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A Novel Wireless Biomedical Monitoring System with Dedicated FPGA-based ECG Processor

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Abstract—A novel portable and wireless biomedical monitoring system featuring on demand wireless data transmission of ECG signals and time-frequency HRV analysis for personal and home healthcare applications is presented in this work. In order to provide comfort and convenience to patients, the device's size, power consumption and portability are of first priority. The ECG processor based on previous hardware design [1] acquires three-channel ECG biomedical raw data through an analog front-end (AFE) circuit, and it measures the time between successive heart beats on lead II as RR intervals for HRV analysis. Functions such as QRS complex peak detection, RR intervals calculation, and time-frequency analysis of HRV have also been developed in hardware. A real-time HRV analysis processor is realized by employing a Lomb periodogram for time-frequency power spectral density (PSD) analysis of the heart rate. The proposed ECG monitoring system has been implemented in Field-Programmable Gate Arrays (FPGA) and it features high integration density, portability, wireless transmission and low cost.

Keywords-Biomedical monitoring system; ECG; heart rate variability (HRV); Lomb periodgram; wireless communication; FPGA

I. INTRODUCTION

In recent years, heart disease is a major concern in the health indicator for the elderly. Cardiovascular diseases are always the leading cause of death in many countries including the United States. Due to the rapid growth of elderly population in recent years, health monitoring systems have played a more important role in the early detection of heart attack and cardiovascular diseases than ever before.

During a medical emergency, whether or not the condition is heart-related, the ECG monitoring system is able to provide critical information regarding the vital signs of the patient. Therefore, a comprehensive ECG biomedical signal monitoring system is most indispensable for real-life applications.

Long-term care is a variety of services that provides medical and non-medical care to people who have a chronic illness or disability. Four out of ten people above the age of 65 will use a nursing home, and many will require long-term home care and other related services. However, traditional ECG diagnostic products from different companies are often too bulky and impractical for patients to use in long-term health monitoring applications.

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Furthermore, these ECG products are too expensive for patients to purchase for personal use at their own home. In view of budgets and convenience of use, we propose an integrated ECG monitoring system with high integration density and low cost feature as an efficient and affordable solution to acquisition of ECG signals for either physiological diagnosis or patient monitoring.

Through its compact integration and wireless transmission capability features, the system is able to provide users with portable, real-time heart beat detection and time-frequency HRV analysis of acquired ECG biomedical signals. An integrated portable ECG monitoring system with the ability to wirelessly transmit data has the following advantages:

- ❖ Increase the mobility of patients and allow for normal routines;
- ❖ Reduce the stress of patients from being attached to a biomedical monitoring system;
- ❖ Enhance the applicability of ECG healthcare;
- ❖ Provide real-time analysis for immediate reaction.

In this work, a real-time ECG monitoring system featuring HRV analysis and wireless data transmission through Bluetooth module based on a System-on-Chip (SoC) development platform is proposed. Due to its high integration density and flexibility, we implement the ECG monitoring system in hardware on FPGA.

Furthermore, a **Universal Asynchronous Receiver/Transmitter (UART)** is used as the communication interface to the Bluetooth module, and the system can also be interfaced to other devices, such as ZigBee modules or a PC. With the recent advancements in wireless technology, many studies have been devoted to the design and implementation of the portable ECG healthcare monitoring system for a wide range of applications.

In a wireless 2-lead ECG system was developed to monitor vital signs and cardiac information with end deployment in an **Intensive Care Unit (ICU)** application. The use of standard wireless technologies such as Bluetooth or ZigBee has also been proposed in many studies.

The rest of the paper is outlined as follows. A system description of the proposed ECG monitoring system is first discussed in Section II. Section III introduces the verification using the SoC development platform. Experimental results are presented in Section IV, and the paper is concluded in SectionV.

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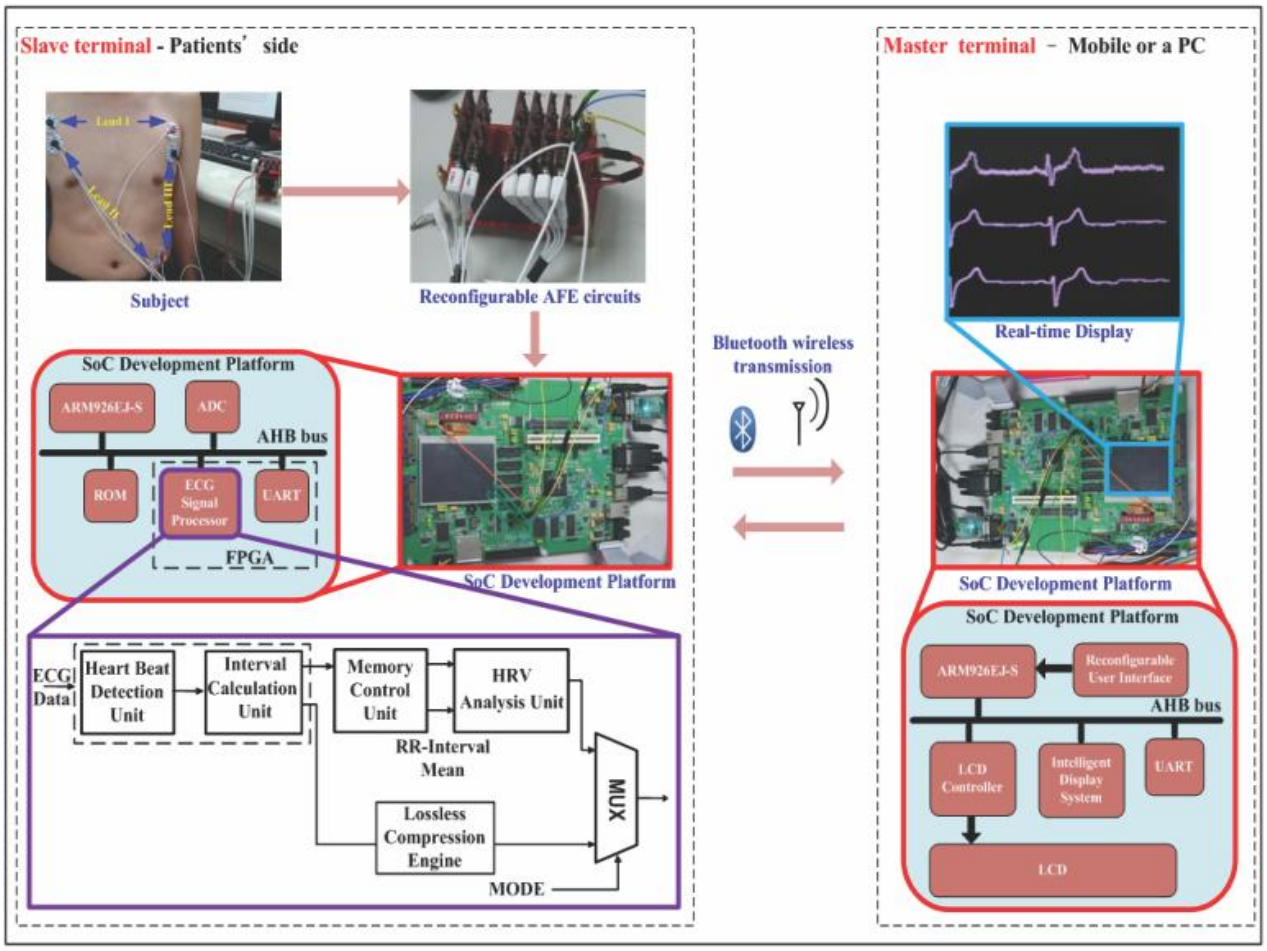

Figure 1. Overall system architecture of the proposed ECG monitoring system.

II. DESCRIPTION OF THE ECG MONITORING SYSTEM

The Cheetah ARM SoC platform solution offered by development of the proposed ECG monitoring system, for its rich set of SoC features and friendly technical support. The overall system architecture of the proposed ECG monitoring system is depicted in Figure 1.

The SoC development platform (slave terminal) includes an ADC to convert ECG raw data received from a reconfigurable analog front-end (AFE) circuit proposed in. An ADC controller embedded in the ECG signal processor is responsible for collecting the data from detection through the technique of digital filtering. Then, a employed to perform time-frequency HRV analysis.

Finally, a lossless ECG compression engine compresses the data, and the compressed stream is transmitted over a wireless Bluetooth communication link. Since UART is employed as the communication interface to the Bluetooth module, interfacing with other devices, such as ZigBee modules or a PC, can also be considered into our system.

In the master terminal, such as mobile or PC applications, an SoC development platform has been employed to monitor the biomedical signal of patients wirelessly. The system configuration mode on the master terminal can be set via a configuration wizard. Configuration options such as enabling

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of HRV analysis or bypassing the ECG signals to the LCD display can be set in the user interface controlled by the ARM926EJ-S^{TM} microcontroller.

III. VERIFICATION USING THE SOC DEVELOPMENT PLATFORM

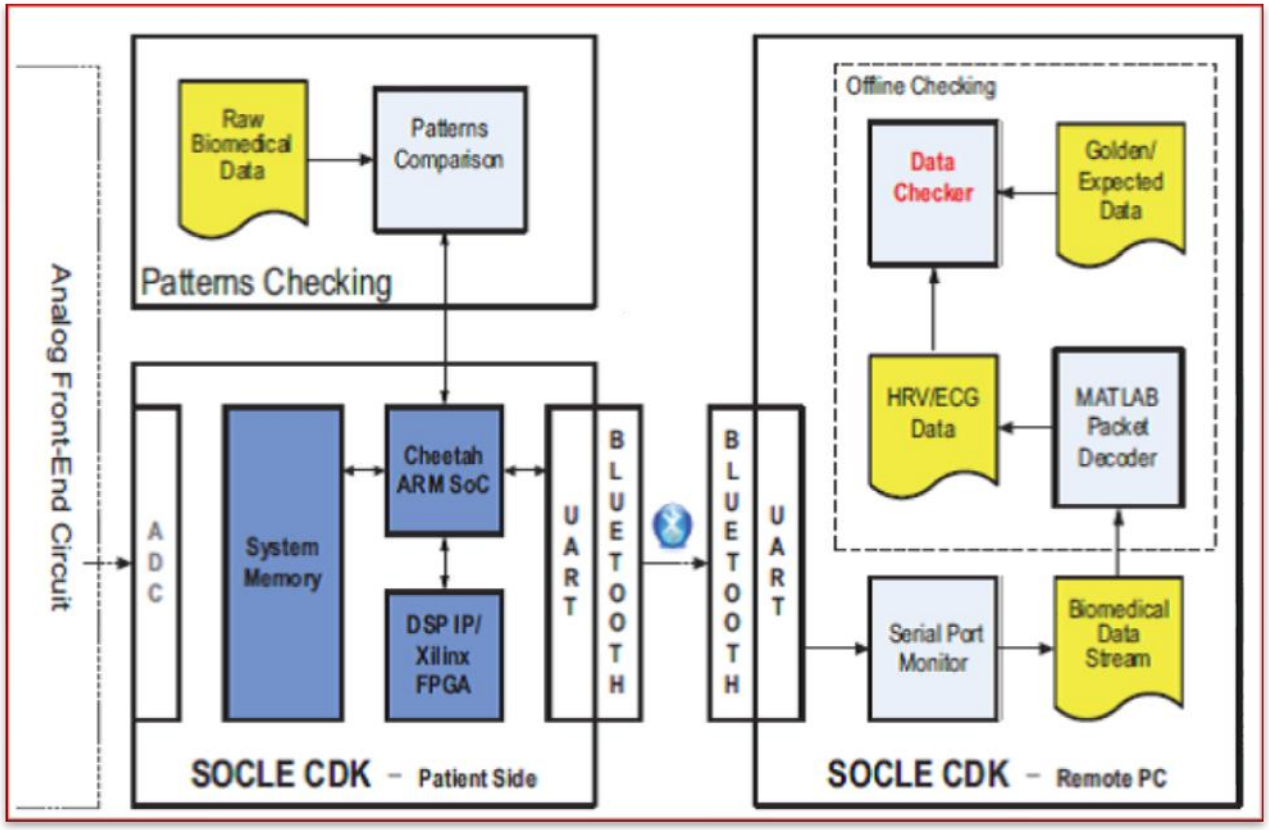

Figure 2. Verification setup on SoC development platform for the ECG biomedical monitoring system.

Verification setup on SoC development platform for the ECG biomedical monitoring system is shown in Figure 2. Raw biomedical data are first pre-loaded into system memory via an in-circuit emulator (ICE) connected to the ARM processor.

Furthermore, we also can acquire real-time biomedical data from the AFE circuit instead of data patterns from memory. The data patterns are sent to the DSP IP – ECG processor and the processed data stream are sent to the remote PC using commercial serial port monitoring software through UART interface connecting a Bluetooth module. Finally, the biomedical data stream are decoded with a MATLAB stream decoder and verified to match with golden expected data.

IV. EXPERIMENTAL RESULTS

Figure 3 shows HRV analysis using Lomb time-frequency distribution (TFD) of ECG data from the on-line MIT-BIH arrhythmia database. The output data received at the master terminal are displayed on the LCD. In addition, the results can also be displayed with an alternate display module on PC aspresented in Figure 4.

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The proposed ECG monitoring system based on the SoC development platform demonstrates that thesystem is capable of displaying the 3-channel ECG signals and calculating time-frequency HRV analysis in real-time, and is feasible for VLSI implementation.

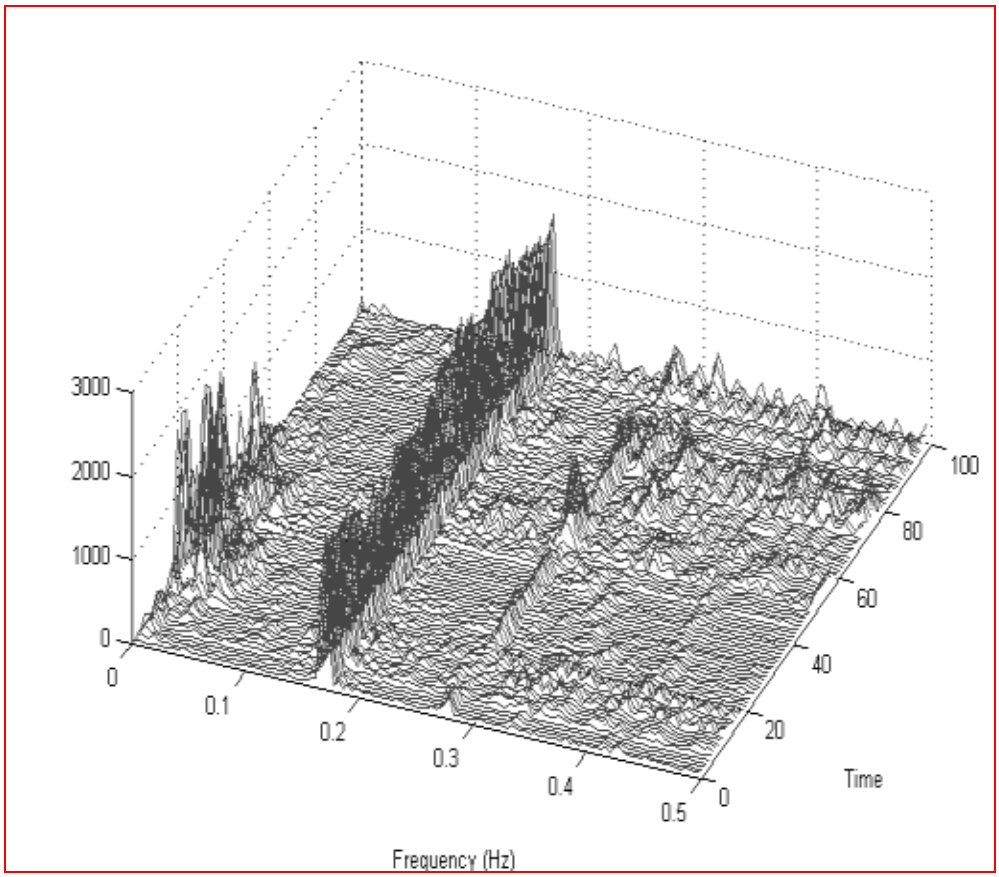

Figure 3. Time-frequency HRV analysis using Lomb TFD

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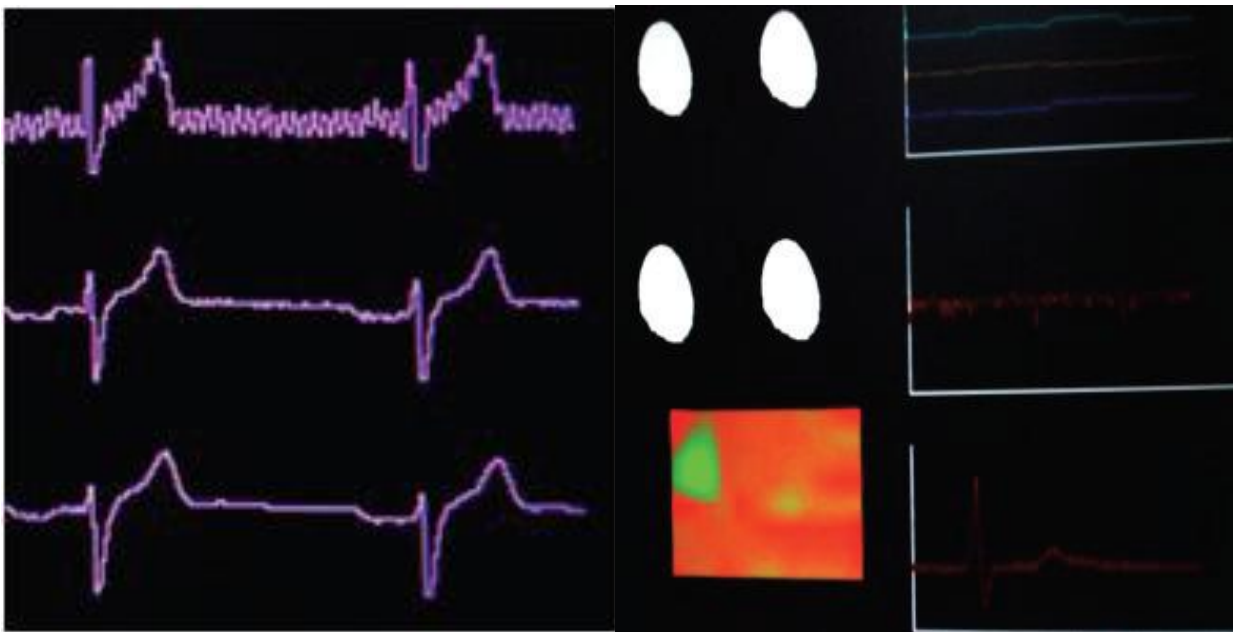
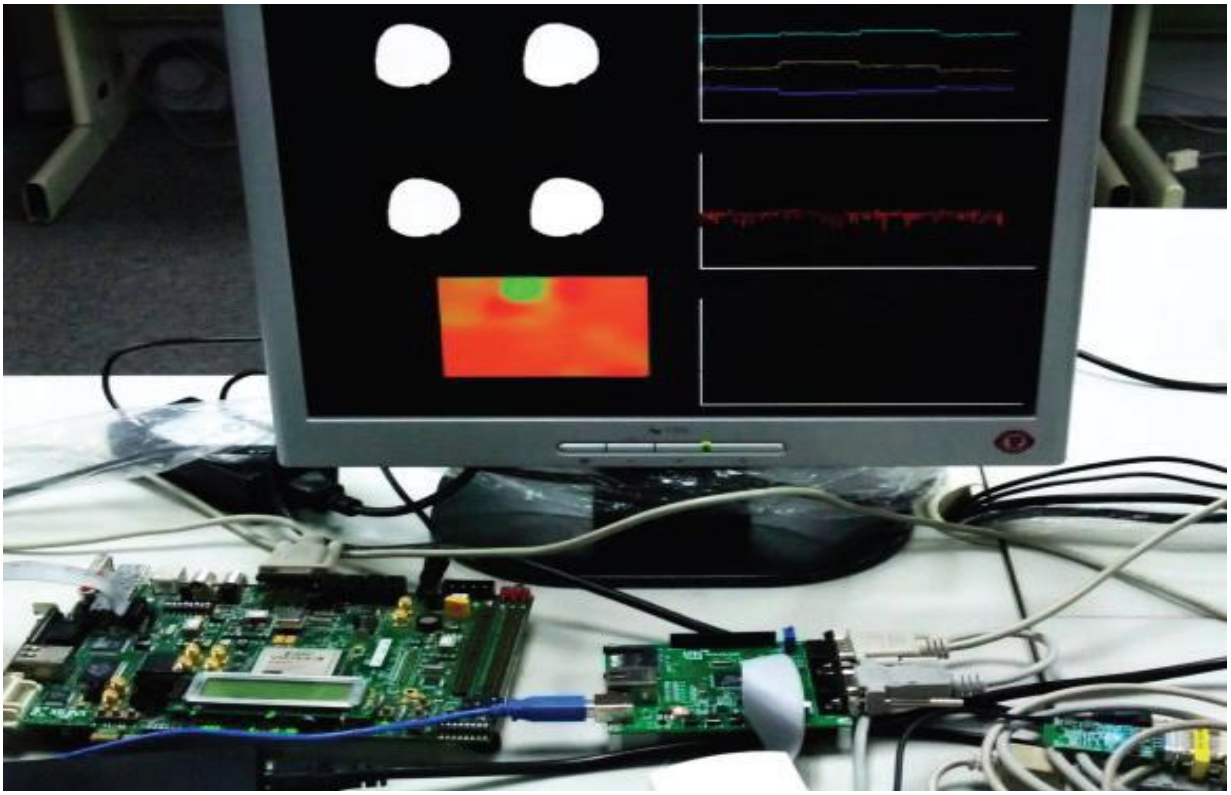


(a) 3 ch. ECG signals close up on LCD (b) Display module on PC



(c) Alternate demonstration setup

Figure 4. Real-time biomedical data display on LCD

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V. CONCLUSION

An ECG monitoring system featuring a dedicated ECG signal processor for real-time, portable, and wireless health monitoring implemented on an SoC FPGA development platform is presented. The proposed system was presented to showcase this work as a proof-of-concept design for the ECG monitoring system. It features important advantages such as comfort, connectivity and portability. Finally, the ECG signal processor is scheduled for tape-out under TSMC 90nm CMOS technology. Due to its high integration density properties, our SoC design can be applied to a wider range of biomedical applications. ACKNOWLEDGMENT This work was supported in part by the National Science Council of Taiwan, R.O.C., under grant NSC101-2220-E-009-049. The authors would also like to express their sincere appreciation to the National Chip Implementation Center for chip fabrication and testing service.

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