

CHAPTER 5 – CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research has succeeded in developing and improving software for the wearable ECG monitor that can recognise ECG segments, such as the presence of P-waves, P-peak location, PQ-interval, Q-wave location, QRS-complexes, R-peak location, S-wave location, QRS-width, RR-interval, and heart rate with its variability. The Pan-Tompkins QRS detector algorithm was used to recognise QRS-complexes and R-peak location, and further calculation results in RR-interval, heart rate, and its variability. The algorithm developed by Iskandar was used to recognise the P-peak location as well as the presence of P-waves, resulting in P:Q ratio for cardiac arrhythmia recognition. Lastly, we combined these algorithms with a QS-wave detector algorithm developed by Kim and adjusted it for QRS-width measurement as well as for the recognition algorithm.

Combining these parameters into an arrhythmia recognition algorithm, this research has succeeded in detecting irregular heartbeats based on the standard deviation of the average heart rate. Alongside with that, the recognition algorithm can recognise in real-time the occurrences/episodes of AFib, as carried out in the previous study by Iskandar, PVC, SVT – PAC or SVES. AFib is notable for the absence of P-waves, PVC is notable for the wide QRS-width, SVT is notable for the narrow QRS-width and high heart rate, and in general, arrhythmias can be recognised based on the high standard deviation of the average heart rate.

The output of the algorithm is carried out and transmitted wirelessly via Bluetooth Low Energy to a smartphone, and the display can easily be read using an application, such as Adafruit Bluefruit or nRF Toolbox. The output in the form of ECG signal plots is available in serial communication mode, by using the serial plotter in Adafruit Bluefruit application, as well as the output in the form of the written summary by using the serial monitor. The output in the form of heart rate measurement (HRM) complete with a plot is available in GATT communication mode, by using the HRM service in nRF Toolbox application.

The average accuracy of the ECG segment characterisation algorithm was 90%. The error mainly came from the failure of the R-peak detection, which was the foundation for all the detection algorithm. The performance tests of the algorithm consist of two phases. Firstly, the database testing phase using four databases obtained from Physionet: nsrdb, mitdb, svdb, and cudb. Secondly, the hospital testing phase by implementing the embedded software on wearable ECG devices involving 33 human subjects, out of 60 weekly patients with cardiovascular diseases risk. The prediction algorithm succeeds to predict PVC, PAC, and SVT from the databases. However, the arrhythmia and diseases found during the hospital implementation were somewhat different from the arrhythmia the algorithm was supposed to predict.

Further research is necessary on fine-tuning the characterisation algorithm and adding more prediction algorithm for more diseases, especially the most common ones in Indonesia. The ECG signal acquired from the wearable ECG did not consistently represent Lead I recordings, thus needs further research on ECG leads and electrodes positions. The smartphone applications have succeeded to provide fast ECG monitoring aid for both doctors and patients in handling cardiovascular diseases. However, an integrated smartphone application is needed to provide all information in one display for more ease of use.

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5.2 Recommendations and Further Improvements

A smart algorithm for cardiac arrhythmias recognition has a highly prominent future in clinical usages, such as to monitor patients' heart activity in real-time during routine consultations. This smart ECG device holds an essential role in the early diagnosis of arrhythmias as well as monitoring patients' condition with known arrhythmias.

Having this smart wearable ECG devices is beneficial for

1. Hospitals, since they are small, lightweight, reusable, and affordable. These devices can be borrowed by the patients; make it benefitable and enjoyable facilities.
2. Medical doctors and cardiologists, since they provide real-time ECG monitoring to better understanding the patients' heart condition, not only in big events but also in routine consultations and daily life.
3. Patients, especially those with cardiac arrhythmia risk, since they provide arrhythmia information with ECG plots to give ease in consulting with the doctors, as well as increasing the awareness of cardiovascular diseases, thus forming a healthy lifestyle.

The challenge found during this research is to provide a recognition algorithm which does not solely depend on the R-peaks detected by the Pan-Tompkins QRS detector algorithm. Other challenges are to improve the accuracy of Q-wave and S-wave locations as well as the QRS-width and to enable variable fine-tuning/amplification.

Other challenges for further studies are to research the electrode locations on the body and their corresponding leads. On most occasions, the acquired ECG signal did not solely represent Lead I; more often, it represented Lead II or III, or even the chest leads (V1-V6).