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Abnormalities State Detection from P-Wave, QRS Complex, and T-Wave in Noisy ECG

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Abstract. In last 5 years Physical Computing has been a constant discussion in the whole world. With so many Physical Computing turned into wearable technology. We are trying to take one of thousands of example, in this case ECG processing, and put it into the test. We tried to expand all the features and pin point all the exact point of the PQRST of the ECG. We also tested it in three state of condition, which is: sitting-rest, walking, and fast-paced walk to see how our program would perform in that particular varies of activity. From the analysis conducted, it can be concluded that the output of our proposed combination of method shown a significant performances.

1. Introduction

ECG signal represents electrical activity of human heart. This is widely known, and it is one of the most popular and information rich approach to detect heart disease. Heart failure is one of the most lethal cause in the world that lead to death. The fact is, the death rate of sudden attacks due to heart failure is relatively high. The cardiac disease may erupt suddenly and cause heart failure or continue in long-term disease due to heart abnormalities. Therefore, ECG analysis and monitoring approach is important [1–2]. To perform the analysis, ECG features need to be obtained beforehand. A typical ECG signal for normal heart condition consist of P wave, QRS complex and T wave as shown in Figure 1. Most of the research on this field, separated getting the QRS-complex [3–6], with P and T wave [7–10] due to various reasons. Anymore, the detection is performed in relatively low amount of noises. Heart monitoring is also important to keep in check of some abnormalities. This approach produce a huge amount of data due to the long duration of monitoring [11–12].

ECG records electrical activity of the heart in a period of time using electrodes placed on certain place of chest or limb. For each heartbeat, depolarisation and repolarisation happen during potential difference (voltage). ECG consists of some waves that show heart activity. The first wave, P wave is generated due to depolarisation of right and left atria. The duration should not be more than 0.11 s and amplitude should not be more than 3 mm. The next wave is the most important, which is the Quantronic Resonance System (QRS) complex. It corresponds to the depolarisation of the right and left ventricles. The QRS complex normally lasts 0.05 to 0.10 s. There is also T wave, represents the repolarisation of ventricles. The height of T wave should not exceed 5 mm. Finally, U wave corresponds to repolarisation of papillary muscles that occasionally appear in ECG signal [13].
In the process of recording ECG signals, it tends to corrupted by noises. Sensitivity of electronic devices, electrode contact, motion artifacts [14–16], and other kind of noise sources lead to the problem of ECG analysis [17]. Data corrupted with noise must either be filtered or discarded. The basic requirement to perform ECG analysis that is to noise-free, therefore filtering is needed. Many methods have been worked on to reduce the noise. Research carried out on the effect from the leads setup [18]. Digital filter studied with the purpose as filter method and various parameters in ECG [19]. A mathematical framework for the model-based Bayesian filtering of single channel noisy ECG recordings [20]. Wavelet transform method is believed to suit in wavelet domain processing ECG [21]. Another transformation technique, morphological filter works in geometrical features [22], and much more research with different approaches and designs [23–24].

In this paper, research is performed to show the feature extraction of ECG in the presence of noise. Experiment is performed under 3 conditions, sitting and relax, walking with slow pace, and walking in fast pace. For noise produces by the setup, signal pre-processing will be performed. After filtered, the features extraction is performed. The first to be done, is to detect R-peak in QRS complex, with P.Hamilton Segmenter method. For every R-peaks detected, Q and S position will be found, and further should be P and T wave, all were carried out assuming it is under normal condition. From the features detected, ECG signals will be classified and recorded if there are some abnormalities in ECG. The record of abnormalities will be made and separated in case, for further examination.

2. Methods and Experiment
The main reason of ECG analysing and monitoring is to obtain information about the heart condition. The attack of heart disease is sudden and even the symptoms are barely shown. Long term monitoring is usually suggested, due to its simplicity and safety reasons. Although, this method has some flaws such as, costly devices and huge amount of data flow produced by the device. Many emerging companies are constantly presenting their technologies with advantages [25–27]. The product presented, also followed by complementary software to use. In this paper, the device that been used is BITalino [28] which is quiet cost-friendly compare to the others. For the huge data flow problem, we proposed to separate abnormalities from data recorded. This means can greatly reduce not only data transferred, also the amount of work for specialist to analyse further. The scheme for this idea is given in Figure 2. First of all, there will be electrode sensors placed on the surface of patient’s chest (chest lead). The sensors will be connected to BITalino and start recording ECG signals. The record will be transmitted via Bluetooth to the system. Then, it will be processed and become presentable. From the records, the system will classify the signals to different file, once abnormalities are found. For

![Figure 1. Main features in ECG waveforms.](image-url)
necessity and further use, the complete records will be stored in local storage. The abnormalities records then will be sent to the cloud, so it can be accessed in the hospital or doctor, and family. Based on this method, the cardiac state of the subject can be monitored anywhere as long as access to the internet network is able. This way also reduce the data needed to be flowed to cloud because just the abnormalities are transferred. Theoretically, the size will be smaller than the complete record. The reliability and accuracy also can be maintained because doctor involvement in the system. This is the case, as long as signal is processed well in the system.

The process performed by the system consists of acquisition signal, preprocessing, feature detection, and classification as shown in Figure 3. To obtain a good quality of record, the first thing to pay attention is the raw signal. Many factors can affect the record produced, such as lead placement and subject conditions. The lead placement means, the position of electrodes attached. There are 3 electrodes used in BITalino, positive, negative and ground or reference. The lead placement that we used is shown in Figure 4. The conditions of the subjects picked are 3 of the most possible daily activities, sitting (relax), walking in normal pace, and jogging. These setups should produce different kinds of ECG records. Pre-processing signal is next applied to the raw signal recorded. This stage means to prepare the signal become presentable.

**Design and Realization of the Filter**

There is FIR filter and Butterworth filter, to remove the noise. Then, smoothing the signal with Moving Average filter. The filter was designed with the following specifications for FIR:
- Order of the filter 0.3 * Sampling Rate.
- Sampling frequency 1 KHz.
- Cutoff frequency 0.5 - 40 Hz.

After being filtered with FIR the filtered signal processed again with Low pass and High pass filter combination which was designed with the following specifications:
- Order of the filter 4.
- Sampling frequency 1 KHz.
- Cutoff frequency 25 Hz.

For low pass and the following specifications:
- Order of the filter 4.
- Sampling frequency 1 KHz.
- Cutoff frequency 3 Hz.

**Figure 2. System proposed for ECG.**
The filtered signals, will be segmented for every QRS complex with Hamilton Segmenter [29]. In other words, this stage means to detect the heartbeats by divide it into segments based on these rules [30]:

- Ignore all peaks that precede or follow larger peaks by less than 200ms;
- If the peak is larger than the detection threshold call it a QRS complex, otherwise call it noise;
- If an interval equal to 1.5 times the average R-to-R interval has elapsed since the most recent detection, within that interval there was a peak that was larger than half the detection threshold, and the peak followed the preceding detection by at least 360ms, classify that peak as a QRS complex;
- The detection threshold is a function of the average noise and the average QRS peak values;
- The average noise peak, the average QRS peak and the average R-to-R interval estimates are calculated as the mean/median of the last eight values

**Design and Realization of the Feature Extraction**

Every heartbeats has features that can be used to identify the cardiac state. Therefore the next stage which is feature detection, is the crucial part. The main point of feature extraction, is to detect every part of ECG. From the parts detected, it can derived any further information needed. In this case, the system detect R-peaks for every heartbeats detected. From there, we can find the turning points which is Q-point and S-point. Further find where Q-point starts and S-point finish, then the location of QRS complex is detected. For P-wave, find biggest wave before QRS complex. Moreover there is thing to check, like the interval between QRS complex and P-wave may not be more than it should be. The case is more or less same, to detect T-wave. Within the end of QRS complex and the next P-wave, and the T-wave may not pass normal interval. In summary it is characterized by the following sequence of steps:

- From detected R peak lines;
- 250ms window moving average;
- Onset detection;
- Detection of Q peaks: search for the ECG signal in the first window before each R peaks;
- Detection of S peaks: search for the ECG signal in the first window after each R peaks;
- Detection of P peaks: search for the ECG signal maximum in a 200ms window before each Q starting point;
- Detection of T peaks: search for the ECG signal maximum in a 400ms window after each S end point;

![ECG signal processing system](image_url)
When all the signal processing have done, classify the features into different classes. If the features are detected in normal interval as shown in Table 1 [31], then it is normal ECG. Otherwise, there are abnormalities.

**Table 1. Normal ECG intervals.**

| ECG Features     | Intervals in ms (milliseconds) |
|------------------|--------------------------------|
| P wave           | 80                             |
| PR interval      | 120 – 200                      |
| PR segment       | 50 – 120                       |
| QRS complex      | 80 – 100                       |
| ST segment       | 80 – 120                       |
| T wave           | 160                            |
| ST interval      | 320                            |
| QT interval      | 420 (less if heart rate is 60 bpm) |

The target for the proposed system is for monitoring subjects during daily activities. It is to be expected that the proposed system will not hindering subject life. Therefore, experiment will be focused on 3 activities that performed by most of the people daily, sitting, walking, and jogging. There are 8 healthy volunteers as subject aged 20 ± 3 years old. Each sampled 2 minutes with sampling rate 1000Hz. The experiment should be done in order. This way ensure the records are reliable and minimize problems due to the activities affecting each other. The sample of ECG recorded for one subject with all conditions is shown in the Table 2. Three conditions are performed by subjects during recording. The first condition, where subjects sit on the chair in comfortable posture while the device is put on the table. Condition II, where subjects walk around with usual pace and holding the device. The third condition, subjects are asked to walk faster and slightly jogging with the device in hand. We compare the heart rate computed with R-peaks detected by algorithm. The data shows satisfying accuracy and can be further investigated.

**Table 2. ECG data collected from experiments.**

| Conditions | R-peaks detected in 2mins | Average Heart Rate (bpm) |
|------------|---------------------------|--------------------------|
| Subject 1  |                           |                          |
| • Condition I | 189                      | 95                       |
3. Results and Discussions

The things that doctor need from an ECG record are the features. It is recommended to perform features extraction from noise-free ECG. This is the main reason why competent filter algorithm is important. Figure 5 shows ECG sample from one of the subject before and after filter is performed. If the signal recorded has smaller frequency than the threshold, or higher than the limit, then it is noise. The features extracted may not have too high or smaller peaks than they should be, otherwise it is noise. Longer or shorter interval than the normal, maybe abnormalities or also caused by noise. The solution is to consider appropriate threshold, but there is too much possibilities, so specialist such as doctor involvement is important.
The main features of ECG is P wave, QRS complex and T wave. The characteristic of every components can determine the heart state of subject. Figure 5 shows the features detected in one of the record. From the R-peak detected, we determine other features.

![Figure 5. ECG comparison: (a) raw signal; (b) filtered signal.](image)

Figure 6. ECG features detection

Table 3 contains main features detected in one of the sample. Features detected are further classified into normal and abnormal. The problem is the abnormalities range are too wide. There might be problem with noise from excessive motion, electrodes problem, or bad setup for recording. Despite that, the programs is designed to detect features in normal range with noisy conditions. Most abnormalities mainly are heart beat faster or slower. Regarding this, the problem of accuracy showed up. It may be affected by subject condition. In this case, data obtained by experiment show increase trends of abnormalities where activity is heavier. This lead to another fact, where abnormalities are not always harmful. For the proposed system, it is not adapted to this condition. One of the reason is, parameters to determine abnormalities danger is not constant. There is too many possibilities, some abnormalities may not be harmful by itself, but can be dangerous if left behind. That is why the proposed system involve doctor assistance to determine the abnormalities causes.

| P-wave | QRS complex | T-wave |
|--------|-------------|--------|

Table 3. ECG results from one of the samples.
4. Conclusions

The proposed system of managing abnormalities has means to monitor subjects in long-term and work effectively either for monitoring programs or doctors. The important properties of ECG, P-wave, QRS complex, T-wave, needed to determine subject’s cardiac state. There are many factors affecting features detection called abnormalities. The technical factor, can be discarded with the help of filtering algorithm. The research shows increase of abnormalities rate directly proportional to how intense activity is performed. The causes are mostly due to noise from motions, electrodes, and chaotic heart beats. For further research, it is suggested to use either better adaptive devices, research on ECG parameters in different kind of activities, or use medic interference in system.

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