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Biomedical sensor ECG, PPG, and spO2 based on Arduino Which Result from Comparison with Portable

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Biomedical sensor ECG, PPG, and spO2 based on Arduino which result from comparison with portable device

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Abstract. This research is aimed to design a new device as a breakthrough in medical technology using an error correction method with high precision. This method is applied to embrace the high precision of the ECG device. The newly designed device is compared to the existing portable device. The portable device is proposed in this research in which results in an error correction as an output of Arduino software. The sample needed is 15 people for men or women with age of 18-73 years old. The number of the sample doesn't meet the requirement due to the Covid-19 pandemic situation. We can use a cheap sensor AD8232, Max30102, and pulse sensor based on heartbeat rate as a module with Arduino uno and pro mini for ECG and PPG graphs. The application pulse sensor like Max30102 for commonly made together within Heart Rate and saturation oxygen, mostly used in hospitals. We need an Arduino software to operate this program and Arduino uno or pro mini as an MCU with an ECG module sensor integrated with FTDI using PCB. For PPG sensor Arduino uno and 2 module sensors are used. PCB is connected by a jumper between pin FTDI and Arduino Pro mini. Arduino pro mini and AD8232 are fixed to PCB that uses a female header. The header requires to be soldered with the wires. The electrode patch single lead sensor AD8232 attach in 3 points that are known as the Einthoven triangle. PPG sensor had fixed PCB and use a jumper for connection between pin Arduino and module pulse.

Keywords: ECG (Electrocardiograph) and PPG (Photoplethysmograph) device, portable device, error correction, Arduino uno and pro mini, the electrical activity of heart, Single Lead Sensor AD8232, FTDI device, Max30102, Einthoven Triangle, Electrode patch, PCB.

I. Introduction

The first ECG had an invention from Willem Einthoven making Standard Limb lead (Bipolar) which using a dog with name jimmy. This invention made the opportunity to develop this ECG Sensor at a low cost. The electrical activity of the heart can detect with this is the device. We make error correction for measuring electrical activity in the heart by using a hospital device. Because we know electrical activity can be charted as an Electrocardiogram.[1] But we have many problems, in humans also called interferences and in a device is noise.

We must know the meaning of pulse which application in Electromyograph (EMG), Electroencephalograph (EEG), and Photoplethysmograph (PPG). In my mind, I think that a heart rate is the same with pulse rate if no blockage and pulse rate is so different in which the value of pulse rate can be different with pulse rate.

We must know the way of blood flow from the heart to the body system and lungs. System respiratory in human have many parameters except one is saturation oxygen (SpO2) using module heartbeat sensor Max30102 that measure blood volume changes in the artery and venous. We know oxygen has much amount that supports lung in the cardiovascular system and respiratory. Why we must know these systems because the cardiovascular system has a higher correlation with the respiratory system than the body system on an internal organ. The correlation between blood and body system also called blood pressure. It is an important parameter in knowing that system and organ in the body can work functionalities appropriate with very good mechanisms every internal organ. We know about heart disease, stroke, diabetes, and patients need transplantation organs must need these indicators. Based on journal IEEE about robust PPG for fitness and e-health application has 2 component these are DC and AC. DC component explains about average blood volume in arterial and venous. AC talks about blood volume change represent a pulsatile physiological waveform attributed cardiac rhythm.[2]

PPG is most often employs non-invasively and operates at a red or infrared wavelength. And waveform is graph pulsatile components of AC. The most recognized waveform feature is the peripheral pulse and it was synchronized to each heartbeat. The shorter wavelength of light is also strongly absorbed by melanin. PPG signal magnitude is affected by melanin concentration of the skin or skin pigments.[3]

A. Objectives

The objective of this research is to easily incorporate live ECG graph data and design the PCB circuit using a heartbeat sensor like AD8232 and Max30102 based on Arduino. Using the AD8232 single lead sensor, maybe we can find is a breakthrough for ECG with good precision and accuracy.

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[1]CaseytheRobot. *AD8232 Heart Rate Monitor Hookup guide,* Sparkfun.

[2] Shokrekhodaei, Maryamsadat. et al. 2018. *A robust PPG-Based Heart Rate Monitor for fitness and e-health Application*, IEEE, 1

[3] Chen, Ian, *Using Reflectometry for A PPG Waveform*, Maxim Integrated

We know the blood whose heart was adjusted by the pump into the internal organ and to the lung. Which that many systems like respiration that include with a brain as a controller. These mechanisms, will not be detailed explained because we are focusing these devices for monitoring actually cardiovascular system problems could be a heart attack that will be a serious matter. We must be controlled BP without error and with tenacity, undoubtedly alert risk of an impact these diseases will be reducing.

I hope this research would have been giving a good design and the problem could be handle. However, this device could be sold to the governance at a low cost and it is might be used by institutional health. To make a device simple low cost and good accuracy is a goal of the study. From these assemble, we have a lot of problems like noise and disturbances. Noise for these devices like a graph ECG cannot describe P, Q, R, S, and T point.

B. Literature/theory support

1. ECG

The initial working activities in atrial and ventricle between left and right at the same time working together. Sino-Atrial (SA) node consists of AV node, bundle His, and Purkinje fibers as a trigger electrical and regulates muscle contraction and so pacemaker that responsibility for heart rhythm. The right ventricle begins to pump deoxygenated blood into the lungs through the left and right artery pulmonary. The pulmonary arteries are carrying deoxygenated blood.[1] They are still called arteries because arteries carry blood away from the heart.[1] The left ventricle is also beginning to pump freshly oxygenated blood through the aorta and into the organ of the body. Vena cava superior and inferior are carrying poor oxygen otherwise with vena pulmonary carry rich-blood oxygen. The work principles are The ECG must be able to detect not only strong signals AC component from 0V -5.0 V but also a DC component from 0-1023 mV (resulting from the electrode-skin contact) We put in 3 points such as RA (Right Arm), LA (Left Arm), RL (Right Leg) because electrical activity in heart can measure and hold into triangle Einthoven in the body.

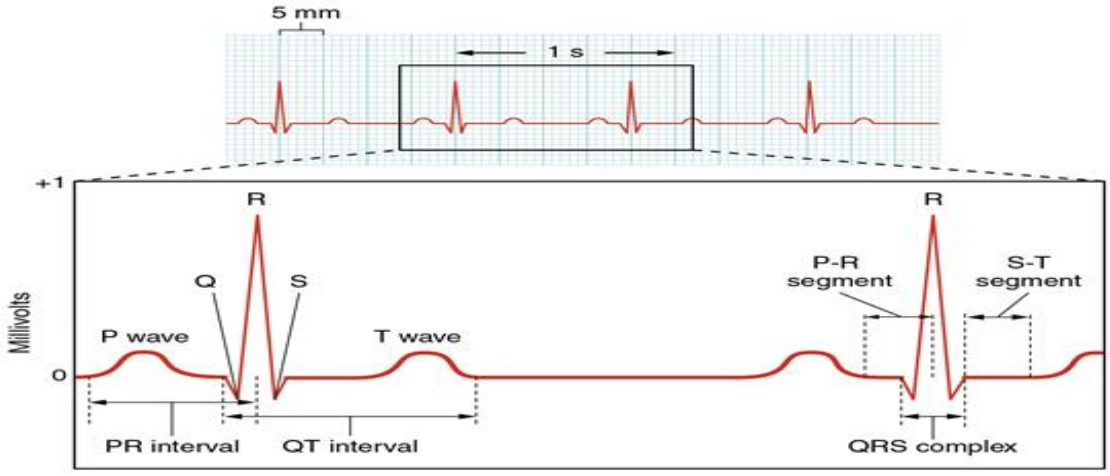

Fig 1. ECG graph for a normal person.

Based on the figure is mechanism electrical activity of the heart divided into 3 segments and 3 waves for electrical activity of the heart. Now we only discuss 2 interval PR and QT intervals. Because it both a critical element, PR interval talk about an electrical impulse traveling from the right atrium to the left.[1]

This is the initial mechanism of the heart. The QRS is a complex process that generates the signature "beep" in cardiac monitors. During QRS both ventricles began to pump. Right, and left ventricle circulate blood to lung and internal organ of the body system by using artery pulmonary and aorta. Aorta had been called the biggest artery. This electrical impulse causes the chambers to "depolarize". As the electrical impulse travels across the top of the heart it then triggers the left atrium to contract. They are still called veins because veins carry blood towards the heart.[1]

After the initial contraction comes to the ST segment. The ST segment is fairly quiet electrically as it is the time where the ventricle waiting to be "re-polarized". Finally, the T wave relaxation phase resets the ventricles to be filled again by the atriums.

I know that sensor AD8232 has six pins they are GND, 3,3V, OUTPUT, LO+, LO- and the last SDN or shutdown. Pin SDN does not use because it is a protocol using for standby.[4] LO is usually known as LOD that means Lead off Detection. It is marked with electrode red and yellow where red means LO- and yellow means LO+ and the third electrode with green color means Ground (GND). The Source of voltage for this ECG sensor is 3,3V. The OUTPUT Pin in this device is using Fast Restore (FR) function to

[1] Ibit

[4] Data sheet, 2012~2018, *Single-lead Heart rate Monitor Front End*, AnalogDevices.

reduce the duration of uploading, give ECG graph within Analog-Digital Converter (ADC) the real-time measure can happen using this sensor.

2. PPG

Before we are using this sensor, we must know about the best places to find your pulse that are in wrist, elbow, neck, and top of the foot.[5] However, in a hospital or medical institution, this sensor device is using in fingertip or earlobe. PPG makes uses of high frequency with low intensity for red and infrared (IR) light. When light travels through biological tissues it is absorbed by bones, skin pigments, and both venous and arterial blood.[6]

To measure saturation oxygen you must know hemoglobin that divided into 2, these are HBO (Rich of Oxygen) and Hb (Poor of oxygen). Two light sources could be an option using red light (660 nm) and Infrared light (940 nm). The principle work for this device using absorb and reflect, if Oxygenated Hemoglobin absorbed by infrared light and red light reflect. And if non-oxygenated Hemoglobin absorbed by red light and reflect the infrared (IR) light.

For the Max30102 saturation oxygen sensor that measured (reflected) light induces a current in the photodiode covert to a voltage by the trans-impedance amplifier that designed with to be stable over wide range frequencies that means when noise must be filtering.[7]

Max30102 could measure heart rate and spO2 in one measurement. The photodiode will detect the reflected light otherwise absorbed by hemoglobin that needs to be used to determine the oxygen levels. We can conclude will be absorbing or reflect with the DC component and Syncronized with the AC component.

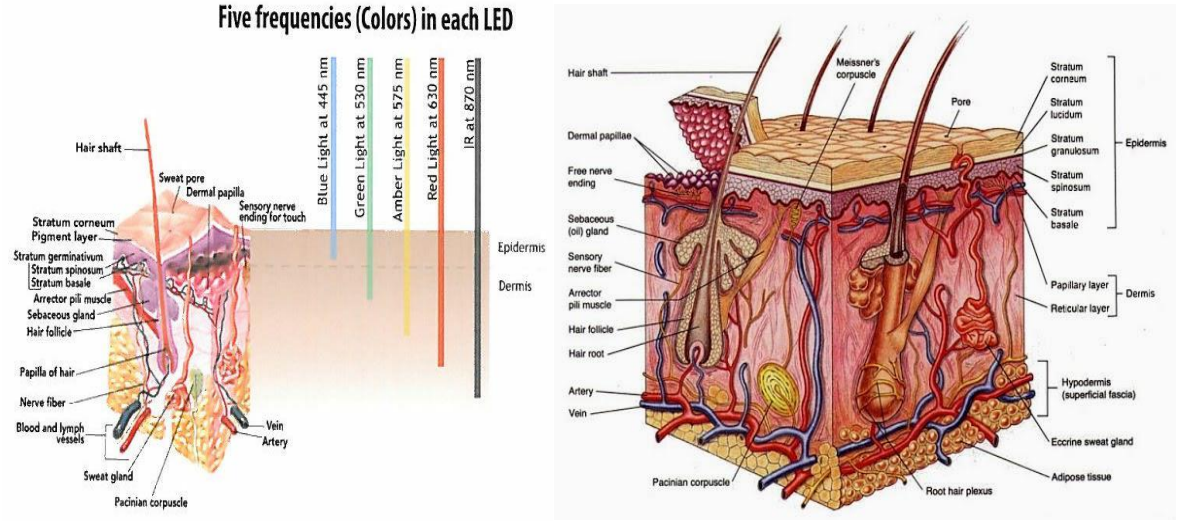

Fig 2. 5 LED colour deep penetration sensor and The detail component of skin tissue

A PPG signal has several components including volumetric changes in arterial blood that used in cardiac activity. Variations blood volume can be detected in venous using PPG signal modulation that showing the tissue and deep penetration sensor LED color, look at the figure above.

II. Material and Method

1) Arduino pro mini,
2) Software Arduino,
3) FTDI FT232RL,
4) Sensor AD8232 ECG
5) Mini-B USB cable,
6) Printed Circuit Board,
7) Electrode patch,
8) Cable jumper and
9) Laptop

[5] AHA team, 2015, *All About Heart Rate (Pulse),* American Heart Association.

[6] Cheriyadath, Susha, 2019, *Photoplethysmography (PPG)*, News Medical Life Science.

[7] Wanneburg, Johan., Malekian, Reza, 2015, *Body Sensor Network for Mobile health Monitoring, a Diagnosis and Anticipating System*, IEEE, 2

We choose Arduino as a microcontroller because this is integration with a laptop. Arduino easy to use and best creative for this research using biomedical sensor ECG, PPG, and spO2. We are using Arduino pro mini for ECG sensor because more sophisticated with nano-size but the performance is very good. But the weakness is always troublesome like troubleshooting when uploading using Arduino IDE and follow the step is complicated enough like connecting with FTDI and bootloader processing. The electrodes of the ECG sensor will conversion heartbeat to the electric signal. ECG Sensors are very lightweight, slim, and accurately to measures continuous heartbeat and give rate data of heartbeat. Wire or jumper must be used to connecting MCU and sensor. For my device, I using PCB to change breadboard and to connecting between pin using a thin wire with soldering in away from left to right or otherwise. The technique must be connecting Arduino pro mini and FTDI. By using N58 we use 2 electrode in the bottom device and touch with 2 finger, thumb and fore finger on the circle smartwatch, don't touch the hand with the device. Because electrode on the smartwatch as a ground. Thus, N58 is accurate ECG calculator for Smartwatch.[8]

1) Connection Arduino pro mini with :

- FTDI FT232RL
  - Arduino DTR-------DTR
  - Arduino GND-------CTS
  - Arduino VCC-----3.3V can switch to 5V
  - Arduino RXI--------TXO
  - Arduino TXO-------RXI
  - Arduino GND------GND

- Sensor ECG AD8232
  - Arduino VCC --------- 3.3V pin through (+) pin in breadboard using jumper
  - Arduino pin 10 -------- L0+ Arduino Pin 11 -------- L0-
  - Arduino Analog 0 (A0) ------- Output
  - Arduino GND ---------- GND

Fig 3. ECG sensor device with PCB circuit

2). Sensor pad placement,

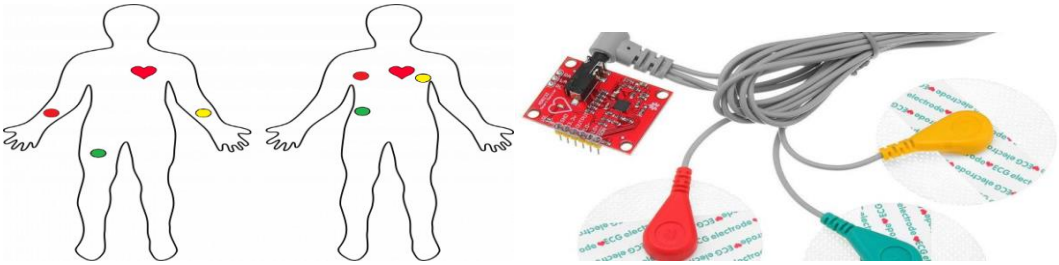

Fig. 4 Electrode pad and module AD8232 placement in the body

3). Connection USB cable type mini-B to laptop with FTDI as a power source plug and entry data for the sketch that connects a PCB and module that read with the Arduino program. **The initial step uses the Arduino IDE,** verify is usually for this step have no problem also give the command "Done Compiling". It is enough to connect it to the computer USB port and the next step is to press the "Upload" icon to start a process that transfers your sketch into the Flash memory of the microcontroller.[9]

The open-source software tool used to program the microcontroller is avrdude. For the Initial phase for this module that FTDI gives red light and Pro mini have green and red blink on L pin. The next step chooses the board and number port that connects with the laptop in the tool menu Arduino IDE. For pro mini choose processor which has been using in this device. If the step complete you can follow the next step in the tools menu choose a serial monitor to see ADC data and serial plotter to see ECG or PPG graph. LED for connection between FTDI and Arduino must be communicated. If you have a problem the device can't be uploading after step verifies that command "error uploading sketch" you must choose bootloader is pro mini (target) and using Uno as a programmer.

To program the bootloader and provide to the microcontroller the compatibility you need to use sketch an In-circuit Serial Programmer (ISP) on file>>example>> choose Arduino IP with the Arduino Software (IDE) then uploading. The process new bootloader goes through four steps: setting board and port that convenient to set up uno using the sketch as ISP, Connect the two devices that is pro mini (target) and Uno (programmer), Burn to the bootloader on tools menu that using pro mini as a board with processor ATmega328P (3.3V, 8Mhz) and the port is same which Arduino uno) and the last test uploading using your FTDI

[8] Team SmartwatchSpace, 2020, *8 best smartwatch with built in ECG sensors*, SmartwatchSpace, 4

[9] SM, 2018, *Arduino as ISP and Arduino Bootloaders*, Arduino.

programmer that using a sketch. If the new bootloader was working, you should see the LED on the FTDI and pro mini showing activity.[10]

PPG is similar to using Arduino but we were using with more sensor modules and less connection pin. Arduino uno, Max30102 (SpO2), and pulse sensor had been using for this research. In the first step, we must bur PCB using a mini drill and make a hole that appropriates with pin Arduino Uno. Next, insert Arduino uno on PCB board and fixed, after that solder a pinhole done, use glue to pulse sensor and attached this. The last step is to fix the cable jumper using the tape to make simple and portable which means integrated with Arduino uno. Follow the instruction from the website:

- Pin S (signal) to digital pin A0 from Arduino uno.
- Pin +(supply) to 3.3V or 5V pin Arduino uno
- Pin - to ground pin Arduino uno

Fig. 5 Pulse sensor with 3 Pin and pulse oximeter Max30102 integrated with PCB circuit

We can make a PPG graph using this is sensor by using serial plotter in Arduino IDE. The price is cheap and tiny size so that the accuracy of the pulse activity more questionable got those. Which similar use Max30102 for measure spO2 and Heart Rate. We spent only 5 $ for these are devices. But this is device have defect would have been using without resistor. Resistor function to connecting power supply (Vin) to pin SCL and SDA.

III. RESULT

These sensors will have tests by cardiologists and health institutions about precision and functionalities. Would it have been using for monitoring or more sophisticated for diagnosis cardiovascular disease it would be more question for an expert? From my research find any problem there are troubleshooting from Arduino software have about 15%. Stability device performance takes a large portion of about 35%. Noise and interference take 50% divided 25 %, respectively. But if you want to make these prototype device you must involve experience people in the electronics field like in my research. I was helped by a friend who has an expert with Arduino to advise about my device, like short in electronic circuits and adjusts the ECG graph using coding. When the detection signal usually they have frequency noise signal 60 Hz distribution should be decrease and possible to divided become three electrodes. When electrode number 3 becomes ground so that the frequency signal separate and electrical signal could be stream until the last electrode making "Einthoven Triangle."

Architecture processor powered by ATmega328 P with a source of voltage 3,3V, 8 MHz, and a bit rate of 57600 (ATmega328P). Software Arduino IDE measures Analog-Digital Converter (ADC) data by serial monitor and ECG graph on the serial plotter. If using a sketch code must need High pass filtering to remove much noise. This filter is an indication for the ECG graph signal because the beginning path form for ECG is similarly using a high pass filter. These filter functions to normalization vertical. We comparison with a portable device like Smartwatch N58 which there are similar with a single lead sensor, by using three-electrode.

Fig. 6 Comparison working principle of ECG Single lead with using smartwatch

[10] Legandir in Circuit, 2016, *Burn a New Bootloader – Arduino Pro Mini*, Instructable circuit.

Fig. 6 indicated that the electrical signal can be transmitted from positive to negative which LL is positive to be ground. For delay, we make 35 and for measure BPM we use formula 300/number R-R peak interval (with big square) for regular rate and for irregular rate because we only using 4 s the formula is the number of R interval *3/2 (the formula using 6 s) *10. The technology consists of MCU using AVR originate from Atmel processor like a microchip and completing with stk500 as a starter kit. The connection is guaranteed with a baud rate of 9600 (software Arduino IDE).1 Processing Data output must be needed PLXDAQ software for analysis data quantitative data. That means the capacity of memory can save 8 bit ECG signals with frequency sampling 8000 Hz. For serial communication using SPI (Serial Peripheral Interface) to control the digital-to-analog ECG data conversion that can be evidenced with 8 bit D/A converter (AD8232-analog device). We using delay 35 that these protocols are matching that 1000/35, that means all 28 test every 1 second and we are uploading the coding or sketch in next my proposal thesis.

We choose these devices as a comparison because the accuracy is very good and the ECG graph pattern shows the activity of P, Q, R, S, and T point. From figure bottom, we could read that peak signal reaches to 600mv with minimum ECG signal reach 350mv as analog data received from ECG sensor AD8232. I use N58 as a comparison for my sensor AD8232 device, we can look at the bottom that box appears is N58 and no box AD8232. But the sampling same that measure for 4 seconds, which means I crop picture ECG graph and compare with sensor ECG AD8232 from up to down and Smartwatch N58 ECG as references my study.

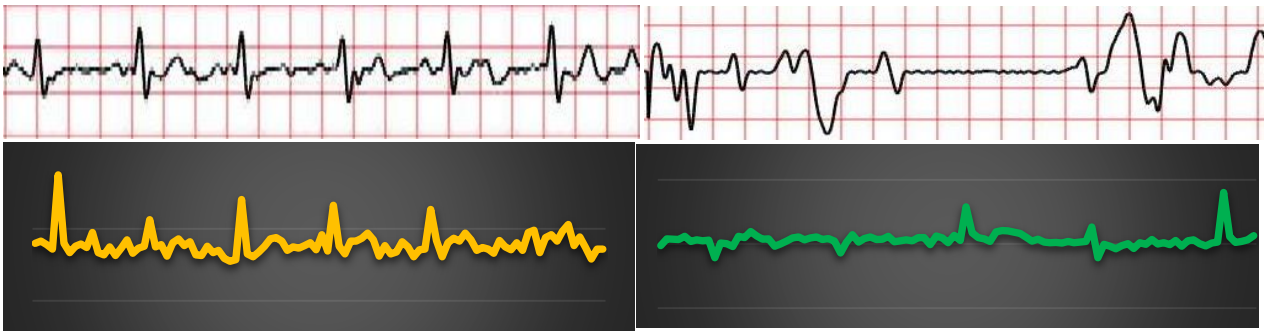

Fig.7 my ECG graph (Left) with regular rate: 98 bpm and my mother ECG graph (Right) with irregular rate: 77 bpm

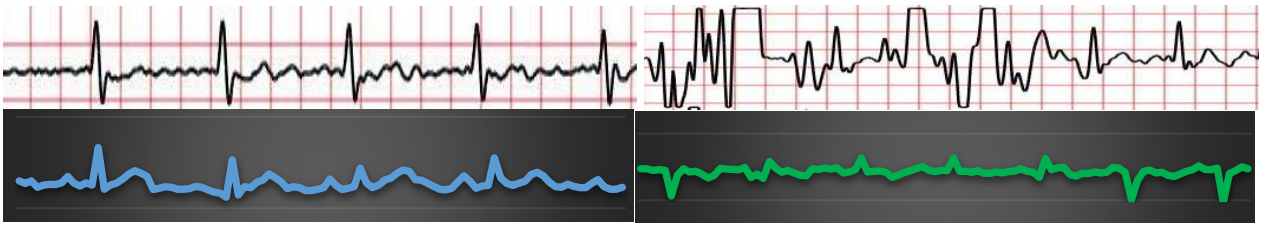

Fig. 8 my father ECG graph (left), regular rate: 75 bpm and old woman (right) 55 years with irregular rate: 108 bpm

From the above figure for regular rate and rhythm have an appropriate ECG graph using N58 and sensor AD8232, but for an irregular rate less appropriated (fig.7) and can't appropriate (fig.8), we can see the deflection of the graph. It was caused by the old age to make an electrical condition changes or the fast heartbeat for this patient to make the health and mental load easy to change and make ECG graph with irregular rate tend of change.

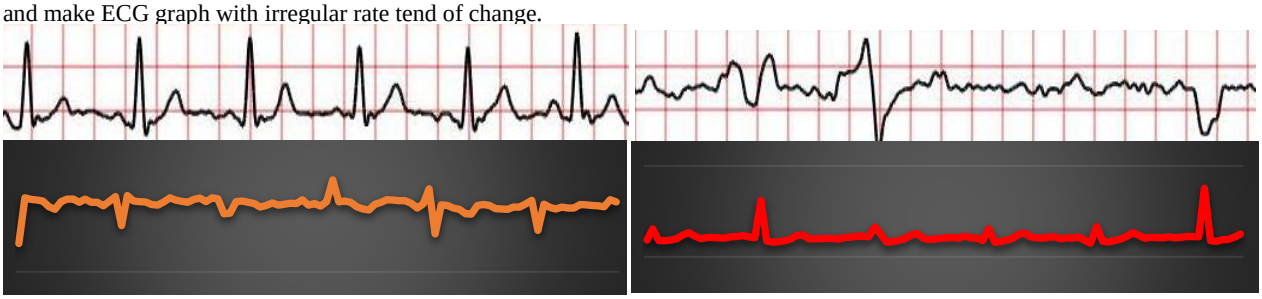

Fig. 9 43 years old woman (left) with obesity, 120 kg & 98 bpm and 33 years old man with an active smoker, irregular rate:85 bpm

In fig. 9 have a regular rate using N58 for an old woman but using sensor AD8232 looked deflection peak comparison with N58 that have six R-peak graphs the same and contrast for a man with active smokers which different result between N58 and AD8232 but have R-R interval same six peaks with deflection. Fig. 9 have a different height graph as a bioelectric signal and the same peak time.

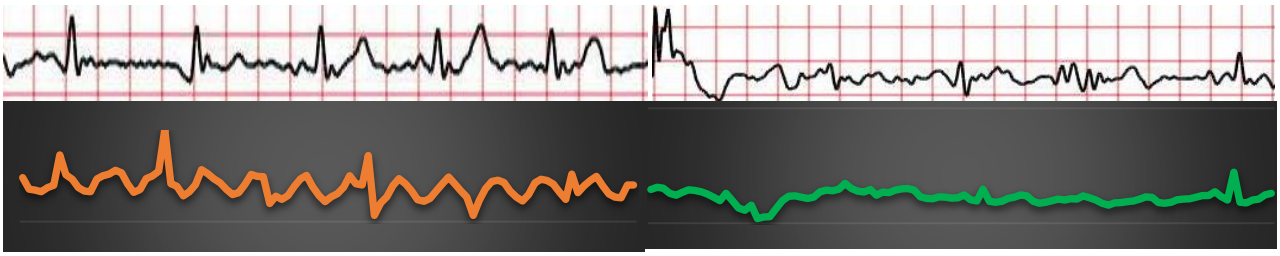

Fig. 10 31 years old woman with ST-elevation, irregular rate: 84 bpm and 18 years old boy (right) with irregular rate: 72 bpm

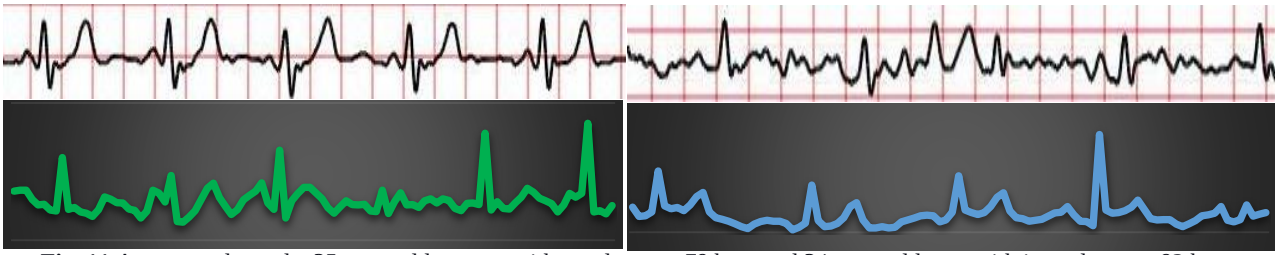

Fig. 11 An engaged couple, 35 years old woman with regular rate: 79 bpm and 34 years old man with irregular rate: 92 bpm

Fig. 10 and 11 for woman patients we look that ST-segment elevation called STEMI by using N58, fig. 10 have irregular rate because of ST-segment elevation that taller than R-peak ECG graph 31 years old woman. But for fig. 11 regulars because of the rhythm same otherwise ST elevation. For man patients in fig. 10 the electrical activity detection is so small and tend of the flat by using sensor AD8232, so that for man patient in fig. 11 have a risk of cardiovascular disease with every point on PQRST excepting R have abnormal graphs by using N58 because his mother has recorded cardiovascular disease and died by myocardial infarction or heart attack.

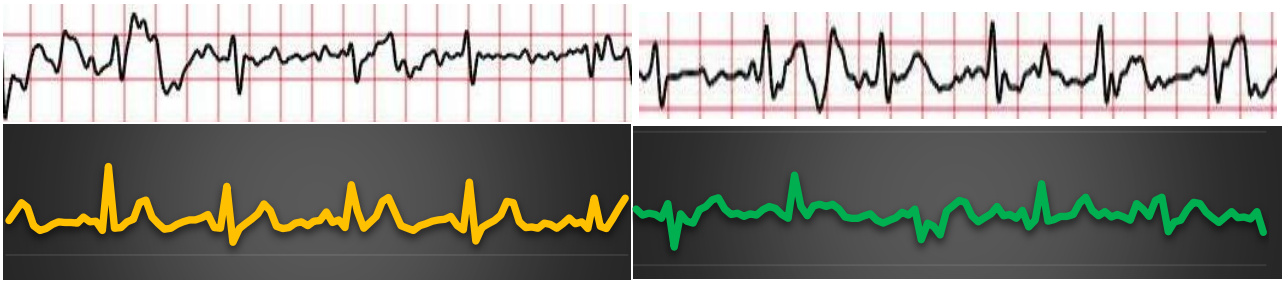

Fig. 12 52 years old man regular rate: 85 bpm by using Sensor AD8232 and 28 years old man with irregular rate: 89 bpm

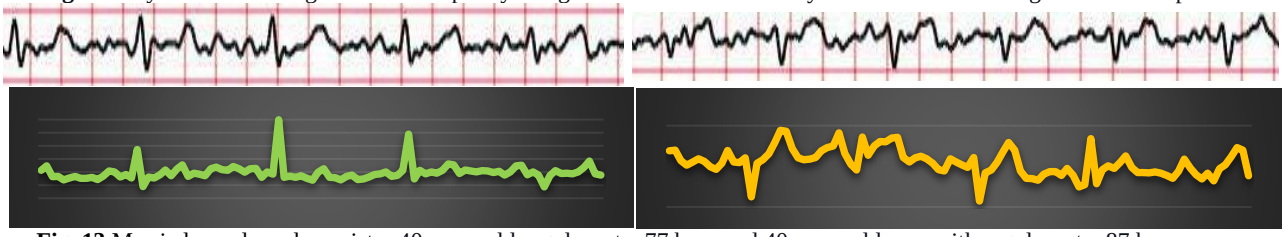

Fig. 13 Married couple and my sister 40 years old regular rate: 77 bpm and 40 years old man with regular rate: 87 bpm

In fig. 12 and 13 for we found the difference rhythm between use N58 and AD8232 ECG sensor, only my sister graph on fig. 13 has a similar measurement using both devices. But the other has a negative R point for my sister's husband it is influencing R-peak to become negative and the number is not similar by N58 6 R-peak and AD8232 only 5 R-peak. On fig. 12 we found that 28 years old have irregular rhythm but a moving line about voltage and time has similarity only the tall and long line different but the pattern may be the same. We could make a study for fig.12 old man (52 years), why on AD8232 have a regular pattern but using Smartwatch irregular? The answer is age and fixes smartwatch to the left-hand influence when using N58 but the pattern is similar with 5 R-peak.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
N58	**98**	**77**	**75**	**108**	**98**	**85**	**84**	**72**	**79**	**92**	**85**	**89**	**77**	**87**	**81**	**76**
Arduino	**62**	**89**	**68**	**100**	**79**	**93**	**95**	**63**	**33**	**91**	**76**	**85**	**93**	**85**	**76**	**86**

Tabel 1. Comparison Heart rate between use N58 and PPG sensor-based Arduino, number 16 patient (columns) and device (row)

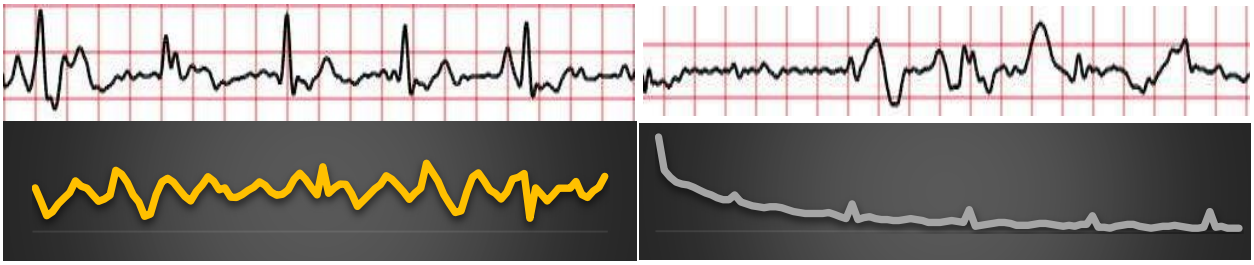

Fig. 14 35 years old woman with cardiovascular disease history with regular rate: 81 bpm and 34 years old man with irregular rate: 76 bpm

From fig.14 found that woman patients have medical history but the rhythm is normal, by using sensor AD8232 if you reading the woman this graph a condition like MI or heart attack with R-peak and no flat for P and T wave. And the last patient man with healthy status has a very good rhythm but when I collected to test the device had been declining performance so the graph sees in fig. 14 with a grey line. Otherwise, by using N58 the ECG graph has a problem with a flat point, we can look in the initial phase.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Max30102	98	98	79	100	91	100	98	100	98	99	97	90	99	98	98	99

Tabel 2. Saturation oxygen using sensor spO2 Max30102

IV. CONCLUSION

Only one old woman patient have fast Heart rate and must be detected with N58 ECG Smartwatch, we have 16 patient for a research study that divided 9 men and 7 women. We must know that using Smartwatch by the left hand and AD8232 3 electrode without a single lead sensor that means we have only 1 graph but different if we use ECG hospital with could be knowing the position a defect in cardiovascular by the position of heart respectively. Before, I only choose 1 test from AD8232 within 5 tests that similar to the N58 ECG graph for analysis rhythm, R-peak for measure beats per minute (bpm), ST-segment, and error correction. With these protocols, we found that the rhythm detected and only the millennial boy find that detected bioelectric in the heart is so small. From these studies, we conclude that we can read the ECG graph if we know the error correction every patient and every BPM. Error correction for my device compare with ECG Smartwatch found that tall for R-peak is the difference with N58 and the P wave could not appear but for Q wave and ST-segment could be read. Many errors found that R-peak negative found with my device and the result is so different from common R-peak, but these problems solve by using my lecture device. The last man for the patient measuring to use AD8232 doesn't accurate because the durability of the device not good so need soldering on PCB circuit pin output of AD8232. Many risk factors such as obesity, smokers, and age make detection of the graph so differences such as R point negative or small detected. Maybe in the future, we will have to make software using a simple electrode and easy point of pulse in finger hand or foot. In the Table above we found that my PPG device has less bottom value than N58 with high value overall. For the PPG sensor, we would have been making error correction for these values. For pulse oximeter, we could not compare with hospital device because pandemic COVID-19 maybe next proposal thesis we attached that. But if you want to know Max30102 spO2 saturation oxygen the result on the table above..

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