Real-time Heart Monitoring and ECG Signal Processing

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Introduction

Arrhythmias are irregular heartbeats caused by faulty electrical signals in the heart. The types of arrhythmias include premature ventricular contractions (PVCs), and three or more consecutive PVCs indicates ventricular tachycardia (VT), a potentially life-threatening condition.

Motivation

Current heart monitoring systems cannot communicate directly with medical staff and require offline processing, either by a physician or at the server level.

Objective

Develop a stand-alone embedded system for continuous heart monitoring that will

- Process electrocardiogram (ECG) data in real time
- Detect PVCs accurately and consistently
- Alert the patient's doctor wirelessly of ventricular tachycardia via SMS messaging

Significance

Doctors are notified of potentially life-threatening arrhythmias quickly and can take necessary preventative action.

Heart Signal Processing Algorithms

The design applies multiple algorithms for preprocessing of the ECG signal, detecting beats, and classifying beats as PVC or non-PVC. If three or more consecutive PVCs are detected, the device will send an SMS message alerting the doctor of VT.

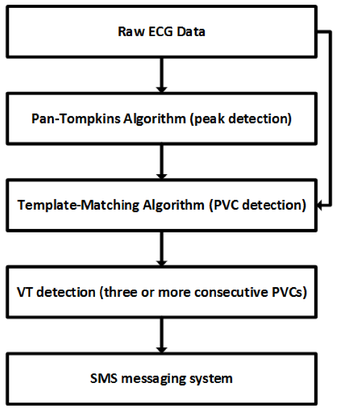

Figure 1. High-level flowchart for algorithms

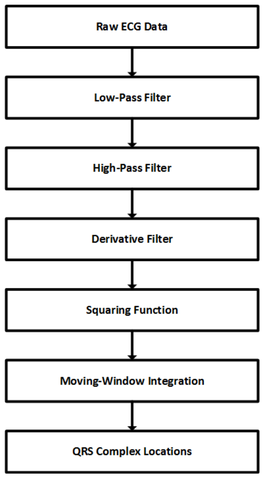

Figure 2. Pan-Tompkins algorithm

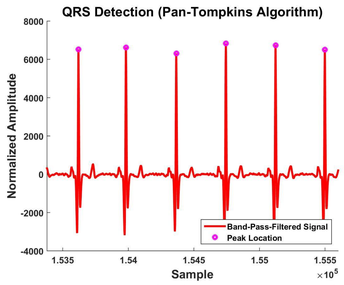

Figure 3. Peak detection results

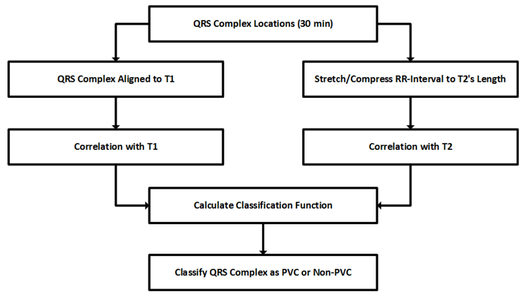

Figure 4. Flowchart of template-matching algorithm

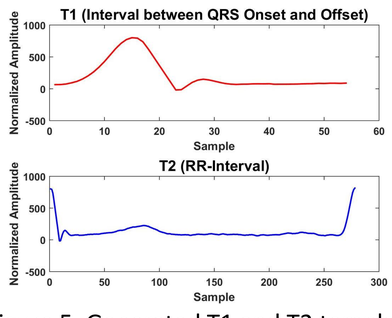

Figure 5. Generated T1 and T2 templates

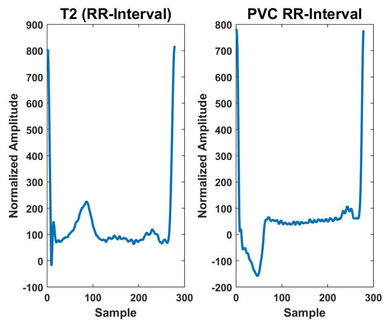

Figure 6. Comparison of T2 template and the RR-interval of a PVC

Hardware

The CC3200 LaunchPad is used for its wireless capabilities and its ARM Cortex-M4 microcontroller. The microcontroller's UART DMA system can receive testing data from a PC. Lastly, the Wi-Fi Internet-on-a-Chip is used to send an SMS message when VT is detected.

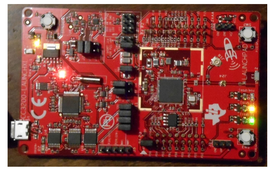

Figure 7. CC3200 LaunchPad

Testing System

- The UART DMA system of the ARM microcontroller accepts buffers of heart data from a computer.
- The detected QRS and PVC locations are written to .dat files for MATLAB validation later.
- A MATLAB toolbox that accesses the MIT-BIH arrhythmia database is used to generate reports of the algorithms' accuracy. The database uses physicians' annotations for comparison.

SMS Messaging System

When VT is detected, the CC3200 will send an SMS that includes a message and an image file to a specific phone number using its Wi-Fi subsystem.

- Temboo is a middleware service that allows different devices (such as the LaunchPad) to access web-based services, such as Twilio.
- Twilio is an SMS messaging service.
- Plotly generates the graph for the image file attached to the SMS.

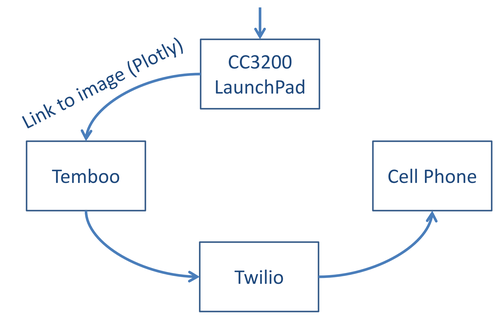

Figure 8. Transmitting an SMS message using the LaunchPad

Results

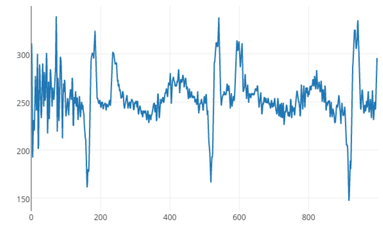

Figure 9. Plotly graph of detected VT event

TABLE I. PERFORMANCE OF TEMPLATE-MATCHING ON THE CC3200

Record	QRS Sensitivity	QRS Positive Predictivity	PVC Sensitivity	PVC Positive Predictivity
116	0.988	0.999	0.972	0.954
119	1.000	1.000	1.000	1.000
201	0.973	0.979	0.864	0.665
203	0.991	0.982	0.854	0.548
205	0.998	1.000	0.958	0.986
208	0.938	0.994	0.826	0.972

Conclusion

In this project, a heart monitoring and ECG signal processing system has been implemented on an embedded device. To test our algorithms, we use heart data from 18 patients that together have 3,303 PVC beats out of 39,815 total beats. Our system is able to correctly detect 99.1% of the QRS complexes and 81.7% of the PVCs. A wireless message is successfully sent when VT is detected. This study suggests a viable, low-complexity solution for real-time heart monitoring and arrhythmia detection.