A Design of Low Cost 12-Lead ECG Acquisition System Using Raspberry PI

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***Abstract*- This paper presents a new design of low cost 12-lead Electrocardiogram (ECG) acquisition system. The system is an integration of a biosignal analog-to-digital front-end evaluation board, supplied by Texas Instrument™, and a widely known controller from Raspberri PI™. These two separately available gadgets were connected and operated by the costom-made software. This acquisition system is made for long-term multi-channel physiological signals recording with its own storage. With no need of an extra computer for operating, the system is stand-alone working at low cost. For more than two hours, our prototype unit was running through a test, acquiring 12-lead ECG signal from a simulator at 500Hz sampling frequency. The restored signals were constantly confirmed. The target groups of this work are the educators and researchers in biomedical engineering area who are demanding the biopotential signals. Our future work is to develop a new user interface and data analysis software.**

***Keywords*- 12-lead ECG;bio signal acquisition system; commercial off the shelf;ADS 1298;Raspberry PI;**

I. INTRODUCTION

Heart diseases such as cardiovascular disease have become one of the most serious diseases [1]. It is said that the main causes of sudden death in elder people are heart malfunctions [2]. Diagnosis and prevention of heart diseases is more and more important in our daily life. Therefore, further development and education of the research of heart diseases will be required.

Electrocardiogram (ECG) is the most widely used clinical test to study the cardiac activity. ECG is the biological electrical signal generated by myocardial cells, which trigger the beating of the heart [3]. ECG signal reflects the working status of the heart from different aspects and levels, it contains the most important and basic body physiological parameters [4]. Especially multi-channels and long-time ECG monitoring is effective for diagnosis and prevention of heart diseases. ECG signal acquisition system is the key part to ensure acquiring a complete and accurate ECG signal; it plays an important role in the process of clinical diagnosis and treatment for heart disease [4].

Usually the medical equipment is rather expensive for research and education in schools. Such kind of equipment is required to be cheap, available, and reliable.

This paper presents a low cost and long-time portable 12-lead ECG acquisition system using raspberry PI. This system is composed of a commercial analog front end board for ECG acquisition and an easily available general commercial one board computer Raspberry PI. We have only to prepare a low spec interface card to assemble the two boards. We can construct the system with lower cost. The one board computer works not only as the controller of the front end board but also as a host PC to analyze the acquired ECG signal. So we do not have to prepare any extra host computers or smart-phones to analyze them. All the components and software are available in low price. Therefore it realizes low cost ECG measurement system not only for medical researchers but also for education of the students of medical school. In experiment using prototype system, we confirmed 2 hours 12-lead ECG signal acquisition.

The rest of the paper is organized as follows. Section II describes the related works. Section III explains the detail of the proposed ECG acquisition system. Section IV gives the experimental results. In section V, we have some discussions about this work according to the results of the experiment. Finally, section VI concludes the paper.

II. RELATED WORKS

Some researchers have proposed portable 12-lead ECG acquisition systems. Gao et al. designed ECG signal acquisition and processing system [5]. This system transfers the acquired data to personal computer using USB-6008. Gnecchi et al. proposed ECG measurement system, namely ECG-ITM-05 eHealth DAQ [6]. This system uses ADS1298 chip like our system for the front-end board. The controller board includes MSP430F2618. Wu et al. proposed high performance and low power 12-lead ECG acquisition system. This system is composed of an in-house front-end board and Silicon Lab's C8051F330 [4]. These three works require extra host computer for data storing and data analysis. Extra host causes extra cost. Consequently it can be a weak point from the view point of educational use. Some of them use in-house board instead of commercial one, which results in higher cost, too.

The ECG acquisition system with wireless communication with bluetooth protocol was proposed [2][3]. Using the wireless communication protocol, the mobile users control the system and acquire ECG data and analyse the data on smartphone wirelessly. However this kind of system requires smartphone to control the system. It is costly, too. Some researchers have proposed hostless ECG acquisition system. Gargiulo et al. proposed 32-channel data logger [7]. The system has touch-screen display and each channel has a programmable gain amplifier (PGA). IN addition, no host is required. Cook et al. designed 12-lead ECG acquisition system [8]. The system includes ARM processor and ADS1298 like our system. However these two systems do not use commercial one board computer but use in-house controller block and front-end block.

Abtahi et al. proposed ECG acquisition system using Raspberry PI without host computer [9]. From the best of our knowledge, it is the 1st work of the portable ECG acquisition system using Raspberry PI. This system uses analog front-end chip ADAS1000. However this system requires two front-end chips to construct the 12-lead ECG measurement system.

III. LOW COST 12-LCEAD ECG ACQUISITION SYSTEM

This section explains the details of the proposed low cost 12-lead ECG acquisition system. First, in sub-section A we describe the concept of the proposed system. Second the commercial components, namely Raspberry PI and ADS 1298, are explained in sub-sections B and C. Finally sub-section D explains the detail of the proposed system.

A. Concept

Figure 1 describes the concept of our system. Our system is composed of the two low cost commercial boards, ADS1298 and Raspberry PI. We have only to prepare a low spec interface card to assemble the two boards to design the system. So it is better not only from the viewpoint of the financial cost but also from the viewpoint of the time cost (in other words, the period for the development). Furthermore, because Raspberry PI is one of the standards of the one board computer, we can easily extend the designed system and no extra host is required.

B. Raspberry PI

Raspberry PI is a credit-card-size single-board computer with an ARM processor [9]. It is developed by Raspberry Foundation. The 1st version Raspberry PI and the 2nd version Raspberry PI 2 have been released. The 1st version includes three models; A, A+, B and B+. Currently, the 2nd version has only single model, model B. In addition to these models, there is Compute Module for use as a part of embedded systems. Raspberry PI support several linux distributions, Raspbian, Open SUSE, Free BSD and so on. You can use all the programming languages supported by Linux. In addition, we can run Simulink on RPI. In this study, Raspberry PI model B+ is used.

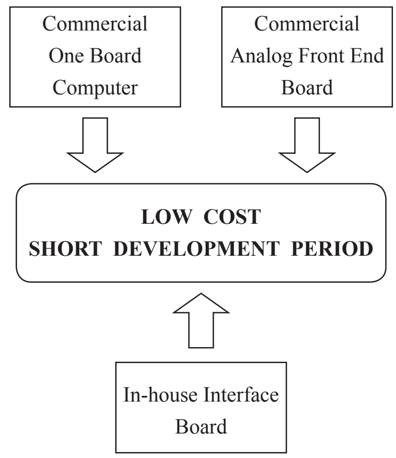

Fig. 1 Concept of proposed low cost acquisition system.

TABLE I
Spec. of Raspberry PI model B+.

Release date	July 2014
Target price	US$25
SoC	Broadcom BCM2835 (CPU, GPU, DSP, SDRAM, one USB port)
CPU	700 MHz single-core ARM1176JZF-S
GPU	Broadcom VideoCore IV 250 MHz
Memory (SDRAM)	512 MB (shared with GPU)

C. ADS1298R

Our system uses the analog front end board included in the ECG Front-End Performance Demonstration KIT ADS1298RECG-FE provided by Texas Instruments [10]. This is for evaluation in laboratory and development environment [10]. Although it cannot be used for diagnostics in clinic, it can be used for research of biomedical engineering and education in medical school.

The front end board includes ADS1298R, a low-power 8-channel 24-bit analog front-end chip for bio-potential measurement by Texas Instruments [11]. The chip has 8 24-bit delta sigma ADCs to acquire bio potential such as 12-lead ECG signals or EEG signals.

The board is configurable for bipolar or unipolar supply operation, internal and external clock, the reference via jumper settings, AC- or DC-coupling inputs, and up to 12 standard ECG leads. The board has external right leg drive (RLD) references, shielded drive amplifier, and Wilson central voltage. It has on-board respiration circuitry for impedance pneumography evaluation.

The kit includes the controller board MMB0. However this board is not suitable for long time measurement because the available amount of memory is limited to 128 Mbit.

As shown in Table II, the 8 ECG analog signals v1-6, LEADI, and LEADII are generated from the 10 electrode data. The remaining 4 signals, LEADIII, aVR, aVL, and aVF, are calculated according to the equations shown in Table III [11].

TABLE II
ADS1298R LEAD MEASUREMENTS [11].

ADS1298R Input Channels	Lead (1)
1	V6 = V6 - WCT
2	LEADI = LA - RA
3	LEADII = LL - RA
4	V2 = V2 - WCT
5	V3 = V3 - WCT
6	V4 = V4 - WCT
7	V5 = V5 - WCT
8	V1 = V1 - WCT

(1) WCT = (LA + RA + LL)/3

TABLE III
DERIVED LEAD CALCULATION [11].

Derived Lead	Formula Used to Calculate
LEADIII	LL - RA - LA = LEADII - LEADI
aVR	RA - (LA + LL)/2 = (LEADI + LEADII) 2
aVL	LA - (RA + LL)/2 = LEADI - LEADII/2
aVF	LL - (RA + LA)/2 = LEADII - LEADI/2

D. Proposed System

Figure 2 shows the block diagram of the proposed system. It is composed of the one board computer Raspberry PI model B+, the front-end board ADS1298R, a monitor with HDMI interface, and input devices. The ADS 1298 generates 8-channel analog signals from the 10 electrodes. The generated analog signals are transformed to the 8-channel digital data. The 8-channel digital data is sent to Raspberry PI and stored to the SD card memory. Using the equations of Table III, the digital 12-lead ECG is obtained.

The data communication is performed with SPI protocol synchronizing to SCLK. The interface between the two boards is shown in Fig. 3. Raspberry PI sends commands through MOSI to DIN of ADS1298R. It receives data through MISO from DOUT of ADS1298R. The output CE_0 is connected to CS to control the enable or disable state of ADS1298R. When a data is prepared, a negative pulse occurs on DRDY. As shown in Fig. 4, one ADS1298 data packet contains 8 channel data (CH1-8) and one status data (STAT). Each channel data uses 24 bits. The status data also uses 24 bits. So the total number of bits is 216 (24 status bits + 24 bits * 8 channels).

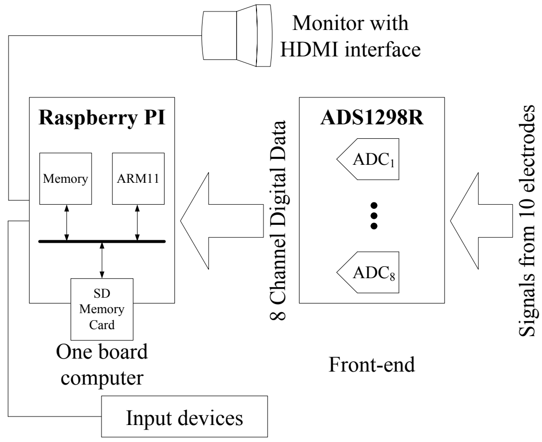

Fig. 2 Block diagram of proposed system.

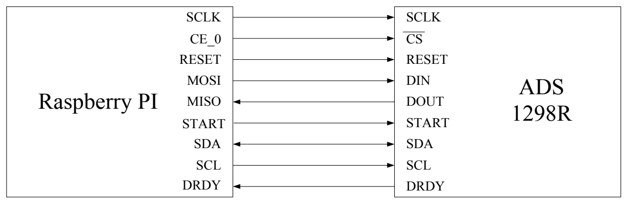

Fig. 3 Interface between two boards.

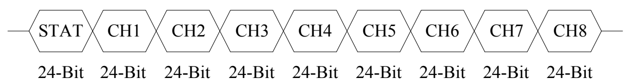

Fig. 4 Data format of acquired data.

Finally the data acquisition sequence is explained. Figure 5 shows the abstract of the data acquisition sequence. First the interface signals are initialized. After that "start command" and "start sequential data read" are sent to start the sequential data acquisition. After that, CE_0 is set to 0. To acquire data, the controller searches the positive transition of DRDY. If the positive transition is detected, the converted data is acquired from MISO and the cnt is incremented. When cnt is equal to N, "stop sequential read command" is sent. CE_0 is set to 1. N is calculated as N = T * d, where d is the data rate.

IV. EXPERIMENT

E. Setup

We designed the prototype of the proposed system. Figure 6 depicts the prototype system. The front-end board is ADS1298R. The controller is Raspberry PI model B+. The controller code is written with C++. The register values of ECG Front-End Performance Demonstration KIT ADS-1298RECG-FE is used for the proposed system, too. The schematic of double layered printed circuit is designed with Altium designer 14.2.3 2014 [12]. The data rate d is set to 500 samples/CH. We use

F. Results

We confirm the waveforms in long time measurement. We perform 2 hour measurement with applying ECG signal using the simulator. Then we check the 2 cycle-waveforms around 0 hour, 0.5 hour, 1 hour, 1.5 hour, and 2 hour. Figures 7-11 show the waveforms. According to these results, we conclude that the prototype system works correctly.

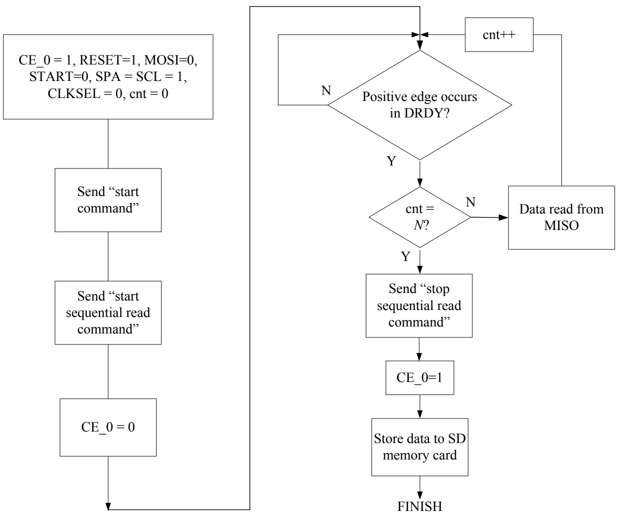

Fig. 5 Data acquisition sequence.

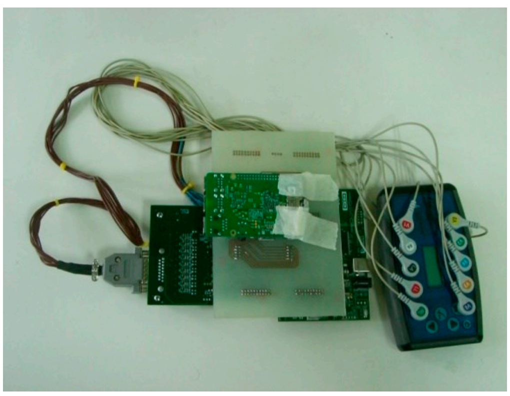

Fig. 6 Prototype of proposed ECG acquisition system.

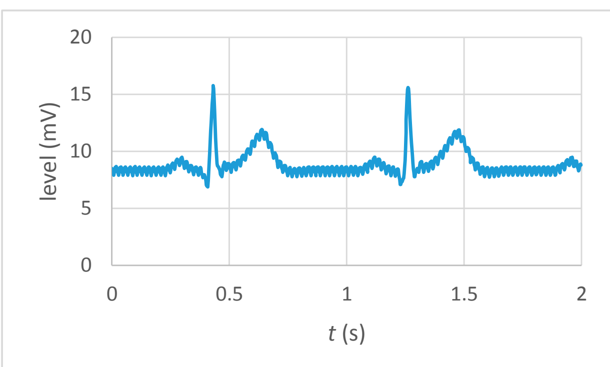

Fig. 7 Waveform of ECG signal of long measurement ($0 \leq t \leq 2$).

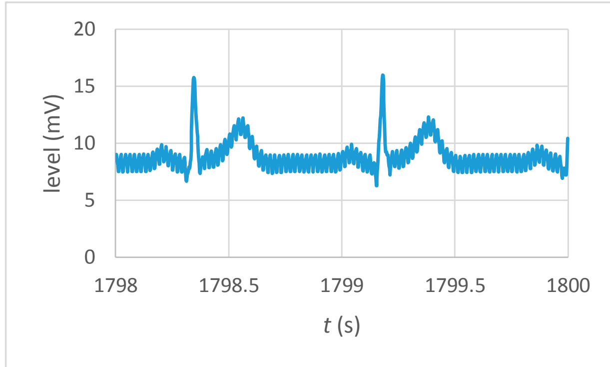

Fig. 8 Waveform of ECG signal of long measurement ($1{,}798 \leq t \leq 1{,}800$).

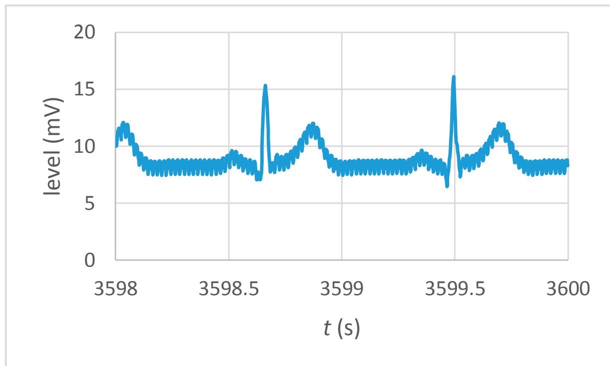

Fig. 9 Waveform of ECG signal of long measurement ($3{,}598 \leq t \leq 3{,}600$).

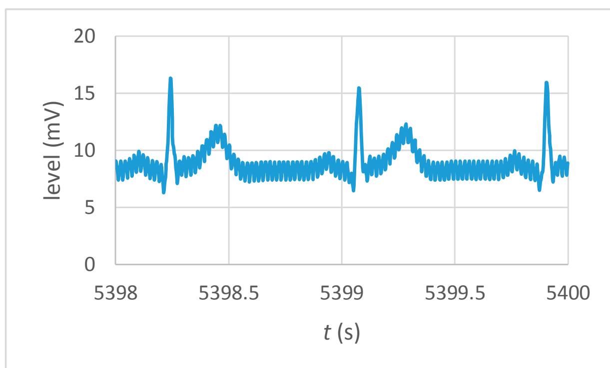

Fig. 10 Waveform of ECG signal of long measurement ($5{,}398 \leq t \leq 5{,}400$).

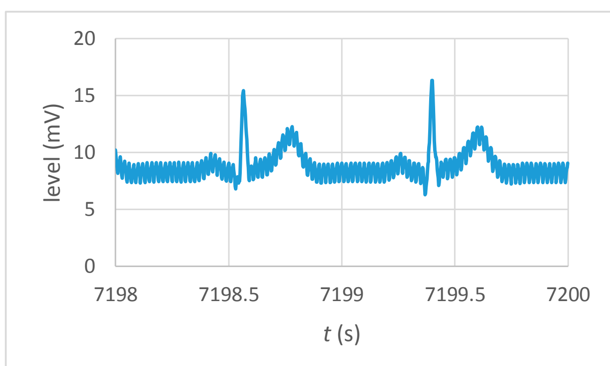

Fig. 11 Waveform of ECG signal of long measurement ($7{,}198 \leq t \leq 7{,}200$).

V. DISCUSSION

Usually, the commercial equipment is expensive. So it is difficult for academic organization to buy a number of the commercial equipment s for student experiment and the laboratory. Lower cos t of such medical equipment will be better. Our system uses general one board computer and the front end board bundled in the evaluation KIT of ADCs for medical use. Furthermore, the one board computer works as host computer to analyse the acquired waveform. So we do not require extra host computers and smartphones. So the cost is lower.

VI. CONCLUSIONS

This paper has presented a long-time 12-lead ECG acquisition system using raspberry PI. This system is composed of a commercial analog front end board for ECG acquisition and an easily available general commercial one board computer. We have only to prepare a low spec interface card to assemble the two boards. We can easily construct the system with lower cost. The one board computer works not only as the controller of the front end board but also as a host PC to analyze the acquired ECG signal. So we do not have to prepare any extra host computers or smart-phones to analyze them. All the components and software are easily available in low price. Therefore it realizes low cost ECG measurement system not only for medical researchers but also for education of the students of medical school. In experiment using prototype system, we confirmed 2 hours 12-lead ECG signal acquisition.

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