Team Project: Developing and testing a software-based prototype of a Heart Rate Variability device [1]

Due Wed Apr 16th at 11:59pm

Team work submitted individually on Brightspace as a tar or zip file named teamX.tar or teamX.zip, where X is your team number. **Mandatory demos** will be **individual** starting on Monday April 17th. The scheduling details will be announced the week before and the project review-demo times will be arranged between you and your assigned TA. The implementation and testing are to be in C++ using the Qt framework on the course VM (COMP3004-F21). You are required to use GitHub: make sure your repository is private and that you provide access to your assigned TA. You are encouraged to check your progress on a weekly basis with myself and the TAs. Do not wait until the last minute.

Overview

Your team has been tasked with designing computer software for a stand alone device called HeartWave. HeartWave will be able to measure, analyze and display HRV (Heart Rate Variability) patterns through the use of an advanced heart rate monitor and provide users with real-time biofeedback on their coherence levels. The goal of this device is to help users reduce stress and achieve a high state of coherence, an optimal psychophysiological state that reflects well being and health. HeartWave is based on technology produced by the HeartMath institute, including their Inner Balance and emWave2 line of products.

Deliverables (5 parts)

- **Use cases**
- **Design documentation** – structure and behavior
  - UML Class diagram
  - Sequence diagrams for these scenarios: normal operation, interruption due to sensor off, and battery low
  - (optional) Activity or state diagram
  - Textual explanation of your design decisions
- **Implementation**
  - Source code of your Qt C++ project that builds and runs on the course VM (COMP3004-F21.ova found at https://git.scs.carleton.ca/downloads/CourseVirtualMachines/2021F-2022W/COMP3004-F21.ova)
  - Tests based on scenarios specified in design
- **Video:** record a video of running your simulation through the scenarios of low and high coherence, interruption of signal and battery low.
- **Traceability matrix**

[1] This project has been specified by Igor Radonjić, with minor changes by Vojislav Radonjić.

Background

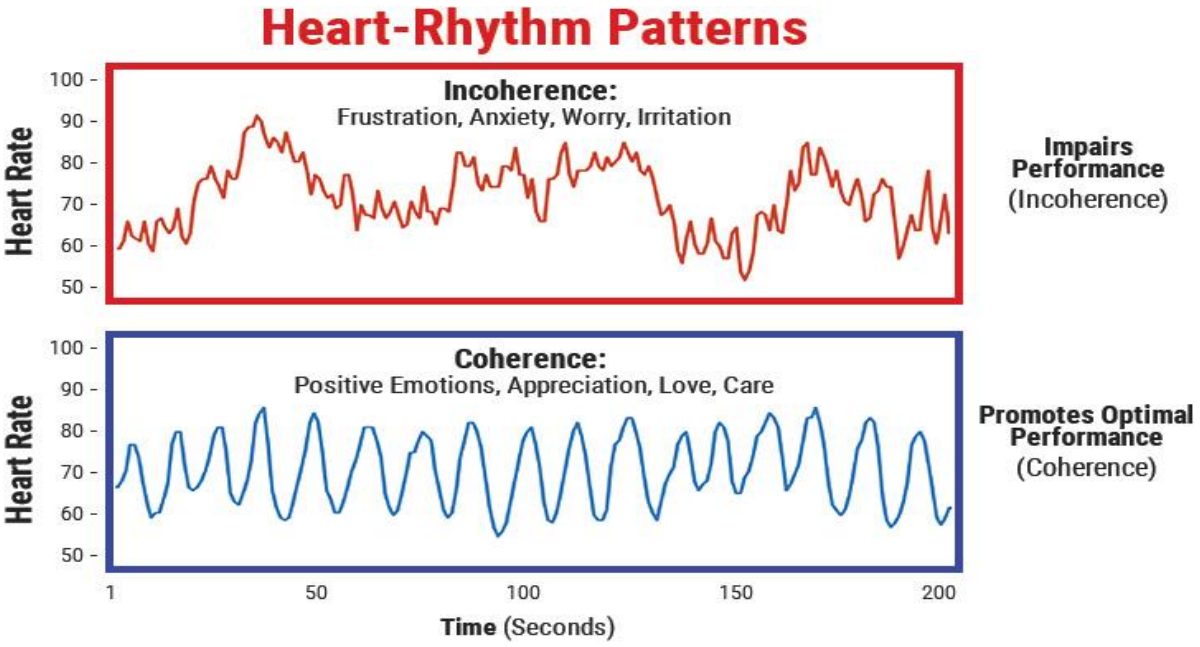
Heart rate variability (HRV) is *not* heart rate as measured in BPM. One's heart rate is not constant, rather it fluctuates. HRV is a measure of the variation in time intervals between heartbeats.

It is a marker of the balance between the sympathetic and parasympathetic branches of the autonomic nervous system. High HRV is generally associated with good physical and mental health, and low HRV is associated with stress, poor health, and an increased risk of certain diseases. HRV is a non-invasive measurement that reflects heart-brain interaction and autonomic nervous system dynamics, which are particularly sensitive to changes in your emotional state.

HRV can be measured using a variety of techniques, including electrocardiography (ECG), photoplethysmography (PPG), and impedance cardiography (ICG). HRV is often used as a tool to assess the effects of stress, exercise, and other factors on the body and to monitor changes in physical and mental health over time.

HeartWave utilizes HRV to analyze the entire heart rhythm pattern in order to indicate and train cardiac coherence. The goal is to achieve a continuous, high level of coherence. Coherence is a state of synchronization between your heart, brain and autonomic nervous system that has been proven to have numerous mental, emotional and physical benefits.

HeartWave displays your heart rhythm in real time providing ongoing biofeedback. A coherent heart rhythm is defined as a relatively harmonic, sine-wavelike signal. The goal for the user is to change the displayed erratic incoherent heart rhythm below into a smooth, regular wave. The device will indicate the level of heart coherence, from low coherence to medium and high coherence.



HRV naturally varies with breathing. As you breathe in HR (heart rate) speeds up, as you breathe out it slows down. This is because inhalation is associated with the signal from the sympathetic nervous system (flight and fight), whereas exhalation signals the parasympathetic nervous system (rest and relaxation). These signals are mediated by the vagus nerve which controls HRV. A high range in HRV is evidenced in the undulating coherent wave pattern that is in-sync with a slow and steady respiratory rate. This is why the HeartWave includes an optional breath pacer for the user to help achieve a high state of coherence.

So, in short, the HeartWave will display the heart rhythm signals in real time for the user, along with a variety of key indicators to help facilitate and measure coherence levels. The device will have a history or log that records data about individual sessions and progress over time. There will also be a settings tab. The features will be listed in the next section. The student is free to design and implement the user interface as they see fit, as long as the key features are included.

For more information, visit the HeartMath institute at www.heartmath.com

Requirements

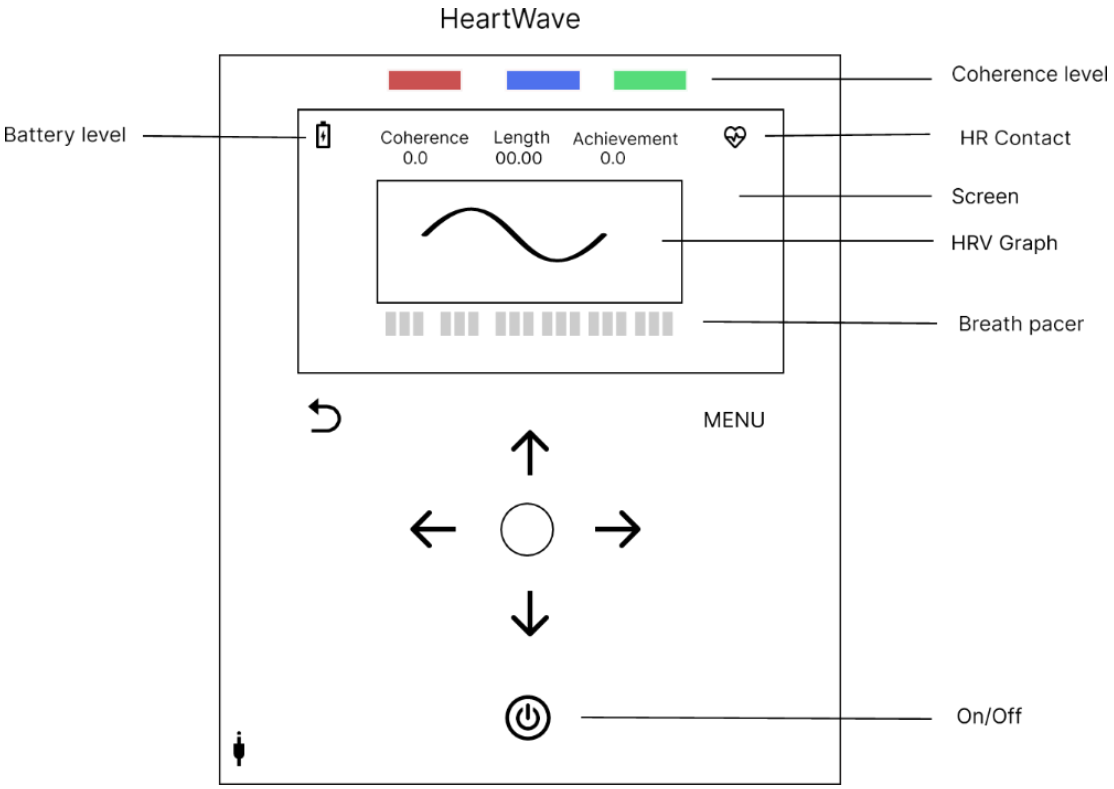


Figure 1: Example User Interface

The HeartWave includes the following features:

- A light on the machine and/or a symbol on the screen that indicates an active pulse reading
- A suggested user interface consists of the following main components: A screen and buttons. The screen contains the menu options and the display graph. There are eight buttons: an off/on button for the device, a menu button, a standard back button which will return the user to the menu, four arrow buttons (up/down,left/right) and a selector in the center of the arrow buttons which also functions as a start/stop button in session mode.
- In addition, the device has a led light that changes to red, blue or green to indicate coherence level
- Press selector to initiate and end a session. The menu options are displayed as default on the session screen. There is an option at the top to start a new session. The menu could consist of the following options: start new session, settings, log/history.
- Session screen must display the main HRV graph (HR vs time) with key metrics
- On the device there should be a light that changes to red, blue or green indicating low, medium or high coherence, depending on the challenge level
- The metrics on the screen include the current coherence score (numerical value), length (duration of session), achievement (total sum of coherence scores sampled every 5 seconds)
- A breath pacer in the form of a strip of lights on the machine itself, or a ball going back and forth on the session screen, default set at one breath every 10 seconds, adjustable in settings
- The settings tab includes challenge level (optional) and breath pacer settings
- (optional) There are 4 challenge levels for coherence, from beginner to advanced, for the user to choose
- The breath pacer, 1-30 seconds, increases time interval between each breath, default at 10 seconds
- When the user ends a session a summary view will appear that includes the following information: challenge level (optional), percentage of time in different coherence levels (low, medium and high), average coherence, length of session, achievement score, entire HRV graph
- The menu contains a log or history tab of all sessions, with dates, when selected show the summary view, as well as the ability to delete a session
- An option to reset, wipe all data and restore the device to the initial install condition
- There is a battery charge indicator on the session screen
- A beep goes off when a new coherence level is reached

Technical Information

Achievement Score: The sum of your individual Coherence Scores during the length of a session. It can be improved by achieving higher Coherence Scores and the length of time spent in Coherence during the session. It is the total of all Coherence. The scoring algorithm updates

your Coherence Score every 5 seconds during an active session and adds them together giving you a sum which is called Achievement on the app displays.

Heart Coherence: Coherence refers to your internal order or harmony. Increased Coherence enables better balance, greater health, and new levels of creativity, resilience and productivity.
Coherence Indicator: The light or coloured circle at the top of the Session View. Reflective of your state of Coherence over the last 64 seconds, it indicates your current state of Coherence. Green for High, Blue for Medium and Red for Low.

Coherence Score: A measure of the degree of Coherence in the heart rhythm pattern. A Coherent heart rhythm is a stable regular repeating rhythm resembling a sine wave at a single frequency between 0.04-0.24 Hz (3-15 cycles per minute). The scoring algorithm continuously monitors the most current 64 seconds of heart rhythm data and updates the score every 5 seconds. The more stable and regular the heart rhythm frequency is, the higher the Coherence Score. Scores range from 0-16. The score range is the guide to setting the Challenge Levell.

Coherence Score Guide
0.5 Basic – good beginner level
1.0 Good
2.0 Very good
3.0+ Excellent

Computing the coherence score is optional, however, you should at least have a table of coherence scores to be read every 5 seconds.

(optional) Challenge Level: These settings are thresholds for the levels of Coherence that determine if you are in low (red), medium (blue) or high (green) Coherence. There are four different Challenge Levels; 1, 2, 3, and 4. As your Coherence Score rises you shift from one range (low, med or high) to the next. The Coherence Score threshold between the three ranges is gradually increased at a rate of 15% for each higher Challenge Level 1 - 3 and 30% between 3 - 4.
The challenge thresholds for the medium level are at level 1, med 0.5-0.9, level 2, med 0.6-2.1, level 3, med 1.8-4.0, level 4, med 4.0-6.0. Below and above these medium ranges are low and high Coherence levels for each challenge level.
Coherence and Achievement Scores are not affected by the Challenge Level Setting.

Heart Rate Variability (HRV): The normally occurring beat-to-beat changes in heart rate. Analysis of HRV is an important tool used to assess heart-brain interactions and autonomic nervous system dynamics (function, synchronization and balance). HRV is considered a key indicator of aging, cardiac health, resilience and overall well-being.

Further Information

Visit the HearthMath website for more information at www.heartmath.com.

The algorithms and coherence scoring system is based on HeartMath technology, including the Inner Balance and emWave2 line of products.

The following is a link to the user manual for the Inner Balance:
https://cdn.heartmath.com/manuals/inner_balance_ios_android.pdf

The following is a link to a more detailed background on the science of HRV:
https://www.heartmath.org/research/science-of-the-heart/heart-brain-communication/

The following is a link to a presentation “Engaging The Intelligence of the Heart” by Howard Martin that includes a demo:
https://www.youtube.com/watch?v=A9kQBAH1nK4

Coherence algorithm (optional):

“A coherent heart rhythm is defined as a relatively harmonic (sine wave-like) signal with a very narrow, high-amplitude peak in the low frequency region (typically around 0.1 Hz) of the power spectrum with no major peaks in the other bands. Coherence is assessed by identifying the maximum peak in the 0.04–0.26 Hz range of the HRV power spectrum, calculating the integral in a window 0.030 Hz wide, centered on the highest peak in that region, and then calculating the total power of the entire spectrum. The coherence ratio is formulated as: (Peak Power/[Total Power − Peak Power])”.

https://help.heartmath.com/v1/en/asmts_hrv.html#p4

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5643505/

https://cdn.heartmath.com/manuals/emWave%20Pro%20Plus%20Assessments%20-%20HRV.pdf

https://help.heartmath.com/v1/en/power_spectrum.html