A System for Multi-Modal Assessment of Cardiovascular Parameters - Design and Results

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Introduction

This work introduces a novel multi-modal vital-parameter measurement system. The system is able to accurately and simultaneously measure a single channel Electrocardiography (ECG), four Photoplethysmography (PPG) signals, the pressure in both ears [1], as well as the broad-band, time resolved thorax bioimpedance [2]. Via the analysis of the different measured waveforms, many significant vital-parameters such as Pulse Arrival Time (PAT), Heart Rate Variability (HRV), Pulse Wave Velocity (PWV), respiration rate (RR), stroke volume (SV) and cardiac output (CO) can be estimated. The used measurement system is based on a System on Chip (SoC) Field Programmable Gate Array (FPGA) in combination with a powerful analog front end (ADS1298). Furthermore the system is in compliance with the IEC60601-1 safety requirements. Different Parameters are extracted through simultaneous acquisition of different signals as illustrated in figure 1. PAT is distance between the R-peak of ECG and peak of PPG signal. ICG signal is obtained through differentiation of the bioimpedance signal over the thorax.

Methods

Figure 2 shows the system architecture of the developed system for multi-modal assessment of cardiovascular parameters. The object under test is connected to different modules with specific sensors to the measurement system. The FPGA controls signal excitation and data acquisition, as well as preprocessing of the measurement data. The embedded system is connected via a galvanic isolated USB link to a host PC, which is responsible for further data processing and analysis.

The data acquisition for cardiometry module is accomplished via a 14 bit, 25 MSPS Analog to Digital Converter (ADC, LTC2296 from Linear Technology). In order to maintain the ADC full-scale usage for varying input voltages, Programmable Gain Amplifiers (PGA, AD8250 from Analog Devices) are employed. In order to maintain the ADC full-scale usage for varying input voltages, Programmable Gain Amplifiers (PGA, AD8250 from Analog Devices) are employed. In order to maintain the ADC full-scale usage for varying input voltages, Programmable Gain Amplifiers (PGA, AD8250 from Analog Devices) are employed. To amplify and digitize the analog signals of the four PPG signals, the two pressure signals in both ears, as well as the ECG signal an Analog Front End (AFE, ADS1298 from Texas Instruments) is used. The AFE has eight channels, each equipped with a PGA and a 24 bit ADC. The data transmission between the PC and the FPGA (LPX2-17E-QN208C from Lattice Semiconductor) is realized with a high speed USB connection.

Results

Figure 3 show the populated Printed Circuit Board (PCB) of the developed measurement system and the implemented measurement algorithms in MATLAB.

Figure 4 gives an overview of the signal processing done on various parameters to extract vital parameters as well as results obtained by measurement on two healthy subjects.

While measuring PAT values the group delay of the system is taken into consideration. Normal PAT values for extremities are in a range of 244 ms to 267 ms [4]. The maximum error of the PAT measurements is estimated with partial derivation to be in the range 5% to 20%.

Summary and Outlook

A system for multi-modal assessment of cardiovascular parameters was developed and used for a pilot-study. The device is able to measure general physiological waveforms like ECG, ICG and PPG, as well as the pressure inside the auditory canals. But due to the simultaneous acquisition of the different signal, cross reference parameters such as PAT, PWV, heart rate variability, stroke volume and cardiac output and respiration rate can be extracted. The overall system seems to be quite accurate, but further investigation and validation is required. Furthermore an analysis of the CO in stress situations is planned with improved mathematical models.

References