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Instantaneous Feedback of HRV for Monitoring Emotional State

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Instantaneous Feedback of HRV for Monitoring Emotional State

A Major Qualifying Project Report

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

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Anvar Niyetkaliyev, MIS	____________________________________

Date: March 19th, 2010

Sponsored by

Yitzhak Mendelson, Ph.D.

President

Advanced Body Sensing

____

Professor Soussan Djamasbi

Project Advisor

Abstract

Existing biomedical research indicates interactions among our body's subsystems are coordinated; psychological state, including mood and emotion, is strongly correlated with various physiological indicators such as heart rate variability (HRV). This project aimed to develop a solution for monitoring HRV for the purpose of training individuals to attain and sustain cognitive coherence, a psychophysiological state marked by enhanced cognitive acuity. A software application was developed to calculate and display a numerical indicator of user coherence level in real-time. This application translates heart rate signals from a wireless pulse oximeter into heart rate variability, which in turn is used to determine an individual's cognitive state of coherence. Appropriate tests were conducted to confirm the accuracy of the program output. As part of a multi-phase development project, future work on the developed application will include the development of a graphical user interface for the application. The final software package is intended for use by the Worcester Police Department to train emergency operators in cognitive coherence and stress management.

Advanced Body Sensing

March 18, 2010

Prof. Soussan Djamasbi
Assistant Professor of MIS
Department of Management
Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609-2280

Dear Prof. Djamasbi:
The purpose of this letter is to summarize my evaluation of the Major Qualifying Project (MQP) conducted by your MIS students Ryan Amin, John Bond, Alexander Gorski, David Mullen and Anvar Niyetkaliyev during the 2009-2010 Academic Year sponsored by Advanced Body Sensing (ABS), LLC.

The long term goal of this project is to develop a user friendly, cost effective and field deployable tool to monitor Heart Rate Variability (HRV) for the purpose of training emergency operators in cognitive coherence and stress management. While the intended use of this tool is for emergency operators, the same monitoring approach could have significant benefits for other professionals engaged in tasks associated with elevated emotional stress.

During the course of this multi-phase and ambitious project, your students have developed a software application and made important recommendations for a future graphical user interface that can calculate and display in real-time a numerical indicator of user coherence level. The core of this application is based on translating instantaneous heart rates into HRV, which in turn is used to determine an individual's cognitive coherence state. The students also conducted preliminary tests to confirm the accuracy of their new software application. To help the MQP group with this important effort, ABS provided technical support and a modified version of a custom made, wireless, battery-operated wearable pulse oximeter to collect HRV data from photoplethysmographic signals that are acquired by the sensor from the forehead.

While the students on the MQP team did not have extensive background in biological signal processing and prior computer programming experience, I was highly impressed with their ability to quickly learn highly technical concepts that were necessary to overcome several technical challenges. I was also very impressed with their level of commitment to the project and their professionalism, especially at the very end of the project when they volunteered to help another student team to continue the project. All in all, I was very pleased with the overall progress accomplished by your MQP team and the quality of the work these students produced over a rather short and intensive period of time. I am looking forward to continue this development work with you and another team of students and hope that we would implement this exciting new application into a future product that ABS could develop to assist in stress management of emergency workers.

Sincerely,

Yitzhak Mendelson, Ph.D.
President,
Advanced body sensing, LLC.
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Authorship Statement

Abstract	David Mullen
Introduction	Ryan Amin, David Mullen
Project Scope	David Mullen
Literature Review	David Mullen
Application Development	Ryan Amin, John Bond, Alec Gorski
Application Testing	Ryan Amin, David Mullen, Anvar Niyetkaliyev
Future Work and Recommendations	John Bond, Alec Gorski, David Mullen
Appendix A	John Bond, Alec Gorski
Appendix B	Ryan Amin
Appendix C	Ryan Amin, Anvar Niyetkaliyev
Appendix D	Anvar Niyetkaliyev
Appendix H	Ryan Amin, Anvar Niyetkaliyev
Appendix I	Anvar Niyetkaliyev
Appendix J	Ryan Amin, David Mullen
Appendix K	Ryan Amin, David Mullen
Appendix L	Ryan Amin, Anvar Niyetkaliyev
Appendix M	David Mullen
Appendix P	Ryan Amin
Appendix Q	David Mullen

Acknowledgements

Sponsor: Advanced Body Sensing

Advanced Body Sensing

Dr. Yitzhak Mendelson

Piyush Ramuka

Special Thanks

Dr. Soussan Djamasbi

Martin Bell

Table of Contents

Table of Abbreviations

Advanced Body Sensing	ABS
Arterial Oxygen Saturation	SpO_2
Autonomic Nervous System	ANS
Discrete Fourier Transform	DFT
Electrocardiograph	ECG
Fast-Fourier Transform	FFT
Graphical User Interface	GUI
Heart Rate	HR
Heart Rate Variability	HRV
Instantaneous Heart Rate	IHR
Photoplethysmograph	PPG
Power Spectral Density	PSD
Respiration Rate	RR
Worcester Police Department	WPD

Table of Figures

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Introduction

Each year there are approximately 200 million[1] 911 calls to emergency dispatchers in the United States alone. Due to the nature of these emergency calls, there may be a considerable amount of pressure and stress on the responding operators. Under these circumstances, dispatchers could potentially make errors during the handling of an incoming call. This project aimed to develop a solution for managing a dispatcher's mental state in order to improve cognitive performance in challenging scenarios, such as an urgent emergency call. Recent research suggests that a significant relationship exists between an individual's emotional state and thinking processes, allowing for the improvement of certain cognitive processes through mental state training.

A software application for monitoring an emergency operator's emotional state would bring significant benefits for dispatchers, as well as those that rely on their services. By receiving heart rate data from a physiological sensor, a graphical user interface (GUI) could present appropriate alerts to the operator when their emotional levels fluctuate outside of an ideal state. This software would aid responders in managing stress and maintaining an optimal mental state in order to minimize the potential mistakes that may occur under stressful conditions. While intended for use by emergency operators, this monitoring package would have potential applications to a range of professions associated with elevated emotional stress including police officers, firefighters, and military personnel.

In order to develop the proposed application for determining and then appropriately displaying user emotional state, the project team worked with Advanced Body Sensing in Worcester, Massachusetts. The team used hardware developed by ABS in order to receive heart rate data, which is then analyzed by the software to determine heart rate variability (HRV). HRV is processed through an appropriate algorithm within the application to determine power spectral density (PSD). This calculated data is then used in further calculations to determine the user's emotional state.

This project involved three areas of research and development; the effect of emotional state on positive thought processing and decision making, the application of existing physiological monitoring technology to determine emotional state, and the development of a software application to display the end-user's emotional coherence using the applicable physiological data.

[1] http://www.technewsworld.com/story/call-centers/58688.html?wlc=1269014585

Emotion and Cognition

There is currently an increasing body of research suggesting that a significant relationship exists between an individual's emotional state and thinking processes, and that the physiological processes of the human body have a significant impact on feelings and emotions. This prior research provided the theoretical foundation for this project, as the main goal of the application developed was to convert raw physiological data into useful information about the emotional state of its end-user.

Biomedical research describes two broad categories of feelings (McCraty, 2006). The first is positive, where the physiological process in the body is operating in an ideal condition. The second type of feeling is negative, where people experiencing this type of emotion do not have a proper balance in their internal processes. All parts of the human body communicate by sending and receiving information through the brain. The changes in patterns of any system can cause a dramatic change in physiological function, cognition and emotion. The term synchronization in physiology means that two systems, the heart and the respiratory system oscillate on the same frequency. According to the Biomedical Research, the connection of the physiological, cognitive, and emotional systems creates "psychophysiological" coherence which is defined as , "a harmonious state of sustained, self-modulated positive emotion, is a primary driver of the beneficial changes in physiological function that produce improved performance and overall well-being." (McCraty, 2006, pg. 3) The long term goal of the project is to deploy an effective tool for training emergency operators to achieve cognitive coherence. The goal of this MQP project is to develop a software application that translates the ABS's device signals into information that can be used for cognitive coherence training.

Recognizing Emotions through Physiological Measures of HRV

An individual's heart rate, the number of times one's heart beats over a set period of time, is not constant and has variability in the length of time between beats. Known as respiratory sinus arrhythmia (RSA), and caused physiologically through respiration, this variation is known to be linked to the body's nervous systems (EHJ, 1996). This variation can be measured through multiple methods to determine heart rate variability, which has been shown to be an indicator of various specific physiological conditions, and more recently, emotional state and psychophysiological coherence. While individuals vary in their baseline HRV, a higher HRV is considered to be correlated with a healthy nervous system. Analysis of HRV will provide the necessary data to understand and display an individual's emotional state (McCraty, 2006).

HRV Monitoring Devices

Vital signs are specific quantitative measures of the human body such as heart rate, blood pressure, respiration rate, and body temperature. There are numerous commercial products currently available that are able to accurately retrieve this information. These machines are attached to the patient through one or more sensors which allow for the collection of certain quantitative data about the patient's vital signs. An example is an electrocardiogram machine attached to a patient through three specifically placed electrodes, where the patient's heart rate is then instantaneously displayed by a line graph. Having this data allows health professionals to closely monitor and make critical decisions when providing treatment to their patients.

Some of the most recently developed devices that measure HRV are wireless physiological sensors. These devices could extend the same benefits for not only stationary patients, but also for monitoring active professionals such as soldiers, firefighters, and police officers. This information can then be relayed back to a software application which can display appropriate physiological data about the user through a graphical user interface. The current wireless technology is a major improvement over older technology that requires users to be attached directly to the monitoring devices. Having a wireless sensor gives the user mobility, which is essential for developing a useful system for active users.

The specific sensor used to collect physiological data for the developed application can be a pulse oximeter. Using red and near-infrared light emitted into the user's skin, pulse oximetry measures oxygen saturation and changes in blood volume by measuring the ratio of absorption of the light transmitted. The hardware uses this data to calculate and output a photoplethysmograph (PPG) signal of the user's heart rate. The PPG data produced by the headband is then transmitted wirelessly to a receiver connected to a personal computer via USB connection. The PPG signal output from the pulse oximeter device provides the necessary heart rate data and therefore can be further used to determine heart rate variability (Lu, 2008).

Advanced Body Sensing

Advanced Body Sensing is a biomedical company dedicated to the development of non-invasive wireless physiological monitoring devices as well as the development of applications which provide real-time feedback of a user's biological signals. ABS intends to develop wireless sensor hardware specifically for the monitoring of individuals involved in emergency and disaster response, as well as military settings. This includes, but is not limited to, firefighters, first responders, medics, and soldiers. The company's research is also focused on developing algorithms to interpret the physiological status of the end user based on data collected through their wireless sensors.

Sample of the ABS wireless physiological sensor.

The monitoring device produced by ABS has several functionalities. The wireless sensor is able to measure heart rate, arterial oxygen saturation (SpO_2), respiration rate (RR), and the orientation of the user. The device is fixed gently to the forehead using an elastic strap, making the device as unobtrusive and comfortable as possible while still gathering vital data about the user. The sensors are very durable and are able to fully operate in adverse environments and hazardous conditions such as building fires or military combat. These sensors are also lightweight and feature low power consumption, adding greatly to the practicality of their implementation. Wireless signals are sent to a USB receiver in real-time, which is necessary for the HRV application developed by this project team.

Advanced Body Sensing is continuing to improve their wireless sensors and create new applications to improve remote triage and casualty status assessment. More information about Advanced Body Sensing can be found at their website: *http://www.absensing.com/*

Project Scope

The application proposed by the project team will take heart rate data provided from existing hardware and calculate a numerical and graphical representation of an individual's current emotional state. The final software package is intended for use by the Worcester Police Department (WPD) to train emergency operators in stress management. It is important that dispatchers are able to properly handle incoming emergencies in any circumstance. A tool for accurately representing emotional coherence in real-time would allow for quantitative feedback of an operator's ability to remain properly composed in stressful conditions. There is currently no system in place at the WPD that provides the functionality of our developed application.

Utilizing the pulse oximeter sensor currently in development by ABS, our team developed software to extend the functionality of the existing device. Our application uses the real-time PPG signal output from the current ABS device to calculate heart rate variability, which was then used to determine an individual's mental state. This application made use of an open source algorithm to analyze a user's HRV and display current feedback of the physiological state of the individual in real-time. In order to do this we first translate HRV into power spectral density and from here we are then able to compute the coherence ratio which provides information regarding a user's emotional state.

The current project team took the proposed application through the software development and initial testing stages. A fixed timeline required that the project scope be limited to the development of a software package with the ability to properly compute a user's numerical coherence score. Further development and testing will be required in order for the proposed application to be fully implemented. Future work on the developed application will include the creation of a graphical user interface, as well as the testing of the usability of that interface. With the help of the GUI, a perspective user will see a dial that displays real time coherence scores. The dial is a semicircle that consists of three colors: green, yellow and red. The green part indicates the desired conditions meaning the calmness of a person or the state of coherence, yellow is warning condition meaning the change in emotions and the red is critical condition meaning a person is probably experiencing stress. Additionally, testing of the accuracy of the program on a larger population will also be required.

Literature Review

The conversion of raw heart rate data output to an intuitive and useful description of the end-user's psychophysiological state involves three major topics; heart rate variability, frequency domain analysis and power spectral density, and the mapping of these indicators with emotion. HRV will be determined from raw heart rate data as provided by existing hardware, and thus a strong understanding of the use of this indicator is important. From HRV, power spectral density is calculated using specific methods outlined in previous research. This PSD analysis will allow for the determination of emotional state.

In addition to these intermediary steps, the actual gathering of the raw physiological data is also a topic of significant importance. HRV is generally calculated using an electrocardiograph (ECG) monitor as evidenced by numerous studies and reports including the European Heart Journal report on HRV (EHJ, 1996). However, this project aims to accurately calculate HRV using photoplethysmography. PPG monitors are much simpler in practice than an ECG system. While simplified ECG systems such as chest band monitors are commercially available, scientific ECG monitors involve the use of multiple leads that must be connected to the user. Alternatively, a PPG monitoring device only requires one point of contact to the user, such as the forehead, earlobe, or fingertip. However, it must be ensured that PPG is capable of obtaining the same results as its ECG equivalent.

Heart Rate Variability

Heart rate variability describes the variation seen in the time between an individual's consecutive heartbeats. On an ECG reading, used to determine the heart rate of an individual, the peaks with the greatest amplitude are known as R waves. The time between the recording of two consecutive R waves is known as an R-R interval as shown in Figure 1. Heart rate variability is the variation in successive R-R intervals over time and is measurable through various methods.

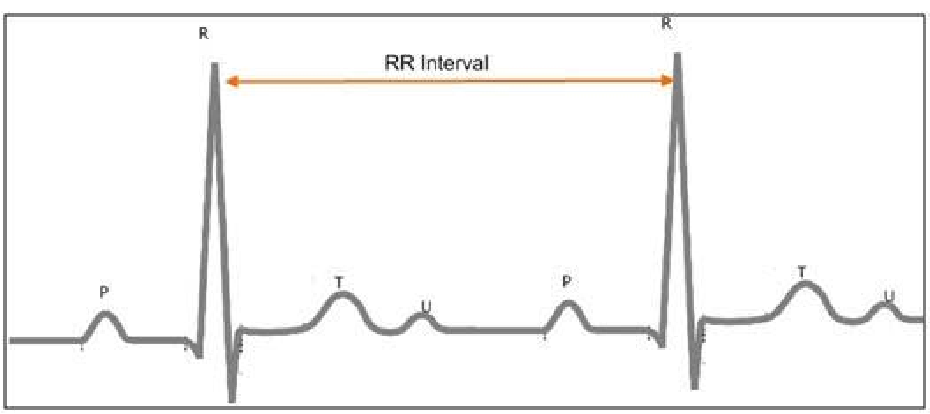

Figure 1. Consecutive R Peaks of a typical ECG Signal and the corresponding R-R Interval. (National Instruments, 2009)

While the variation in heart rate intervals has been documented as early as 1733, a report by the European Heart Journal dates its first clinical relevance to a study in 1965 (EHJ, 1996, pg. 354). Numerous studies over the past few decades were conducted on correlates of HRV, examining a variety of clinical uses for the measure, linking HRV to various conditions including anxiety (Kawachi, 1995), general cardiovascular health (Lu, 2008), internal states and stress (Choi, 2009), and depression (Frasure-Smith, 2009), among others.

Much interest has been placed on the connection with risk of coronary heart disease, as evidenced in many studies. It has been noted that the noninvasive nature of HRV analysis has led to considerable interest in its ability to detect and diagnose cardiac arrhythmias, among other conditions (Lu, 2008). "HRV reflects the dynamic interplay between perturbations to cardiovascular function and the dynamic response of cardiovascular regulatory systems. It is clear from the work by Akselrod et al. in the early 1980s, as well as numerous publications since, that maintaining ANS balance is important for cardiovascular health (Lu, 2008, pg. 23)."

In 1996 a task force from the European Society of Cardiology and the North American Society of Pacing and Electrophysiology was established in order to "…standardize nomenclature and develop definitions of terms; specify standard methods of measurement; define physiological and pathophysiological correlates; describe currently appropriate clinical applications; and identify areas for future research (EHJ, 1996, pg. 354)." This report was followed in 1997 by a committee report from the Society for Psychophysiological Research (Berntson, 1997), meant to extend the findings of the European Health Journal report.

HRV has been shown to be a sign of the body's autonomic nervous system (EHJ, 1996). Due to its strong relation to the body's internal systems, HRV has become a significant topic of interest as an indicator of numerous physiological and, more recently, psychological conditions. The autonomic nervous system (ANS) controls visceral functions in the body, including heart rate and respiration. The ANS is regulated by two major systems, the sympathetic nervous system and the parasympathetic nervous system. These two systems work in conjunction to react to internal and external conditions and maintain an acceptable physiological state within the body, with the sympathetic nerves generally increasing activity while the parasympathetic nerves work to reduce activity in their regulated systems (McCraty, 2006, pg. 6). The "slowing" effect of the parasympathetic system is controlled by the vagus nerve, providing regulation between the heart and the brain. As heart rate is regulated by the autonomic nervous system, heart rate variability has been shown through appropriate analysis to be a reliable indicator of the state of these systems (EHJ, 1996).

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Testing

Further testing will be required for the device in order to determine its accuracy when applied to a larger population. While testing on project team members indicated that the determined coherence ranges were appropriate, this would need further testing on a larger sample size to prove the software's effectiveness. Testing for the GUI will also be required for final implementation of the application.

Implementation

This project was sponsored by Advanced Body Sensing with the ultimate purpose of being used to train Worcester Police Department emergency operators in maintaining an ideal emotional state for optimal job performance. While this goal was considered during development of the current software, implementation of the application is beyond the scope of this project and will need to be considered after the development of the software is finalized. Additionally, while the ABS pulse oximeter used to collect heart rate data was found to be sufficient for the purposes outlined in this project, it was not designed to be used for providing data for coherence calculations. Therefore, alternative or modified hardware may be considered in the final implementation.

Conclusions

In an effort to provide a tool for coherence training for emergency operators at the Worcester Police Department, this project team completed the first segment of a multi-phase development project. Research was conducted on appropriate background material including the potential benefits of maintaining an ideal mental state, emotional coherence, and the use of heart rate variability as an indicator of psychophysiological state. Advanced Body Sensing's existing wireless pulse oximeter device was applied for this newly developed function of calculating and displaying coherence through a software package.

The project team successfully developed the proposed application for the conversion of heart rate to HRV to emotional coherence. Appropriate testing was conducted to ensure the accuracy of the software paired with the ABS device. Additionally the team has made recommendations for further development of the project including a graphical user interface and the implementation of the software as a training tool. A software application for monitoring an emergency operator's emotional state would bring significant benefits for dispatchers, as well as those that rely on their services. While intended for use by emergency operators, this monitoring package would have potential applications to a range of professions associated with elevated emotional stress.

Abbreviated References

Berntson, G. G., Bigger, T. J., Eckberg, D. L., Grossman, P., Kaufmann, P. G., Malik, M., et al. (1997) Heart rate variability: Origins, methods, and interpretive caveats. Psychophysiology, 34, 623–648.

Choi, J., Gutierrez-Osuna, R. (2009) *Using Heart Rate Monitors to Detect Mental Stress*. College Station, TX: Texas A&M University.

Isen, A. M., Daubman, K. A., & Nowicki, G. P. (1987). Positive affect facilitates creative problem solving. *Journal of Personality and Social Psychology*, *52*, 1122-1131.

Kawachi I., Sparrow D., Vokonas P.S., Weiss, S.T. (1994) Symptoms of anxiety and risk of coronary heart

MSDN. (2009) *Jagged Arrays (C# Programming Guide).* Retrieved 10/13/2009. *http://msdn.microsoft.com/en-us/library/2s05feca.aspx*

Appendices

List of Appendices

Appendix A

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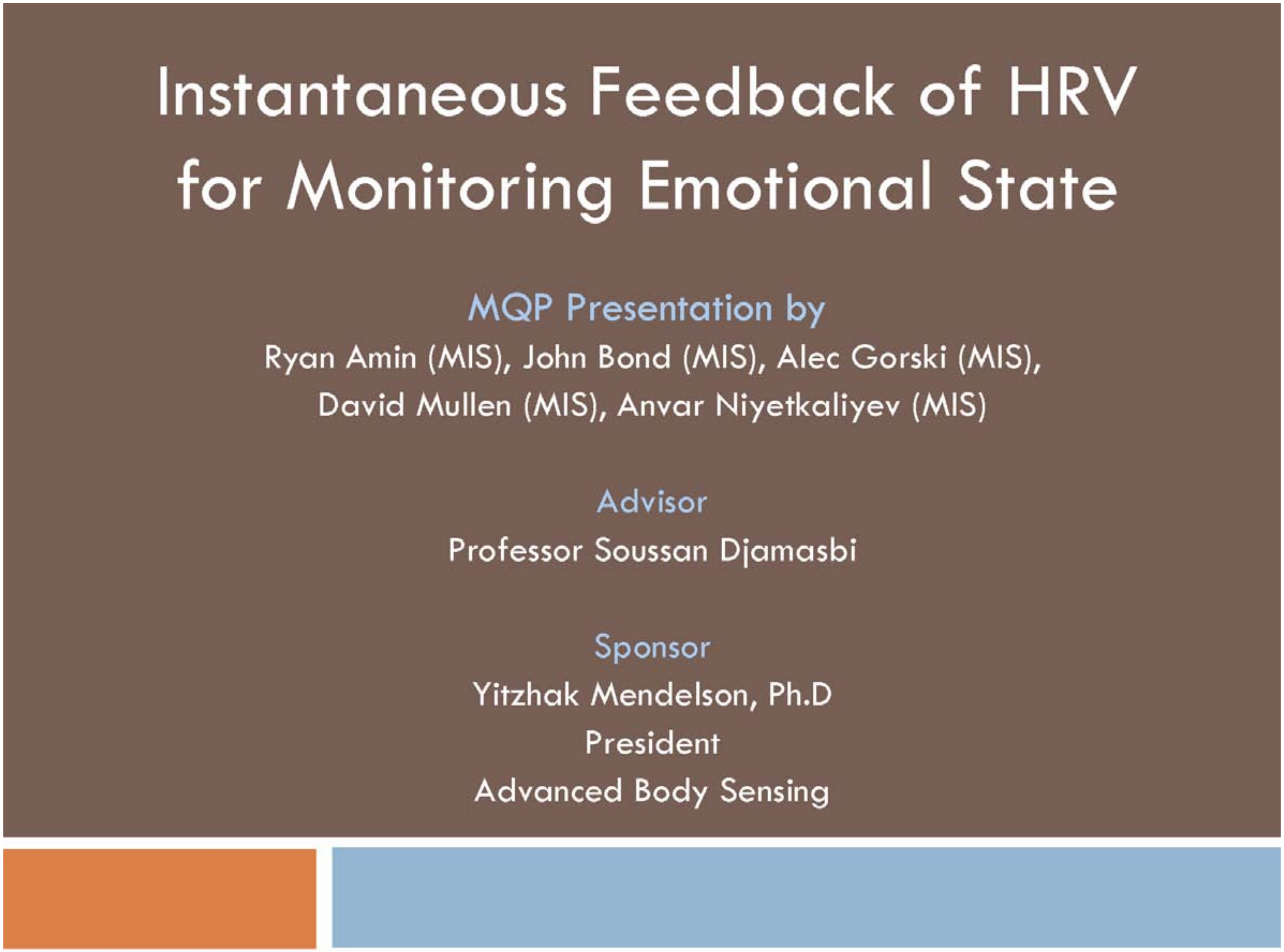
Appendix P



Slide 1

Project Goals

- Develop new application for pulse oximeter device
  - Determine feasible algorithm for calculating HRV
  - Understand the relationship between emotions and heart rate variation

Project Milestones

- A-term:
  - Researched/Understood Heart Rate Variation
  - Determined algorithm
  - Investigated possible GUI designs
- B-term:
  - Determined multiple HRV formulas
  - program implementation
  - IRB training
  - BioPac training
- C-term:
  - Implemented program
  - Conducted BioPac tests
  - Formulated hypothesis for mapping HRV
  - Documented all procedures for future use
  - Verified program
  - Trained next team
- D-Term:
  - Will be available for next team; 2hrs per week

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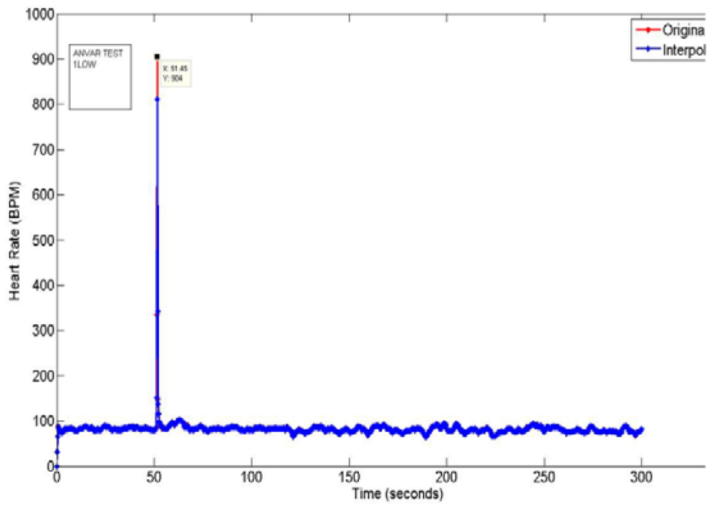
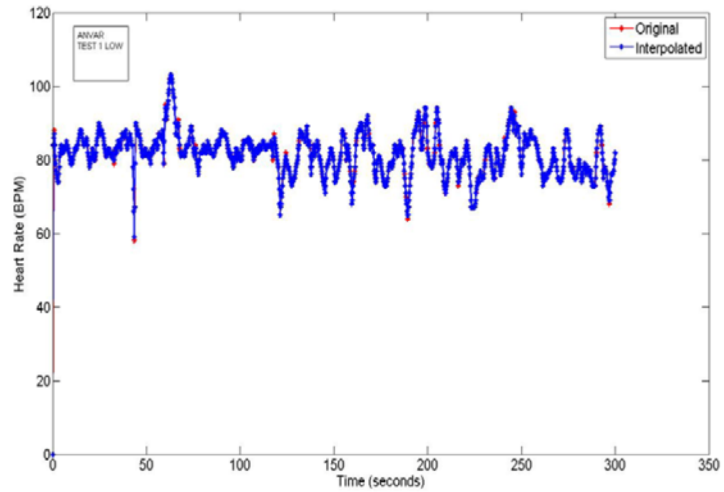
Slide 9

Anomalies in ECG collection





				Corrected				Anomalies		
State	Dist	Peak X	Peak Y	CRd	CRf	CRg		CRd	CRf	CRg
Test1Low	0.0032	0.1032	1001	0.013133	0.015424	0.49984		0.009519	0.009646	0.28594

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Summary

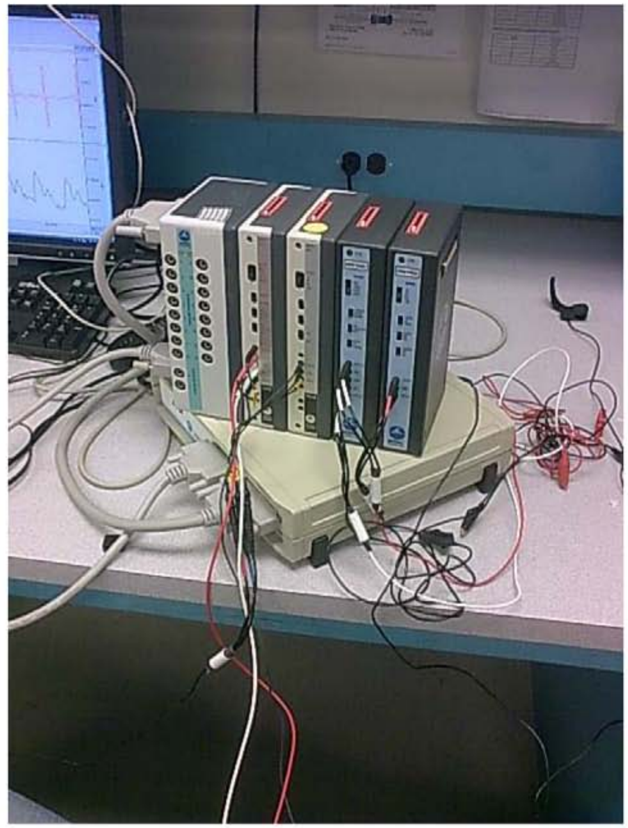
- Completed the first phase of a multi-development project
  - Conducted background research
  - Developed working application
  - Provided detailed documentation
  - Trained new team on current practices
  - Time budgeted for further consulting

Acknowledgements

- Dr. Yihtzak Mendelson (ABS)
- Piyush Ramuka
- Martin Bell
- Professor Soussan Djamasbi

Questions

Appendix D – Testing Photos



Appendix Q: MQP Poster

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