Capstone Design Report

Biometric Feedback Stress Reducer




Team C

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Executive Summary

Problem Identification and Preliminary Design

In this section, the team covers the scope of the project including the problem statement, technical constraints, and project requirements. The problem that the team aims to address is reducing stress by raising the user's HRV by modulating tempo of music. Constraints include using MATLAB to design this system while several requirements allow the vision of the project to be narrowed into a full design.

Detail Design

The design of this project is a feedback control system where the input is a user's heart rate and heart rate variability and it goes into a controller that reads in that data and modulates the tempo of music based on these inputs. The plant is the user and their output is the adjusted HRV that constantly goes back into the system until the desired HRV is reached.

Build

The build of this project consists of the original design where the user connects to a Polar H10 to read their biometric variables and that data is sent to a Raspberry Pi which runs the code and sends the modulated music to the speaker to continue to play out loud. After reconsideration and testing for this project, the team realized that the Raspberry Pi is incompatible with MATLAB so the final design runs on a laptop instead of the Raspberry Pi but in an additional portion of the project, the team created a framework for the controller in Python that follows the original build with all the components.

Test Plan, Test Results, Re-Test

In this section, the team discusses the various different tests that had to take place in order to ensure that all necessary components can work harmoniously. Since there are 2 different components to this project, Software and Hardware, there was a need to have two different scopes of testing. The Software Test delved into the MATLAB code and ensured that music was able to be modulated and the system can read in one's heart rate. The Hardware test involved the reliability and comfortability of the hardware components in the project such as the Polar H10 chest strap as well as the JBL Speaker.

Redesign and Final Assembly

This section goes into how the team had to redesign certain components and implement different techniques in order to reach the overall end goal of this project. The team had to design a PI Controller instead of the original PID controller. This section goes more into the reason those changes were made and how they were executed. This section also discusses the Python Framework that the team designed in order to lay a foundation for the next team of engineers to implement.

User Manual

This section details how to operate the project. The section also lists a few possible problems that the user may come across while operating this project. There are solutions provided by the team for commonly occurring issues.

Project Management

This section goes into the methods of success the team used in order to ensure that the proper progress was attained throughout the duration of the project. This section goes into the roles and responsibilities each member of the team had and their overall experiences. This section also contains the team's gantt chart which goes more in depth in the tasks that were completed.

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Chapter 1: Problem Identification and Preliminary Design

1.1 Problem Definition

Stress is a state of mental tension as a result of demanding situations. [1] It can cause mental, emotional, and physical unwellness that can hinder someone's quality of life. The American Psychology Association found that in 2022, 34% of adults feel high levels of stress that it is detrimental to their daily productivity. [2] This problem is important to solve because "prolonged and intense stress can lead to mental health problems or the exacerbation of existing mental health problems, such as in the mood disorders." [1] Solving these problems can improve high-stress individuals' mental and physical health along with improving morale, productivity, and happiness.

This project has four stakeholders. The first stakeholder is Dr. Kevin Passino. Dr. Passino has researched the correlation between sound and stress and produced previous versions of this project. When the group presented this project, a general design was also presented. This design used sound modulation to reduce the user's stress. The second and third stakeholders are instructors for this section of capstone, Clayton Greenbaum and Dr. Drew Phillips. Their stake in this project is due to their involvement in guiding the group through designing, testing and building the project. The final stakeholder is the general population who suffers from anxiety, as they are the target this project is meant to help.

There are four main needs for this project. The first need is the project must reduce the stress of the individual. If the project fails to reduce the user's stress, then the entire project is a failure. The second need is the project must modulate the music or sound the user is listening to. The design given by Dr. Passino uses the modulation of sound to reduce the user's stress. The third need is ease of use. For this project to benefit a large target audience, it must be easy for anyone to use. The fourth need is a long battery life. This project must have the ability to be used all day and/or all night for optimal results.

Two constraints were specified for this project. The first constraint is the project must use a Raspberry Pi. The Raspberry Pi will be used to improve the speed at which the code is processed and improve the project's portability. The second constraint is using a chest strap style heartbeat sensor. Dr. Passino's previous studies found this to be the most accurate and efficient way to track heartbeat that is commercially available.

Table 1: Project Requirements

Needs	Requirement	Units	Range	Ideal
Reduce Stress	Lower Heart Rate	Beats per minute (BPM)	60-100	70
Reduce Stress	Raise Heart Rate Variability	Milliseconds	24-62	40
Modulate Music	Change Pitch, Tempo, Volume	Hz, BPM, Decibel	-	-

Safety	Max volume is at a safe level	Decibels	70-90	80
Battery Life	Stay on all night	Hours	8-24	24
Easy to Use	Portable	Grams	30-80	50
Easy to Use	Read common file types	.wav, .mp3	-	-

Table 1 demonstrates the requirements derived from the needs of the project. The first 2 requirements relate to the need to reduce stress. The project must lower heart rate to 60-100 BPM and raise heart rate variability to 24-62 milliseconds. To modulate music, the project must vary pitch, tempo and volume. This music must also be output at a safe level under 90 dB according to standards set by OSHA [3]. Next, the battery life of the project needs to be at least 8 hours with a goal of 24 hours. Finally, the project must be under 80 grams of weight and be able to read a range of file types to allow for easy operation for the user.

1.2 Research and Initial Design Ideas

To properly implement the project's design, the team had to conduct thorough market and technical research. When analyzing the current market's products, the team found that many of the products currently on the market do not effectively meet the needs of the user. There were two main issues with the products currently on the market today. The first problem was that many of the products on the market were too general, meaning they had no way to personalize the product for a particular individual. A personalized device would allow every person to feel relaxed and experience decreased stress compared to only a specific demographic of people. The second problem in the current market is that many of the products are repeat purchase products. This means users will have to keep purchasing the product over long periods of time to feel the product's effects. This can be extremely costly for the user if they plan on using the product continuously. With the current market research, the team felt that by addressing these two problems with the current market, the team would effectively be aiding the stakeholders of the sleep community.

The initial idea that was given to the team by Dr. Passino included a negative feedback control system that would read biometric data from the consumer and modulate music that the consumer would hear over a speaker. The biometric data would be read through a HR10 chest band that would send the Heart Rate (HR) and Heart Rate Variability (HRV) of the user to a Raspberry Pi Controller which would then modulate the music's tempo, pitch, and frequency to effectively reduce the consumer's stress. This process will continuously loop which allows the controller to learn what music modulation best reduces the stress of the consumer. The team decided to follow through with this approach as our advisor, Dr.Passino, has significant documentation regarding the concept of a negative feedback loop involving biometric variables and music modulation. The documentation will allow us to have a "jump start" on the project and be able to go into development of the software that the controller will use to modulate the music.

One major decision that the team had to make was the mode of delivery of the music for the consumer. Initially, the team along with Dr. Passino agreed that the user should use over the ear headphones. This would allow the user to be able to hear the music very clearly and would have a mitigated chance of ear drum damage to the user as the music would not be going straight into the ear canal. Although, upon further examination the team decided to use a speaker as the mode of delivery rather than the headphones which were initially determined. The team decided to make the switch as over the ear headphones would not be the most comfortable for the user while they are sleeping. The headphones would have a high probability of falling off the user and causing discomfort. The speaker would allow the user to sleep freely without interference and still be able to output the modulated music.

Another potential idea that the team decided to implement was an accelerometer for sleep usage. The accelerometer is a device that the consumer would wear on their wrist, that would measure their movements while they are asleep. This data would also be read through by the Raspberry Pi along with user's Heart Rate and Heart Rate Variability. The movement of the consumer provides valuable information regarding the stress levels of the individual while they are asleep. If an individual moves above a certain threshold the controller can read in that data and determine that the individual is experiencing high stress. The controller would then modulate the music based off the data given by the accelerometer and the HR10 chest band to reduce the consumer's stress while they are asleep.

1.3 Preliminary Design

The preliminary design of this product has several features that allow simplicity for easy use, effectiveness to correspond to a wide range of users, and affordability. The purpose of the continuation of this project is to create a quick and portable device that can actively modulate music based on the biometric variables of a person to ultimately reduce their stress.

The preliminary design consists of a negative feedback system where the inputs are the desired heart rate, heart rate variability, and overall movement of the user. These target values are dependent upon age, sex, and activity level. Joining these target values in a summer is the output values of the user's heart rate, heart rate variability, and movement. These values are read in via an electrocardiogram to read heart rate and heart rate variability, and an accelerometer to track the person's movement. As long as the desired values do not match the active values, all this information will be sent into a controller which holds the algorithm to ultimately reduce the user's stress. This is a Raspberry Pi system that will read in the output values and modulate the pitch, volume, and tempo of different music to lower heart rate and raise heart rate variability. In real-time, this cycle will continue until the feedback data matches the target data which means the persons stress levels have been reduced. A block diagram depicting this system is shown in Figure 1.

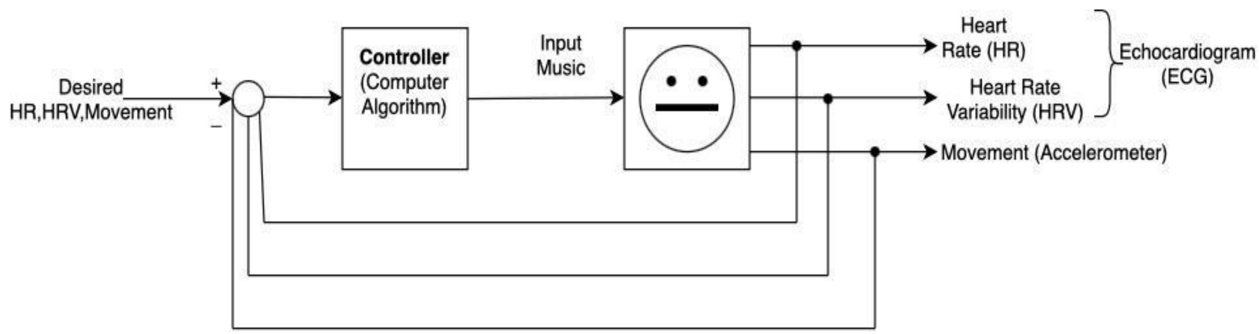

Figure 1: Initial Design Block Diagram

Figure 1 illustrates the preliminary design in a block diagram. It shows all the inputs, outputs, and feedback in the system. This block diagram has influenced the napkin sketch of the design which depicts the same functionality as the block diagram, instead showing the uses of the electrocardiogram and accelerometer on the person, and how it is read into the system. This napkin sketch is shown in Figure 2.

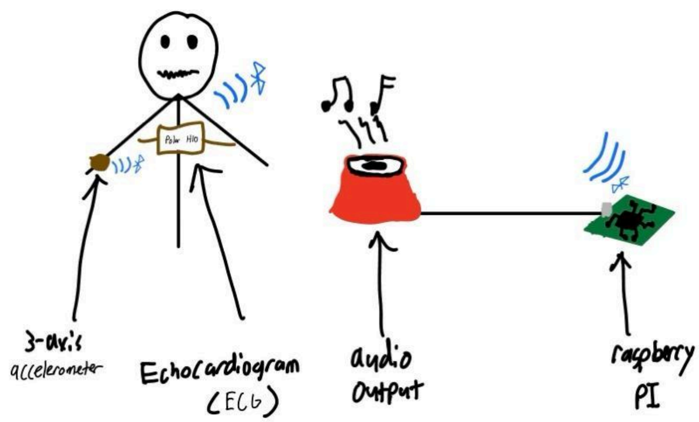

Figure 2: Napkin Sketch of Initial Design

The audio output is an important part of this design as a decision was made on how to play the modulated music out loud. Ultimately, a Bluetooth hub will be used where the user can connect any headphones or speakers to the device to play the music. It is all connected to the Raspberry Pi, so it will be one product that will include all components in a portable device

Chapter 2: Detail Design

2.1 Development of Detail Design

Dr. Passino presented the group with a design previously tested with new, additional constraints. The physical design will consist of a Raspberry Pi and the Polar H10 heart rate monitor. The audio output is designed to be modular, so that the user can equip almost any audio device with an AUX cable. The Raspberry Pi will receive or transmit all signals for this project, receiving the heart rate and audio input while transmitting the audio output.

2.2 MATLAB Software Design

MATLAB was chosen as the software for the controller due to the rich libraries and functions available for control systems. MATLAB also allows for Bluetooth connection to receive live data streaming from the Polar H10 chest band. The team split up the software into 4 main parts: Bluetooth Streaming, Variable Calculation, Music Output and Modulation and Feedback Design. Bluetooth Streaming focuses on the connections and streaming of live data from the Polar H10 chest strap to the controller. Variable Calculation is an algorithm that calculates metrics such as HR and HRV used in feedback control. Music Output and Modulation focuses on the successful playing of music and minor modulations of tempo, volume and pitch. Finally, Feedback Design focuses on the implementation of all previous areas into a functioning live updating controller using negative feedback.

2.2.1 Bluetooth Streaming

The MATLAB command *ble* was used to connect the software to the Polar H10. This command connects to the Polar H10 based on its Bluetooth ID if present and creates an object including all Bluetooth services and characteristics. The main characteristic of importance for the team was HR Data, which provides HR and RR values from the Polar H10 taken at a frequency of 1 Hz. An example of the data provided by this characteristic can be seen in Figure 3. The output data is seen as 4 numbers. The first number is a flag for whether HR is presented as a 16 int or 8 int data type, the second is the sampled HR value and the final two contain the bytes for the RR interval (in 1/1024 seconds). This streaming of Polar H10 data is continuous while the code is running and by sampling the data every second for a certain window can allow for calculation of important variables for the controller.

```
data =

    16    58    94     4

>>
```

Figure 3: Example Data Input from Polar H10

2.2.2 Variable Calculation

The variables of importance for this project from the Polar H10 are Heart Rate and Heart Rate Variability. Heart Rate is simply the average BPM pulled from the Polar H10 at the 1 Hz sampling frequency over a certain time period. The chosen variable for Heart Rate Variability was the RMSSD, which calculates the root mean square of the standard deviation of RR intervals pulled from the H10 over a certain time window. The time window selected for these two variables is 30 seconds. This is mainly based on the RMSSD metric's ability to allow for fast and reliable values that are long enough to make the effects of outliers minimal. These window HR and RMSSD values are important as the negative feedback used for the controller design.

$$\Delta RR(k) = RR(k) - RR(k-1)$$

$$RMSSD(M) = \left(\frac{1}{M-1}\sum_{k=2}^{M}\left(\Delta RR(k)\right)^2\right)^{\frac{1}{2}}$$

Figure 4: Equations for RMSSD Calculation

2.2.3 Music Output and Modulation

Music is uploaded to MATLAB as an mp3 file which can be played continuously until the algorithm is paused. Once music is playing one of 3 music modulations can be implemented into music. The first is tempo, which when modulated increases the speed of the music. The MATLAB code for this modulation has already been designed by Dr. Passino's research team. Next is volume, which is modulated by adjusting the amplitude of the music wave. Finally, the pitch of the music can be modulated by designing a pitch-step algorithm. Every modulation done to the music will be to a minor degree. This ensures that when the controller modulates music it doesn't overshoot stress reduction levels. Finally, the code for music and modulation will contain an ability to "reset" music to normal tempo volume and pitch. This will ensure music stops modulating once the controller brings HR and HRV values back to normal levels.

2.2.4 Controller Design

The controller algorithm design consists of parts: input calibration, output variables and music modulation. To start, the algorithm will perform a calibration test with the subject to receive baseline HR and HRV values. This will be done by having the subject relax and performing a 5-minute test, to determine a long-term HR and HRV baseline. This baseline performs as the input that the negative feedback is compared to. Relaxing music is then played and HR and HRV output values are then calculated in 30 second windows as discussed in Section

2.2.2. The algorithm compares the 30 second window to the baseline values to determine if HR has raised or HRV has gone down, indicating stress. If so, the algorithm will then implore music modulation to help relax the subject back to their baseline values. Once back to baseline HR and HRV, the music will return to its normal output until more stress is detected. This constant feedback and modulation will continue to occur until the controller is stopped by the subject.

The actual controller chosen was a PI controller as this controller gave the best response to a step input. The first step to the controller design was seeing the response to a step change in the tempo from normal speed to 2x speed to track the plant response to stress input.

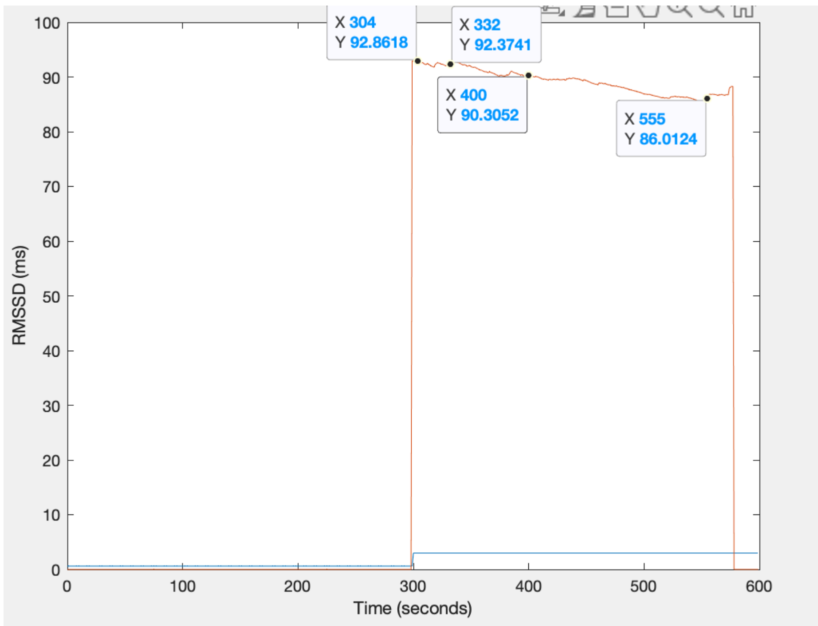

Figure 5: Plant Step Response

With this response the plant could be modeled as a first order system $H(s) = \frac{83.7591}{56+1}$. These system parameters were found as the average steady state value of the system and average time delay to drop 63% to final value over 5 tests. With a model for the plant, a PI controller could now be designed. The design used the values of average time delay and gain parameters for Nichols Ziegler Tuning seen below. The value calculated for T = 29 and L=135, and for Kp=.031 and Ki=.0074.

Controller	K_p	T_i	T_d
P	$\frac{T}{L}$	∞	0
PI	$0.9\frac{T}{L}$	$\frac{L}{0.3}$	0
PID	$1.2\frac{T}{L}$	2L	0.5L

Figure 6: Ziegler Nichols Tuning Calculations

The final step for the PI controller was to manually tune the parameters for the best step response. The final results were Kp=2 and Ki=.0074. Kp had a significant jump due to the desire for a quick rise time in the step response. The final step response of the controller can be seen in Appendix A. Overall, the final equation for the PI controller in the time domain can be seen below.

$$U(t) = 2 * e(t) + .0074 * \int e(t)dt$$

Figure 7: Final PI Controller Equation

2.3 Physical Components

2.3.1 Raspberry Pi 5 Controller

The Raspberry Pi 5 was chosen as the Controller for the team to implement the biometric feedback system to reduce stress because it is the fastest, most efficient, and effective solution. One of the main advantages of using this microcontroller is its portability. Stress can occur in any setting regardless of the location, so a device that can be used anywhere is integral to the success and effectiveness of this product. The MATLAB program that reads the heart rate and heart rate variability data and modulates the music will be loaded onto the Raspberry Pi and in live time as the values change, the music output will be changed.

2.3.2 Polar H10 Chest Band

The H10 Chest Band from Polar companies was chosen as the primary chest band for the team for a variety of reasons spanning from reliable sensor readings to a long battery life. The H10 Chest Band uses an electrocardiogram that accurately reads the user's heart rate through measuring the electrical signals that their heart outputs through the liquids on their skin. This method of reading in Heart Rate is significantly better than using the conventional OHR (Optical Heart Rate) method. This is because the traditional method measures Heart Rate through LED's and photodiodes which measure the changes in the size of the blood vessels under the user's skin which may not be as accurate as using an ECG. In addition to the accuracy of the H10 Chest Strap, the device provides a long battery life of up to 400 hours (about 2 and a half weeks) as well as being comfortable with a soft textile strap that secures onto the user. The final reason for why the team chose to use the Polar H10 chest band is that the device is Bluetooth and ANT + compatible. This connectivity allows the team to create software based off the input given from the chest strap.

2.3.3 Audio Output

The Audio Output will be modular due to the 3.5mm audio output jack. This is accomplished using a USB to audio jack (USB DAC) on the Raspberry Pi. This option allows the user to operate the project with any audio device that has a 3.5mm plug. Therefore, if the user is asleep, they can connect the product to a speaker and if they are in a quiet setting, they can connect headphones. This provides the flexibility for the user to use this device in any setting with the same effectiveness.

Chapter 3: Build

Due to compatibility restraints, the constraints of the project required modification. The compatibility between the Raspberry Pi 4 and the Matlab code used in this project were not as compatible as research showed. The design would have required a computer to run its code through an internet connection with the Raspberry Pi and even then multiple Matlab libraries used were unable to run. The Raspberry Pi was meant to increase speed and decrease size of the project however a trial found that was not the case and the Raspberry Pi was removed.

The final design includes the Polar H10 heart rate sensor, a speaker with aux cable and a computer to run the program on. The Polar H10 connects to the computer via bluetooth and the speaker connects via 3.5mm aux cable. The laptop receives heart rate data from the Polar H10 and using the program converts those readings into Heart Rate Variability (HRV). These readings are then used by the program's PI controller to manipulate the audio being produced by the speaker, affecting the person's HRV. This cycle continues until the HRV of the person has reached their optimal value. The build for the MATLAB program PI controller is shown below, where the program is run on the laptop and the Polar H10 chest strap is worn by the user.

Figure 8: Build Prototype for PI Controller

Due to this build consisting of only a few physical parts that were purchased as whole products, the majority of this build is software. This change is due to several challenges that the team faced trying to implement the MATLAB program on the Raspberry Pi.

The first challenge was finding the right audio toolbox on MATLAB with the capabilities to manipulate audio in real time. This took trial and error, finding which command was the smoothest and could work continuously.

The next challenges were all related to implementing the Matlab code onto the Raspberry Pi. The first problem was that MATLAB cannot be installed as a program. This is not supported by the Pi however the user can use MATLAB online or the Raspberry Pi support package on their computer to work around this. The next issues were that the audio tool boxes were not supported on the Raspberry Pi when using MATLAB Online or the RPi Support package. The group then attempted to use another program GNU Octave, which works similarly to Matlab but is supported as a program on the Raspberry Pi. This program did not have the right audio tool boxes that would work with the program. Because of this, the team decided to go in two directions with the project, refine the PI controller program in MATLAB to make it as robust as possible, and create a framework program in Python to build upon in the future. With this solution, the Raspberry Pi is still enabled and can be used in the future, if Python were to be decided to be implemented.

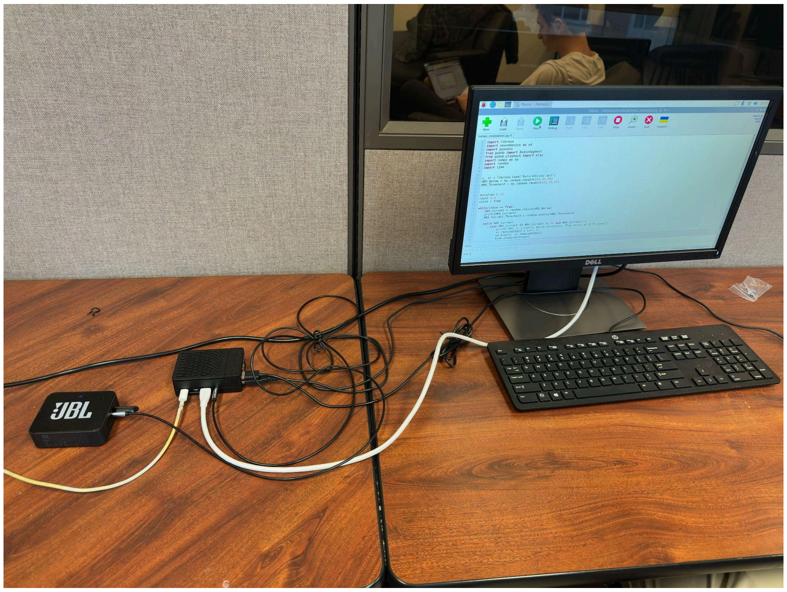

Figure 9: Build Prototype for Raspberry Pi Implementation

This image shows the build for the Raspberry Pi implementation where the Raspberry Pi is connected to the speaker via auxiliary cable and the program is run on the to be played for the user. This can be built on in future explorations related to this project.

Chapter 4: Test Plan, Test Results, and Re-test

Hardware Test Plan

The team will also include a hardware test plan to ensure that the hardware within the project is working properly and correctly communicating with the software. This test plan will entail correct readings from the Polar H10 chest strap, proper communication to the Raspberry Pi, and implementation of the speaker to output the modulated music.

Purpose

This test plan will verify the products purchased and the software developed meet project standards. The products being tested are the Polar H10 heart rate sensor, Raspberry Pi 4 and speaker. The Polar H10 must read heart rate accurately and often. The Raspberry Pi and speaker must work as advertised.

Scope

The hardware tests will first ensure that the physical components of the project work properly. This will include the components being able to turn on and perform their standard functions. The tests will also verify the components can properly work with other components and perform the functions required for the project to work. Certain functions of the hardware that are not required for this project (for example bluetooth mode on the speaker) will not be tested.

Software Test Plan

The team will have a software test plan to verify the software developed performs the task it was intended to do. This test plan will confirm the software can actually modulate music based on a given user's heart rate and heart rate variability.

Purpose

The software will be put through multiple tests, testing each aspect at multiple stages of development. The main aspects of the software are reading the heart rate/HRV, modulating the sound and the response characteristics of the feedback controller.

Scope

The tests conducted by the team will ensure that each element of the software is working properly. The tests could be limited by the amount of test subjects and data that can be collected, as they are fairly comprehensive tests, making it difficult to perform on several different people with different stress levels. Another factor that was considered when planning these tests was that each person responds to various types of music differently which can affect test results.

Table 2: Requirement/Verification Cross-Reference Matrix

Classes of Verification: I- First Article, II-Environmental, III-Acceptance Test, IV- None

Methods of Verification: A- Analysis, T-Test, D-Demonstration, I- Inspection

Project Requirements	Test Names	Verification Class				Test Procedure Location
		I	II	III	IV	
	Section 1: Hardware Testing					**Appendix B**
Polar H10 Must Read Proper HR	1.1 Polar H10 Must Read Proper HR	A				**Appendix B.1**
Polar H10 Must Read Proper HRV	1.2 Polar H10 Must Read Proper HRV	A				**Appendix B.2**
Polar H10 Proper Sampling Rate of 1 Hz	1.3 Proper Sampling Rate of 1 Hz	A				**Appendix B.3**
Polar H10 must be Comfortable for the User	1.4 Must be Comfortable for the User			D		**Appendix B.4**
Modulator Provides Clear/Safe Sound Audio Output	1.5 Speaker Provides Clear/Safe Sound Audio Output	T		D		**Appendix B.5**
	Section 2: Software Testing					**Appendix C**
Proper Volume,Tempo, Pitch Modulation		T		T		**Appendix C.1**
Feedback Response Characteristics		A				**Appendix C.2**

4. Tests on Hardware

This section describes the scope, procedure and type of test for each physical component of the system. These tests are to ensure proper calibration and functionality of the music modulation feedback controller hardware for both functionality and safety. The hardware test procedures are available in Appendix B.

4.1.1 Polar H10 Heart Rate Readings

To test and verify that the heart rate readings are accurate, the readings are compared to the readings of another high quality product. The product used to find these readings is a Garmin Forerunner 165. The established margin of error for this test is 5 bpm deviation after running both devices for a minute. This standard was established due to other products in the industry using a similar deviation. If there is a large difference between the two products and the accuracy of the Polar H10 cannot be determined then another Polar H10 will be purchased.

4.1.2 Polar H10 Heart Rate Variability Readings

To test and verify that the heart rate variability readings are accurate, the readings are compared to the readings of other products of high quality. Similar to the Heart Rate readings, a Garmin Forerunner 165 can be used to compare the readings from the Polar H10 to ensure accuracy. If there is a large difference between the two products and the accuracy of the Polar H10 cannot be determined then another Polar H10 will be purchased.

4.1.3 Sampling Rate of 1 Hz

The Polar H10 must be able to sample HR and HRV values every second. This will be tested in MATLAB using a 60 second run time of the code. The code must produce 60 RR interval and HR values or else the test will fail. If the values are not produced, then the team will decide whether a new device should be used to sample HR and HRV.

4.1.4 Polar H10 is Comfortable for the User

The comfort of the Polar H10 will be tested via inspection. Multiple subjects will wear the device for an hour while performing normal daily tasks. The subject will then rate the comfort on a scale of 1-10, 10 being the most comfortable. A passing grade will be an average score of 8.

4.1.5 Speaker Provides Clear and Safe Audio Output

In order to ensure audio is outputted well, clear and safe output will be tested. The maximum decibel output for the audio will be 75 dB to ensure safety for the user, and qualitative measures will determine clearness of the audio output. If the speaker cannot produce audio within the safety range, then the team will buy a new speaker that can fit the specifications.

4.2. Tests on Software

This section describes the scope, procedure and type of test for the MATLAB software of the system. These tests are to ensure proper calibration and functionality of the music modulation feedback controller software for full functionality and safety. The software test procedures are available in Appendix C.

4.2.1 Proper Volume, Tempo and Pitch Modulation

The modulation capabilities will be tested first on a computer running MATLAB, followed by on the Raspberry PI 4. This test is done both as a first article to test the actual functionality of the modulation, as well as for safety of the user. The volume will be tested with an iOS application sound meter to measure dB of sound produced. The test will fail if either there is not a 1 dB change in sound output measured, or if the dB value exceeds 75 dB. For tempo, a stopwatch will be used for a set interval of a sound file. If the time difference recorded does not match within 1% of the tempo adjustment, the test will fail. If the test fails, the team plans to revisit and alter the code in order to match the needed specifications.

4.2.2 Feedback Response Characteristics

The feedback response of the controller will be measured by analysis in MATLAB. The controller will run through both an impulse and step response, and characteristics such as rise time, settling time and steady state error will be recorded. This test will fail if the rise time, settling time or steady state error do not meet the decided criterion range. If the test fails, the team plans to work on altering the code in order to ensure that rise and settling time as well as the steady error meet the criterion.

Chapter 5: Redesign and Final Assembly

Due to the simplicity of the physical design, change in the design was limited. As previously mentioned, the Raspberry Pi was not compatible with the Matlab code that was developed. The Raspberry Pi does not have the ability to install Matlab as a program and run software. The Pi does support using Matlab Online but does not support the audio toolboxes used in the code and would require a wifi connection to run, further slowing down the program. This change affected the constraints of the project due to the inability to use Matlab and the Raspberry Pi simultaneously. Using Matlab to code the project was more important to keep in this iteration of the project. The design was updated to include a personal computer (PC) as the controller.

The final design includes the PC, Polar H10 heart beat sensor, speaker and AUX cable. The PC is used to run the program and is connected to the Polar H10 via bluetooth and speaker via 3.5mm auxiliary cable. This assembly is not complicated or labor intensive but is modular. Any computer with the program and bluetooth capabilities could connect to both the Polar H10 and use any audio device to run the system.

The software assembly for this project consists of reading in the HRV data into MATLAB, using toolboxes to refine the data, modulating the tempo of a song, obtaining PI controller parameters, and implementing the controller into the main MATLAB code.

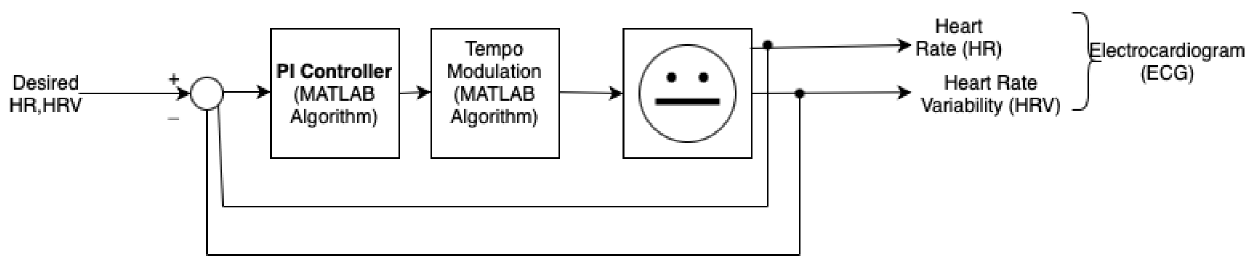

Figure 10: Updated Design Block Diagram

Shown in Figure 6 is the updated design block diagram that indicates the changes that the team made over the duration of the project. The PI controller was chosen for the controller design after numerous tests and validation procedures to determine the best algorithm and controller to use in the feedback loop. Additionally, this figure shows tempo solely as the music modulator, as this was a design decision made after several tests and conversations with the team's sponsor to determine the easiest and most effective way to raise HRV. The inputs and outputs of the block diagram are the same but the feedback loop shows only Heart Rate and Heart Rate Variability entering the feedback loop as tracking movement was abandoned early on in the project.

Chapter 6: User Manual

Product description and goal

The product is designed to lower someone’s overall stress level by decreasing their heart rate(HR) and increasing their heart rate variability (HRV). The product achieves this by continuously reading the user’s HR and HRV to then modulate music to best calm the person, thus decreasing their overall stress. By

Product Usage

Requirements

This product requires a personal computer that can run Matlab or Matlab online with support for all toolboxes. The personal computer must also have bluetooth capability and 3.5mm auxiliary port.

Safety Requirements

The only safety concern regarding this product is potential ear damage if the speaker’s volume were to be set to high. In order to avoid this, the volume set on the speaker by the user should be set to their desired comfortable level. This is so the system can modulate the volume dependent on the upper bound set by the user.

How to operate the system/product

Step by step guide:

1. Turn on PC, Polar H10 and speaker.
2. Wear the Polar H10 by wrapping the strap around your body just below the chest
3. Connect Polar H10 to PC via bluetooth
4. Connect speaker to PC via 3.5mm audio cable
5. Open the PI Controller program in Matlab
6. Click “Run”
7. Allow the music to play for 5 minutes as a baseline
8. Continue listening to the music as tempo changes until goal HRV is reached.

Basic troubleshooting and common issues

What should I do if the Polar H10 is not connecting?

If the Polar H10 is not connecting to the PC, use a damp paper towel to dampen the backside of the strap where the electrodes are and place it on your chest.

Maintenance

The only maintenance that would be required for this product is the battery life of the Polar H10 Chest Band as well as the JBL speaker. In order to save as much battery in the Polar chest band, the main device should be removed from the strap after each use, as if it stays connected the battery drains significantly faster. The battery life of the Polar H10 during proper use is estimated to be 400 hours. Since the Polar H10 does not have a rechargeable battery, the user must replace the battery within the system once it dies. This is the CR2025 battery and can be found in many local stores. The JBL Speaker should be turned off after use in order to maximize its battery longevity. The estimated playing time for the JBL is around 5 hours of continuous music on one charge. The time to charge the JBL to its full charge is 2 hours.

Engineering Troubleshooting report

Problem 1

What to do if the Raspberry Pi is not connecting to the Internet or is not allowing to run any program?

- The engineers in Team DANC encountered similar issues regarding not being able to connect the Raspberry Pi to the internet as well as having problems running software. A solution that quickly solved this dilemma was to reboot the operating system loaded onto the Pi. This allowed the Pi’s OS to start fresh and cleanse itself from any previous programs or files that were hindering its performance.

Problem 2

How to connect the Polar H10 Chest Band to the Raspberry Pi using Python?

- The engineers in Team DANC initially had a hard time in being able to connect the Polarh10 to the Raspberry Pi as there was no clear way to connect both devices. After much research the team decided to use the terminal within python to sense all the surrounding MAC addresses. Through this the team was able to find the MAC address of the Polar H10 and implement that into the python script to ensure that a sound connection was made. This allowed the Raspberry Pi to be able to read in data from the Polar H10.

Chapter 7: Project Management

To start the project management, a Team Charter was created to outline the project objectives, logistical guidelines, and member commitments. Any disputes or conflicts will be resolved with methods outlined in the charter and it will be a document to reference throughout the duration of the project. The conflict resolution strategies are group mediation, documenting participation and contacting the professor. The full Team Charter can be found in **Appendix D.**

The team will meet at least once a week outside of class and meet with the sponsor biweekly. Tasks will be assigned after a group discussion. Skills, specializations and workloads will all be considered when assigning a task. General roles were also given to each team member to oversee each part of the project. After the congregation, the team assigned the roles of Project Manager, Software Lead, Project Documentation and Hardware Lead to the members based on their skills and experience.

Outside of meetings, the team communicates daily through their group chat on iMessage. The constant communication the team has avoids any miscommunication and allows the team members to know their role each step. The team chose to use iMessage compared to other messaging software as it would be the most convenient and efficient way for the members of the team to communicate.

7.2 Project Risks

Potential Risks for this project include going over budget, difficulties implementing the code, and shipping times for materials. The first risk, going over budget, was found to be a likelihood of “LOW” with an impact of “LOW” as well. Since this project has only a few components, going over budget is not likely to happen. Regardless, to mitigate this risk the group will plan out their purchases beforehand. The second risk, difficulties implementing the code, has a likelihood of “HIGH” with an impact of “HIGH”. To mitigate this risk, the group will perform thorough background research and spend most of their time working on the code. The third risk, shipping times for materials, was found to have a likelihood of “MEDIUM” with an impact of “HIGH”. To mitigate this risk, the group will order their materials as soon as possible and communicate often with the supplier.

7.3 Project Documentation and Resources

A Gantt Chart was created in Microsoft Excel to help the team track achievable and timely goals for the project. These goals were created based on project needs and requirements listed in **Chapter 1** and consist of 5 main categories: Initial Research, Documentation, MATLAB Code, MATLAB Testing and Physical Components. Each of these categories had a variety of subtasks with start and end dates listed. In addition, each category was assigned a leader based on the team roles described above. The full detailed Gantt Chart can be found in **Appendix A**.

A key resource needed initially was a space for the team to work in and some of the initial materials for our project. This was graciously provided to the team by Dr.Passino, the team's advisor. This allowed the team to have a space free from distractions that would allow for ample testing of the product as the system would need to be in an environment with low noise.

Along with the room the team was given a basic HR10 Chest band as well as an Empatica E4 accelerometer. These two devices allowed the team to start basic testing and configurations until the team's order could be processed.

7.4 Project Finalization Updates

To properly manage this project, the group prioritized communication. The group met at minimum twice a week for around 1.5 hours. There were many instances when members would arrive early or stay late to increase productivity. The group also kept an open line of communication 24/7. Using a text chat and GroupMe to communicate during any time of the day. This allowed for the group to schedule additional meetings or collaborate on the project without being in the same room. Not only did the group meet internally twice a week, they met with the sponsor once a week for 15-45 mins.

The group assigned members to lead different aspects of the project. These roles developed during the process of creating the project. The roles were defined as Anthony Awad is the Project Lead, Nathan Close is the Software Lead, Deepak Prabaharan is the Hardware Lead and Coleman Groff is Project Documentation. Even with these primary roles, each member of the group helped in every step of project development. The Project Lead's main role is to keep the project on track. This is done by communicating with each member and the sponsor. They also verify that the group avoids scope creep. The Software Lead is responsible for coding and debugging the project. The Hardware Lead is responsible for obtaining and testing the physical components. The Project Documentation Lead is responsible for taking notes during meetings and recording test results.

Coleman Groff, Project Documentation:

Throughout this project my main contribution was mainly taking notes. During meetings I would record what was discussed and review what occurred weekly. I also made a lot of contributions by supporting the other members on my team. I did a lot of research about Matlab coding and implementation on the Raspberry Pi. When another member of the group was struggling with Matlab code or the Pi, I would do research and supply suggestions while assisting with troubleshooting.

Deepak Prabaharan, Hardware Lead:

During this project my main contribution was working on ensuring the hardware components worked together well. During team meetings, I would help coordinate with other group members on gathering the hardware needed for the project. I also contributed to trying to figure out potential ways to implement the MATLAB code onto the Raspberry Pi. Near the end of the project, I also developed the Python Framework that was able to modulate music's tempo based on a given HRV value that was generated.

Anthony Awad, Project Lead:

For the duration of this project, I was responsible for scheduling and preparing for meetings with our sponsor, as well as the Capstone instructor. I made sure that deadlines were met and coordinated the best course of action for any issues we faced along the way. Additionally, I provided support for hardware and software components of this project by administering tests to verify functionality, researching and implementing PI controller parameters, assisting the development of the Python framework for an extension of this project, and enabling the usage of the Raspberry Pi for this project.

Nathan Close, Software Lead:

Throughout the project I was responsible for the software design, implementation and troubleshooting in MATLAB. This included the Polar H10 bluetooth connection to MATLAB, tempo modulation using time audio scale functions and PI controller design and testing. I also focused on designing robust test plans to ensure the software was working as predicted consistently. I also provided support to the hardware team for the implementation of the software on the Raspberry Pi, helping to lay out a flow diagram for the python framework.

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Appendix A

Biometric Feedback Sensor for Stress Reduction Project Autumn Schedule

Team DANC inc.

Project Start Date 8/20/2024 (Tuesday) Display Week 2

Project Lead Anthony Awad

WBS	TASK	LEAD	START	END	DAYS	% DONE	WORK DAYS
1	**Physical Components**			-			-
1.1	Purchase and Gather all Components	C.G.	Tue 8/20/24	Tue 9/03/24	15	100%	11
2	**Documentation/Presentation**			-			-
2.1	Final Technical Report	C.G.	Tue 8/20/24	Wed 11/27/24	100	100%	72
3	**MATLAB Coding/ Python Coding**			-			-
3.1	All Music Variables Modulated based off Heart Rate	A.A.	Sat 8/10/24	Sat 11/30/24	20	100%	80
3.2	Develop a PI Controller through MATLAB	A.A.	Tue 8/20/24	Sun 11/17/24	90	100%	64
3.2.1	Obtain and calculate PI Parameters to implement in Model	A.A.	Tue 9/03/24	Sun 12/01/24	90	100%	64
3.2.2	Develop a Python Framework to modulate Music	A.A.	Fri 11/01/24	Wed 11/20/24	20	100%	14
3.2.3	Use all Variables for Feedback Controller	A.A.	Wed 10/16/24	Mon 12/02/24	48	100%	34
3.3	Sample Tempo in MATLAB as a responese of HRV	A.A.	Tue 9/17/24	Mon 11/25/24	70	100%	50
4	**Hardware Construction**			-			-
4.1	Create Prototype of Physical Device and Connections	DP	Wed 8/21/24	Fri 9/13/24	24	100%	18
4.2	Test Prototype on Multiple Users	DP	Mon 9/16/24	Fri 9/27/24	12	100%	10
4.3	Create Final Version of Device With all Parts Integrated	DP	Mon 9/30/24	Thu 11/28/24	60	75%	44
5	**Physical Components**						
5.1	Choose Speaker/Headphones for Method to Recieve Music Modulation	N.C.	Mon 9/02/24	Sun 9/08/24	7	100%	5
5.2	Successfully Connect all Components Together	N.C.	Wed 8/28/24	Thu 9/26/24	30	66%	22

Figure A.1: Autumn Gantt Chart

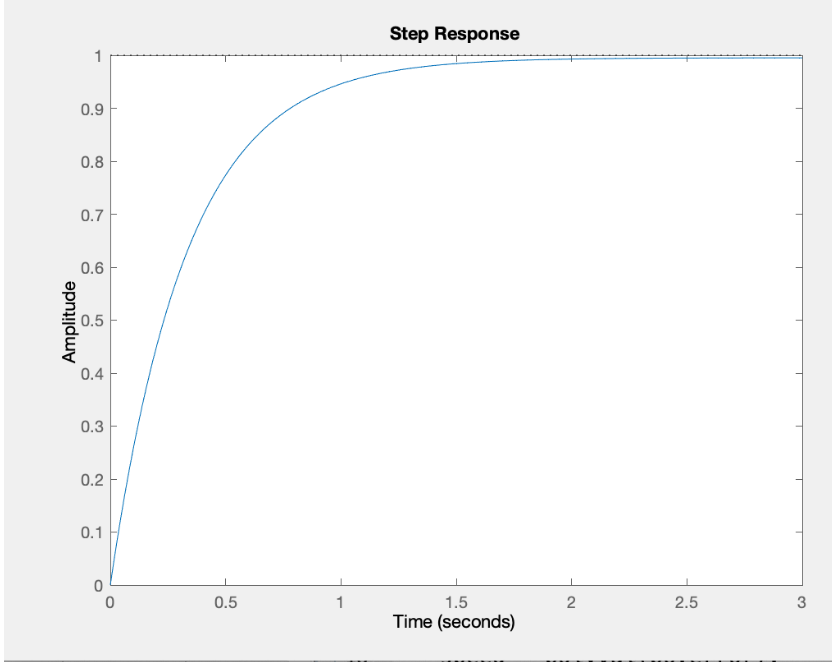

Figure A.2: PI Step Response

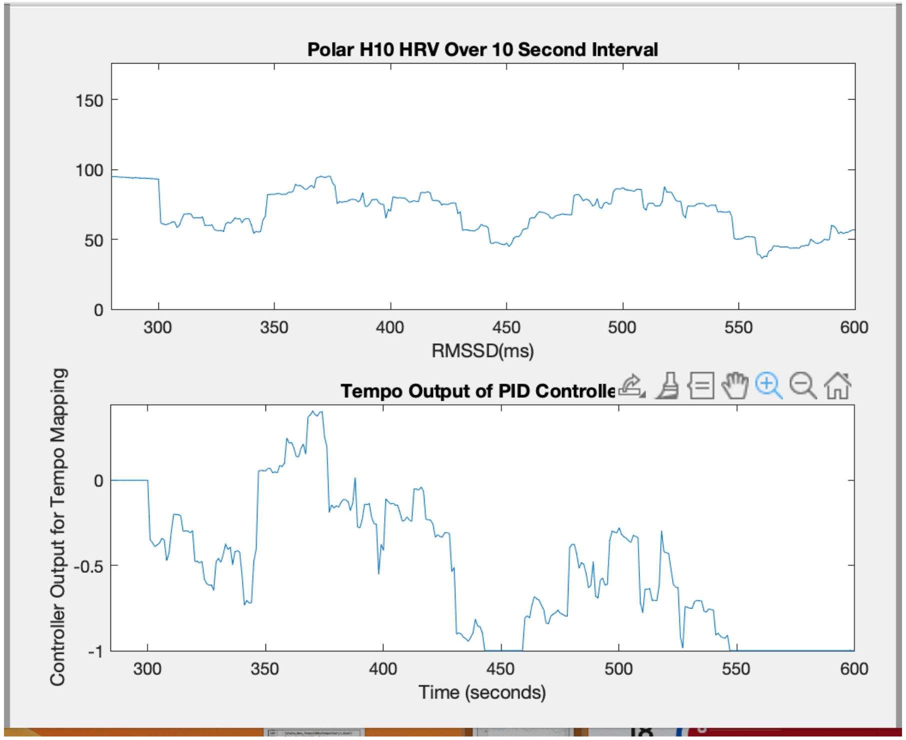

Figure A.3: PI Controller Response for 10 Minute Test

Table A1: Parameter Values for PI Controller

Parameter	Value
T	29 ms
L	135 s
Kp (Untuned)	0.031
Ki (Untuned)	0.0074
Kp (Tuned)	2
Ki (Tuned)	0.0074

Appendix B

B.1 Polar H10 must read proper Heart Rate	
Method of Verification: Test, Demonstration	
Type of Test: Acceptance	
Date(s)/ Total Times: N/A	**Location: N/A**
Test Equipment: Example: Laptop, Polar H10, MATLAB, Garmin Forerunner 165	
Test Engineer: Anthony Awad **Witness:** Coleman Groff	
Criteria for Success: ☒ **Passes –** Average HR value of Polar H10 for 1 minute interval is within 5 BPM range of Garmin Forerunner 165 for the same interval for all 5 test runs ☐ **Fails –** Average HR value of Polar H10 for 1 minute interval is greater than 5 BPM range of Garmin Forerunner 165 for the same interval for any of the 5 test runs	
Test Procedure: 1. Subject wears both devices 2. Run MATLAB code to record average Polar H10 HR for 1 minute interval 3. Collect Garmin average HR for same 1 minute interval 4. Compare the Garmin and Polar HR values 5. Test is repeated 5 times	
Test Results: The Polar H10 was able to gather the proper Heart Rate reading from the given user. This was corroborated with the Garmin Forerunner watch. The data values were very close together.	
Action Items: The Team decided that the Polar H10 Chest Strap was adequate to read Heart Rate from the User for this project.	
Test Engineer: Anthony Awad	Witness: Coleman Groff

<table>
<tr><td colspan="2">B.2 Polar H10 must read proper Heart Rate Variability</td></tr>
<tr><td colspan="2">Method of Verification:
Analysis</td></tr>
<tr><td colspan="2">Type of Test:
Acceptance</td></tr>
<tr><td>Date(s)/ Total Times: N/A</td><td>Location: N/A</td></tr>
<tr><td colspan="2">Test Equipment: Example: Laptop, Polar H10, MATLAB, Garmin Forerunner 165</td></tr>
<tr><td colspan="2">Test Engineer: Nathan Close
Witness: Coleman Groff</td></tr>
<tr><td colspan="2">Criteria for Success:
☒ Passes – Average HRV value of Polar H10 for 1 minute interval is within 5 ms range of Garmin Forerunner 165 for the same interval for all 5 test runs

☐ Fails – Average HR value of Polar H10 for 1 minute interval is greater than 5 ms range of Garmin Forerunner 165 for the same interval for any of the 5 test runs</td></tr>
<tr><td colspan="2">Test Procedure:
1. Subject wears both devices
2. Run MATLAB code to record average Polar H10 HRV (RMSSD) for 2 minute interval
3. Collect Garmin average HR for same 2 minute interval (Health Snapshot Widget)
4. Compare the Garmin and Polar HR values
5. Test is repeated 5 times</td></tr>
<tr><td colspan="2">Test Results:
Polar H10 readings were compared to Garmin Forerunner 165 at 1 minute intervals for 5 separate tests and met satisfactory standards.</td></tr>
<tr><td colspan="2">Action Items:
Implement Polar H10 into final project</td></tr>
<tr><td>Test Engineer:
Nathan Close</td><td>Witness:
Coleman Groff</td></tr>
</table>

B.3 Proper Sampling Rate of 1 Hz	
Method of Verification: Analysis	
Type of Test: Acceptance	
Date(s)/ Total Times: N/A	**Location: N/A**
Test Equipment: Example: Laptop, Polar H10, MATLAB	
Test Engineer: Nathan Close **Witness:** Coleman Groff	
Criteria for Success: ☒ **Passes –** Number of samples over a 60 second period is within 59-61 samples for 5 consecutive tests(1.016-.984 Hz) ☐ **Fails –** Number of samples over a 60 second period is outside 59-61 samples (1.016-.984 Hz) for any of the 5 tests	
Test Procedure: 1. Subject wears Polar H10 chest strap 2. HRV/HR collection code is ran for 60 seconds 3. Vector lengths of RR interval and HR vectors checked 4. Length is compared to desired value of 60 5. Test is repeated 5 times	
Test Results: After 5 tests, results fell into satisfactory range	
Action Items: Continue with further testing of the system	
Test Engineer: Nathan Close	Witness: Coleman Groff

B.4 Must be Comfortable for the User	
Method of Verification: Demonstration	
Type of Test: Acceptance	
Date(s)/ Total Times: 1 Time	**Location: General Meeting Room**
Test Equipment: Example: Polar H10	
Test Engineer: Deepak Prabaharan **Witness:** Nathan Close	
Criteria for Success: ☒ **Passes –** Subject deems Polar H10 causes no discomfort while wearing for 60 minutes ☐ **Fails –** Subject deems Polar H10 causes discomfort while wearing for 60 minutes	
Test Procedure: 1. Subject puts on Polar H10 chest strap 2. Subject wears Polar H10 for 60 minutes while performing daily tasks 3. Subject notes any discomforts while wearing the chest strap	
Test Results: A member of the team wore the Polar H10 Chest Band for an hour and described no signs of discomfort throughout the entire duration of the test.	
Action Items: Test Confirmed, Implement Polar H10 to Project	
Test Engineer: Deepak Prabaharan	Witness: Nathan Close

B.5 Speaker Provides Clear/Safe Sound Audio Output	
Method of Verification: Demonstration/Test	
Type of Test: Acceptance	
Date(s)/ Total Times: N/A	**Location: N/A**
Test Equipment: Example: Laptop, MATLAB, Raspberry PI 4, Speaker	
Test Engineer: Coleman Groff **Witness:** Deepak Prabaharan	
Criteria for Success: ☒ **Passes –** Noise comes out of speaker clearly and at a safe audio output under 80 dB ☐ **Fails –** Noise comes out of speaker distorted or at an audio output over 80 dB	
Test Procedure: 1. Speaker is attached to Raspberry PI 4 2. Music is played using MATLAB code 3. Music tested for clear output 4. Music tested using decibel meter for audio level	
Test Results: The audio output from the software onto the speaker had no signs of audio distortion and would not play the audio extremely loud where it could cause harm or be uncomfortable.	
Action Items: Keep the purchased Speaker and use it in final project	
Test Engineer: Coleman Groff	Witness: Deepak Prabaharan

Appendix C

C.1 Music must modulate volume by 3 dB and tempo by 5% of original BPM	
Method of Verification: Refer to the lecture Analysis	
Type of Test: Refer to the lecture Acceptance	
Date(s)/ Total Times: N/A	**Location: N/A**
Test Equipment: Example: Laptop, Matlab, Raspberry Pi	
Test Engineer: Anthony Awad **Witness:** Deepak Prabaharan	
Criteria for Success: ☒ **Passes –** Music (.mp3 file) volume fluctuates 3 dB and 5% of original BPM within 2 second intervals ☐ **Fails –** Music (.mp3 file) volume does not fluctuate 3 dB and 5% of original BPM within 2 second intervals	
Test Procedure: 1. Load .mp3 file into MATLAB 2. Run MATLAB code to modulate volume/tempo 3. Collect minimum and maximum dB/BPM 4. Ensure that it meets threshold 5. Repeat test 5 times 6. Redo this test for whichever volume/tempo has not been tested	
Test Results: Music successfully modulated within test parameters	
Action Items: Continue forward with music modulation implementation	
Test Engineer: Anthony Awad	Witness: Deepak Prabaharan

Appendix D – Team Charter Document

Team Name

DANC Industries

Team Mission and Objectives

1. Complete the design and construction of a biometric feedback scanner to the specifications of the customer
2. Create a strategic plan of action and closely follow throughout project
3. Communicate clearly and often about progress

Team Decision Making Guidelines

4. Make sure everything is discussed with all group members
5. Try to follow average member opinion and be willing and able for compromise
6. Ask professor if disagreements or issues arise
7. If no progress is made, we can do a vote. If split two and two, compromise is created.

Team Decision Making Model

8. Expert Member - If someone has expertise or is assigned to something, they can make educated decision
9. Average member opinion
10. Consensus
11. Majority control - If it gets to this point, a vote will be conducted. Last resort

Meeting Guidelines

Time: Thursdays 12:10 - 12:40, can schedule additional meetings if needed

Track by spreadsheet, each team member updates on what they have done the previous week. Then, group discussion about plan of action and any underlying concerns.

Team Roles

12. Meeting minutes/spreadsheet: Coleman
13. Budgeting/materials: Deepak
14. Main communicator with sponsor: Nathan
15. Deadline manager: Anthony
16. Coding: Deepak, Anthony
17. Circuit Design: Coleman, Nathan

Conflict Resolution

18. In initial conflict between two people, other members act as a mediator to solve conflict

19. If persists, reach out to professor or sponsor
20. Every meeting, each member will be evaluated to make sure we're staying up to date
21. Meeting attendance mandatory unless something comes up

Team Member Commitment

We commit to putting forth full effort and staying honest in the work that we're doing. We commit to getting stuff done by deadline. If something causes you to not get it done by deadline, reach out early and communicate to the team.

Signed: Nathan Close Anthony Awad Coleman Groff Deepak Prabaharan

Team Schedule

22. We will meet as a group every Thursday from 12:10 - 12:40 pm
23. We will meet with our sponsor every other Thursday from 4 - 5 pm

Virtual Space for Project Documentation

- Capstone One - Biometric Feedback