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Prototype of Portable Heart Monitoring System using BITalino

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ABSTRAK

Jantung adalah organ vital yang menuntut perhatian khusus, terutama untuk orang dengan resiko serangan jantung. Bagi orang kategori ini, diperlukan detektor detak jantung yang bekerja secara kontinu dan real-time yang dapat mendeteksi adanya gangguan jantung secara dini. Pada penelitian ini, penulis mengajukan prototipe sistem monitoring jantung portable (PSMJP) dengan menggunakan modul bio-signal BITalino. Hasil pengukuran diproses pada perangkat komputer yang terhubung dengan BITalino melalui transmisi Bluetooth. Suatu program pemroses sinyal dirancang dengan menggunakan Algorithma Hamilton. Tingkat keberhasilan deteksi pada pengujian terhadap sampel EKG mentah dan pengukuran EKG mentah adalah 100%. PSMJP diujikan kepada 15 naracoba untuk kondisi duduk dan kondisi berjalan. PSMJP berfungsi baik pada 29 dari 30 pengukuran, dimana sinyal elektrik dari jantung terbukti dapat diproses dan memberikan hasil akhir berupa fitur-fitur gelombang detak jantung dan laju detak jantung.

Kata kunci*: denyut jantung, algoritma Hamilton, BITalino, EKG*

ABSTRACT

The heart is a vital organ that requires special attention, especially for people with heart attack risk. For people of this category, a heart rate detector that works continuously and in real-time is needed so that heart problems can be detected. In this study, the authors proposed a prototype of a portable heart monitoring system (PPHMS) using the BITalino bio-signal module. The measurement results are processed on a computer device connected to BITalino via Bluetooth transmission. A signal processing program was designed using Hamilton Algorithm. The detection success rate on testing for a raw ECG sample and raw ECG measurement was 100 %. PPHMS was tested on 15 subjects for sitting conditions and walking conditions. PPHMS works well in 29 of the 30 measurements, where electrical signals from the heart are proven to be successfully processed. The final results in the form of heart wave features and heart rate can be provided.

Keywords*: heart rate, Hamilton Algorithm, BITalino, ECG*

1. INTRODUCTION

Health is one of the important aspects that decide the life quality. One of the human's vital organs is the heart. Based on the data of the Ministry of Health, Republic of Indonesia, on Basic Health Research 2018 **(Kementerian Kesehatan, 2019)**, cardiovascular disease is the number one cause of death in Indonesia, followed by diabetes, stroke, and rheumatic diseases. According to the research, the all-ages prevalence of cardiovascular diseases is 1.5%. Here, cardiovascular disease is defined as a disease caused by impaired functioning of the heart and its blood vessels.

There are a number of cardiovascular diseases such as coronary heart disease, heart arrhythmias, heart failure, heart valve disease, heart muscle disease, peripheral arterial disease, and aortic disease. The most commonly occurring is coronary heart disease.

Cardiac arrhythmia is irregular heart rhythm, whether beating too fast or too slow. In many cases, heart arrhythmia may be harmless. However, if the irregularity is high or the cause is a weak or damaged heart, it may lead to severe and potentially fatal symptoms and complications. The usual heart rate is 60 to 100 beats per minute (bpm). If the heart rate is less than 40 bpm or more than 150 bpm, this indicates an abnormality and thus an arrhythmia is indicated **(Stroobandt, Barold, & Sinnaeve, 2016)**.

The picture of the human heart can be seen in Figure 1. The upper parts of the heart chambers are called the right atrium and the left atrium. The lower parts of the heart chambers are called the right ventricle and the right ventricle.

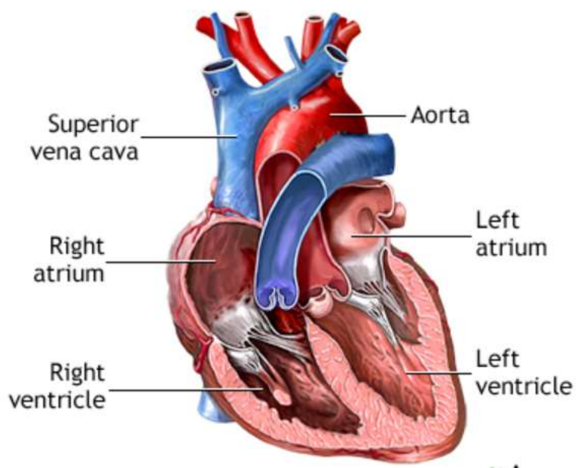


Figure 1. The Diagram of the Human Heart (Dugdale, 2020)

A heartbeat can be sensed by a set of electrodes, known also as leads. The electrodes convert the heartbeat into electrical signals. The recorded heart's electrical activity as the function of time is called an electrocardiogram (ECG). The frequency range of an ECG signal is between 0.05 Hz and 100 Hz. Its electrical dynamic range is between 1 mV and 10 mV **(Stroobandt, Barold, & Sinnaeve, 2016)**. Based on the ECG, the duration and the shape of the waves can be measured and evaluated, in order to decide whether the heart is in normal condition or irregular condition. The duration of the captured electrical activity of the heart muscle helps to show whether some part of the heart is abnormally expanding or whether the heart is fatigued.

A typical shape of the ECG signal is shown in Figure 2. The signal is characterized by five maximum and minimum peaks, represented by the letters P, Q, R, S, and T. The intervals between peaks are called *heart wave features*. These features are useful to understand the heart activity at a certain heartbeat phase which involves the atriums and the ventricles at a certain rhythm. A feature can be between two identical peaks (such as RR-interval or TT-interval) or involve two or more different peaks (PR-interval or QRS-interval/complex). The horizontal part of the waveform after the T-wave and before the P-wave is commonly referred to as the baseline or isoelectric line. P-wave, QRS-complex, and T-wave reflect the electrical rhythmic depolarization and repolarization of the myocardium (muscular layer of the heart) associated with the atrial and ventricular contractions and expansions. The P-wave represents atrial depolarization. The QRS-complex represents the combination between atrial repolarization and ventricular depolarization, which occur almost simultaneously. Finally, the T-wave represents ventricular repolarization.

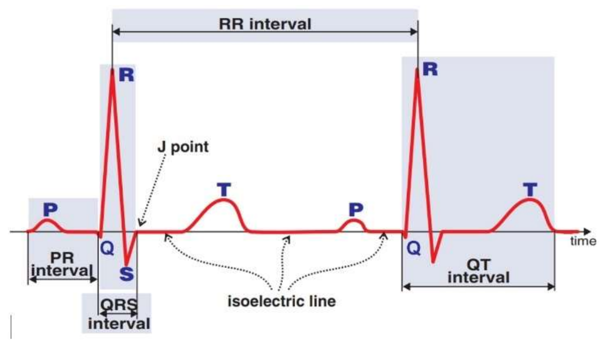


Figure 2. Two Consecutive Typical ECG Signals
(Stroobandt, Barrold, & Sinnaeve, 2016)

The accuracy of heart diagnostic is based on how accurate and how reliable the QRS-complex and the T- and P-waves can be detected **(Hossain, et al, 2019)**. Furthermore, in practice, QRS-interval detection is one of the fundamental problems in automatic ECG signal analysis **(Heryan, et al, 2021)**. Besides, other useful features of the signal are the PR-interval, QT-interval, and RR-interval. After the QRS-interval has been evaluated, a thorough examination of the ECG signal can be carried out. The shape, the amplitude, and the duration of the QRS-interval are very helpful in diagnosing heart diseases such as cardiac arrhythmias, conduction abnormalities, ventricular hypertrophy, and myocardial infections **(Zago, et al, 2015)**.

The importance of the heart leads to the importance of its monitoring, especially for people who are at risk of a heart attack. Other studies have been carried out on health monitoring, for general purposes such as in **(Wei, Park, and Lee, 2019)** and **(Ali, Alyasseri, & Abduhmonson, 2018)**, or for military purposes such as in **(Gondalia, et al, 2018)**. The study of **(Ganesh, 2019)** proposed a system with a pulse rate sensor, blood pressure sensor, and heart sound sensor.

In an attempt to implement a heart monitoring system, the first matter to be chosen is the platform. In the open-source segment, Arduino and Raspberry Pi offer low-cost applications and are currently the main option for the majority of users **(Toral, et al, 2019) (Mahajan & Kaul, 2022)**. However, BITalino provides a platform that is specifically designed for biomedical applications. BITalino is developed and tried to be an Arduino-like platform for biomedical acquisition and classic clinical applications with performance compared to a specific advanced system **(Alves, et al, 2013)**. A BITalino electrocardiography sensor works principally on analog signal acquisition, digitalization via microcontroller, and wireless data communication to a computer or a mobile phone. BITalino is also equipped with a rechargeable battery.

In this research, the authors propose a prototype of a portable heart monitoring system (PPHMS). The system uses the BITalino board. BITalino is a low-cost bio-signal modular kit specially made to build a medical device and health tracker **(Plux, 2020)**. The PPHMC will use three electrodes to acquire the electrocardiogram signal from the subjects. The signal is then transmitted from BITalino via Bluetooth connection to the receiving personal computer (PC). The signal processing is to be conducted to detect the features of the electrocardiogram waves by using the Hamilton Algorithm. The uniqueness of the proposed system is its emphasis on portability by utilizing the Bluetooth connection and its self-developed algorithm for heart wave feature extraction. Through portability, the user can move freely because the data transfer is conducted wirelessly. While in the current condition the portability is still limited by the mandatory availability of a laptop, this can be mended by further developing an application to accommodate the execution of the algorithm in a smartphone. The PPHMS is expected to be able to operate continuously and the signal processing is expected to be real-time and to be tested on 15 subjects to evaluate its measurement durability and accuracy. Statistical data analysis is to be conducted and its possibility to be used in detecting heart problems such as heart attacks and heart rate abnormalities will be assessed.

2. METHODS

2.1 The Hamilton Algorithm

The Hamilton Algorithm **(Hamilton, 2002)** is chosen to be implemented in the PPHMS. This method is based on **(Pan & Tompkins, 1985)**. The Hamilton Algorithm is divided into the pre-processing stage and the decision stage. This algorithm is preferred due to the simplicity of the realization of its pre-processing stage, *i.e.*, the differentiation (derivative) process and rectification process. These processes can be realized by using simple mathematical operations.

The block diagram of the pre-processing stage is presented in Figure 3 **(Porr & Howel, 2019)**. The first part of this stage is a bandpass filter with a passband of 8-16 Hz, which is implemented as a first-order Butterworth IIR filter. The second part of the stage is the differentiation of the signal. This process acts as a quasi-high-pass filter to highlight the sharp slopes of the QRS-complex. Afterward, in the third part, the signal is rectified by keeping the positive values and inverting the negative values. The final part is a window of moving average with a width of 80 ms. The output of the moving average window is a processed electrocardiogram signal.

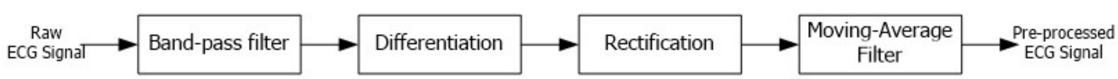


Figure 3. The Block Diagram of the Pre-Processing Stage

The result of the pre-processing stage, the pre-processed electrocardiogram signal, is fed to the decision stage, to locate the features of the heart wave. The detection starts with finding the R-peak. Afterward, the Q-peak and S-peak are located. Finally, P-peak and T-peak are identified. Further alternative approaches to identifying these five peaks can be found in **(Costa, et al, 2021)** and **(Turnip, 2019)**.

The decision stage is based on the following rules:

1. The distance between a detected R-peak and the previously detected R-peak must be at least 300 ms. A detection threshold is to be set to adapt to the data. An R-peak is counted as a QRS-complex if its amplitude is greater than the detection threshold. A missed R-peak happens if the distance between two detected R-peaks is more than one and a half times the average RR-interval
2. A missed R-peak miss is to be tracked back and its amplitude must be at least half of the detection threshold. The distance between a missed R-peak and the last successfully counted R-peak must be at least 360 ms.
3. A detected R-peak with an amplitude greater than the detection threshold will be the new member of a buffer that contains 8 greatest QRS-peak amplitude. A detected R-peak with an amplitude lower than the detection threshold will be the new member of a buffer that contains 8 smallest QRS-peak amplitude. The detection threshold is calculated as:

$$detection\ threshold = 0.55\ ALP + 0.45\ AGP \tag{1}$$

where *ALP* is the average of the 8 lowest peaks and *AGP* is the average of the 8 greatest peaks. The ratio of 0.55 for *ALP* and 0.45 for *AGP* is empirically determined, in order to make the detection threshold small (*i.e*. closer to *ALP* than to *AGP*), especially at the beginning of the algorithm execution, where the members of ALP and AGP are not yet mutually exclusive and completely 8 each.

4. The Q-peak and S-peak are determined by locating the local minima before and after the R-peak. These local minima are indicated by the zero values of the differentiation.
5. Adding to the basic Hamilton Algorithm, the P- peak and the T-peak are determined by locating the local maxima after and before an isopotential line, where the value and the difference of value are zero. The applied window width is 200 ms for P-peak and 400 ms for T-peak.

2.2 Hardware of the System

The PPHMS consists of the BITalino module and 3-lead-electrodes, as shown in Figure 4. The electrodes convert the heartbeats into electric signals and conduct them to the BITalino. In the current realization, it does not have a casing yet. The BITalino uses a rechargeable 3.7 V Lithium Polymer battery as the power source. BITalino is a single-board computer equipped with open-source hardware designed for education, prototype development, and biomedical research. The BITalino takes the data samples and transmits them to a laptop via Bluetooth connection. With its onboard ECG module, the BITalino provides the raw ECG signal only. The extraction process to get the heart wave features is conducted by using the self-developed Hamilton Algorithm, with the modification to also detect the P-peak and T-peak.

The Hamilton Algorithm, as the signal processing phase, is conducted on the laptop. The algorithm is programmed in the form of Python's SciPy library. The received signal from the BITalino is directly processed in real-time by the program and gives the identified intervals and heartbeat rate in a minute (bpm).

Figure 4. The Portable Heart Monitoring System

At the current condition, the portability of the PPHMS is limited by Bluetooth connectivity with a range of up to 10 m (in line of sight). If the system and the laptop are separated by a distance of more than 10 m, the data cannot be sent anymore. Nevertheless, the system already offers improved mobility compared to a completely wired system. The portability of the PPHMS can be increased further in the future by developing a suitable signal processing application so that the laptop can be replaced by a smartphone.

The 3 electrodes are RA, LA, and LL. The placement is shown in Figure 5. RA (positive electrode) is to be placed on the right clavicle, near the right shoulder. LA (negative electrode) is to be placed on the left clavicle, near the left shoulder. Finally, LL (ground lead electrode) is to be placed on the left side, below the solar plexus.

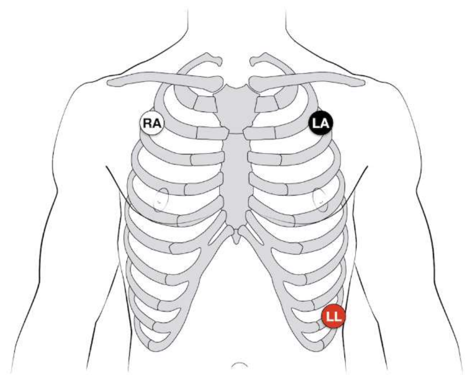


Figure 5. Placement of the Electrodes (Cadogan, 2022)

2.3 Experiment Setup and Procedure

Prior to the experiment, the Hamilton Algorithm was already tested by using samples provided by BITalino. After being tested by using these raw ECG data, the algorithm was practiced to perform extraction from the data measured by the authors from one test subject for the measurement duration of 1 minute. The practice gave a 100% success rate in detecting all peaks of the heart wave features. This convinced the authors that the developed algorithm can be generalized to detect the heart wave feature with high accuracy. Thus, the PPHMS was validated by using raw ECG samples and raw ECG measurements but was not compared with any medical-grade ECG sensor.

To further test the functionality of the PPHMS, an experiment was carried out in two locations, at the house of a research team member in Nagreg on Saturday, 16 October 2021, and at Padjajaran University, Jatinangor on Wednesday, 10 November 2021. The experiment was taken in two different places and at two different times to gather enough number of subjects willing to participate. 15 subjects volunteered to join the experiment. The main criterion for the subjects was generally healthy conditions to perform the activity of sitting and walking. This criterion is found adequate since the main objective of the experiment was to test the functionality of the proposed system to extract heart wave features, not examining specific heart abnormalities. In its current condition, this is beyond the ability of the algorithm. The subjects were mostly students complemented by members of three collaborating research teams.

Two conditions were given to each subject: a 2-minute sitting followed by a 2-minute walking. Before the electrodes were pinned to the subject's body, the subject was required to sit and relaxed for 2 minutes. The pause between two conditions is not a significant factor, because the activity changes from less physical to more physical, from sitting to walking. Throughout the experiment, the gelled self-adhesive disposable Ag/AgCl electrodes were used. Each subject used brand-new electrodes. The placement of the electrodes was alternately conducted by the authors, carefully locating the proper electrode positions at the upper right diaphragm, the upper left diaphragm, and the left solar plexus.

During the experiment, the heart activity of each subject was recorded by using the PPHMS. The measurement data were analyzed in real-time by using the developed program written in Python in the form of the SciPy library. Afterward, statistical analyses were conducted on the processed data.

From the electrocardiogram data, the following feature will be obtained: PR-interval, QRS-interval, QT-interval, RR-interval, and the corresponding heart rate. Every feature has its normal range. Thus, finding data outside a normal range will mean that a certain subject will require further thorough investigation regarding the measurement accuracy of the PPHMS or the subject’s heart condition.

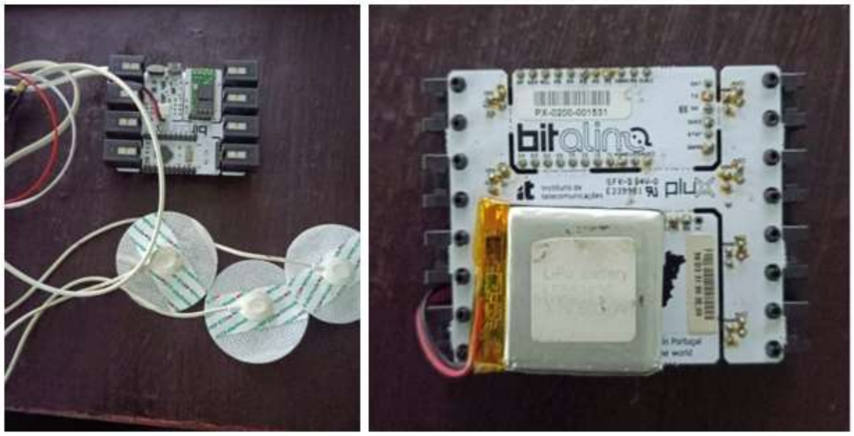
3. RESULTS AND DISCUSSION

3.1 Experiment Results

The subjects who participated in the experiment were asked to sit and walk for 2 minutes each. In every condition, the subjects’ heartbeat was measured and recorded by the PPHMS. Figure 6(a) and Figure 6(b) show the pictures of two subjects while conducting the experiment. As explained in the previous section, there is no data storage process in BITalino. The raw ECG signal is directly transmitted via Bluetooth from the BITalino to the laptop, to be processed further. During the experiment, the distance between the PPHMS and the laptop was always kept within the Bluetooth connection range, which is up to 10 m. The walking path was made circular. The BITalino and the electrodes can be seen in Figure 7(a). The energy source of the prototype, a rechargeable 3.7 V Lithium Polymer battery is shown in Figure 7(b).

(a) (b)

Figure 6. Two Subjects Undertaking the Experiment While (a) Sitting Condition and (b) Walking Condition



(a) **(b)**

Figure 7. The BITalino Peripheral (a) The Electrodes (b) The Rechargeable 3.7 V Lithium Polymer Battery

Figure 8 shows the sample of electrocardiogram signal for complete data of a 2-minute recording of a subject's heartbeats. The sampling time used is 1000 Hz, which is the maximum value made available by BITalino. Furthermore, the analog data is digitized by connecting the electrodes to two input plugs with 6-bit analog-to-digital converter (ADC). The BITalino also provides other input plugs with 10-bit ADC. Due to the small peak-to-peak range of the signal, 6-bit digitization is found adequate by the authors.

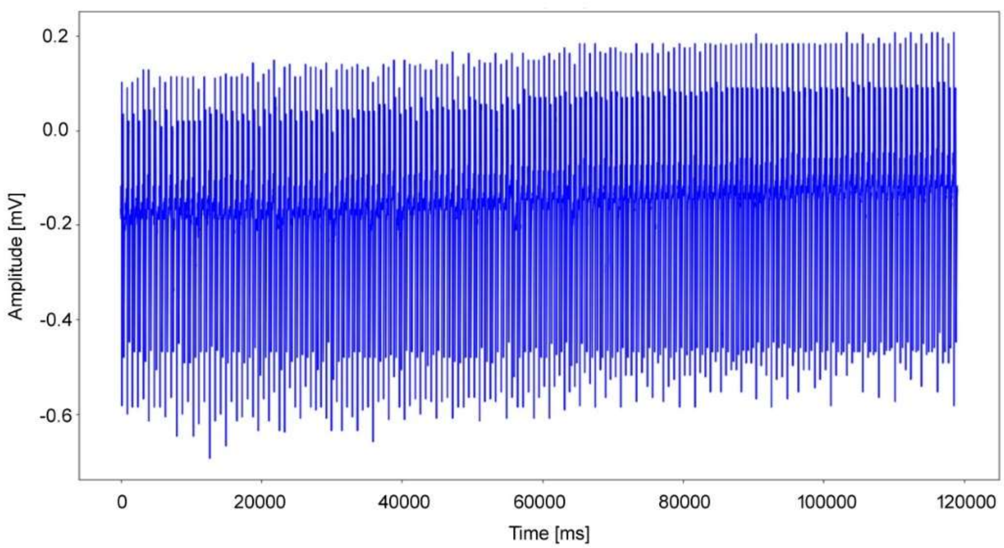
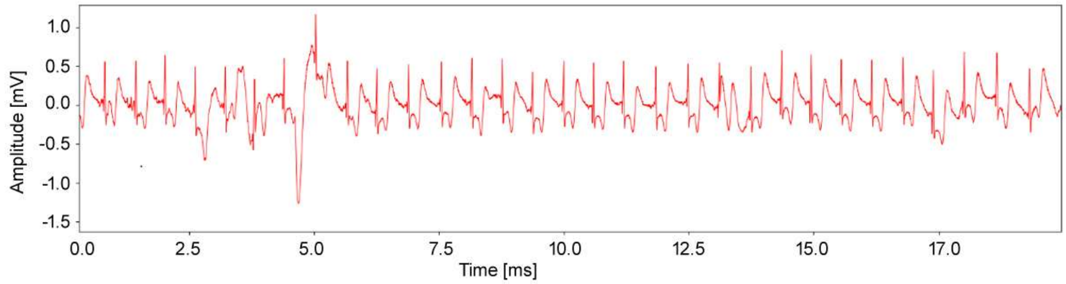
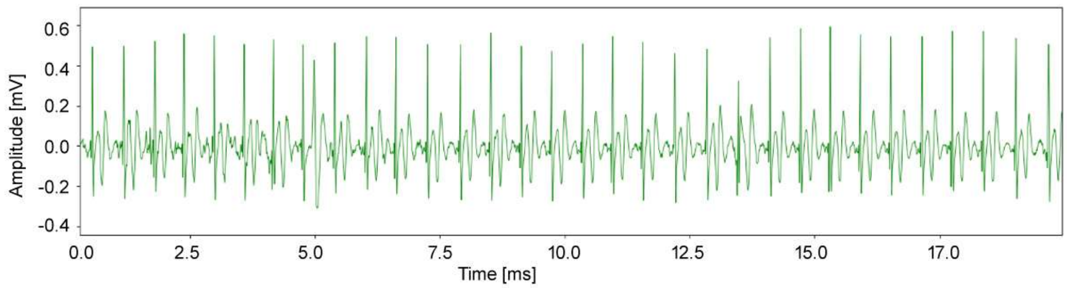


Figure 8. The Sample of Raw Electrocardiogram Signal for A Complete 2-Minute-Record Duration

Figure 9 shows the comparison of electrocardiogram signals before the band-pass filtering (a) and after the band-pass filtering (b). Both figures would be compared based on their peak-to-peak amplitude range and how the DC component of the signals can be filtered to make the detection of the R-peaks by the Hamilton Algorithm easier. No frequency analysis was taken. The filter removes some fraction of the signal's frequency contents. The wave spikes are removed, making the amplitude range change. Before, the amplitude varies between −1.5 and 1.0 mV and afterward between −0.4 and 0.6 mV. Besides, it is visually clear in Figure 9(b), that peaks of the wave become distinctive and easy to be detected when the rules of the decision stage are applied.



(a)

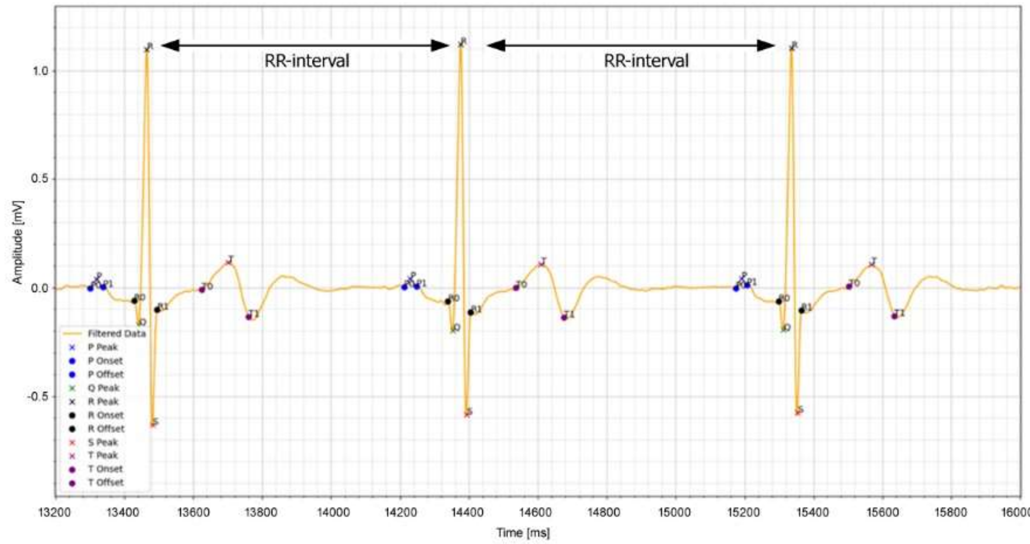


(b)

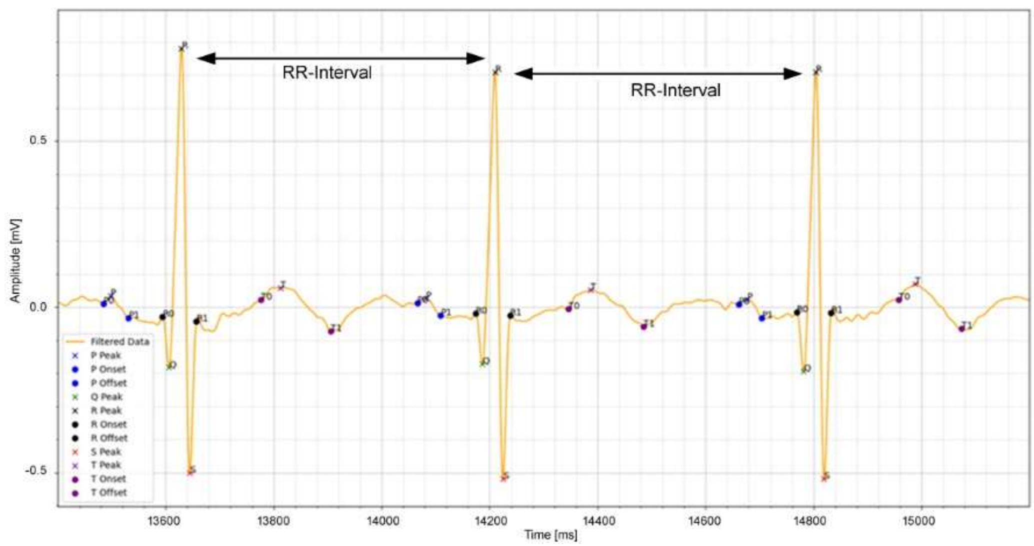
Figure 9. The Electrocardiogram Signal
(a) Before Filtering (b) After Filtering

Figure 10 shows the sample of the result of the feature detection algorithm after the five peaks are located. All signal features of P-wave, QRS-wave, and T-wave can be acquired perfectly. For P-wave, R-wave, and T-wave, the onsets, the peaks, and the offsets were detected. Only the peaks of Q-wave and S-wave are detected, to be used to mark the starts and the ends of the QRS-complex.

Visual assessment can be done to prove that the algorithm is successful to detect the accurate points that will lead to accurate measurement and diagnosis. The duration of a heartbeat can be observed from the distance between two R consecutive peaks (or so-called RR-interval). The RR-interval in the sitting condition is approximately 900 ms, while in the walking condition approximately 580 ms. This can be explained that the heartbeat frequency when a person does physical activity (such as walking or running) is higher than when the person is at rest (sitting). Thus, when the heartbeat frequency is higher due to walking, the heartbeat period (or the RR-interval) is lower.



(a)



(b)

Figure 10. The Peak Detection Result of the Electrocardiogram Signal (a) Sitting Condition (b) Walking Condition

3.1 Data Processing Results and Discussion

The data processing results of the 15 subjects are presented in Table 1 for the sitting condition and Table 2 for the walking condition. From each subject, the data of PR-interval, QRS-interval, QT-interval, and RR-interval are obtained. For the quantity of data obtained during the 2-minute measurements, the mean value (μ) and the standard deviation (σ) of the data are obtained.

From the obtained data, the heart rate can be calculated by using the RR-interval. RR-interval shows the average duration required for one heartbeat, while the heart rate is the number of heartbeats in one minute (60 seconds). The heart rate results are presented in the rightmost column.

Table 1. Average Values and Standard Deviation of The Segment Intervals, with The Subjects Under The Sitting Condition

Subject	PR-interval (ms)		QRS-interval (ms)		QT-interval (ms)		RR-interval (ms)		Heart rate (bpm)
	μ	σ	μ	σ	μ	σ	μ	σ	
S1	112	27.06	68	11.48	323	11.24	754	25.95	80
S2	140	32.73	71	1.70	207	81.58	856	55.91	70
S3	117	5.21	71	0.89	318	8.62	726	77.88	83
S4	107	37.53	95	13.63	182	47.24	669	39.77	90
S5	120	32.46	76	6.55	223	35.73	635	46.35	94
S6	123	12.27	49	1.79	285	21.78	635	24.58	94
S7	130	49.63	86	17.90	203	76.92	709	167.39	84
S8	122	29.96	118	41.17	323	51.15	822	132.2	73
S9	80	29.38	88	23.21	211	40.05	563	45.45	107
S10	134	8.46	66	0.67	333	7.49	803	51.87	74
S11	103	27.74	122	27.24	339	85.53	780	73.12	77
S12	128	30.00	86	4.71	311	17.23	727	52.55	83
S13	142	21.89	81	8.68	226	71.00	937	198.21	64
S14	125	36.00	76	12.28	248	68.84	679	52.77	88
S15	96	23.34	91	23.12	320	23.46	677	36.50	89
Average	118.6	26.9	82.9	13.0	270.1	43.2	731.5	72.0	83.3

Table 2. Average Values and Standard Deviation of The Segment Intervals, With The Subjects Under The Walking Condition

Subject	PR-interval (ms)		QRS-interval (ms)		QT-interval (ms)		RR-interval (ms)		Heart rate (bpm)
	μ	σ	μ	σ	μ	σ	μ	σ	
S1	112	68.45	69	17.31	287	49.46	607	74.60	99
S2	143	68.84	77	25.65	216	69.88	600	63.81	100
S3	149	53.16	86	46.06	249	57.62	620	97.48	97
S4	121	60.15	101	23.62	203	64.78	581	21.37	103
S5	120	32.46	76	6.55	223	35.73	634	50.06	95
S6	93	19.30	49	9.70	231	61.67	506	20.60	119
S7	91	37.04	86	11.94	215	76.27	573	32.19	105
S8	96	17.89	141	42.14	281	30.41	621	34.41	97
S9	111	136.79	949	700.00	281	132.88	454	244.27	132
S10	111	14.31	65	1.79	281	32.88	588	37.21	102
S11	100	7.46	140	4.33	306	20.64	687	59.80	87
S12	86	30.81	85	9.13	261	54.39	597	29.96	100
S13	113	21.36	71	16.12	286	61.97	657	60.98	91
S14	107	12.97	86	8.86	193	52.58	645	47.64	93
S15	128.73	54.66	91	23.87	302	22.57	592	38.55	101
Average	112.1	42.4	144.8	63.1	254.3	54.9	597.5	60.9	101.4

For the purpose of creating a statistical measurement range, the mean values (μ) among the subjects are compared. The comparison results are shown in Figure 11. The RR-interval in the walking condition should be lower than the RR-interval in the sitting condition. Figure 11(a) shows this phenomenon, except for Subject 5, with only 1 bpm lower between the walking condition compared to sitting condition 5. The cause of this can be the state of the subject which was not fully relaxed during the sitting condition, making the heartbeat not significantly lower.

For other aspects such as the mean values (μ) of PR-interval, QRS-interval, and QT-interval, it can be seen that most of the mean values obtained are close to each other, with no clear correlation between the sitting condition and walking condition. Apparently, an outlier can be located at Subject 9 in walking condition. In this case, the QRS-interval of Subject 9 is significantly different compared to the interval of other subjects. Eventually, this huge difference can be traced to be caused by the measurement quality of the signal that makes the identification of the features for QRS-interval erroneous. The error can also be rooted in the electrode installation error or the interference during data retrieval. Overall, the outlier only occurs in 1 out of 30 measurements.

The average standard deviation values (σ) can be observed to increase for PR-interval, QRS-interval, and QT-interval, but decrease only for RR-interval. This indicates that, compared between the sitting condition and the walking condition, the measurement results of RR-interval get closer to each other as its mean values decreases.

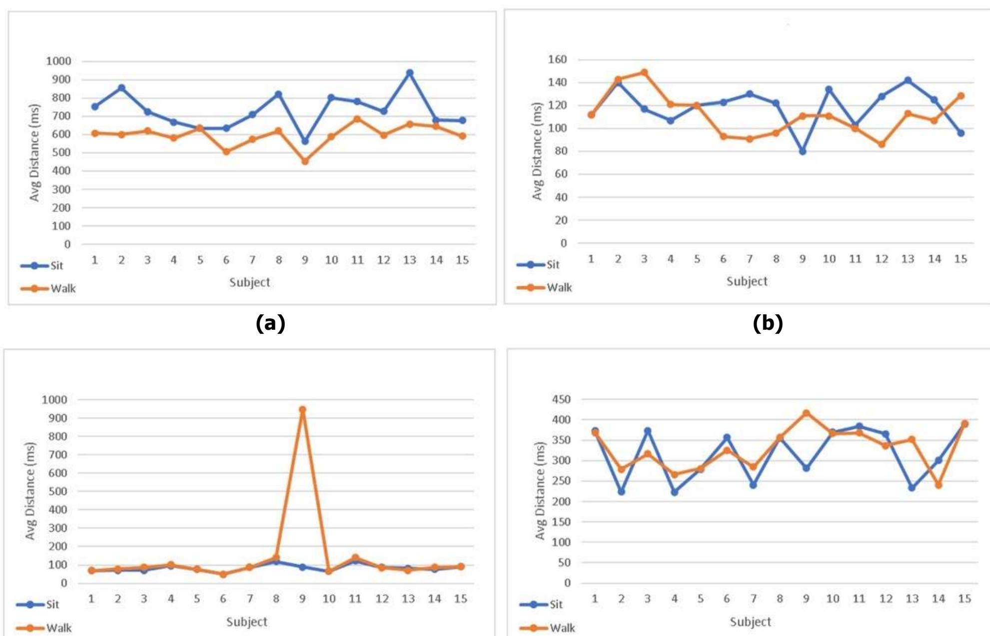
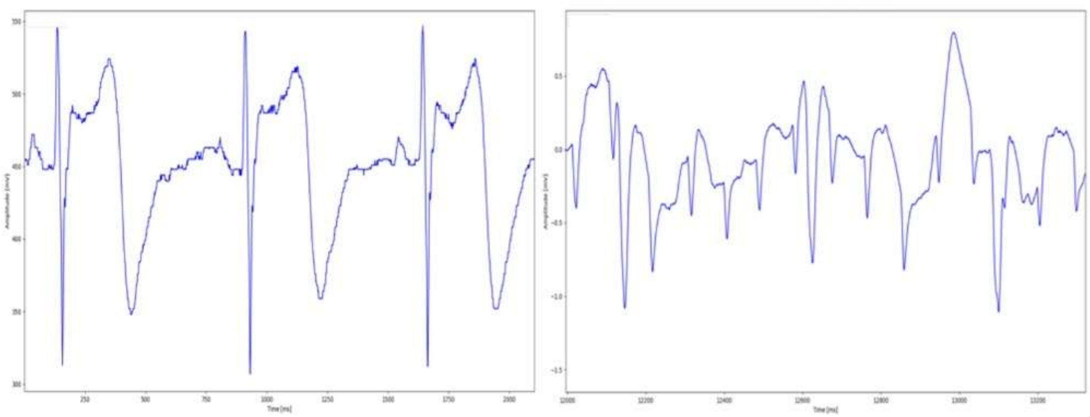


Figure 11. The mean interval of wave segment for all participating subjects (a) Average RR-interval (b) Average PR-interval (c) Average QRS-interval (d) Average QT-interval

A comparison between erroneous measurement data superimposed with noise from Subject 9 and good measurement data from Subject 1 can be seen in Figure 12. The periodical property and the potential R-peaks of the wave can be observed in Figure 12(a), with an approximate period of approximately 1 second. Figure 12(b) shows a noisy record, with an indistinguishable periodical shape. The detection algorithm could not detect the features correctly, giving a large distance between two consecutive peaks. In general, the erroneous measurement data of Subject 9 can already be detected from the quantitative abnormality due to the large mean (for QRS-interval, equals 949) and the large standard deviations (for PR-interval, equals 136.79; for QRS-interval, equals 700.0; for QT-interval, equals 132.88; and for RR-interval, equals 244.27). These values can be found in the shaded row of Table 2. Further frequency analysis can be conducted to see the frequency spectrum and the frequency magnitude of the error. However, as the measurement error is already obvious from the comparison of mean values and standard deviation values, the frequency analysis was not conducted.

From this finding, the authors suggest that this kind of statistical comparison among the subjects is found useful to find measurement mistakes. By finding the mistakes, an obvious erroneous measurement can be repeated for a certain subject. Although the average values for RR-interval, PR-interval, and QT-interval of Subject 9 seem to be within an acceptable range in comparison to other subjects, the outlier of QRS-interval makes all these three data invalid and a new measurement must be conducted for Subject 9.



(a) **(b)**

Figure 12. The comparison of measurement data quality;
(a) Record with good quality (from Subject 1) (b) Record with noise (from Subject 9)

For the purpose of constructing an individual database, the authors suggest extending the measurement history of a single subject. Afterward, the actual measurement can be compared with the measurement history, to find whether the actual value differs significantly from its historical mean and its historical standard deviation. Based on this data, the condition of a certain subject can be assessed in case further cardiac health examination is required to cope with a potential heart attack or heart rate abnormalities.

4. CONCLUSIONS

A prototype of a portable heart monitoring system using BITalino was successfully implemented. The Hamilton Algorithm was used for the data processing. The applied algorithm was able to detect and extract the features of heart waves such as RR-interval, PR-interval, QRS-interval, and QT-interval. These values, especially RR-interval, are useful to gain insight information regarding the heart condition of the subject. Initial testing includes the feature extraction of raw ESG signal from the samples provided by BITalino and self-measurement, with a 100% success rate in detecting all peaks of the heart wave features. An extensive experiment was conducted, involving 15 subjects, with 15 data when the subjects were in sitting condition and 15 data in walking condition. The proposed system is proven to deliver good measurement results, with 29 successful measurements and only 1 erroneous measurement during walking. Future improvements include the improvement of the signal processing algorithm and the optimization of the filters used to reduce signal noise due to abnormal movements and electrode placements. Besides, long-time record history and its statistical data such as mean and standard deviation will be desirable so that a quick and accurate warning regarding the heart condition of a subject can be derived.

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