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Design of ECG Homecare:12-Lead ECG Acquisition using Single Channel ECG Device Developed on AD8232 Analog Front End

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***Abstract*—Electrocardiogram (ECG) devices measure electrical activity of the heart muscle to determine heart conditions. ECG signal quality is the key factor in determining the diseases of the heart. However, the availability of ECG devices is causing ECG diagnosis slow and difficult. This paper presents the design of single channel portable ECG device developed on AD8232 chip platform. To extend the capability of an ECG portable device, a 12-lead ECG acquistion technique is also tested out. The results showed the single channel ECG module with additional 12-lead ECG acquisition technique can serve the function of ECG Homecare device, thus making the ECG diagnosis much more accessible.**

Keywords—portable one-lead ECG device, twelve-lead ECG acquisition technique, ECG Homecare.

I. Introduction

Today, heart disease is one of the prominent cause of death wolrwide. In Indonesia, roughly 700 thousands mortalities per year is caused by heart attack. To prevent heart attack from becoming severe, early diagnosis is of utmost importance. One of the diagnostic technique is Electrocardiogram (ECG). ECG devices record electrical signal from cardiac muscle to predict the abnormality present in the heart.

However, existing ECG devices in Indonesia mostly are situated only in big hospitals. The patient with heart attack will have to wait for the ambulance to come and escort him to the hospital. While waiting the ambulance, the important signal associated with the heart attack may be diminishing, thus making the doctors loss traces of the causes of the heart attack. The other patients are too busy to do ECG check-up unless something wrong happened to their heart. ECG check-up is bothersome.

Therefore, it is very important to develop portable ECG devices. The portability of the devices will make it possible to place the devices in community health center (Puskemas) or even in one's home. The diagnosis will also be much easier and cheaper. The special condition such as patient with heart attack will also be accommodated with portable ECG Homecare device. Furthermore, it is possible to acquire 12-lead ECG using single lead ECG [1]. The electrode placement for 12-lead ECG aquisition is pictured in Fig I.

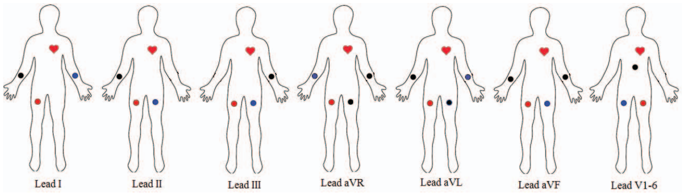


Fig. 1. 12-lead electrode placement, red colour is ground electrode, while blue and black color is postive and negative electrode, respectively.

Recent research of ECG in Android such as HeartToGo developed by Zhanpeng Jin [2] is able to detect R peak and calculate beat detection. The system also capable of detecting sinus bradycardia, ventricular flutter, and left bundle branch block. Mobile ECG developed by Harri Kailanto [3] has combined the Android with server to enable storage and web transmission of ECG data. QRS and arrythmia detection are the features of Mobile ECG. However, from the two paper the analysis is limited to only one-lead ECG.

In this paper, we design an ECG Homecare device that is capable to acquire the 12-leads ECG signal. The device portability is made possible using single channel ECG Analog Front End (AFE) AD8232. Our contribution will be the testing of twelve-lead ECG acquisition technique that enables single channel ECG to help early diagnosis of various diseases.

II. Device Specification

A. ECG Signal Characteristics

Before we derive the technical specification, first we examine the characteristics of ECG signal.

ECG signal consists of low amplitude signal superimposed on high common voltage and noise [4]. The common voltage comes from electrode-skin offset and can be as high as 300 mV. ECG signal itself has frequency content of 0.05-100 Hz with amplitude ranging from 0-3.0 mV. The noises that presents in ECG signals are caused by:

- Powerline interference on 50 or 60 Hz harmonics
- Electrode offest noise caused by skin-electrode contacts, DC signal of amplitude 300 mV

- Muscle contraction caused by patient movement
- Baseline wander caused by patient respiration, low frequency AC signal
- Electromagnetic interference from another electronic devices, usually high frequency signal

B. Technical Specification

According to Rachit [5], ECG bandwidth specification is dependent with its application. The bandwidth specification is presented in table 1.

TABLE I. ECG APPLICATION AND ITS FREQUENCY BANDWIDTH

Application	Bandwidth (Hz)
Display	0.5-40
QRS Detection	0.5-40
Arryhtmia detection	0.05-60
ST segment monitoring	0.05-60

In this paper, we develop Homecare ECG device, which is used primarily for display and QRS detection. Hence, bandwidth of 0.5-40 Hz is chosen. The four electrodes system is employed to be able to acquire the augmented leads. Input is provided by 9-V home battery. For complete specifications please refer to Table II.

TABLE II. ECG HOMECARE SPECIFICATION

Parameter	Value
Application	QRS Detection & Display
Channel	Single channel
Lead Reading	Up to 12 leads w/ 4 electrodes
Bandwidth	0.5-40 Hz
CMRR	80 dB
Resolution	Better than 5 μV
Gain	More than 1000 V/V
Sampling Frequnecy	Faster than 250 samples / second
Input Voltage	5-12 V
Connectivity	Serial Cable and Bluetooth

III. SYSTEM DESIGN AND IMPLEMENTATION

To tackle all the specification as mentioned in Table II, we design the hardware using step-by step method. The design starts with level 0 design, continued by level 1 design, and so on until every level can be implemented using specific hardware.

A. Design Overview

Fig. 2. Level 0 Functional Block of ECG Homecare Device

TABLE III. ECG HOMECARE BLOCK DESCRIPTION

Module	ECG Homecare Device
Input	Heart Voltage (0.01-250 Hz, 0-3 mV)
Output	Serial Data
Function	Conditioning heart voltage (filtering, amplifying, digitizing) to be serial data which is sent to PC or Smartphone

The level 0 block diagram in Fig. 2 is analyzed further and defragmented in level 1 block diagram in Fig. 3.

ECG signal from patient is first tapped using three electrodes for all leads except augmented leads, where we use one additional electrode. Bandpass filter and amplifier are implemented using integrated Analog Front End (AFE) ECG chip. Microcontroller handles the ADC conversion, and bluetooth transmitter/serial cable transmit digital data to smartphone/PC. All system is powered by a 9V battery.

B. Implementation

- Electrode is implemented using gel electrode. Eventhough gel electrode is disposable, it is cheaper and more convenient to use, because no external gel is needed. Another electrode, clamp electrode is more expensive and needs extra gel for good conductivity.
- HC-05 is used for Bluetooth transmission. HC-05 uses Bluetooth version 2.0 Its data speed range from 9600-460800 bps. We choose 10-bit ATMega in Arduino Uno R3 board for the microcontroller. The microcontroller is powered by 9V battery. Connectivity to PC is achieved using Arduino serial cable.
- Bandpass Filter and Amplifier is explained in section C.

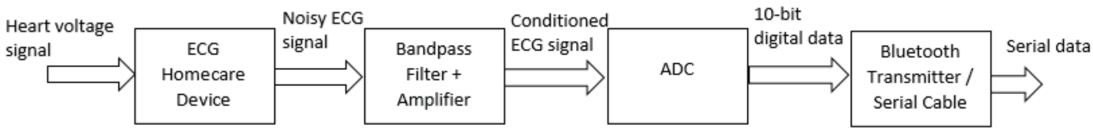


Fig. 3. Level 1 Functional Block of ECG Homecare Device

C. Bandpass Filter and Amplifier

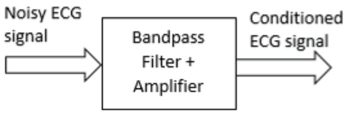


Fig. 4. Level 0 Functional Block of Bandpass Filter + Amplifier

TABLE IV. BANDPASS FILTER + AMPLIFIER BLOCK DESCRIPTION

Module	ECG Homecare Device
Input	Heart Voltage (0.01-250 Hz, 0-3 mV)
Output	ECG Signal 0-3.3 V, 0.5-40 Hz
Function	➢ Filtering high frequency and low frequency component ➢ Provide >1000 V/V voltage gain ➢ Rejecting common mode signal

One of the solution for realizing block in Fig. 4 is using cascade of instrumentation amplifier and operational amplifier. Instrumentation amplifier has DC rejection and differential amplification features, which makes instrumentation amplifier serves the function of highpass active filter. For the second stage, operational amplifier is implemented to achieve lowpass active filter. These design solution is pictured in Fig. 5.

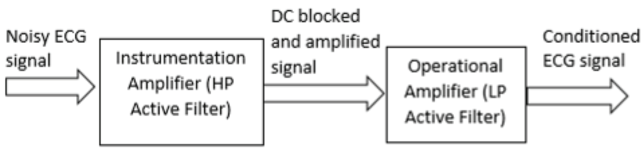


Fig. 5. Level 1 Functional Block of Bandpass Filter + Amplifier

TABLE V. HIGH PASS ACTIVE FILTER BLOCK DESCRIPTION

Module	ECG Homecare Device
Input	Heart Voltage (0.01-250 Hz, 0-3 mV)
Output	ECG Signal 0.5-250 Hz, amplified
Function	➢ DC Blocking ➢ Provide first stage amplification

TABLE VI. LOW PASS ACTIVE FILTER BLOCK DESCRIPTION

Module	ECG Homecare Device
Input	Heart Voltage (0.05-250 Hz, amplified)
Output	ECG Signal 0.5-40 Hz, 0-3.3 V
Function	➢ Low Pass Filtering ➢ Provide second stage amplification

There are a number of available analog front end (AFE) ECG chips available in the market. Comparison of several chip can be seen in Table VII [6,7,8].

TABLE VII. AFE ECG CHIP COMPARISON

Parameter	Chip		
	AD8232	***HM301D***	***ADS1191***
Company	Analog Devices	ST Microelectronics	Texas Instruments
CMRR	80 dB	100 dB	95 dB
Output Impedance	10 GΩ	50 MΩ	100 MΩ
Gain	100 V/V	64 V/V	12 V/V
Feature	Rail to rail output	3-channel ECG	Low noise PGA & high-res ADC
Price	$ 19.95 (board)	$ 125 (evaluation board)	$ 7.96 (chip)

AD8232 is preferred over another chips. HM301D is three channel, while we only need single channel ECG. ADS1191 doesn't provide high enough gain to get good resolution. AD8232 has the best output impedance and gain. The high-pass and lowpass filter designs are available in AD8232 datasheet [6]. For highpass filter, two-pole HPF is used and for lowpass filter, two-pole Sallen-Key LPF is used. Sparkfun^{TM} provides readily available 0.5-40 Hz ECG board with AD8232. We implement the Active Filters using this integrated board.

D. Shield

All the hardware above need to be packed in compact form. A shield is desgined to place all the component together. The shield is stacked right above the Arduino. Battery, Bluetooth, and ECG chip are stacked above the shield. Battery supplies the power to Arduino board while the Arduino 3.3 V output supplies the power to HC-05 and AD8232 (see Fig. 6).

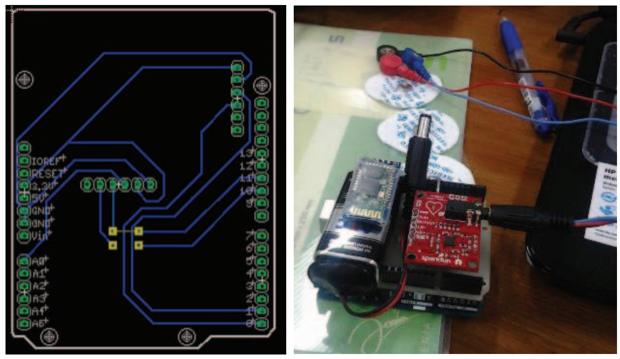


Fig. 6. Left: design of PCB Shield, right: ECG Homecare prototype

E. Software

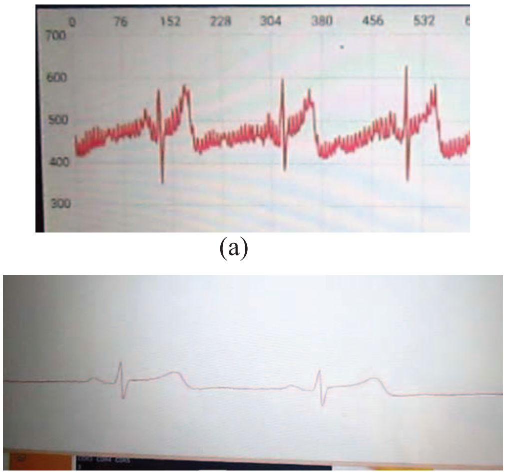
- Arduino IDE is used to program the microcontroller Becaues it has easier languange to implement. The program in microcontroller is used to detect lead and send the data.
- Processing is software on PC. Processing code is used to graph the incoming data and store the data in .txt format along with its timestamp

- Bluetooth Graphics is an apps on Android. Bluetooth graphics display the real-time data and also has capability to log the incoming data.

IV. Testing

A. Wireless and Wired Data Transmission

Wireless data is sent via Bluetooth. Asus™ Zenfone 5 graphs and logs the data using Bluetooth Graphics™ apps. For wireless data transmission, clean signal is difficult to obtain. Wired data transmission results in much clearer signal (see Fig. 7). In wired data transmission, the drawback is the data can become unstable. Faster data corrresponds to shorter recording time.



(a)

(b)

Fig. 7. ECG signal display (a) in Android, (b) in PC

TABLE VIII. Wired Data Transmission Performance

Baud rate (bps)	Data rate (sample / second)	Notes
9600	192	Very stable
14400	288	Data unstable after one minute
19200	365	Data unstable after 42 second Data rate varies from 331-386 sps

B. Comparison with Clinical ECG

The data is transmitted at 19200 bps baud rate. Clinical ECG used to compare the data is Nihon Kohden™ Cardiofax 9620. Nihon Kohden has sample rate 500 sps and bandwidth 0.05-75 Hz, with notch filter on 50 Hz [9]. Data acquistion is carried out while patient is on sleeping position, minimizing motion artifacts. Laptop is not connected to powerline to prevent AC 50 Hz noise. For each subject, 12-lead ECG is taken. Table IX showed the quantitative comparison between data acquired with ECG homecare device and standard device.

TABLE IX. Quantitative Comparison Between Data Acquired With ECG Homecare and Nihon Kohden

Lead		Subject One	Subject Two
I	abs	(0.1117 ± 0.10)	(0.0338 ± 0.05)
	rel	(18.62 ± 17)%	(7.521 ± 11)%
II	abs	(0.5001 ± 0.10)	(0.4592 ± 0.05)
	rel	(20.84 ± 4.2)%	(43.74 ± 4.8)%
III	abs	(0.5978 ± 0.10)	(0.5062 ± 0.05)
	rel	(24.91 ± 4.2)%	(67.50 ± 6.7)%
aVr	abs	(0.1459 ± 0.10)	(0.3076 ± 0.05)
	rel	(11.22 ± 7.7)%	(43.95 ± 7.1)%
aVl	abs	(0.1471 ± 0.10)	(0.2859 ± 0.05)
	rel	(11.31 ± 7.7)%	(95.31 ± 17)%
aVf	abs	(0.6800± 0.10)	(0.5127 ± 0.05)
	rel	(27.20 ± 4.0)%	(60.32 ± 5.9)%
V1	abs	(0.4466 ± 0.10)	(0.7855 ± 0.10)
	rel	(31.90 ± 7.1)%	(41.34 ± 5.3)%
V2	abs	(0.7179 ± 0.10)	(0.4651 ± 0.10)
	rel	(27.61 ± 3.8)%	(16.61 ± 3.6)%
V3	abs	(0.4772 ± 0.10)	(0.2367 ± 0.10)
	rel	(26.51 ± 5.6)%	(8.160 ± 3.4)%
V4	abs	(0.4772 ± 0.10)	(0.4145 ± 0.10)
	rel	(26.51 ± 5.6)%	(18.84 ± 4.55)%
V5	abs	(0.9328 ± 0.10)	(0.2090 ± 0.10)
	rel	(40.56 ± 4.3)%	(9.953 ± 4.8)%
V6	abs	(1.414 ± 0.10)	(0.1586 ± 0.10)
	rel	(64.29 ± 4.5)%	(15.86 ± 10)%

Abs = absolute error (mV), rel = relative error (%)

V. Discussion

Purpose of the design, which is to acquire 12-lead ECG using single channel ECG is fulfilled. Prototype has been made and tested against standard clinical ECG. For most lead on the two subjects, the waveform acquired has similar shape with the standard device (see appendix). For amplitude accuracy, the best that can be achieved is 7 % and the worst is 95 %, with average accuracy 33%. The cable transmission results in clean signal. However, the Bluetooth data transmission need to be debugged to obtain cleaner signal.

The ECG signal obtained by ECG Homecare device are stored as .txt file which is compliant with MIT-BIH standard. The signal can be processed by Java application, which my two laboratory mates are currently making. Processing the 12-lead ECG enables the early detection of various heart abnormalities.

Futher development should concern with the development of low power ECG device that can last long enough for a day. Accuracy needs to be improved. Adjustment of filter bandwidth can be implemented to provide multi purpose portable ECG. Internal memory is useful to store the ECG data when the user doesn't bring along any laptop or Android.

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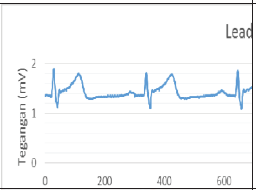
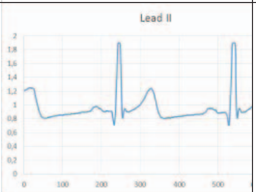
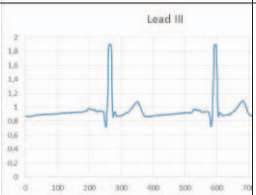
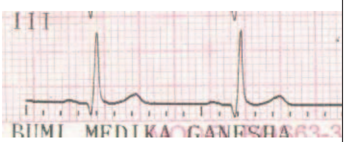
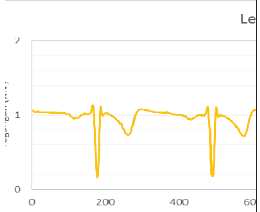
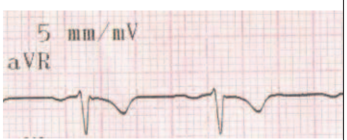
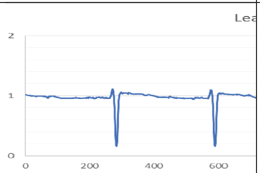
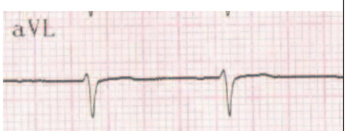
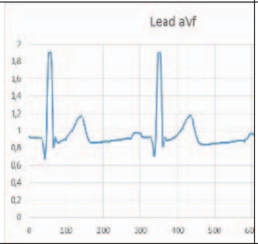
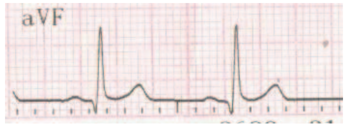
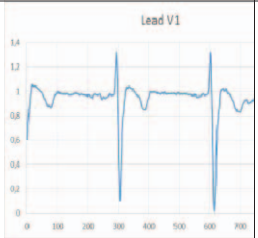
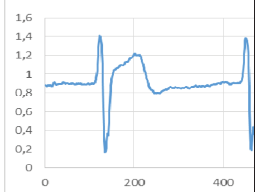
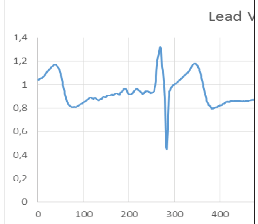
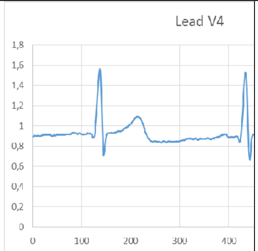
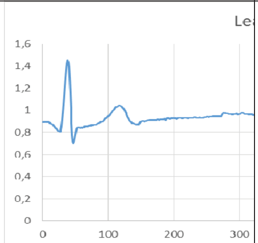
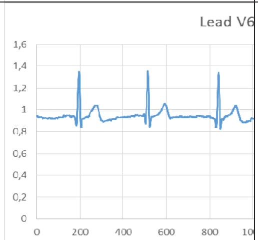
[8] HM301D Datasheet, ST Microelectronics™

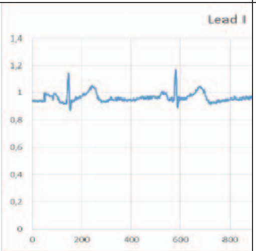
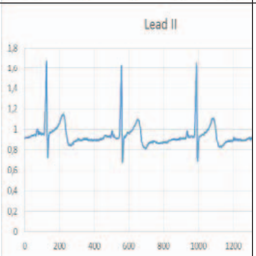
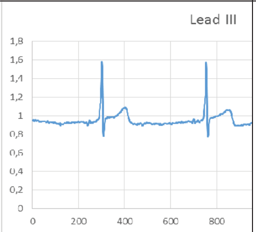
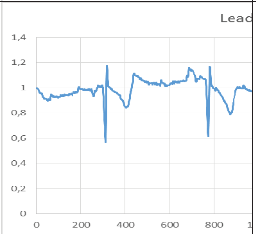
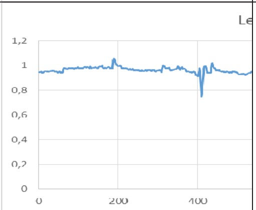
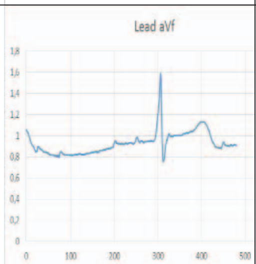
[9] Nihon Kohden Cardiofax 9620 Repair Manual, Japan: Nihon Kohden™

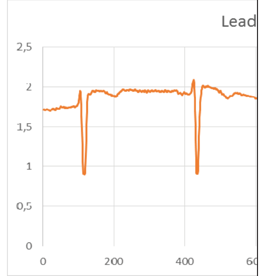
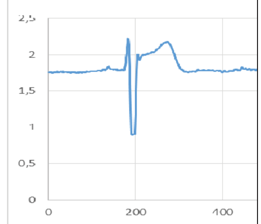
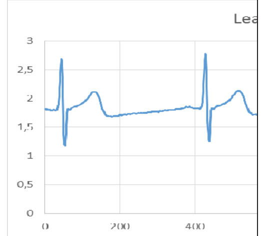
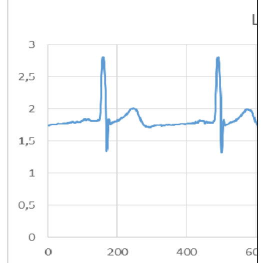
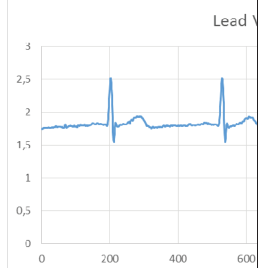
ATTACHMENT

SAMPLE ECG DATA ACQUISTION FOR SUBJECT ONE

Le ad	ECG Homecare	Nihon Kohden
I		
II		
III		
aVr		
aVl		
aVf		
V1		
V2		
V3		
V4		
V5		
V6		

SAMPLE ECG DATA ACQUISTION FOR SUBJECT TWO

Lead	ECG Homecare	Nihon Kohden
I		
II		
III		
aVr		
aVl		
aVf		

Lead	ECG Homecare	Nihon Kohden
V1		
V2		
V3		
V4		
V5		
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