Real-time Heart Monitoring and ECG Signal Processing

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Contents

Introduction and Overview

- Problem Background
- Problem Statement
- Constraints

Problem Background

- Arrhythmias
  - Are irregular heartbeats caused by defective electrical signals in the heart [1]
  - Include premature ventricular contractions (PVCs)

Problem Background

- Premature ventricular contractions (PVCs)
  - Up to 40-75% of people have occasional PVC beats [2]
  - May lead to ventricular tachycardia (VT)

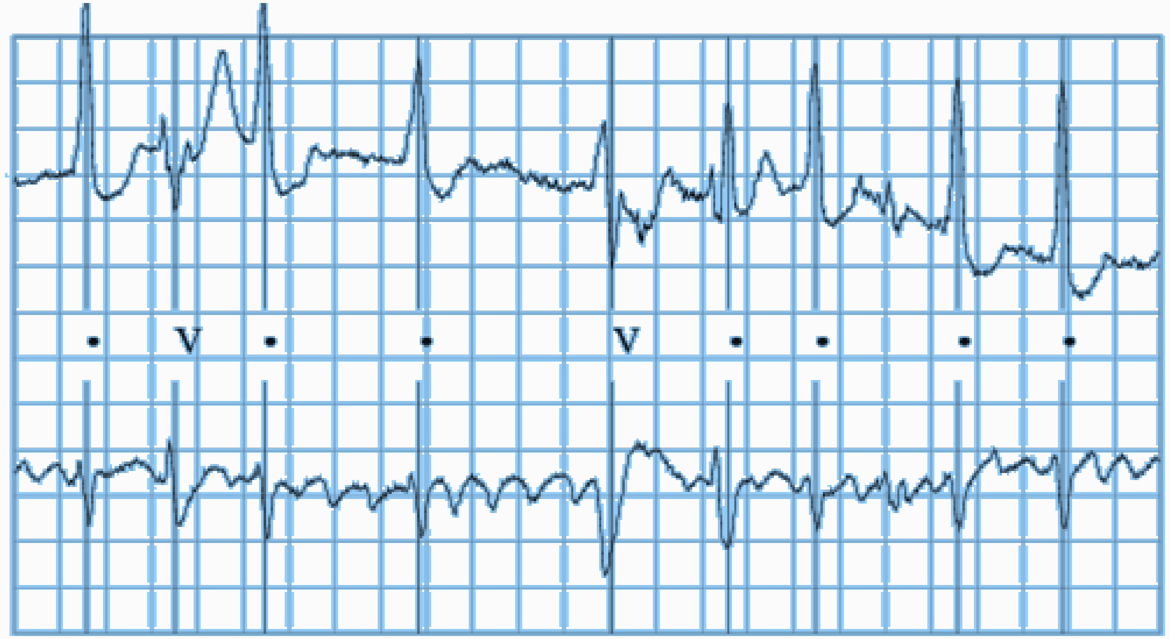

Figure 1. Electrocardiogram with “V” labels for PVCs [3]

Problem Background

- Ventricular tachycardia (VT)
  - Involves the ventricles contracting before they have filled completely with blood
  - Limits blood flow to the body

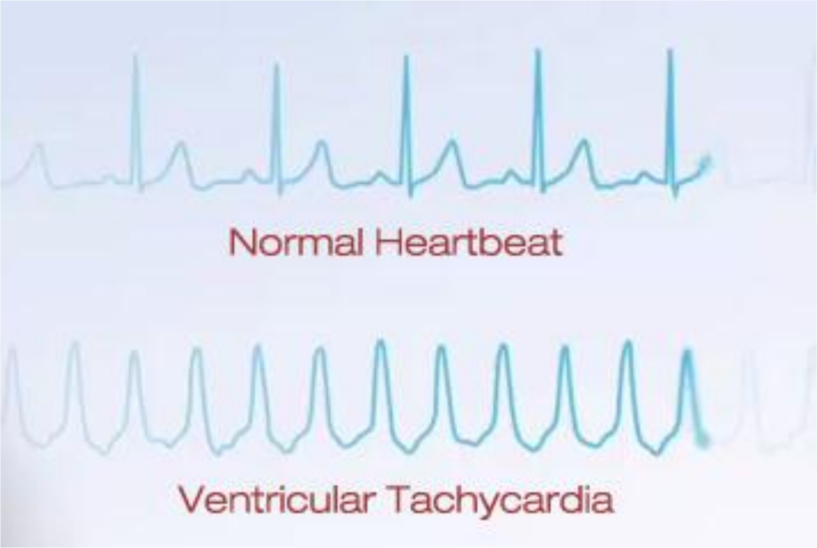

Figure 2. ECGs for normal heart rhythm and ventricular tachycardia [1]

Problem Background

- An electrocardiogram (ECG) describes the heart's electrical activity
- An ECG can be recorded using a Holter monitor or event monitor

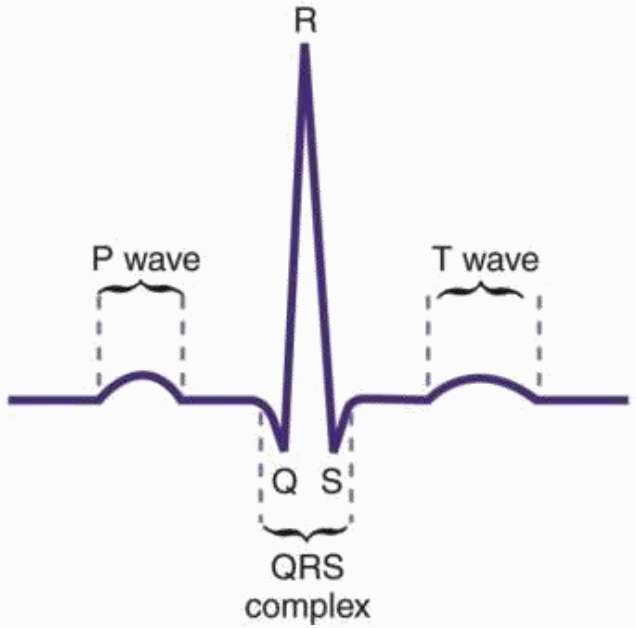

Figure 3. Features of a normal ECG [4]

Problem Background

- Holter monitor

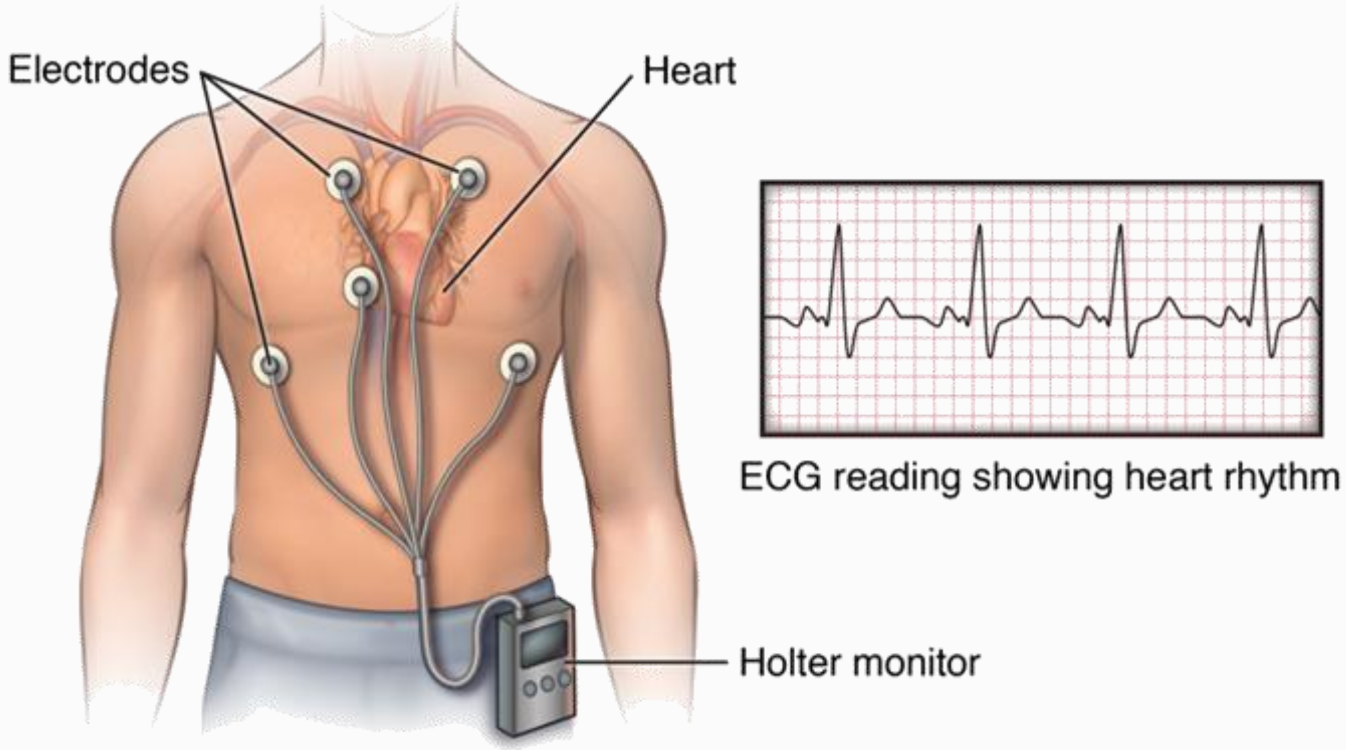

Figure 4. Holter monitor with ECG reading [5]

Problem Background

- Event monitor

Figure 5. Wireless event monitor system [6]

Problem Background

- Holter and event monitors are limited in functionality
  - Utilize some in-platform signal processing for diagnostic assistance
  - Must perform some signal processing offline
  - Are unable to address medical issues in real time

Problem Statement

- Develop a low-power, stand-alone embedded system for continuous heart monitoring that will
  - Process ECG data in real time
  - Detect PVCs accurately and consistently
  - Alert the patient’s doctor wirelessly of ventricular tachycardia

Constraints

- Real-time ECG signal processing
- On-board signal processing computations
- Battery-powered functionality

Scope

TABLE I. SCOPE OF HEART MONITORING SYSTEM

In Scope	Out of Scope
ECG signal processing	Electrode interfacing, battery circuit
PVC and VT detection	Detection of other types of cardiac arrhythmias
High-level wireless communication	Security issues (encryption, data integrity, etc.)

Contents

- Introduction and Overview
- **Design Approach and Method of Solution**
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- Division of Labor
- Societal and Environmental Impacts
- Summary and Conclusions

Design Approach and Method of Solution

- System Block Diagram
- State Diagram
- Nonfunctional Requirements
- Functional Requirements
- Description of Solution
- Solution Testing

System Block Diagram

Figure 6. Overall heart monitoring system diagram

State Diagram

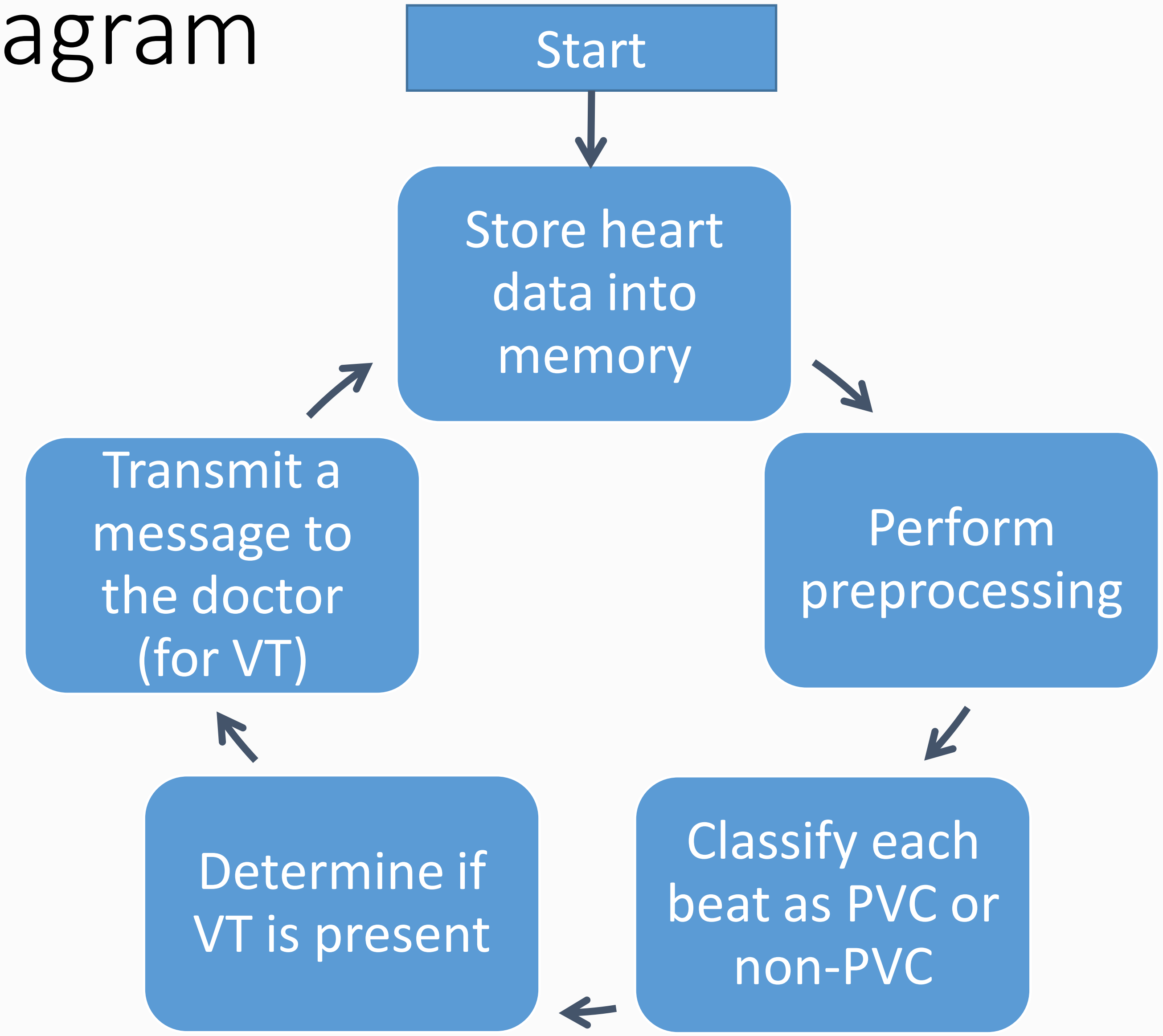

Figure 7. State diagram for heart monitoring system

Nonfunctional Requirements

- Compatible with all patient data in the MIT-BIH database [3]
- Reasonably priced
- Portable
- Low-power

Functional Requirements

- Storing heart data input into memory
  - The embedded device must have an internal memory of at least 25 kB

Functional Requirements

- Performing preprocessing on the heart signal
  - Filtering/normalization must prepare the heart data for the QRS, PVC, and VT detection functions
  - QRS detection must have at least 90% sensitivity and 90% specificity [8]
  - QRS detection must be tested using heart data from the MIT-BIH arrhythmia database [3]

Functional Requirements

- Classifying each QRS complex as PVC or non-PVC
  - Must have at least 90% accuracy [9]

Functional Requirements

- Determining whether ventricular tachycardia is present using PVC detection results
  - Must have at least 90% accuracy

Description of Solution

TABLE II. SELECTED DESIGN FOR HEART MONITORING SYSTEM

Functions	Means
Storing heart data	RAM
Preprocessing (Filtering/QRS detection)	Pan-Tompkins
PVC detection	Template matching
Ventricular tachycardia detection	Three or more consecutive PVCs
Wireless functionality	CC3200 LaunchPad

Description of Solution: Hardware

- SimpleLink Wi-Fi CC3200 Launchpad
  - Inexpensive: $30.00
  - Simplifies data transmission
  - 256 kB RAM

Figure 8. CC3200 Launchpad [10]

Description of Solution: QRS Detection

- Pan-Tompkins algorithm [11]

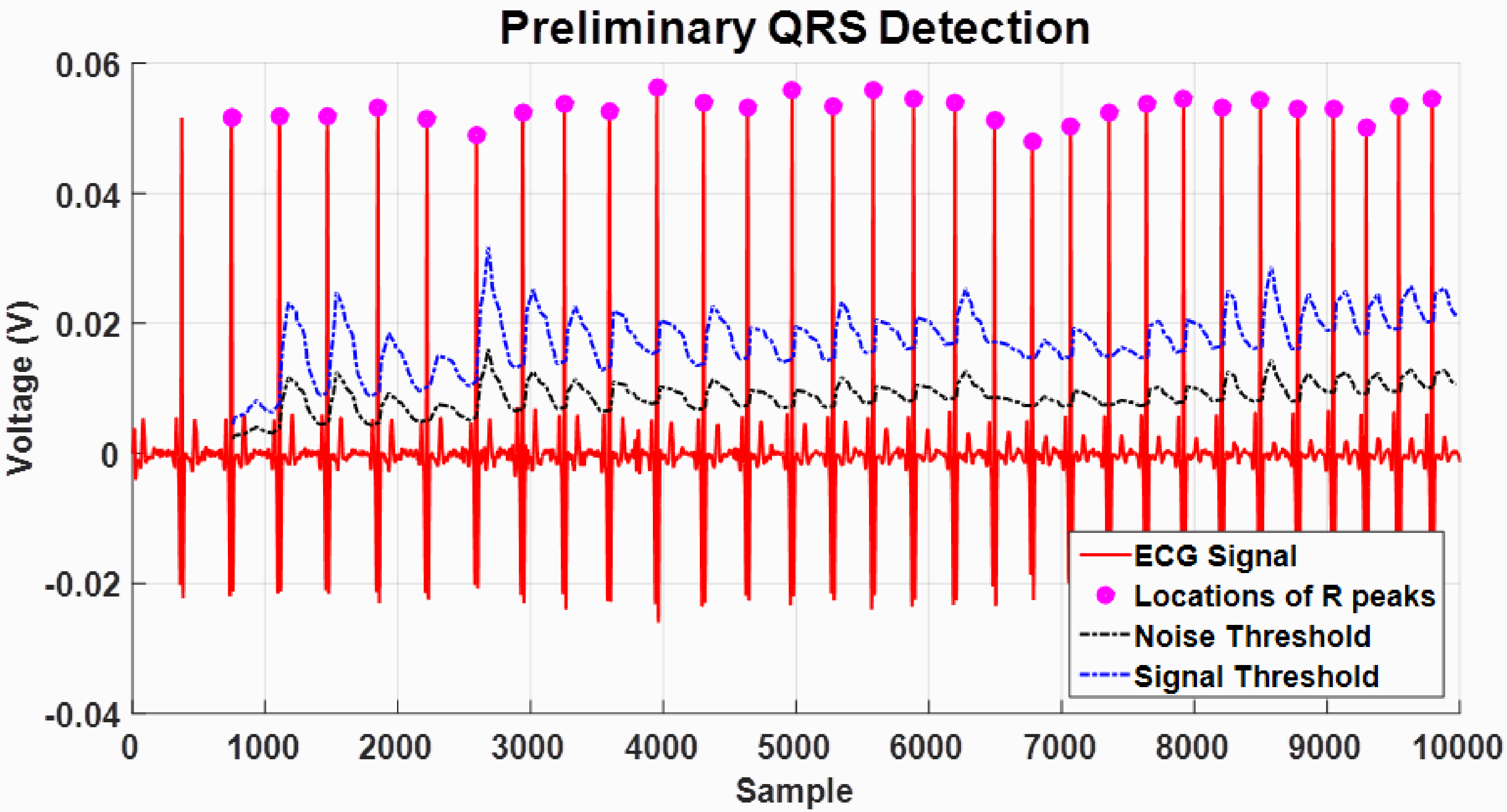

Figure 9. Preliminary QRS detection using the Pan-Tompkins algorithm and MATLAB

Description of Solution: PVC Detection

- Correlation with normal QRS-complex and RR-interval templates
- Low correlation signals PVC

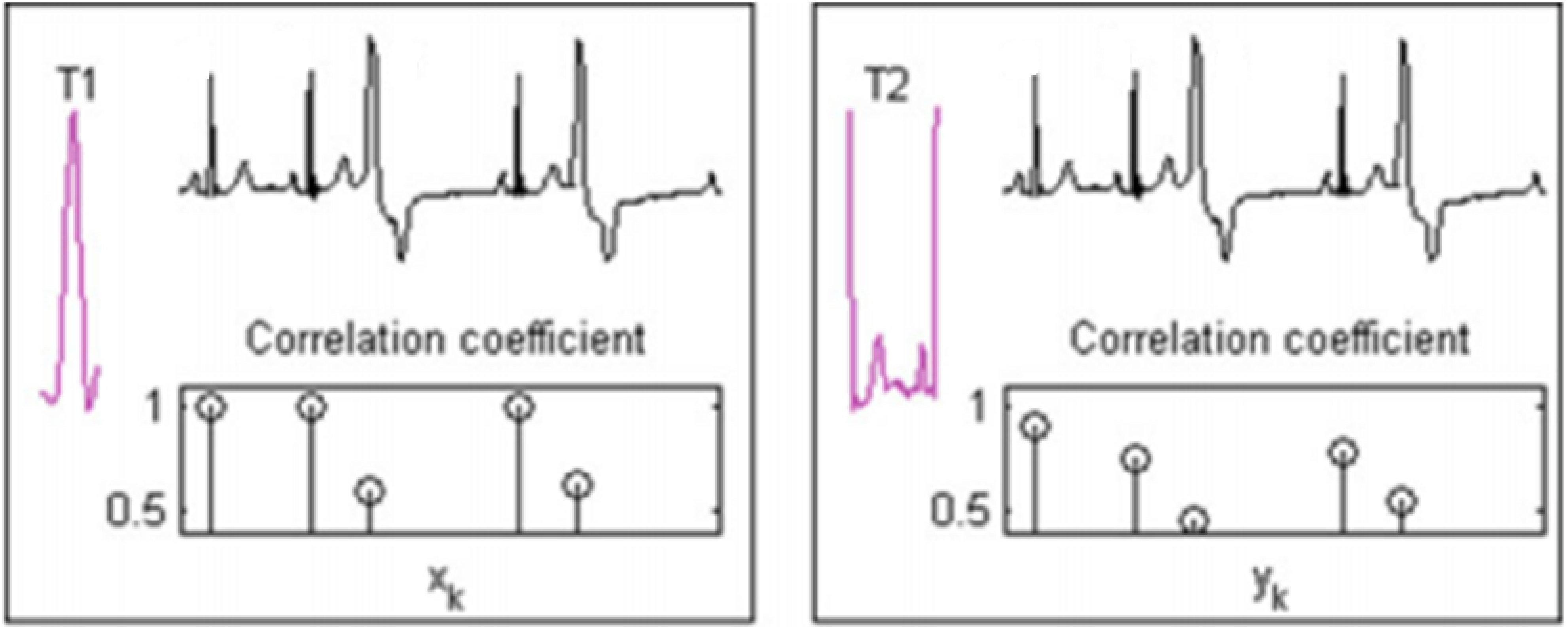

Figure 10. QRS and RR-interval templates and correlation [9]

Description of Solution: Ventricular Tachycardia

- Three or more consecutive PVC beats
- Wireless message transmitted to medical authorities

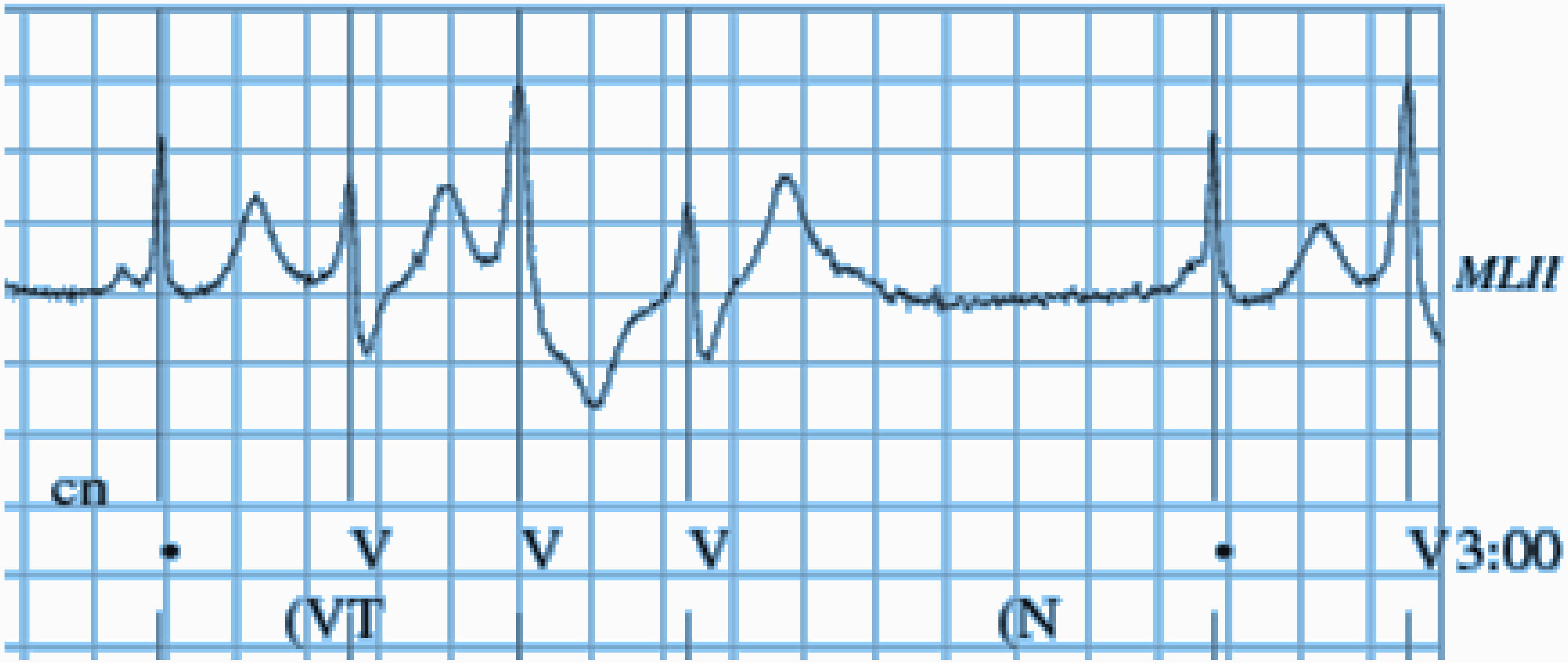

Figure 11. ECG demonstrating ventricular tachycardia [3]

Solution Testing

- MATLAB simulation of QRS, PVC, and VT detection
  - Use MIT-BIH arrhythmia database for testing data
  - Ensure that accuracy, sensitivity, and specificity are at least 90% using the WFDB toolbox
  - Estimate the execution time

Solution Testing

- C implementation of QRS, PVC, and VT detection
  - Store the heart data in the board’s memory and export the detection results to a file
  - Evaluate number of clock cycles required and quantization error propagation
  - Test the amount of time needed to send heart data from a PC to the board

Solution Testing

- Wireless communication
  - Use a packet sniffer to verify wireless communication
  - Verify that testing data sent from the board matches the data that the doctor would receive

Solution Testing

- System integration (C implementation and wireless communication)
  - Evaluate the delay between uploading the heart data and the doctor’s access to the data
  - Verify that heart data input with three or more consecutive PVCs correctly transmits a message to the doctor

Contents

Economic Analysis

TABLE III. PROJECT COSTS FOR HEART MONITORING SYSTEM

Component	Cost
CC3200 LaunchPad	$30.00

Contents

Schedule

TABLE IV. PROJECT SCHEDULE

Task	Duration (hours)
PVC Algorithm (MATLAB)	65
PVC Algorithm (C)	100
Wi-Fi Communication	150
Progress Report I	80
Progress Report II	80
Final Presentation	80
Final Report	80

Schedule

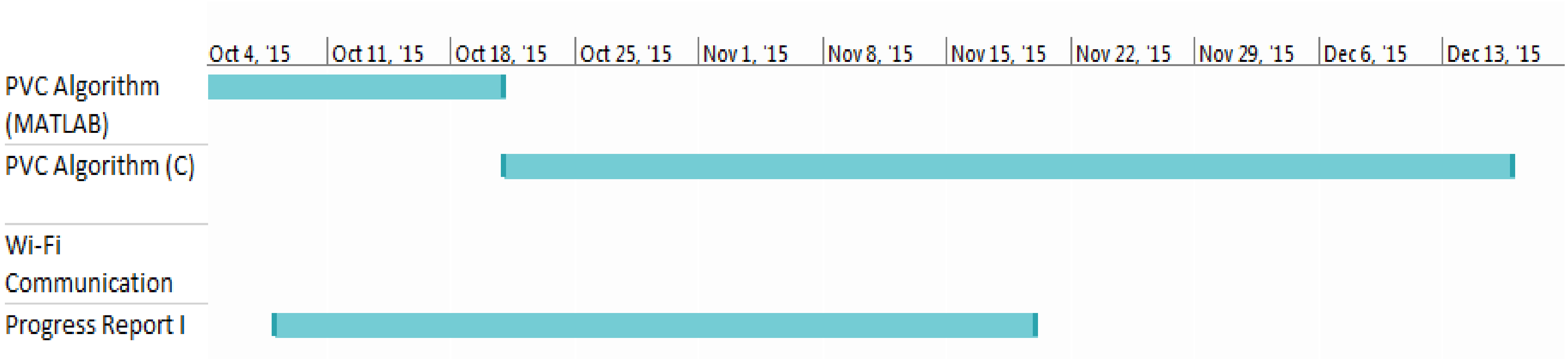

Figure 12. Gantt chart for the fall semester

Schedule

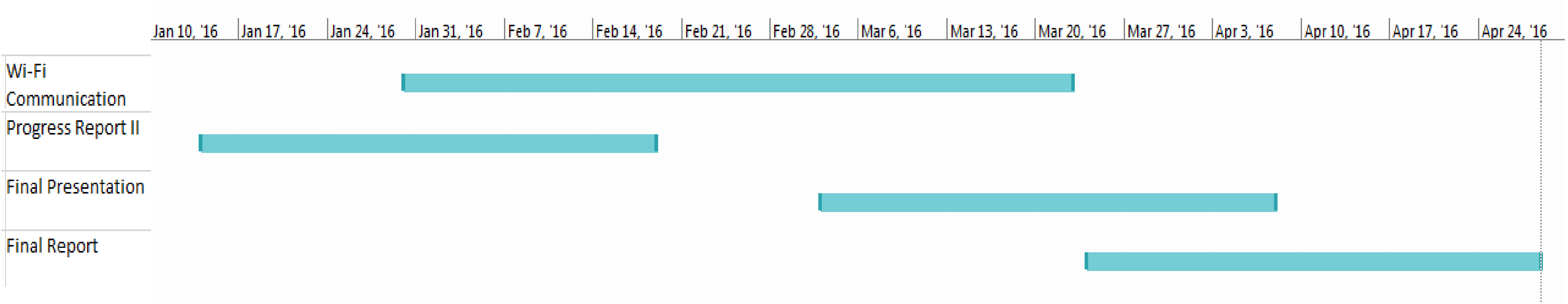

Figure 13. Gantt chart for the spring semester

Contents

Division of Labor

- MATLAB Simulation (PVC detection)
  - Shannon/Fatima
- C Programming (PVC detection)
  - Claire/Shannon
- Wi-Fi Communication
  - Fatima/Claire

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Societal and Environmental Impacts

- Low-power modes minimize battery consumption
- Testing data contains no personally identifiable information
- Wi-Fi technology allows for additional security [10]

Contents

Summary and Conclusions

- PVCs are irregular heartbeats that may lead to VT
- An embedded device is proposed that will detect PVCs in real time and wirelessly alert the patient’s doctor of VT

Summary and Conclusions

- Design should be compatible with all patient data in the MIT-BIH database, reasonably priced, portable, and low-power
- Design must include real-time ECG signal processing, on-board signal processing computations, and battery-powered functionality

Summary and Conclusions

- Proposed Design
  - CC3200 LaunchPad (Texas Instruments)
  - Pan-Tompkins algorithm for QRS detection
  - Template matching for PVC detection
  - Three consecutive PVC beats for VT detection
  - Tested using MIT-BIH arrhythmia database and MATLAB

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Detailed Gantt Chart (1)

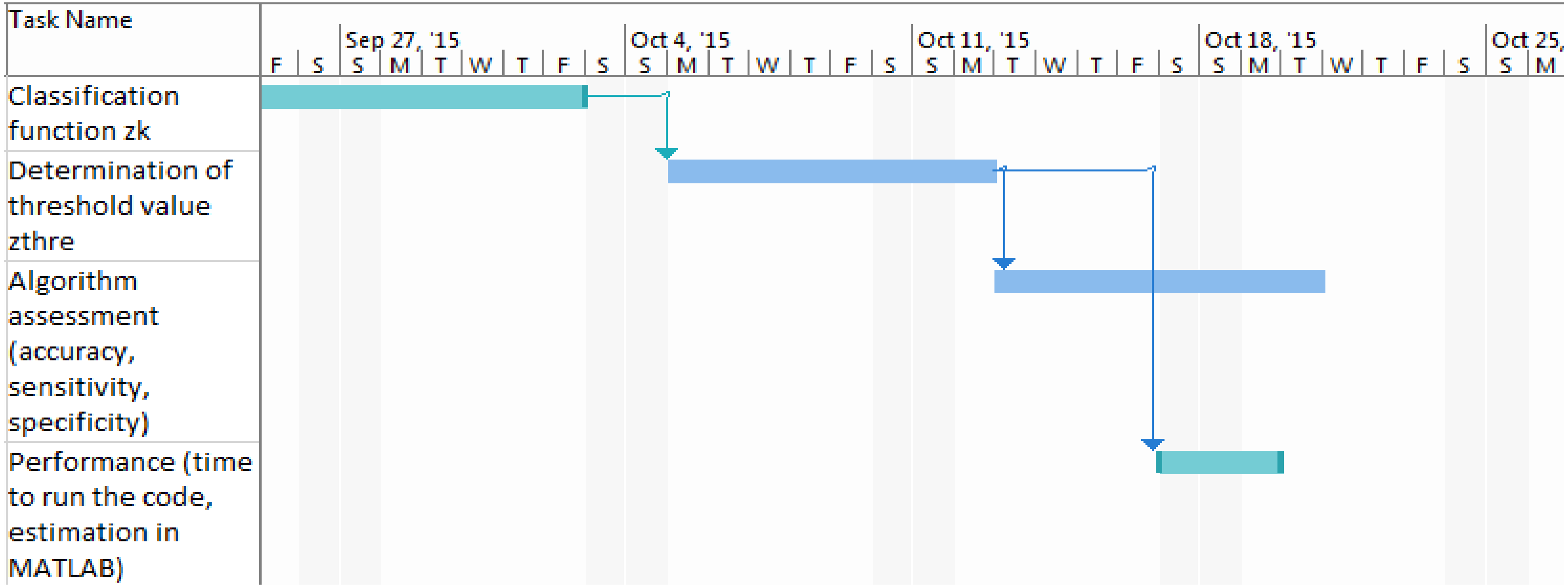

Figure 14. Gantt chart for the MATLAB simulation (PVC algorithm) phase of the project

Detailed Gantt Chart (2)

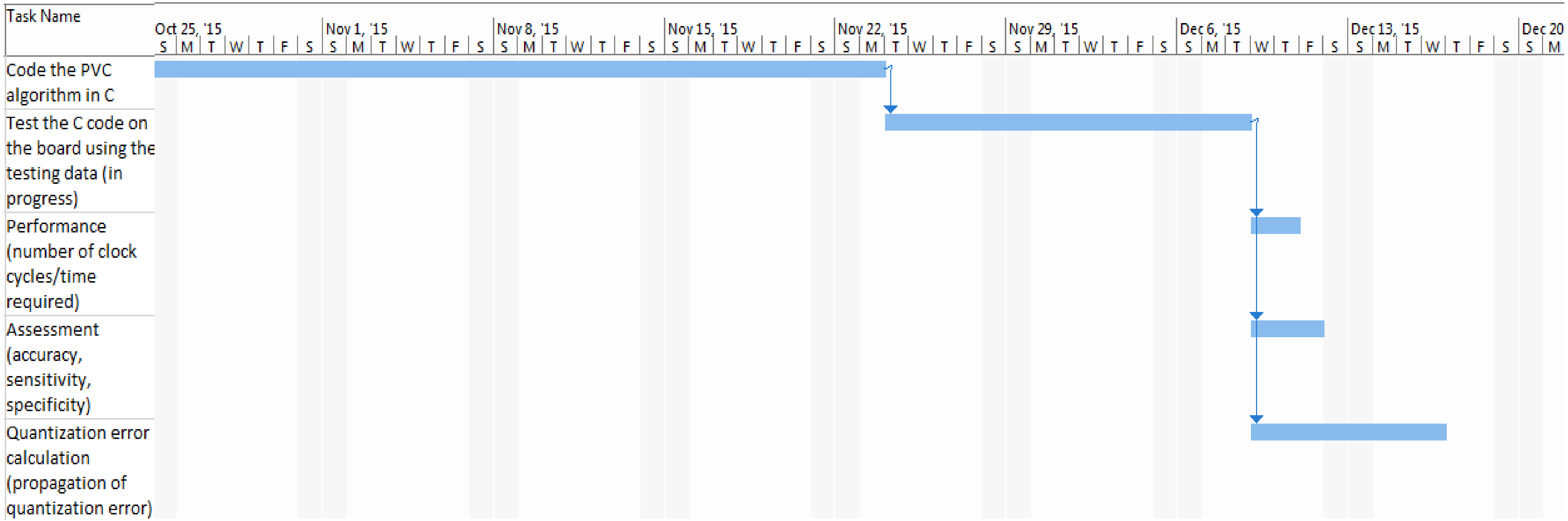

Figure 15. Gantt chart for the C implementation (PVC algorithm) phase of the project

Detailed Gantt Chart (3)

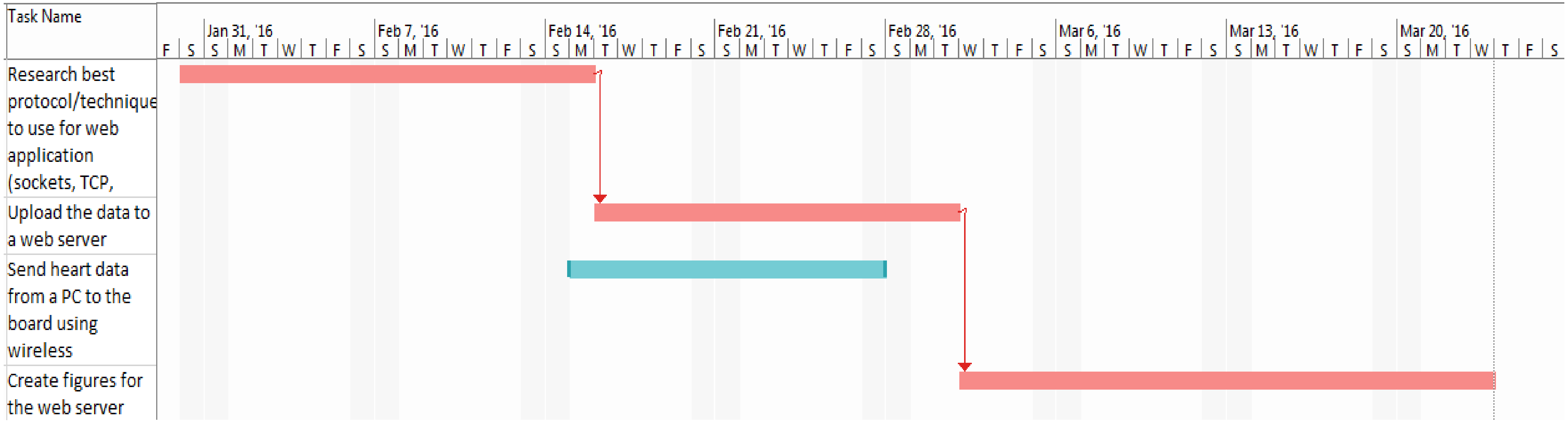

Figure 16. Gantt chart for the wireless development phase of the project

Specificity and Sensitivity [8]

$$SP = \frac{TN}{TN + FP} \qquad SE = \frac{TP}{TP + FN}$$

- TP (True Positive): detected QRS complex that is present in the signal
- TN (True Negative): data point between QRS complexes that does not contain a QRS peak
- FP (False Positive): incorrect identification of QRS peak
- FN (False Negative): QRS peak that was not detected by the algorithm

Memory Requirements

- Sampling rate for ECG signal (MIT-BIH arrhythmia database): 360 Hz
- Number of samples required for 30 seconds of ECG data: 10,800
- Amount of memory required: 21 kB

Problem Background

- Heart disease is the number one cause of death in the United States

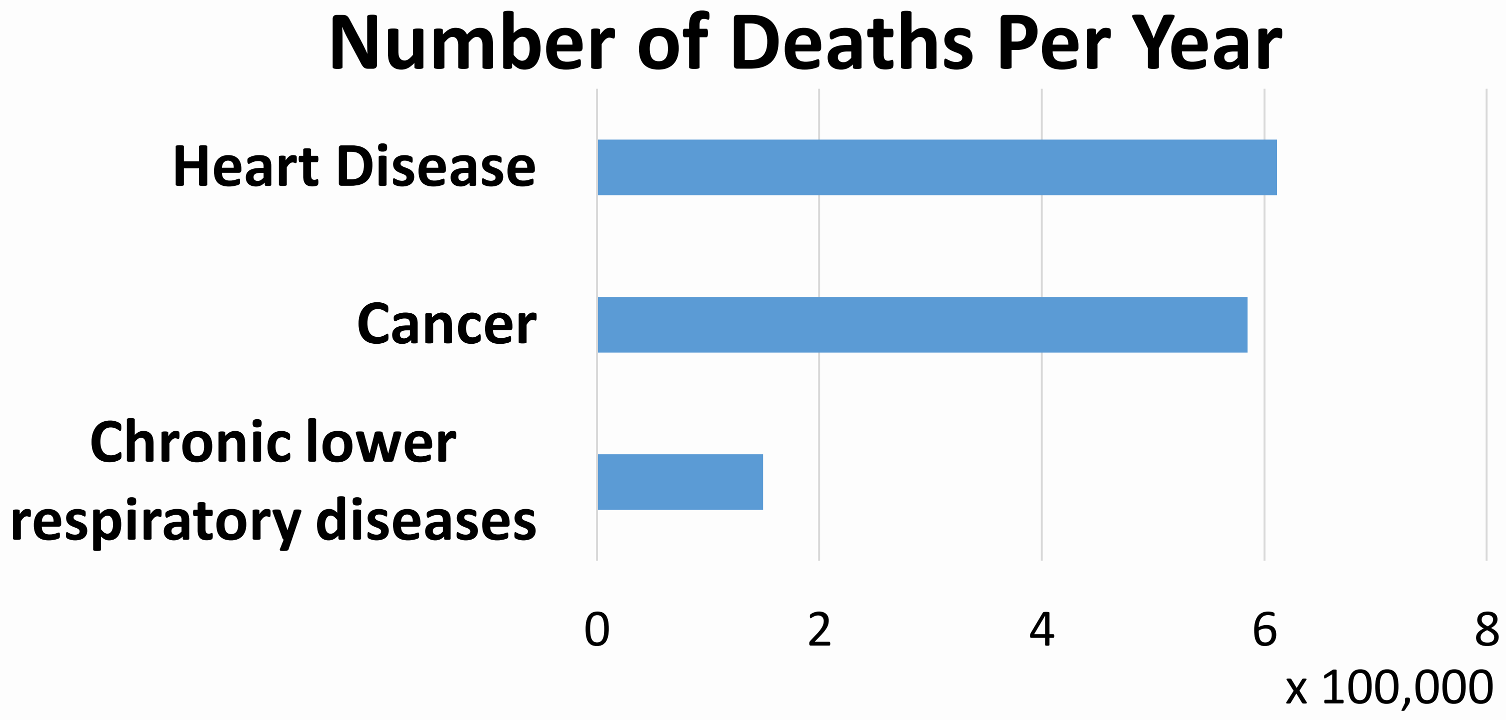

Figure 17. Chart of the three leading causes of death in the United States
Source: Centers for Disease Control and Prevention [17]

Nonfunctional Requirements: Metrics

Objective: The device should be compatible with all patient data in the MIT-BIH database. [3]

Metric:

• Highly compatible:	10 points
• Very compatible:	7.5 points
• Compatible:	5.0 points
• Somewhat compatible:	2.5 points
• Not compatible:	0 points

Nonfunctional Requirements: Metrics

Objective: The device should be portable.

Metric:

- Very easy to carry around: 10 points
- Easy to carry around: 7.5 points
- Portable: 5.0 points
- Uncomfortable to carry around: 2.5 points
- Difficult to carry around: 0 points

Nonfunctional Requirements: Metrics

TABLE VI. QUANTITATIVE PERFORMANCE LEVELS FOR REAL-TIME HEART MONITORING [8, 9]

Power Consumption in 24 Hours of Continuous Use (W)	Price ($)	Value Scaled
1.50	500	10
2.50	600	7.5
3.25	700	5
4.00	800	2.5
4.75	900	0

Design Evaluation: Morphological Chart

TABLE V. MORPHOLOGICAL CHART FOR HEART MONITORING SYSTEM [10,11,12,13,14,15,16]

Functions	Means		
Storing heart data	Flash memory	RAM	
Preprocessing (Filtering/QRS detection)	Pan-Tompkins	Wavelet transform	Wavelet transform and Pan-Tompkins
PVC detection	Wavelet transform	Template matching	RR-interval
Ventricular tachycardia detection	Three or more consecutive PVCs	Three or more consecutive PVCs, heart rate greater than 100 beats per minute	Statistical analysis
Wireless functionality	eZ430-RF2500	CC2540 (Bluetooth)	CC3200

Design Evaluation: Design Alternatives

- Total design space: 162 designs
- Two designs analyzed in detail

Design Evaluation: Design 1

TABLE VIII. FIRST DESIGN FOR HEART MONITORING SYSTEM

Functions	Means
Storing heart data	Flash memory
Preprocessing (Filtering/QRS detection)	Pan-Tompkins
PVC detection	RR-interval
Ventricular tachycardia detection	Three or more consecutive PVCs and heart rate above 100 beats per minute
Wireless functionality	CC2540 (Bluetooth)

Design Evaluation: Design 2

TABLE IX. SECOND DESIGN FOR HEART MONITORING SYSTEM

Functions	Means
Storing heart data	Flash memory
Preprocessing (Filtering/QRS detection)	Wavelet transform and Pan-Tompkins
PVC detection	Wavelet transform
Ventricular tachycardia detection	Three or more consecutive PVCs
Wireless functionality	eZ430-RF2500

Design Evaluation: NEM

- The two designs were then evaluated against the constraints and objectives

TABLE X. CONSTRAINTS AND OBJECTIVES FOR HEART MONITORING SYSTEM

Constraints	Objectives
Real-time ECG signal processing	Compatible with all patient data in the MIT-BIH database [3]
On-board signal processing computations	Low-power
Battery-powered functionality	Reasonably priced
	Portable

Design Evaluation: NEM

TABLE XI. NUMERAL EVALUATION MATRIX

Design / Constraints	Design 1	Design 2
Real-time ECG signal processing	+	+
On-board signal processing computations	+	+
Battery-powered functionality	+	+

+ : Constraint met

Design Evaluation: NEM

TABLE XII. NUMERAL EVALUATION MATRIX

Design / Objectives	Design 1	Design 2
Compatible with all patient data in the MIT-BIH database	7.5	10
Low-power	10	10
Reasonably priced	10	10
Portable	10	10

Alternative Solution: Hardware

- eZ430-RF2500 (Texas Instruments)
  - MSP430F2274 MCU
  - CC2500 wireless transceiver
  - 32 kB flash memory

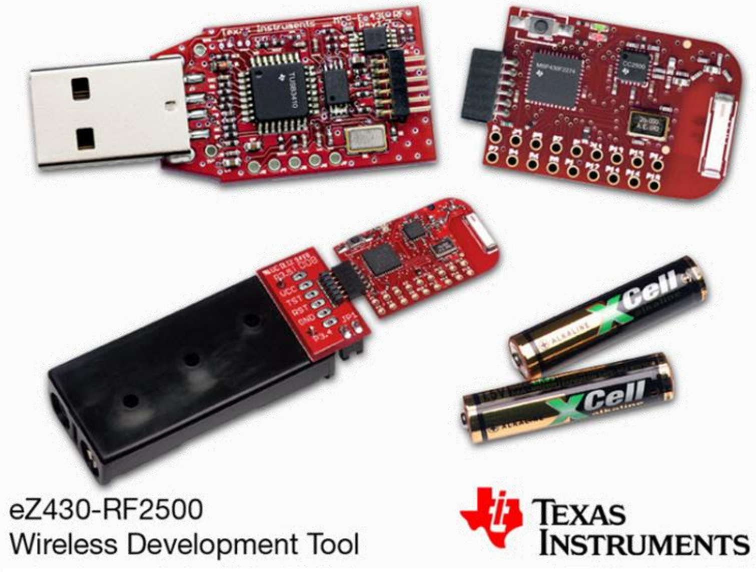

Figure 18. eZ430-RF2500 Development Kit [12]

Alternative Solution: Software

- PVC detection
  - Wavelet transform algorithm [13]
  - RR-interval algorithm [14]