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PRELIMINARY PERFORMANCE TESTS OF A WIRELESS BODY BALANCE MEASUREMENT DEVICE

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by

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ABSTRACT

PRELIMINARY PERFORMANCE TESTS OF A WIRELESS

BODY BALANCE MEASUREMENT DEVICE

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The University of Texas at Arlington, 2017

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A thorough preliminary performance on the validity of a wireless Postural Stability Sensing Unit (PSSU) was performed. The tests were performed with the device attached to self, and the following scenarios were conducted for standing on both legs and standing on dominant/right leg: eyes open, eyes closed, eyes open with moderate instability in the medial-lateral plane, eyes open with moderate instability in the anterior-posterior plane, eyes open with severe instability in the medial-lateral plane, and finally eyes open with severe instability in the anterior-posterior plane. In most trials, the PSSU was able to provide information on how unstable my body was in a variety of scenarios. Standing on the right leg with eyes open and severe instability in the Anterior-Posterior plane showed the most displacement in terms of angular sway, with values going up to ±40° over 10 seconds. With the same stance but with severe instability in the medial-lateral plane, although there was a significant amount of angular displacement, the amplitude was nearly

half of that of anterior-posterior, approximately ±20°. Unfortunately, the result of the tests did not provide a percentage score of how stably my body performed. However, it was substituted with other indicators such as absolute mean values for each of the trials. These findings provide insight into not only how the human body system maintains stability, but also how PSSU and similar devices can be developed to aid in human performance research and provide a decent direction for further projects to continue.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

CHAPTER 1

INTRODUCTION

The overall goal of the project is to do preliminary validations of a designed wireless body balance system for telemedicine. While the title of the project gives a very broad description of what is to be expected, because of this project numerous details must still be explained: such as, its requirements, relevance, and the impact on the field of telemedicine. To understand the requirements of the project and its impact, a firm knowledge in a few fields must be established. This section will begin by giving a broad overview of the field of telemedicine, then an introduction to postural stability, and the relevance of this project.

1.1 Telemedicine

1.1.1 What is Telemedicine?

This entire project concerns this field, yet its exact meaning and importance in this project are, at this point, unknown. Telemedicine, as defined by the U.S. government, "seeks to improve a patient's health by permitting two-way, real-time interactive communication between the patient and the physician or practitioner at the distant site." [1] Communication in this sense is the flow of information from the patient to the physician, where this flow can be achieved through a variety of means–smartphones, Skype™, or in the case of this project, a sensor system. It can be argued that the basic required components for a telemedicine system can be summarized into five key points: a system to acquire information or data from the patient that is relevant to the physician at the site of the subject (questionnaires, sensors, pictures, etc.), a patient from whom the information / data is to be acquired a means of remote (i.e. not face-to-face) communication between the patient and physician, a database to store the acquired data/information, a system to allow the physician to access the database (web portals, etc.), and a physician to interpret the data and advise the patient.

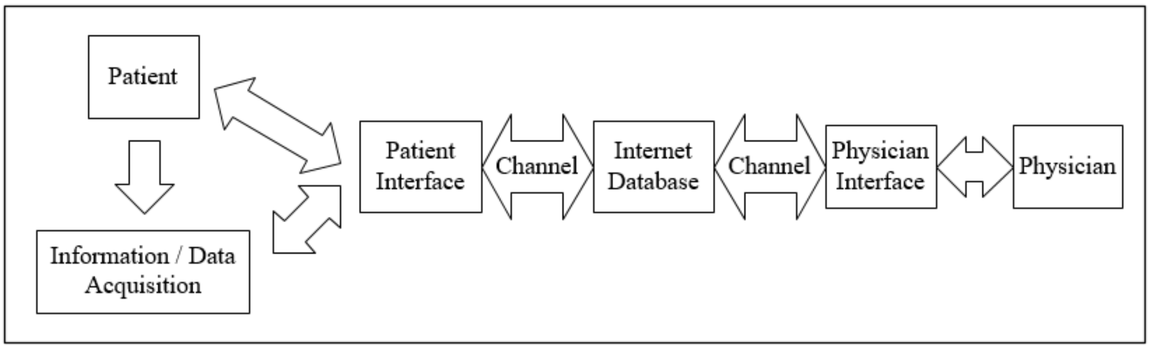


Figure 1.1: The Basic Elements of a Telemedicine System [2]

The system is designed to be used in human performance research and/or evaluation. As such, it is necessary to understand beyond the standardized elements of the telemedicine system to remove the implication that it should only be used only by patients and physicians.

1.2 Postural Stability

The main motivation behind this project will now be described in further detail, the topic being postural stability. The main goal of this section is to establish what the concept of postural stability is, specifically in relation to anthropomorphic systems such as the human body.

1.2.1 What is Postural Stability?

Beginning with the general definition of postural stability, it is feasible to examine the meaning of each word separately to get the overall understanding of the phrase, eventually applying the definition specifically to anthropomorphic systems. Posture is, according to the Cambridge Dictionary, “a position of the body, or the way in which someone holds the body when standing, sitting, or walking.” [3] Stability is “the state of being firmly fixed or not likely to move or change.” [4] When these two are combined, the sense of evaluating a subject’s postural stability can be taken to mean an evaluation of how little the subject’s body moves during an established interval of time. To get a sense of evaluating the stability of a system, typically a model of some kind is needed. Preliminary research into the topic of anthropomorphic modeling illuminates the extreme complexity of the human system in accomplishing even the basic task of standing. While reading on these topics can be done to improve one’s overall understanding of the biomechanical operation of the human body, it is not necessary to understand the relatively simple model used in this project. Further details on this mathematical model will be explained in Section 2.1 of the paper.

1.3 Significance of Project

Balance is considered a high-level task despite being accomplished at a subconscious level. The act of balancing involves a combination of various human body subsystems, each accomplishing specific functions to allow the overall system, i.e. human body, to maintain balance. The body can be described as a complex feedback system that uses a variety of senses to maintain balance. These senses can be separated into two main groups: vestibular and neuromuscular. The vestibular system “detects the motion and position of the head in space. It uses this information to regulate postural reflexes and control movement.” [5] For the neuromuscular system, it relates to the nerves and muscles of the human body (e.g. eyes, ears, arms, legs, torso) that all provide spatial feedback to the brain to determine the subject's position and relation to its surroundings. Injuries sustained to any of these areas of the neuromuscular system could lead to postural instability and other possibly bodily injuries such as broken bones from tumbles and falls. [6] In these cases, it is possible to monitor a subject's postural stability and determine whether their condition is improving or degrading with time. However, acute onset of some conditions or unnatural degradation of these senses should be detected as early as possible to ascertain the cause and remedy of the ailment. A good example of an unnatural degradation would be Benign Paroxysmal Positional Vertigo (BPPV), an age-related disorder which causes nausea and difficulty in walking.

The second application of this type of system is the monitoring of patients in two main categories: those who are undergoing physical rehabilitation because of limb amputation(s), with leg amputations having the largest impact on a patient's ability to maintain balance; and those who are undergoing physical rehabilitation or monitoring for general medical purposes (e.g. patients who have been in accidents, or suffered from strokes). The interest in monitoring patients undergoing physical rehabilitation because of amputation is that due to the loss of certain muscles and ligaments in the legs, the initial ability of the body to maintain postural stability and balance is greatly reduced. Patients who have suffered trauma to the head or various muscle groups because of an accident or medical condition (but not involving amputation) can experience loss in basic motor functions, such as hand-eye coordinator, walking, or even full-body motion. [7] [8] [9]

While applications that have been discussed have been primarily medical in nature, they can also be applied in the realm of human performance research and evaluation. The final point to discuss in this section is that this system could potentially eliminate or alleviate the need for the patient to visit their clinician in person for a physical evaluation. In most cases, evaluations are scheduled days, if not weeks, in advance to maintain a steady business flow. However, patients and clinicians must take time from their own schedules during a period which may be inconvenient for either side of the party. By validating a system that is designed to allow clinicians to acquire necessary data while eliminating the need for a face-to-face with their patients, both parties can conduct examinations whenever it is convenient for them.

CHAPTER 2

LITERATURE REVIEW

2.1 Mathematical Model: Inverted Pendulum

For this project, a common mathematical model referred to as an "inverted pendulum" is used to approximate a rigid human body system. The inverted pendulum is a low-level model that is used to simplify the mathematical framework of the project and reduce the complex calculations of the system's postural stability. While most applications using this model assume a uniform mass distribution of the pendulum, the same could not be said to human systems as they do not possess this characteristic. Additionally, the inverted pendulum model also assumes the system has a rotation about its pivot point in a single plane, or has one Degree of Freedom (DOF), at either the sagittal or coronal plane (or the Left/Right, Anterior/Posterior sections respectively). For this project, a slightly modified model has been used to represent the human body that has a 2-DOF revolute joint, and a center of gravity with varying positioning along the length of the pendulum, or in this case the subject's body. To conform to a standard representation, a 3-dimensional right-handed coordinate system will be used (refer to Figure 2.1 below) where the Euler angles of roll, pitch, and yaw represent rotations about the x, y, and z-axis respectively.

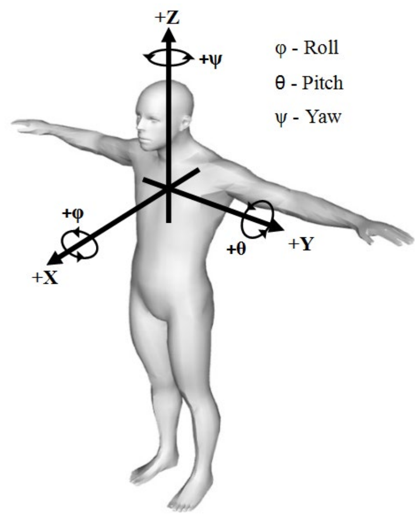


Figure 2.1: Subject Coordinate Frame

2.2 Pre-Existing Methods

In this section, current methods for determining postural stability will be presented and the similarities and differences to this project will be discussed.

2.2.1 Physical Observations

The predominant method that has been used in research, training, and physiotherapy is that of visual evaluation of what could be considered postural stability. These methods rely greatly on the abilities of the examiner and are subjective in nature, as two different examiners would likely assign two different "stability scores" to the same subject trial. These scores consist of various point and grade systems but fall short of assigning a consistent stability score. [10] [11] [12] As such, there have been relatively few attempts to establish a "percent stability" test that allows interested parties to simply get an objectively obtained measurement of the postural stability of a patient, or how this stability has changed over time. Also, these attempts that have been made to quantify the stability of the system are simple and do not account for the variations in patient body type, such as height, weight, and stance width. [13] Two systems of evaluation will now be presented.

The first of the two visual tests to be discussed is the Balance Error Scoring System, or BESS, test. [14] [15] In this examination, subjects undergo a series of tests that involve different combinations of standing positions with their eyes opened or closed. These stances include one-legged (either right or left), two-legged, and tandem. Additionally, these stances are performed once on a hard or stable surface, such as a tiled floor, and then again on a soft or unstable surface, such as a foam pad. During the trial, deviations from the "ideal" stance are noted and assigned a score based on the overall severity of the deviation. Deviations can include: moving hands from the hips, opening eyes during the closed-eye test, steps, stumbles, or falls. At the end of the period, these deviation scores are added up and compared to a standard scale and a percentile score is assigned to the subject.

The second test is the Star Excursion Balance Test or SEBT. This procedure requires the evaluation area's floor to be marked with eight directions each 45° apart, corresponding to each of the vertical anatomical planes. [16]

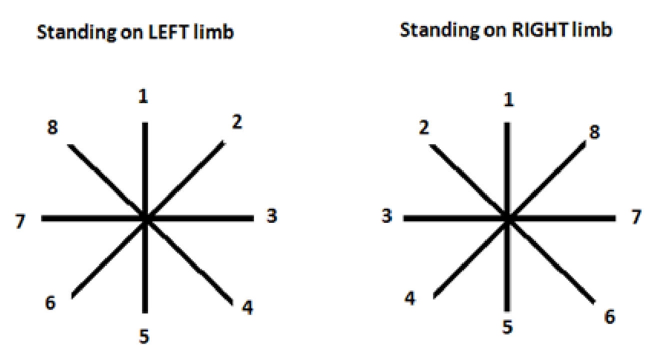


Figure 2.2: Star Excursion Balance Test (SEBT) [16]

The subject is to balance on one leg and extend the other as far as possible in each direction of the star without touching the ground sequentially. Then, the patient will lightly tap the floor in the direction of the star before bringing it back into the center. Meanwhile, the distance from the center of the star to where the patient tapped the ground is measured. However, the trial is nulled and retried if the subject commits any deviation throughout the exam. Deviations can include: tapping the ground too hard, resting the raised foot on the ground, losing balance, or being unable to maintain limb control during the test. While both systems provide a general means of evaluating a subject's stability while also being highly accessible and easy to use, both systems are still highly subjective in nature.

2.2.2 Electronic Examinations: Force Plate

Because of the subjective nature of tests like BESS and SEBT, in conjunction with the rapid growth and implementation of technology in medicine, a wide variety of systems have been developed that can provide consistent and objective measurements. One example is the use of force or pressure plates to monitor the movement of the subject's center of pressure (CoP). In these kinds of tests or examinations, a platform that contains force or pressure sensors communicates with a local computer to acquire measurement information from the sensors. This data is then used in a variety of calculations to obtain some resulting measurement from the test. Once finished, the calculated and original data are stored in an online database. In tandem with a central processing unit (CPU), these sensors are used to determine the CoP of the patient, which then can be used in mapping the overall motion of the patient's CoP. [17] The interest of balance and stability has even found its way into the consumer market in the form of games, such as Nintendo's Wii Balance Board.

CHAPTER 3

METHODOLOGY

The purpose of this project is to validate a built wireless Postural Stability Sensing Unit. To meet the general requirements of this project, the successful design of the project must be explained. This section will provide the overall process that was done for this specific project. Although there is more to the operational scenario and functionality to this system, it can be read in Section 3 "Design" in the report *Senior Design Project 179: Wireless Body Balance Measurement System for Telemedicine* by Christian Smith, et al., which is the basis for this project. The first section will present a brief overview of the system operation will be presented. Second, the general testing environment will be given. Finally, the major system components that were required for the project will be discussed.

3.1 System Overview

The system requirements and constraints were provided by the project advisor during the Senior Design Project phase in the Spring 2017 semester. Further requirements and constraints were identified with former SDP group members. The complete table that summarizes the original constraints and requirements can be found within the Senior Design Project report, but for this project, the constraints and requirements that are related to this Honors project will be listed below.

Table 3.1 Summary of the Constraints and Requirements of This Project

Identifier	Description
Constraints	
C1	Inertial Measurement Unit – InvenSense MPU-9250
C2	Incorporation of prior works into current design
Requirements	
Communication	
X1	Communication range of 5m
X2	Bandwidth can support data transfer rate
System	
S1	Small / Compact
S2	Lightweight
S3	Attaches to body by strap
S4	Audible test-start notification *
S5	Tests
S6	a. Two legs, eyes open
	b. Two legs, eyes closed
	c. Right leg, eyes open
	d. Right leg, eyes closed
	e. Left leg, eyes open
	f. Left leg, eyes closed
* These are requirements identified by the senior design team.	

To provide a general understanding of the system and what it is meant to accomplish, a high-level view of the system operation will now be presented. This will serve as an introduction to *how* the system will proceed. Firstly, the total system consists of two primary systems: a Postural Stability Sensor Unit (PSSU), which is worn by the test subject and acquires a measurement of their postural stability, and the user interface to select which tests will be performed through a computer device. For this project, the PSSU system will be focused on primarily. The PSSU system uses an InvenSense MPU-9250 Inertial Measurement sensor chip, which measures and collects data such as linear acceleration (a) and rotation velocities (ω).

3.2 Testing Environment

The general testing procedure of the project will be discussed in the next chapter. However, to maximize the accuracy and precision of the collected data, a general understanding of the preparation and testing environment must be understood. This brief section will discuss the limitations of the BLE communication software of the program and the proper remedies to them. Additional considerations such as having a third-party assistant and solid, stable testing floor will be addressed.

For the Bluetooth communication portion of the project, the method by which the device is programmed and paired with the computer interface is not as extensive as in most other systems in use. When the user needs to pair the computer terminal with the PSSU device, the UI scans for all Bluetooth capable devices near the testing area. These include devices such as smartphones, smartwatches, and including other computing devices. The user can keep on scanning for the correct device through the user interface, but to minimize the wait time and effort to pair up the system correctly, the testing area must be cleared of other Bluetooth electronic devices.

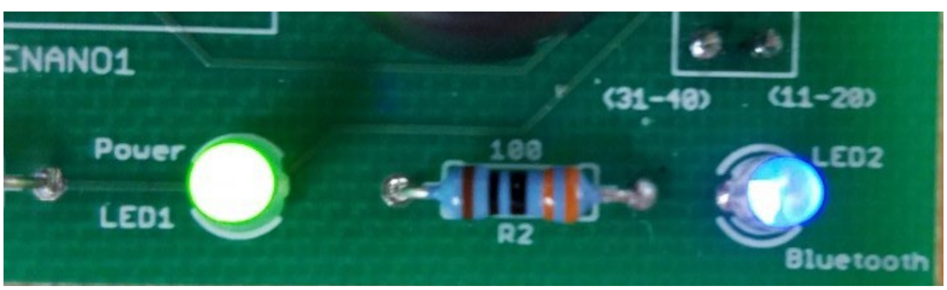


Figure 3.1: Successful Initialization and Bluetooth Connection of the Device

To ease the testing procedure, having a third-party assistant/volunteer would help with selecting the desired test options as well as keeping time for the Pass-Through option that collects the raw data from the device. As for the testing area itself, the project is aimed to validate the efficiency of the PSSU device at a base level. Therefore, the area must have a stable, solid testing ground, such as tile or concrete. Advanced testing while using an unstable testing surface, such as a foam pad, could be used in future examinations.

3.3 Major System Components

For the overall system to perform correctly, a general understanding of the necessary major components must be understood. Other than the PSSU Hardware, there are other considerations for hardware and software that are needed. The table below provides a summary of the required components for the testing procedure.

Table 3.2 Summary of Hardware and Software Requirements

Identifier	Description
Hardware	
H1	Postural Stability Sensing Unit
H2	Apple Mac laptop/computer - Bluetooth Low Energy Compatible
Software	
S1	Code Composer
S2	Node.js
S3	a. Node.js v. 6.9.1
	b. Node-Red v. 0.15.2
	c. Node-Red-Contrib-Noble
	d. Node-Red-Contrib-PSSU
	e. Node-Red-Contrib-Dashboard

3.3.1 Hardware

Other than the actual PSSU hardware, the preferred computer interface to use through the testing is an Apple Mac laptop or computer, preferably one that has Bluetooth Low Energy capabilities. There are two reasons behind this configuration. One is that the hardware communicates with the computer interface through Bluetooth connectivity. The second is that the actual plug-in for Node-Red was designed on a Mac laptop, and it works beston similar systems. This will be explained further in the next section.

3.3.2 Software

In the software requirements for the project, Code Composer is used primarily to compile the file codes for the device for any changes in operational values. These consist of variables such as the test subject's height, foot length, and stance width in centimeters. However, Node.js is the primary software needed that serves as the basis for the communication between the PSSU, user interface, and Bluetooth communication. Node.js is an open-source, cross-platform JavaScript service that allows users to create Web services and other networking tools. This project uses a third-party plug-in/extension called Node-Red. Node-Red is also an open-source, flow-based programming software. It is a visual tool to create "flows of service" for the internet of things (IoT). A "Node" is a visual icon on the editor that can be dragged and dropped onto a canvas and wired with other "Nodes." Every node can be classified into three categories: input, operation/function, and output—each programmed with their own functionality that will form a logical flow of an application. Since the software is open-sourced, community-contributed nodes are available to use in the application of this project. For this project, the minimum versions for Node.js and Node-Red are v.6.9.1 and v.0.15.2 respectively. The custom PSSU node was created with these versions of the software installed, and to maintain consistency it is recommended to download those versions instead of the latest releases.

For this project, the Node-Red flow is designed to work on a locally hosted server on a computer. Once initialized, the application launches a User Interface page on a web-browser compatible with the software. The page is used to send commands to the PSSU to locate and communicate with the device and select the test that needs to be taken.

Additional plug-ins are needed for Node-Red for the system to work properly. One of the prerequisite plug-ins for the system is Node-Red-Contrib-Noble. Noble is a Node.js that allows the service to communicate to devices through Bluetooth Low Energy. For Mac OSX computer devices, an installation through "npm install node-red-contrib-noble" command line through a terminal is all that is required for this plug-in. The Node-Red-Contrib-PSSU plug-in, however, is a custom-made file archive. It must be manually installed after unpacking the archive in the "~/.node-red/node-modules" folder path on the hard drive. Finally, for the user interface, Node-Red-Contrib-Dashboard can be installed using a similar command line in the terminal program, "npm install node-red-contrib-dashboard." Dashboard is used to create a web-browser application that will allow the user to send JSON-based commands to the PSSU by clicking on-screen buttons in the browser.

CHAPTER 4

TESTING AND RESULTS

4.1 Testing Procedure

After scheduling a date for testing the device with the third-party assistant, the overall testing procedure can be summarized in the following section below. Note that the procedure is being applied to the first operational mode: standing on both legs with both eyes open while maintaining a stable posture. The other stances will be described further on in the chapter.

After logging into the Mac Apple laptop or computer device, the assistant will wait for the project manager to put on the device. The assistant will then be instructed to launch Node-Red through their command terminal and open up the user interface in their preferred web browser.

Figure 4.1: PSSU Placement on Body

At this point, when the PSSU device has been secured against the project manager's body, initialization of the device must be performed. To do so, the device must be simply turned on; however, the project manager must stay still as best as they could for approximately 10 seconds for the IMU to calibrate itself. Once the device has sufficient time to calibrate itself, the assistant can begin to connect the device to the host computer. After finding and successfully pairing the devices, the assistant can begin the testing in Pass-Through mode and keep track of time.

There are two different positions for the testing trials: standing on both legs for 30 seconds and standing only on the dominant leg for 10 seconds. For ease in explaining the procedure, the following sections will be described in the two-leg scenario.

The project manager will have a 30-second delay to prepare for the trial. Once it begins, they will have to keep still and stable with their eyes open for approximately 30 seconds while the PSSU collects the data and outputs a text file for the trial. During the testing, the IMU will collect rates of degrees/seconds for the roll, pitch, and yaw measurements. The programmed sensor fusion algorithm will then use those data points to produce angles of displacement in degrees.

Once the test trial has reached approximately 30 seconds and the assistant stops "Pass-Through" mode, the device itself must be turned off and back on again, the project manager maintaining a stable and still posture. This is because the device is programmed to go into a shut-down state/mode after the conclusion of a test mode or when the user presses "Stop" in the UI browser application. The same stance is repeated for an additional two trials.

The following table below provides a summary of the additional testing stances and their conditions of instability. For the instability trials, the project manager must simulate the sway of the desired planes, with severe instability being much greater than that of moderate instability.

Table 4.1 PSSU Testing Scenarios

Test Type	Time (s)	# of Trials
Two Legs, Eyes Open, Stable stance	30	3
Two Legs, Eyes Closed Stable stance	30	3
Two Legs, Eyes Open, Moderate Instability in Medial-Lateral Plane	30	3
Two Legs, Eyes Open, Moderate Instability in Anterior-Posterior Plane	30	3
Two Legs, Eyes Open, Severe Instability in Medial-Lateral Plane	30	3
Two Legs, Eyes Open, Severe Instability in Anteriro-Posterior Plane	30	3
Right Leg, Eyes Open, Stable stance	10	3
Right Leg, Eyes Closed Stable stance	10	3
Right Leg, Eyes Open, Moderate Instability in Medial-Lateral Plane	10	3
Right Leg, Eyes Open, Moderate Instability in Anterior-Posterior Plane	10	3
Right Leg, Eyes Open, Severe Instability in Medial-Lateral Plane	10	3
Right Leg, Eyes Open, Severe Instability in Anteriro-Posterior Plane	10	3

4.2 Results

Figure 4.2: Two Legs, Eyes Open and Closed, Steady Trials

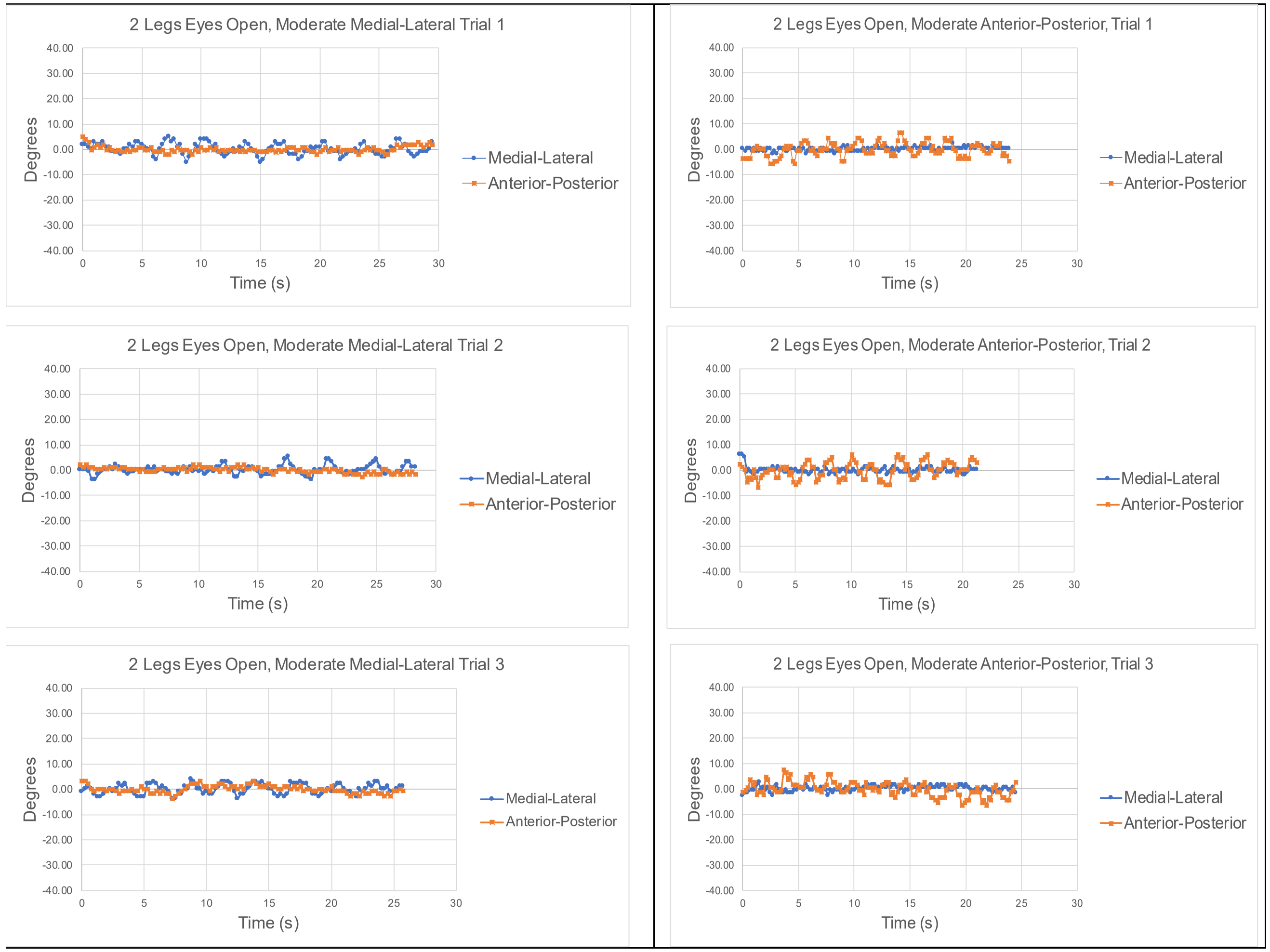


Figure 4.3: Two Legs, Eyes Open, Moderate Instability in Medial-Lateral and Anterior-Posterior Plane Trials

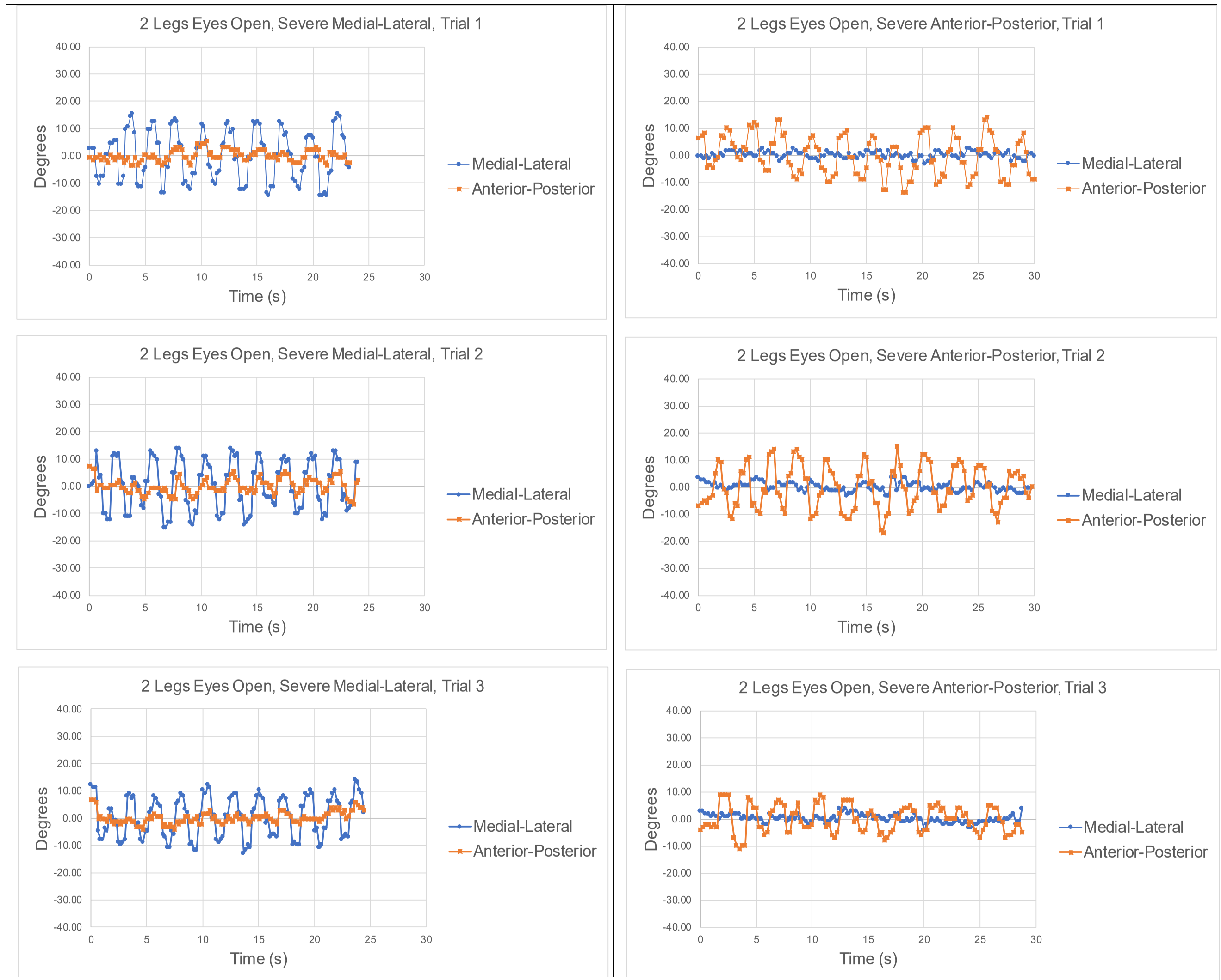


Figure 4.4: Two Legs, Eyes Open, Severe Instability in Medial-Lateral and Anterior-Posterior Planes Trials.

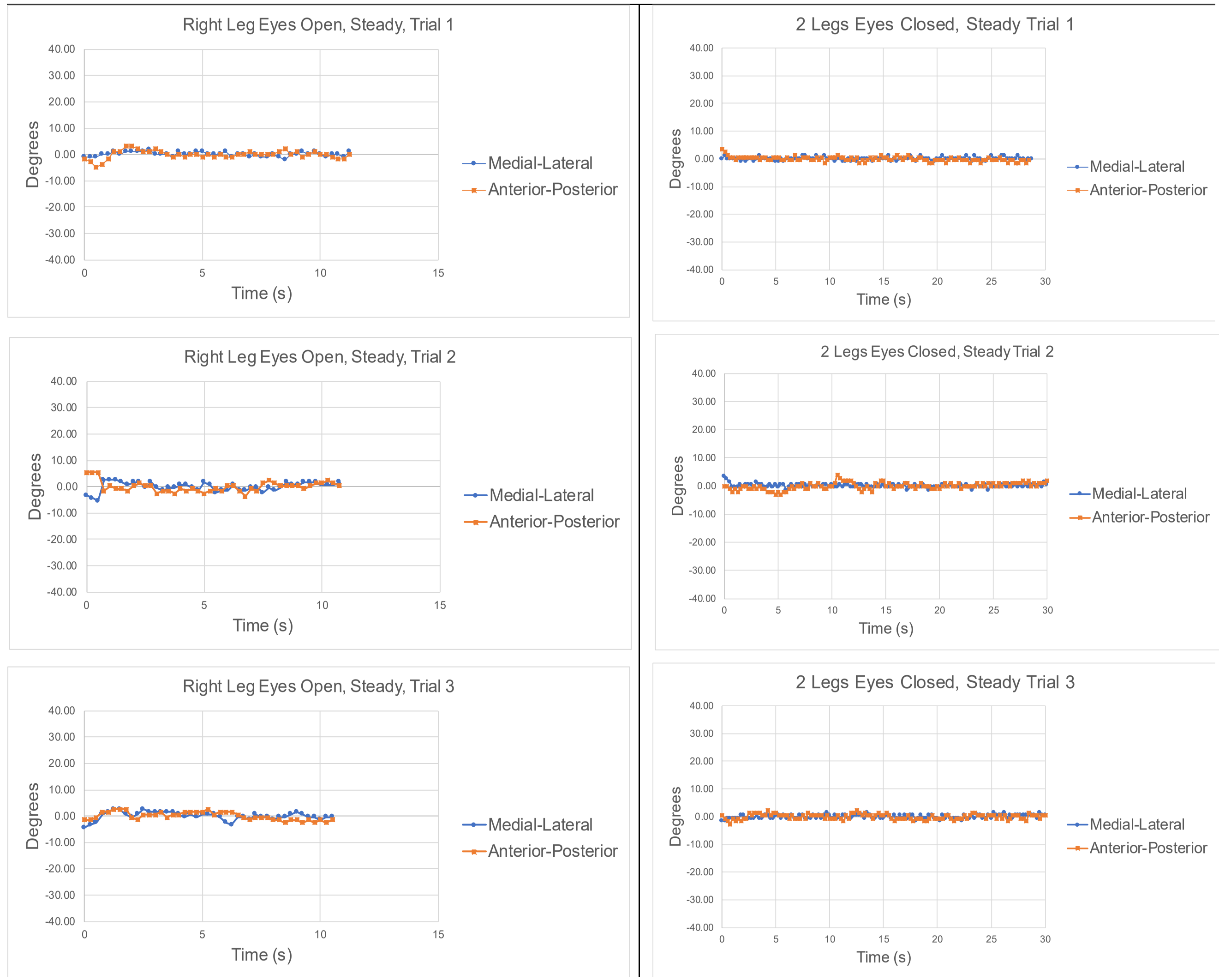


Figure 4.5: Right Leg, Eyes Open and Closed, Stable Trials

Figure 4.6: Right Leg, Eyes Open, Moderate Instability in Medial-Lateral and Anterior-Posterior Planes Trials

Figure 4.7: Right Leg, Severe Instability in Medial-Lateral and Anterior-Posterior Planes Trials

4.2.1 Angles of Displacement Analysis

The method used for presenting the angle of displacement angles collected is in the form of scatterplots. The data used in the figures above have been corrected for offset by finding the averages for roll and pitch for each trial and then subtracting them. However, while collecting data for yaw, there was an unusual accumulation of angle displacement throughout the trials. See Appendix A for a graph of a trial for the first testing stance that includes yaw values. According to Senior Design Project report, the in-built Sensor Fusion algorithm inside the IMU adversely affected the trial time due to a large amount of processing within the chip. [2] The team has corrected this issue by reducing the sampling rate of the IMU and processing frequency of the sensor fusion algorithm. Additionally, a customized Sensor Fusion algorithm has been implemented. Though the roll and pitch values were the focus of the algorithm, it could be assumed that the yaw had little consideration with its conception. Since the IMU measures rates of change in degrees, it can be inferred that there was a constant rate for the yaw, therefore resulting in an accumulating displacement in degrees.

After collecting the data and correcting the offset for the trials, the absolute mean average for Medial-Lateral and Anterior-Posterior for the trials has been collected. This has been done by taking the absolute of the corrected values, then finding the average for each plane in each trial. The table below provides the collected data for each test type and their overall averages in each plane.

Table 4.2: Calculated Absolute Averages in Medial-Lateral and Anterior-Posterior Planes for Each Scenario and Trial

Test Scenario	Trial Number						Averages	
	Trial 1 Abs Avg		Trial 2 Abs Avg		Trial 3 Abs Avg		MD	AP
	MD	AP	MD	AP	MD	AP		
2 Leg Eyes Open, Stable	0.57	0.44	0.43	0.87	0.51	0.66	0.50	0.65
2 Leg Eyes Closed, Stable	0.35	0.69	0.60	0.88	0.59	0.77	0.51	0.78
2 Leg Eyes Open, Moderate MD	1.86	0.93	1.30	0.93	1.62	1.24	1.59	1.03
2 Leg Eyes Open, Moderate AP	0.59	2.23	0.86	2.66	0.83	2.27	0.76	2.38
2 Leg Eyes Open, Severe MD	8.11	1.66	8.01	2.29	6.71	1.68	7.61	1.88
2 Leg Eyes Open, Severe AP	1.00	5.87	1.35	6.86	1.27	4.33	1.21	5.68
Right Leg Eyes Open, Stable	0.60	1.12	1.39	1.49	1.20	1.36	1.06	1.32
Right Leg Eyes Closed Stable	1.22	1.22	3.73	3.59	1.47	1.97	2.14	2.26
Right Leg Eyes Open, Moderate MD	6.08	2.29	4.62	1.42	5.76	2.32	5.49	2.01
Right Leg Eyes Open, Moderate AP	3.18	7.83	1.91	4.24	3.77	9.37	2.95	7.15
Right Leg Eyes Open, Severe MD	10.72	4.92	10.41	3.76	n/a	n/a	10.57	4.34
Right Leg Eyes Open, Severe AP	4.29	13.42	3.95	15.43	4.86	15.45	4.37	14.77

MD = Medial-Lateral
AP = Anterior-Posterior

From the data collected, based on the type of instability, the PSSU device does have the capability to display which plane of the human body suffers instability the most. It can also be interpreted from the data that in most stable posture scenarios the Anterior-Posterior planes have a higher average of the angle of displacement than that of the Medial-Lateral plane. This makes sense, as there is more area for stability along with a person's Medial-Lateral plane, unlike Anterior-Posterior.

Furthermore, not only were the overall averages significantly higher in the moderate and severe Anterior-Posterior plane trials, but it appears that the Medial-Lateral plane also measured an increase of instability measurements. Since there is less area of stability in the former plane, the human body must have compensated by stabilizing stability partially in the latter plane.

CHAPTER 5

CONCLUSION

5.1 Project Discussion

The overall design of this project began with the idea of validating a designed and constructed Postural Stability Sensing Unit to determine if such a device could be applied in a real-world scenario. This method of approach was used to allow the project to commence testing in an early and timely manner. However, many challenges appeared throughout the project, which can be summarized into two main points: limitations in the hardware, particularly the host computer, and limitations in the PSSU programming.

One of the primary limitations of the PSSU project is its restrictions on useable computer platforms. During the Senior Design Project involving the PSSU, the custom-made node for Node-Red was composed on a Mac machine. When there were earlier attempts in using the same plug-in on a Windows machine, there were additional programs and external Bluetooth communication devices that were needed for the Node-Red flow to theoretically work. It may be due to differences in the hardware and operating system, but when all the prerequisites were supposedly matched on a Windows machine, the plug-in did not initiate when Node-Red launched. For future designs and projects that may be carried over, it is recommended that the creation of custom programming functions consider being compatible with all types of computer machines.

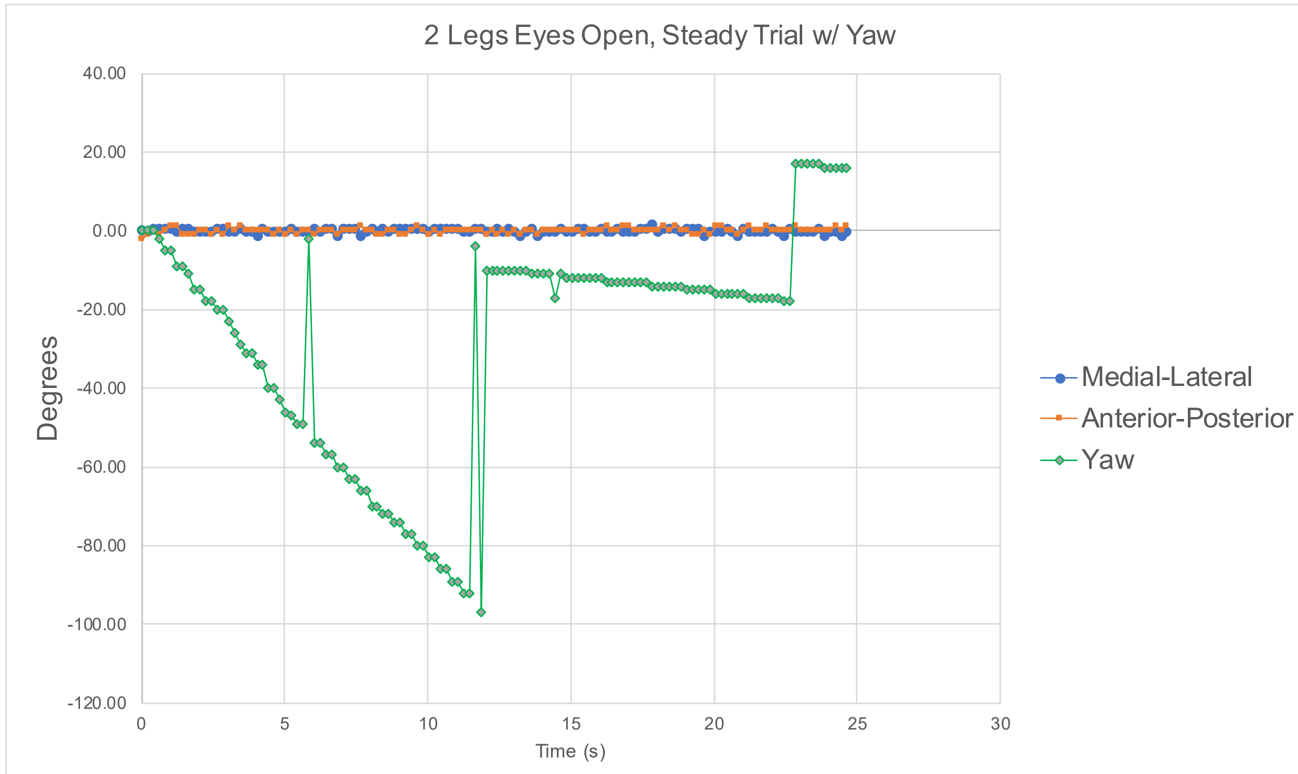
During the testing of the device, it was brought up that the specific test modes for the PSSU only outputted a percent stability score from 0 to 100. The raw data gathered from the IMU was not recorded and saved as a local file in the computer. This can be circumvented by launching the tests through the "Pass-Through" mode, where the raw data is being outputted from the device. However, this mode runs continuously until the user presses "Stop" in the Node-Red web browser application. This causes issues in getting a consistent number of samples throughout each of the trials and scenarios presented. Future recommendations for similar future projects include having the raw output data collected and stored in a separate file and the percent stability score in another. This will allow future projects to not only retrieve their desired outputs, but also the data collected that is used to generate a said outcome.

Additionally, the lack of percentage scores due to the previous software limitations hindered in validating the system's effectiveness. Although other data such as the Indicators from Table 4.2 can be calculated that can be analyzed for patterns and trends. In this case, the higher mean absolute value indicates more instability in one plane than the other. Although these indicators are not specifically what was specifically aimed at in the project, it is a good step in the right direction for future projects that will build and improve on it.

APPENDIX A

SCATTERPLOT OF ROLL, PITCH, AND YAW OF TWO LEG,

EYES OPEN, STEADY TRIAL



Two Legs, Eyes Open, Steady Trial with yaw Values

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BIOGRAPHICAL INFORMATION

Jonathan Nufable graduated from the University of Texas at Arlington with an Honors of Bachelor of Science in Electrical Engineering and a minor in Mathematics. Additionally, he passed the Fundamentals of Engineering Exam for Electrical and Computer Engineering and is certified in the Unmanned Vehicle Systems Program. Jonathan plans to obtain a Master's Degree in Electrical Engineering and seek employment within the military contract sector.