**SFRWENG 3K04**

Assignment 1

Part 1: Pacemaker Modes

Gurleen Kaur Rahi (400377038)

Yash Bhatia (400362372)

Daniel Lupas (400396848)

Varunan Varathan (400375287)

Connor Usaty (400409624)

*Table of Contents*

1. **Introduction………………………………………………………………………**
2. **Variables…………………………………………………………………………**

**2.1 Measured………………………………………………………………………………**

**2.2 Constant……………………………………………………………………………**

**2.3 Controlled………………………………………………………………………….**

**2.4 Internal………………………………………………………………………………**

**3. Modes……………………………………………………………………………..**

**3.1 VOO………………………………………………………………………………………..**

3.1.1 Description…………………………………………………………………………..

3.1.2 Variables…………………………………………………………………………….

3.1.3 Requirements…………………………………………………………………………

3.1.4 Future Changes…………………………………………………………………………….

3.1.5 Stateflow………………………………………………………………………………………..

3.1.6 Testing…………………………………………………………………………………………….

**3.2 AOO……………………………………………………………………………..**

3.2.1 Description…………………………………………………………………………..

3.2.2 Variables…………………………………………………………………………….

3.2.3 Requirements…………………………………………………………………………

3.2.4 Future Changes…………………………………………………………………………….

3.2.5 Stateflow………………………………………………………………………………………..

3.2.6 Testing…………………………………………………………………………………………….

**3.3 AAI……………………………………………………………………………..**

3.3.1 Description…………………………………………………………………………..

3.3.2 Variables…………………………………………………………………………….

3.3.3 Requirements…………………………………………………………………………

3.3.4 State Transitions…………………………………………………………………………….

3.3.5 State Details………………………………………………………………………………………..

3.3.6 Future Changes……………………………………………………………………

3.3.7 Stateflow………………………………………………………………………………………..

3.3.8 Testing……………………………………………………………………………………………

**3.4 VVI……………………………………………………………………………..**

3.4.1 Description…………………………………………………………………………..

3.4.2 Variables…………………………………………………………………………….

3.4.3 Initial Values…………………………………………………………………………….

3.4.4 Requirements…………………………………………………………………………

3.4.5 State Transitions…………………………………………………………………………….

3.4.6 State Details………………………………………………………………………………………..

3.4.7 Future Changes……………………………………………………………………

3.4.8 Stateflow………………………………………………………………………………………..

3.4.9 Testing……………………………………………………………………………………………

1. **Introduction**

The Part 1 of this project is described in the accompanying documentation in a clear and generic manner that is targeted toward the end user. This project's goal is to build a functioning pacemaker that behaves and responds to its surroundings as a typical pacemaker would. The State flow Implementation in this documentation will receive all the attention. The 4 pacing/sensing modes (AOO, VOO, VVI, and AAI) are simulated using MATLAB Simulink. There will be more pace settings added in the project's second phase. The introduction of these 4 modes will be given, but the documentation will give a more thorough study of every mode.

Pacing is the depolarization of the atria or ventricles. Signals from the chamber are discovered by sensing. Pacing and cardiac sensing are both offered by the VVI and AAI modes. The ventricles are modeled using VVI, and the atrium is modeled using AAI. These two operating modes function on an inhibited basis, which means that the pacemaker is turned off in response to a specific activity from the appropriate chamber. Atrium and ventricle sensing is not done by AOO or VOO; they only pace.

1. **Variables**
   1. Measured Variables

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Units/Type** | **Range** | **Description** |
| t | ms |  | Time period since the pulse is started |
| Pul\_detect\_in\_atr | Boolean | {True, False} | Atrium Pulse Detected |
| Pul\_detect\_in\_ven | Boolean | {True, False} | Ventricle Pulse Detected |

* 1. Constant Variables (Programmable Parameters)

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Units/Type** | **Description** | **Value/Range/ToI** |
| p\_pacingState | y\_pacingState | Pacing state | PERMANENT |
| p\_pacingMode | int | Pacing mode | VVI |
| p\_hysteresis | boolean | True if hysteresis is to be used,  False, if not | False / True-False |
| p\_hysteresisInterval | mSec | Additional delay interval used when hysteresis is included | 300 / 200-500 / ± 4 |
| p\_lowrateInterval | mSec | Delay Interval that specifies maximum delay after a ventricle pace without a spontaneous sense or another pace | 1000 / 343-2000 / ± 8 |
| p\_ventricularPulseAmplitude | mV | Desired amplitude of a ventricular pace | 3500 / 500-7000 / ± 12% |
| p\_ventricularPulseWidth | mSec | Desired width of a ventricular pace | 0.4 / 0.1 – 1.9 / 0.2 |
| p\_atrialAmplitude | mV | Desired amplitude of a ventricular pace | 3500 / 500-7000 / ± 12% |
| p\_atrialPulseWidth | mSec | Desired width of a ventricular pace | 0.4 / 0.1 – 1.9 / 0.2 |
| p\_VRP | mSec | Duration of ventricular refractory period | 1. 150 – 500 / ± 8 |

2.3 Controlled Variables

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Units/Type** | **Description** | **Range** |
| s\_atrialPaceStart | Boolean | Commencement of atrial pulse | {True, False} |
| s\_ventricularPaceStart | Boolean | Commencement of ventricular pulse | {True, False} |
| s\_paceStart | Boolean | Output will be paceStart regardless of Atrium or Ventricle | {True, False} |

1. **Modes**

*3.1 VOO*

*3.1.1 Description:*

The rate set by p\_lowrateInterval is used to pace the ventricle in VOO mode. Because the top rate restriction is not in use, it is not incorporated into the design.

*3.1.2 Variables:*

*Measured Variables:*

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
| t | t | 2.1 |

*Constant Variables (Programmable Parameters):*

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
| p\_lowrateInterval | LRI | 2.2 |

*Controlled Variables:*

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
| s\_ventricularPaceStart | VPS | 2.3 |

*3.1.3 Requirements:*

|  |  |
| --- | --- |
| **t** | **Pace** |
| t < LRI | False |
| t = LRI | True |

*3.1.4 Future Changes:*

There are no future changes for this mode.

*3.1.5 Stateflow:*

A screenshot of a computer

Description automatically generated

*3.1.6 Testing:*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Testing Outcomes** | | | | |
| **Test Case** | | **Expected Result** | **Actual result** | **Pass/Fail** |
| **Natural Atrium** | **Natural Ventricle** |  | | |
| OFF | OFF | No response | No response | Pass |

1. Only one test scenario (when both the atrium and the ventricle are not functioning) can show that our pacemaker is accurate in VOO mode because we are not monitoring any chambers at that time. The graph below shows the screenshot from Heartview.

A screenshot of a computer

Description automatically generated

*3.2 AOO*

*3.2.1 Description:*

The atrium is paced in AOO mode at the rate specified by p\_lowrateinterval. The design does not feature the higher rate restriction because it is not in use.

*3.2.2 Variables:*

*Measured Variables:*

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
| t | t | 2.1 |

*Constant Variables (Programmable Parameters):*

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
| p\_lowrateInterval | LRI | 2.2 |

*Controlled Variables:*

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
| s\_atrialPaceStart | APS | 2.3 |

*3.2.3* *Requirements:*

|  |  |
| --- | --- |
| **t** | **Pace** |
| t < LRI | False |
| t = LRI | True |

*3.2.4 Future Changes:*

There are no future changes for this mode.

*3.2.5 Stateflow:*

A diagram of a computer code

Description automatically generated

*3.2.6 Testing:*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Testing Outcomes** | | | | |
| **Test Case** | | **Expected Result** | **Actual result** | **Pass/Fail** |
| **Natural Atrium** | **Natural Ventricle** |  | | |
| OFF | OFF | No response | No response | Pass |

1. Only one test scenario (when both the atrium and the ventricle are not functioning) can show that our pacemaker is accurate in AOO mode because we are not monitoring any chambers at that time. The graph below shows the screenshot from Heartview.

A screenshot of a computer

Description automatically generated

*3.3 AAI*

*3.3.1 Description:*

The atrium is pace in AAI mode at the rate specified by p\_lowrateInterval unless a pulse appears on its own. Following a spontaneous or natural pulse, spontaneous pulses that occur during the atrial refractory phase are not processed. The pacing rate will be slower if hysteresis is enabled and the previous pulse was spontaneous. p\_hysteresisInterval was reached. The previous interval between pulses and the current interval are recorded if rate smoothing is enabled and the heart rate is computed.

*3.3.2 Variables:*

*Measured Variables:*

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
| t | t | 2.1 |
| Pul\_detect\_in\_atr | PDA | 2.1 |

*Constant Variables (Programmable Parameters):*

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
|  |  |  |

*Controlled Variables:*

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
| s\_atrialPaceStart | APS | 2.3 |

* + 1. *Requirements:*

#### Hysteresis and Rate Smoothing Disabled

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Last Pulse Type | Last Period | t | Spontaneous pulse resets timer | PS |
| X | X |  | false | false |
|  | true | false |
|  | true |

#### Hysteresis Disabled and Rate Smoothing Enabled

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Last Pulse Type | Last Period | t | Spontaneous pulse resets timer | PS |
| X | X |  | false | false |
| X |  | true | false |
|  |  | true |
|  |  | false |
|  | true |
|  |  | false |
|  | true |

#### Hysteresis Enabled and Rate Smoothing Disabled

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Last Pulse Type | Last Period | t | Spontaneous pulse resets timer | PS |
| X | X |  | false | false |
|  | true | false |
| Sensed |  | false |
|  | true |
| Paced |  | false |
|  | true |

#### Hysteresis and Rate Smoothing Enabled

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Last Pulse Type | Last Period | t | Spontaneous pulse resets timer | PS |
| X | X |  | false | false |
| X |  | true | false |
| Sensed |  |  | true |
|  |  | false |
|  | true |
|  |  | false |
|  | true |
| Paced |  |  | false |
|  | true |
|  |  | false |
|  | true |
|  |  | false |
|  | true |

### *State Transitions:*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Next State  Current State | INITIAL | PACED | SENSED | UPPER RATE LIMIT | LOWER RATE LIMIT | HYSTERESIS LIMIT | RATE SMOOTHING DOWN | RATE SMOOTHING UP |
| INITIAL | – | HE = true  t = HL  **or**  HE = false  t = LRL | PD = true | – | – | – | – | – |
| PACED | – | – | – | – | RSE = true  LP ≥ LRL(1-RSD)  LP ≤ LRL(1+RSU)  **or**  RSE = false | – | RSE = true  LP < LRL(1-RSD) | RSE = true  LP > LRL(1+RSU) |
| SENSED | – | – | – | RSE = true  LP≤URL(1-RSD) | HE = false  RSE = false  **or**  HE = false  RSE = true  LP≥ LRL(1-RSD) | HE = true  RSE = true  LP≥HL(1-RSD)  **or**  HE = true  RSE = false | HE = true  RSE = true  LP > URL(1-RSD)  LP < HL(1-RSD)  **or**  HE = false  RSE = true  LP > URL(1-RSD)  LP < LRL(1-RSD) | – |
| UPPER RATE LIMIT | – | t = URL | PD = true | – | – | – | – | – |
| LOWER RATE LIMIT | – | t = LRL | PD = true | – | – | – | – | – |
| HYSTERESIS LIMIT | – | t = HL | PD = true | – | – | – | – | – |
| RATE SMOOTHING DOWN | – | t=LP(1+RSD) | PD = true | – | – | – | – | – |
| RATE SMOOTHING UP | – | t=LP(1-RSD) | PD = true | – | – | – | – | – |

### *State details:*

|  |  |
| --- | --- |
| **State** | **Description** |
| INITIAL | When hysteresis is enabled, the pacemaker waits p\_hysteresis\_limit seconds after sensing pulses before pacing. |
| PACED | Sends a 1-ms pulse on s\_atrialPaceStart and waits for p\_arp to finish |
| SENSED | Waits until p\_arp has finished. |
| UPPER RATE LIMIT | Until p\_upper\_rate\_limit, listens for felt pulses |
| LOWER RATE LIMIT | Until p\_lower\_rate\_limit, listens for perceived pulses |
| HYSTERESIS LIMIT | Listens until p\_hysteresis\_limit for detected pulses |
| RATE SMOOTHING DOWN | Until a limit set by the maximum permitted rate reduction, listens for felt pulses |
| RATE SMOOTHING UP | Listens for observed pulses up till the maximum rate increase limit |

* + 1. *Future Changes:*

There are no future changes for this mode.

* + 1. *Stateflows:*
    2. *Testing:*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Testing Outcomes** | | | | | | |
| **Test Case** | |  | | **Expected Result** | **Actual result** | **Pass/Fail** |
| **Natural Atrium** | **Natural Ventricle** | **Heart Rate (bpm)** | **Pulse width (ms)** |  | | |
| ON | OFF | 30 | 1 | Pulse is given after every 1000ms | Pulse is given after every 1000ms | Pass |
| ON | OFF | 30 | 10 | Pulse is generated with a gap which is larger than 1000ms | Pulse is generated with a gap which is larger than 1000ms | Pass |
| ON | OFF | 50 | 1 | Pulse is provided so that the delay is accounted | Pulse is provided so that the delay is accounted | Pass |
| ON | OFF | 50 | 10 | Artificial pulse is not provided | Artificial pulse is not provided | Pass |

1. Test case #1: (Natural Atrium: **ON**, Natural Ventricle: **OFF**, Pulse Width: **1 ms**, Heart Rate: **30 bpm**)

Since the heart beats at a rate of 60 beats per minute (bpm), which corresponds to a pulse after every 1000 milliseconds, the pacemaker is intended to generate a pulse even at very low heart rate and pulse width. The graph below illustrates how our pacemaker fills in the gap with a pulse every 1000 milliseconds.

GRAPH

1. Test case #2: (Natural Atrium: **ON**, Natural Ventricle: **OFF**, Pulse Width: **10 ms**, Heart Rate: **30 bpm**)

When the pulse width is increased to 10 ms while the heart rate remains constant, the time between two successive pulses is still greater than 1000 ms, which indicates that the pacemaker should still generate the pulse. The graph below shows that our pacemaker performs the similar function by giving a pulse to fill up the time gap.

GRAPH

1. Test case #3: (Natural Atrium: **ON**, Natural Ventricle: **OFF**, Pulse Width: **1 ms**, Heart Rate: **50 bpm**)

A pacemaker is intended to deliver an artificial pulse when the heart rate is just below the natural rate but the pulse width is insufficient to match the natural rate (60 beats per minute or a pulse every 1000 milliseconds).

GRAPH

1. Test case #4: (Natural Atrium: **ON**, Natural Ventricle: **OFF**, Pulse Width: **10 ms**, Heart Rate: **50 bpm**)

Pacemakers are not supposed to produce any artificial pulses when the heart rate is below normal but the pulse width is sufficient to fill the gap. The graph below demonstrates that there is no additional pulse being sent to the heart by our pacemaker.

GRAPH

* 1. *VVI*

*3.4.1 Description:*

If a spontaneous pulse is not found, the ventricle is paced in VVI mode at the rate specified by p\_lowrateInterval. After a natural or spontaneous pulse, spontaneous pulses that happen during the ventricular refractory phase are not processed. The pacing rate is lowered to p\_hysteresis\_limit if hysteresis is enabled and the previous pulse was spontaneous.

The most recent interval between pulses is noted and the current heart rate is computed if rate smoothing is enabled. The pulsing rate tends towards either p\_lowrateInterval or p\_hysteresisInterval, lowering or increasing by a maximum amount determined by p\_rate\_smoothing\_down or p\_rate\_smoothing\_up. The pacemaker will never pace faster than the rate specified by p\_upper\_rate\_limit in any circumstance.

*3.4.2 Variables:*

*Measured Variables:*

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
| t | t | 2.1 |
| Pul\_detect\_in\_vent | PDV | 2.1 |

*Constant Variables (Programmable Parameters):*

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
|  |  |  |

*Controlled Variables:*

|  |  |  |
| --- | --- | --- |
| **Name** | **Abbreviation** | **Reference** |
| s\_ventricularPaceStart | VPS | 2.3 |

* + 1. *Initial Values:*

s\_ventricularPaceStart = false

|  |  |
| --- | --- |
|  |  |
|  |  |
|  |  |

* + 1. *Requirements:*

#### Hysteresis and Rate Smoothing Disabled

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Last Pulse Type | Last Period | t | Spontaneous pulse resets timer | PS |
| X | X |  | false | false |
|  | true | false |
|  | true |

#### Hysteresis Disabled and Rate Smoothing Enabled

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Last Pulse Type | Last Period | t | Spontaneous pulse resets timer | PS |
| X | X |  | false | false |
| X |  | true | false |
|  |  | true |
|  |  | false |
|  | true |
|  |  | false |
|  | true |

#### Hysteresis Enabled and Rate Smoothing Disabled

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Last Pulse Type | Last Period | t | Spontaneous pulse resets timer | PS |
| X | X |  | false | false |
|  | true | false |
| Sensed |  | false |
|  | true |
| Paced |  | false |
|  | true |

#### Hysteresis and Rate Smoothing Enabled

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Last Pulse Type | Last Period | t | Spontaneous pulse resets timer | PS |
| X | X |  | false | false |
| X |  | true | false |
| Sensed |  |  | true |
|  |  | false |
|  | true |
|  |  | false |
|  | true |
| Paced |  |  | false |
|  | true |
|  |  | false |
|  | true |
|  |  | false |
|  | true |

### *State Transitions:*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Next State  Current State | INITIAL | PACED | SENSED | UPPER RATE LIMIT | LOWER RATE LIMIT | HYSTERESIS LIMIT | RATE SMOOTHING DOWN | RATE SMOOTHING UP |
| INITIAL | – | HE = true  t = HL  **or**  HE = false  t = LRL | PD = true | – | – | – | – | – |
| PACED | – | – | – | – | RSE = true  LP ≥ LRL(1-RSD)  LP ≤ LRL(1+RSU)  **or**  RSE = false | – | RSE = true  LP < LRL(1-RSD) | RSE = true  LP > LRL(1+RSU) |
| SENSED | – | – | – | RSE = true  LP≤URL(1-RSD) | HE = false  RSE = false  **or**  HE = false  RSE = true  LP≥ LRL(1-RSD) | HE = true  RSE = true  LP≥HL(1-RSD)  **or**  HE = true  RSE = false | HE = true  RSE = true  LP > URL(1-RSD)  LP < HL(1-RSD)  **or**  HE = false  RSE = true  LP > URL(1-RSD)  LP < LRL(1-RSD) | – |
| UPPER RATE LIMIT | – | t = URL | PD = true | – | – | – | – | – |
| LOWER RATE LIMIT | – | t = LRL | PD = true | – | – | – | – | – |
| HYSTERESIS LIMIT | – | t = HL | PD = true | – | – | – | – | – |
| RATE SMOOTHING DOWN | – | t=LP(1+RSD) | PD = true | – | – | – | – | – |
| RATE SMOOTHING UP | – | t=LP(1-RSD) | PD = true | – | – | – | – | – |

### *State details:*

|  |  |
| --- | --- |
| **State** | **Description** |
| INITIAL | When hysteresis is enabled, the pacemaker waits p\_hysteresis\_limit seconds after sensing pulses before pacing. |
| PACED | Sends a 1-ms pulse on s\_atrialPaceStart and waits for p\_arp to finish |
| SENSED | Waits until p\_arp has finished. |
| UPPER RATE LIMIT | Until p\_upper\_rate\_limit, listens for felt pulses |
| LOWER RATE LIMIT | Until p\_lower\_rate\_limit, listens for perceived pulses |
| HYSTERESIS LIMIT | Listens until p\_hysteresis\_limit for detected pulses |
| RATE SMOOTHING DOWN | Until a limit set by the maximum permitted rate reduction, listens for felt pulses |
| RATE SMOOTHING UP | Listens for observed pulses up till the maximum rate increase limit |

* + 1. *Future Changes:*

There are no future changes for this mode.

* + 1. *Stateflows:*
    2. *Testing:*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Testing Outcomes** | | | | | | |
| **Test Case** | |  | | **Expected Result** | **Actual result** | **Pass/Fail** |
| **Natural Atrium** | **Natural Ventricle** | **Heart Rate (bpm)** | **Pulse width (ms)** |  | | |
| OFF | ON | 30 | 1 | After previous pulse is greater than 1000ms, artificial pulse is provided | After previous pulse is greater than 1000ms, artificial pulse is provided | Pass |
| OFF | ON | 30 | 10 | Pulse is generated to fill the gap from original pulse | Pulse is generated to fill the gap from original pulse | Pass |
| OFF | ON | 50 | 1 | Pulse is provided so that the low pulse width is accounted | Pulse is provided so that the low pulse width is accounted | Pass |
| OFF | ON | 50 | 10 | Artificial pulse is not produced | Artificial pulse is not produced | Pass |

1. Test case #1: (Natural Atrium: **OFF**, Natural Ventricle: **ON**, Pulse Width: **1 ms**, Heart Rate: **30 bpm**)

When the heart rate is extremely low, the pacemaker is anticipated to provide pulses frequently enough to keep the heart rate generally normal. In order to maintain a normal heart rate of 60 beats per minute or a pulse every 1000 milliseconds, our pacemaker generates artificial pulses anytime the interval between pulses is greater than 1000 milliseconds, as shown in the graph below.

GRAPH

1. Test case #2: (Natural Atrium: **OFF**, Natural Ventricle: **ON**, Pulse Width: **10 ms**, Heart Rate: **30 bpm**)

When the heart rate is low, a high pulse width cannot close the gap, so the pacemaker is designed to deliver pulses to ensure the heart is working properly.

It is evident from the graph below that our pacemaker keeps the heart operating normally by giving it fake pulses.

GRAPH

1. Test case #3: (Natural Atrium: **OFF**, Natural Ventricle: **ON**, Pulse Width: **1 ms**, Heart Rate: **50 bpm**)

Pacemaker is anticipated to activate and begin sending pulses to the heart when heart rate is slightly below normal but pulse width is insufficient to close the gap. We can see from the graph below that our pacemaker performs just as it should.

GRAPH

1. Test case #4: (Natural Atrium: **OFF**, Natural Ventricle: **ON**, Pulse Width: **10 ms**, Heart Rate: **50 bpm**)

Pacemakers shouldn't activate when heart rate is barely below normal and pulse width is sufficient to close the gap.

The graph below demonstrates that our pacemaker is not generating any artificial heartbeats.

GRAPH