Development of portable ECG with Bluetooth connection utilizing MCU ARM

Everton L. Uehara and Samuel E. de Lucena

UNESP - São Paulo State University, Guaratinguetá, Brazil.

lincoln.uehara@gmail.com

Abstract - *The ischemic heart disease has been one of the principal causes of death in the last decade, and the electrocardiograph (ECG) is the main equipment to evaluate the heart condition of the patient. In this paper, a portable 12-lead ECG acquisition system is presented. The proposed system was developed using a designed printed circuit board with Wilson Resistor Network, ADG725 (multiplexer) and ADS1291 (instrumentation amplifier and Analog-to-Digital Converter), where a development board (TIVA TM4C123G) and a Bluetooth module (EGBT-046S) is stacked. The visualization is made on Android mobile device, using a user-friendly application called "Bluetooth Electronics". This kind of ECG register has the potential to reduce traditionally expensive equipment and also allow population living far from large cities has their ECG exams verified by specialists, since the data is on smartphone. The results indicate the feasibility of proposed ECG equipment.*

Keywords: *ECG, ARM, embedded, wireless, healthcare.*

I. INTRODUCTION

According to World Health Organization the ischemic heart disease has been one of the principal causes of death in the last decade [1]. At a research held in 2013 in Brazil, 6 million of citizens with 18 years old or more had some medical diagnosis of some type of heart disease [2]. The same research highlights that "cardiovascular illnesses have the higher costs with regard to hospital admissions".

In the year of 2013 Brazil invested 8,3% of Gross Domestic Product (GDP) in health expenditure, from which 45,8% are proceeding from public funds [3] [4]. Countries like Italy and Korea invest similar percentage to Brazil (9,2% and 7,4% of GDP, respectively). However, when examined per capita data, it is found that Brazil expends US$947,00, while Italy and Korea expend US$3,258.00 and US$2,060.00, respectively [5]. Although Brazil has GDP similar to these countries, it has much larger population, which justify such low per capita value. Therefore, the employment of cost-effective solutions is very important for ischemic heart disease issue for the government and citizens.

In this scenario, the diffusion of portable ECG devices not only promote home care, but as well can reduce expenses related to medical appointments, travel costs and waiting time, and could be even a tool for preventive medicine. The portable electrocardiograph connected to mobile phone or another device with Bluetooth or Wi-Fi connection can send clinical data of patients to medical center or offices, and through manifestation in ECG signal shown in the data it could predict the majority of cardiovascular diseases symptoms [6], and appropriate medical instructions could be offered to patient upon early symptoms detection [7].

Many studies have been done to develop portable ECG equipment. Shin-Chi et al [8] showed that is possible to construct one lead ECG equipment using operational amplifiers and 8-bit Arduino platform. Huang et al [9] [10] designed 7-lead equipment using ADS1298 and an ARM Cortex M3 microprocessor. Sun et al [11] developed a 12 lead ECG equipment using ADS1298 and MSP430. These studies demonstrated that it is possible to construct an equipment using user-friendly development boards, and focused the studies in compression ratio to save energy on transmission system. However still lack details about the hardware construction, firmware optimization for better hardware components choices, and about the precision of the instrumentation.

In this paper, we designed an ECG device based on Wilson Resistor Network, ADG725, ADS1291, TIVA TM4C123G and EGBT-046S, capable to acquire the 12-leads ECG signal. The circuit is supplied by batteries, and its structures is made by PLA on 3D printer. In Section II, we provide the overall view about the hardware design. In Section III, application test results are given, and conclusion and future works are described in Section IV. Our contribution is to inspire future professional ECG equipment.

II. SYSTEM DESIGN OVERVIEW

The proposed system, as shown in Figure 1, consists of electrodes and cable that are position of the 12-lead system, as seen in Figure 2. Each signal is multiplexed on ADG725, and its output is connected to the input of ADS1291, an instrumentation amplifier and Analog-To-Digital Converter, which outputs a 24 bit of data and feasible to obtain 8000 samples per second. In our project we utilized smaller rate, 4000 samples per second, because of its Efficient Number of Bits (ENOB) is superior to previous rate, accordingly to ADS1291 datasheet. Then at this rate of sampling for all 12 leads, we have 333 Hz of sampling for each channel, with ENOB of 15.29 in conditions of 2.42 V Reference and Programmable Gain Amplifier (PGA) of 12. The 24-bit resolution demands for low amplification, avoiding any saturation on following sections.

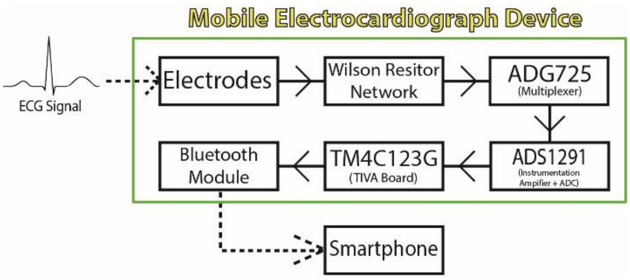

Figure 1. System design

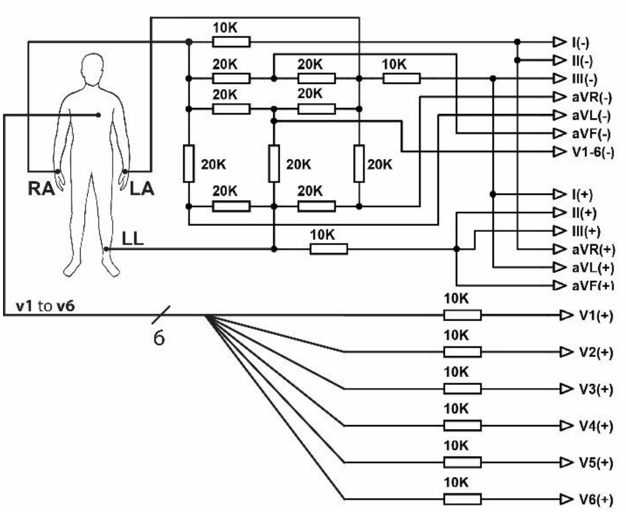

Figure 2. Electrode points and Wilson Resistor Network circuit

The data is sent to TM4C123G microcontroller, a 32-bit microcontroller that offers 80 MHz Cortex-M4 with Floating Point Unit (FPU), which is terrific for processing 24-bit data from ADS1291, enabling to apply Finite Impulse Response (FIR) Bessel on firmware. The information is sent through Bluetooth module EGBT-046S, and it will be displayed on "Bluetooth electronics" app on smartphone. At Figure 3 is shown the constructed device. The box was made on 3D printer using polylactic acid (PLA).

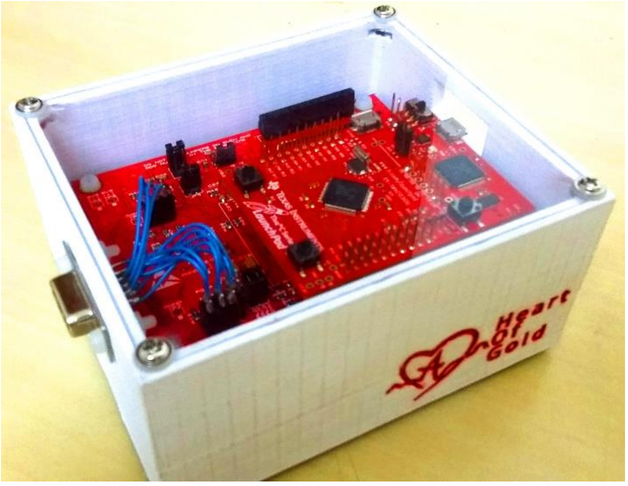

Figure 3. Contructed ECG portable device

III. RESULTS

A free Android application called “Bluetooth Electronics” is used because it is very easy to customize, which reduced the design-cycle time. In Figure 4 is demonstrated the connection between equipment and cardiac signal simulator. The lead V1 obtained from the simulator is shown in Figure 5. We tested on a patient, which result is seen at Figure 6.

Figure 4. Connection between ECG Portable Device and ECG signal simulator

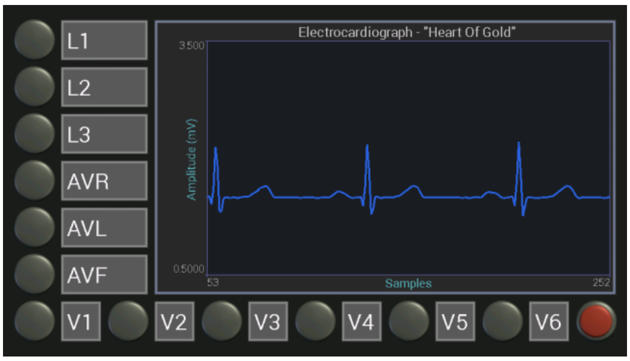

Figure 5. View of V1 from ECG signal simulator on Android application

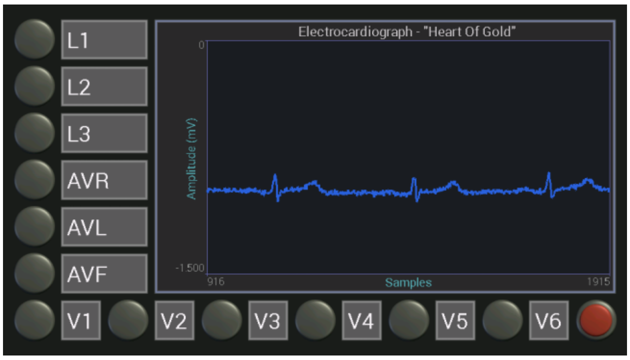

Figure 6. View of V1 from patient on Android application

The processing time is illustrated in Figure 7. If setting ADS1291 to make 4000 samples per second, consequently TIVA have to do all the processing in less than 250 µs. Using Tiva's µDMA and optimization in firmware compiling, all the processing is done in 31 µs. If none of these were used, the processing time takes 173 µs to be done. In our analysis, using µDMA makes the processing time 74,6% faster, and compiling techniques optimizes 82,3%.

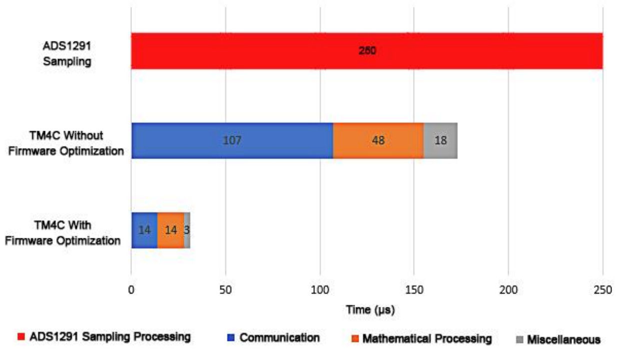

Figure 7 – Processing time optimization

Each part of equipment and its total price is on Table 1. Compared with traditional clinical product sold in Brazilian market, our equipment is 10 to 20 times cheaper.

Table 1. Materials value

Component	**Price (U$)**
Printed Circuit Board	92,71
Integrated Circuits	73,05
3D printed box	4,27
Cable	6,10
Screws, nuts, washers, connectors, etc.	8,71
TOTAL:	184,86

The measured power consumption was about 300mW. The equipment was designed to be supplied by 4 AA batteries, either 1.2V or 1.5V each one. There is a Single-Ended Primary-Inductor Converter (SEPIC) circuit that regulates 4.8V or 6V to 5V at output.

IV. CONCLUSION AND FUTURE WORKS

In this paper, the design of portable 12 lead ECG acquisition system is described. The system is made from state-of-art-components, and using a user-friendly app it was possible to reduce the design cycle time. The signals obtained on the screen of the smartphone were consistent with produced from the simulator. Some other basic tests were taken like DC/AC calibration of the equipment, and the results were agreeing with ADS1291 datasheet. We adopted ADS1291 because of its low price and simplicity to programming. In conjunction with ADG725 there is no need to obtain another instrumentation amplifier with higher number of inputs like ADS1298. With some few more resistors and change in the PCB layout, it is possible even to design up to 16 leads.

On the other hand, the UART data rate is insufficient to transmit all the 12 leads values simultaneously, but is formidable to watch each single of them at a time. In our future works we will focus about the transmission data, choosing better wireless module, studying about compression ratio, and storage in SD card module.

ACKNOWLEDGEMENT

This work would not have been possible without the financial support of The São Paulo Research Foundation (FAPESP), and Engineering Faculty of Guaratinguetá from São Paulo State University (FEG-UNESP). I am especially indebted to my professor Dr. Samuel Euzédice de Lucena, and my colleague Thiago Ribeiro Filadelfo.

REFERENCES

[1] The World Health Organization. (2014, May). The Top Ten Causes of Death. Fact sheet no. 310. [Online]. Available: http://www.who.int/mediacentre/factsheets/fs310/en/
[2] Instituto Brasileiro de Geografia e Estatística – IBGE. (2014). Pesquisa Nacional de Saúde 2013: percepção do estado de saúde, estilos de vida e doenças crônicas: Brasil, grandes regiões e unidades da federação, [Online]. Available: http://biblioteca.ibge.gov.br/visualizacao/livros/liv91110.pdf

[3] The World Bank Group. (2016). Health expenditure, public (% of GDP), [Online]. Available: http://data.worldbank.org/indicator/SH.XPD.PUBL.ZS

[4] The World Bank Group. (2016). Health expenditure, total (% of GDP), [Online]. Available: http://data.worldbank.org/indicator/SH.XPD.TOTL.ZS

[5] The World Bank Group. (2016). Health expenditure per capita (current US$), [Online]. Available: http://data.worldbank.org/indicator/SH.XPD.PCAP

[6] D. De Bacquer, G. De Backer, M. Kornitzer, H. Blackburn, "Prognostic value of ECG findings for total, cardiovascular disease, and coronary heart disease death in men and women." Heart, vol. 80, no. 6, p. 570–577, Dez. 1998.

[7] J. N. Cohn, L. Hoke, W. Whitwam, P. A. Sommers, A. L. Taylor, D. Duprez, R. Roesslera, N. Florea, "Screening for early detection of cardiovascular disease in asymptomatic individuals". Amer. Heart J., vol. 146, no. 4, p. 679–685, Out. 2003.

[8] S.-C. Lai, T.-H. Hung, W.-C. Li, Y.-S. Jhang, K.-Y. Chang, W.-H. Juang, C.-H. Luo, "Low-Cost Prototype Design of a Portable ECG Signal Recorder", 2016 IEEE Asia Pacific Conference on Circuits and Systems (APCCAS), Oct. 2016.

[9] A. Huang, C. Chen, K. Bian, X. Duan, M. Chen, H. Gao, C. Meng, Q. Zheng, Y. Zhang, B. Jiao, L. Xie, "WE-CARE: An Intelligent Mobile Telecardiology System to Enable mHealth Applications", IEEE Journal of Biomedical and Health Informatics, vol. 18, issue 2, pp. 693 – 702, Mar. 2014.

[10] H. Gao, X. Duan, X. Guo, A. Huang, B. Jiao, "Design and tests of a smartphones-based multi-lead ECG monitoring system", 2013 35th Annual International Conference of the IEEE on Engineering in Medicine and Biology Society (EMBC), Jul. 2013.

[11] C. Sun, J. Liao, G. Wang, B. Li, M. Q. -H. Meng, "A portable 12-lead ECG acquisition system", 2013 IEEE International Conference on Information and Automation (ICIA), Aug. 2013.

[12] S. E. de Lucena, D. J. B. Sampaio, B. Mall, M. Meyer, M. A. Burkart, F. V. Keller, "ECG Monitoring Using Android Mobile Phone and Bluetooth" 2015 IEEE I2MTC – International Instrumentation and Measurement Technology Conference, May 2015.