibration recordings or circulatory reaction recordings with other bio-signals is expected to both enhance the analysis of vibrations of the heart and circulation, and help in deriving variables that are troublesome to obtain otherwise (e.g., continuous systolic blood pressure).

Due to the large number of people suffering from heart diseases or circulatory problems (Lawes, Hoorn, & Rodgers, 2008; Lopez, Mathers, Ezzati, Jamison, & Murray, 2006; Young, 2004), the need for inexpensive and effective assessment of cardiac and circulatory function is obvious. BCG has been shown to be a valuable tool when relative changes of cardiac parameters of one person are analyzed (Mandelbaum & Mandelbaum, 1953; Starr & Wood, 1961) and could be a potential solution to the need (Giovangrandi, Inan, Wiard, Etemadi, & Kovacs, 2011). BCG’s newer variants such as SCG are also considered valuable (Tavakolian et al., 2011). To be widely accepted as a diagnostic or even prognostic tool, clinical validation and standardization of BCG and its newer modifications is needed. However, recent BCG and related studies seem to focus more on data acquisition techniques rather than analyzing the phenomenon itself. This may be due to compromises made to make a technique easy-to-use (Junnila, Akhbardeh, Varri, & Koivistoinen, 2005). On the other hand, some authors have successfully presented the need for easy-to-use and compact BCG instrumentation that doesn’t reduce the clinical relevance of the system (Inan et al., 2009). Although BCG research has been conducted for over a century, many uncertainties still remain. One of the most important issues is that it is not clear how cardiac vibrations couple to the human body making the interpretation of the waveforms difficult. Some uncertainties remain also in the cardiac event detection. Zanetti compared SCG with echocardiography (ECHO), and found that the mean absolute difference from the ECHO was 7.9 ± 8.1 milliseconds for systolic SCG points and 11.8 ± 11.5 milliseconds for diastolic SCG points (Zanetti et al., 1991). Recently, some groups have made further efforts to analyze the genesis of the BCG and its modifications with the aid of modern imaging techniques (Akhbardeh et al., 2009; Tavakolian, Blaber, Ngai, & Kaminska, 2010).

Measurement series where large numbers of people are studied, possibly at multiple sites, are prone to errors. In medical studies, such as precordial vibration studies, the results can be deteriorated by errors in sensor placement and configuration of separate measuring units (Hyman, 1988). Avoiding these errors is especially important when relative changes in the acquired signals of one person are analyzed. The presented errors are related to human factors...
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