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Golf Swing Trainer using Wii Balance Board

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Image from Huang et al.

THE UNIVERSITY of TENNESSEE
KNOXVILLE

CAPSTONE STUDY CONDUCTED FOR
Byron Williams — Fairways and Greens Golf Center

Golf Swing Trainer using Wii Balance Board

May 2020

by

Mechanical, Aerospace and Biomedical Engineering (MABE)
Undergraduate Students

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CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

Table **Page**

ACRONYMS

Symbol	Meaning	Units
α	Angle Through which A has Rotated to any Downswing Position	°
β	Wrist-Cock Angle Clockwise from Extension of A	°
θ	Angle through which Rod A has Rotated from Downward Direction	°
a	Horizontal Acceleration	m/s^2
g	Gravitational Constant	$kg\text{-}m/s^2$
I	Second Moment of Inertia of Rod C	m^4
J	Second Moment of Inertia of Rod A	m^4
KE	Kinetic Energy	Joule
L	Lagragian Function	Joule
MC	Mass of Golf Club	kg
O	Center of Rotation	
PE	Potential Energy	Joule
Q_α	Any Outside Torque Applied to the Arms	N-m
Q_β	Any Outside Torque Applied to the Club	N-m
R	Length of Arms	m
S	First Moment of the Club about the Wrist-Cock Axis	m^3
SA	First moment of Arms about Axis O	m^3

EXECUTIVE SUMMARY

The Golf Swing Senior Design Capstone Teams, as a part of the Mechanical, Aerospace and Biomedical Engineering Department in the Tickle College of Engineering at the University of Tennessee, Knoxville, was tasked with creating a golf swing training aid to consistently replicate the hip slide occurring on the downswing of a student receiving lessons. At the request of professional golfer Byron Williams, the teams worked to remedy concerns that, because of the nature of the hip slide movement, students were not able to proficiently comprehend the current instruction method that Mr. Williams used to teach this piece of the golf swing. To this effect, the team and Mr. Williams were able to come to an agreement on the main objectives of the project including designing a tool for helping the student learn the concept of a one-piece backswing, develop, design and build a platform that captures the Center of Gravity in the x- and y- coordinate planes, and develop a slide platform to help consistently replicate the hip slide occurring on the downswing of a student striking the golf ball.

The project began with a literature review of the current state of golf swing analyses. Publications from Jorgensen, McNally, Okuda, and Huang formed the basis for our design and provided valuable insight into the advantages of studying the golf swing in this capacity. Next, the team members began studying specific portions of the golf swing and accompanying factors to create a holistic picture of all the components leading to a successful golf swing and what technology is already available. Included in this report is a section on the fundamental differential equations driving the golf swing, a consultation with the Biomechanics Laboratory at the University of Tennessee, Knoxville, swing improvement devices, motion capture equipment, golf club shaft specifications, and an interface program to produce the visual aids.

As these separate pieces were coming together, it became apparent that not all of them led directly to the three stated objectives of the project. For this reason, the project centered on a foot board system that graphed the force and pressure distribution of the golfer during their swing. This device quantitatively analyzes the golf swing in a way that allows the student to visual their miscues and produce better swings with the guidance of Mr. Williams. Additionally, two swing aids were conceptualized, and further testing will be needed before integrating those into the final deliverable. The final product will have pieces that can be used separately or in unison to best meet the needs of the student receiving a lesson.

The team members who are available anticipate continuing to work on the project into the early summer before delivering the product to Mr. Williams. Final testing of the connectivity and functionality of the system needs to be carried out before it is set for student use. The available members will seek to experimentally validate the data collected and output by the Wii Balance Board. This verification process will ensure that the product helps both the student and Mr. Williams better understand the student’s swing. Future research will focus on the shaft specification analysis to better understand how different players execute their swings with different types of clubs and different club specifications. This will be combined with the motion capture equipment to better study the swing with each club in a student’s bag. The long-term future of this product is a budget friendly swing analysis system that gives the student the necessary feedback needed to make swing improvements without bombarding them with information that is not relevant to a novice player.

1. INTRODUCTION

The objective of this Senior design project is to design and build 3 training aids to help improve a person's golf swing. The training aids can be used separately or in conjunction while the person is taking lessons from a professional golf instructor. Each training aid helps the student subjectively learn good technique for striking the golf ball. The key objectives are:

1. Design a tool for helping the student learn the concept of a one-piece backswing. The arms, and shoulders should move in unison on the backswing.
2. Develop, design and build a platform that captures the Center of Gravity in the x- and y-coordinate planes (COGx and COGy). The tool uses a Nintendo Wii Balance Board to map the COGx and COGy of the golf student. Plots of the data show the professional and student can swing faults due to poor balance and poor posture during the golf swing.
3. Develop a slide platform to help consistently replicate the hip slide occurring on the downswing of a student striking the golf ball.

Professional golfer Byron Williams reached out to our group and identified these lacking components in the golf swing of many amateurs that come to him for lessons. It was our assignment to take his thoughts and the experiences of many amateurs and translate that into devices that better equips golfers to perform well on the course. We sought to do this through various independent mechanical devices and data analytics tools that represent the holistic golf swing and better inform the player of their weaknesses.

The team designed a device that connects the lead forearm to the trailing shoulder to restrict errant movements during the swing; objective 1. Wii Balance Boards were procured and used in conjunction with a software tool (BrainBLOX[1]) developed by the University of Colorado at Boulder. This program provides real time graphs of the weight and pressure distribution of the student receiving lessons so that adjustments can be made if they are making balance and posture mistakes; objective 2. Currently, the hip slide players need to better their game is taught through hours of lessons and intangible statements about a "feeling" of drifting forwards during a precise moment of the downswing. This golf tool will utilize a foot board to track the weight distribution and centers of gravity and pressure to better visualize the motion of the student's swing; objective 3. This immediate feedback will help the player make the necessary personal adjustments that cannot always be gained from a conversation. The culmination of these 3 items will help Mr. Williams teach his students better mechanics of the golf swing.

Finally, we conducted a literature review and compiled a system of equations that can be input to MATLAB to model the golf swing or ball trajectory of the player in two dimensions.

2. BACKGROUND

The golf swing is an incredibly complex and intricate feat of human performance that spans the fields of biomechanics, multibody dynamics, optimal control, solid mechanics, and aerodynamics. With one seamless motion, the swing can produce a golf shot that even surprises the professionals that make money by getting the ball into the hole in the least number of strokes. Conversely, these same professionals may have one uncharacteristic motion in their swing that sends the ball out of bounds and ruins the round of golf. This, in a nutshell, is the beauty and heartbreak that golf brings to the player each and every time they take to the course.

[1] BrainBLOX is the abbreviation for UCB's software tool Brain and Biomechanics Lab in a Box

It would be impossible to analyze and critique every opinion held about golf swings and which ones produce the best results. Rather, this design project focused on a few critical studies of the fundamental equations driving the golf swing to better understand the feeling golfers have during the drift of the hips. The main reference text is Theodore P. Jorgensen's *The Physics of Golf.* In his book, Jorgensen studies a particular swing by a professional golfer and tries to match it with a calculated model [1]. The calculated model produced in this text is the base of our analysis and will be used as a benchmark for our continued study.

William McNally's thesis on the forward dynamic simulation of a golf drive served as an aspirational goal of this project and will guide the next steps of this project. McNally created a three-dimensional, six degree-of-freedom biomechanical model of a golfer, a Rayleigh beam model of a flexible club, an impact model based on volumetric contact, and a spin-rate dependent ball flight model [2]. This amount of nuance was not requested by Mr. Williams for our yearlong project, so we simplified our model to two dimensions with a stiff beam model of the club and was limited to only the golf swing. We also referenced the article by Okuda et al. over trunk rotation and weight transfer patterns of skilled and low skilled players [3]. This report will be used to corroborate our collected data and verify the accuracy and precision of the Wii Balance Board with the results found in the swing analysis system by Huang et al. [4].

3. PRODUCTS

3.1 2D EQUATIONS OF MOTION

As Mechanical Engineering students, it is vital to understand the physics of the system under investigation. To this effect, it was of priority to reference the literature and reconstruct the two-dimensional equations of motion to better grasp the fundamentals of the golf swing in order to better understand where improvements could be made. From Jorgensen, the Two-Rod Model of the golf swing is described by a set of differential equations and solved using the Lagrangian Method following from p. 152.

$$L = KE - PE \tag{1}$$

$$PE = -(SA + MC \cdot R)(g cos\theta + a sin\theta) - S[g cos(\theta+\beta) + \text{asin}\,(\theta+\beta)] \tag{2}$$

$$KE = \frac{1}{2}[J + I + MC \cdot R^2 + 2RS cos\beta]\dot{\alpha}^2 + \frac{1}{2}I\dot{\beta}^2 - [I + RS cos\beta]\dot{\alpha}\dot{\beta} \tag{3}$$

For this system, the Lagrangian is taken with respect to α and β to acquire the generalized forces.

$$\frac{d}{dt}\left(\frac{dL}{d\dot{\alpha}}\right) - \frac{dL}{d\alpha} = Q_\alpha \tag{4}$$

$$\frac{d}{dt}\left(\frac{dL}{d\dot{\beta}}\right) - \frac{dL}{d\beta} = Q_\beta \tag{5}$$

Applying the Lagragian function described in Equations 4 and 5 to Equation 1, the following equations are produced.

$$\begin{gathered}(J + I + MC \cdot R^2 + 2RS cos\beta)\ddot{\alpha}^2 - (I + RS cos\beta)\ddot{\beta} \\ +(\dot{\beta}^2 - 2\dot{\alpha}\dot{\beta})RS sin\beta - S[g sin(\theta+\beta) - \alpha\cos(\theta+\beta)] \\ -(SA + MC \cdot R)(g sin\theta - \alpha cos\theta) = Q_\alpha\end{gathered} \tag{6}$$

$$I\ddot{\beta} - [I + RScos\beta]\ddot{\alpha} + \dot{\alpha}^2 RSsin\beta + S[gsin(\theta + \beta) - \alpha\cos(\theta + \beta)] = Q_\beta \quad (7)$$

These equations can then be input to a computer software like MATLAB or Python and solved with the necessary variables retrieved from the Wii Balance Board in combination with a future motion capture system.

3.2 BIOMECHANICS MOTION LABORATORY STUDY

Throughout the duration of this project, we discussed potentially using motion capture equipment to analyze the golf swing. However, we had relatively minimal experience in this area. It came to our attention that the University of Tennessee department of Kinesiology has an extensive biomechanics motion capture laboratory that we could potentially use for our project. As a group we were able to tour this facility and discuss its capabilities and general concepts of motion capture with Dr. Joshua Weinhandl from the kinesiology department. Throughout this process we gained valuable insight that provided useful in the later stages of this project.

The Biomechanics Motion Capture Laboratory at the University of Tennessee is equipped with nine high-speed motion capture cameras. The use of multiple cameras positioned at different angles allows for accurate 3-dimensional motion capture. Additionally, the lab has two force platforms that can be used to measure ground reaction forces occurring throughout a movement. In order to capture data, participants are fitted with a variety of different sensors placed at various locations on their body. These sensors are passive sensors which transmit an analog signal back to each of the cameras for data acquisition.

We also found that this motion capture lab has a variety of different capabilities that could be useful for multiple portions of our project. These capabilities mainly include recording and measuring joint and segment angles, velocities, accelerations and moments. The two main types of motion capture methods used in this lab are inverse dynamics methods and forward dynamics methods. Using inverse dynamics, participants movements are recorded and then processed using multi-joint dynamics which convert this position data into moments. These moments are then manipulated using information about musculoskeletal geometry to predict the forces associated with the recorded movements. In comparison, using forward dynamics, forces are measure in a 3-dimensional reference plane and then these forces are processed using musculotendon dynamics which produce moments. These moments can then be used to find accelerations, velocities and position data associated with the recorded forces. In its essence, forward dynamics is used to describe motion using force data.

For our project, we were most interested in the use of forward dynamics. This method would allow us to obtain performance information for a specific golfer by simply measuring how their weight shifted throughout their swing. We planned to use the Biomechanics Motion Capture Laboratory as a means of verifying and validating our designs. This would be accomplished by capturing a golfer’s swing before and after using our training device. We could then use the acquired data to analyze the differences that occurred between the two different swings. This would enable us to see if our device was achieving the team’s performance objectives. Additionally, the Biomechanics Motion Capture Lab at the University of Tennessee could provide us with a means of verifying the data we obtained from our own model. We could accomplish this by comparing the data obtained using our model to the data obtained from the laboratory. The comparison of these data sets would assist in further formulation, validation and benchmarking of the team’s constructed model. Unfortunately, due to the extraordinary circumstances that unfolded mid-way through the Spring semester, we were not able to use the motion capture laboratory for these validation purposes. However, our tour and continued correspondence with Dr. Weinhandl provided us with a great deal of valuable information that proved to be useful in the later stages of our project.

3.3 LEAD FOREARM CONNECTION

One of the key issues that plagues most amateur golfers is the ability to properly time the backswing and forward swing with the movement of the upper and lower body. The term timing refers to the ability one has to move hands, arms, and shoulders all in one smooth motion to create good contact with the golf ball. Simply put, players with a one-piece takeaway tend to hit the golf ball solidly more frequently than players who have a complicated, busy takeaway move. It is important to have a smooth, even tempo in your golf swing. The purpose of the designed tool was to show the golfer what it feels like to have your shoulders and arms move in unison. This shows the golfer a good foundation of how their backswing should feel at the start of the swing. This will keep their swing in plane as well as show them what good timing feels like to generate more power.

At the beginning of the Fall semester, the team brainstormed on how to create a great takeaway in the golf swing. By September, we saw devices like Pilon’s that act as a guided movement mechanism, and a swing plane ring and thought of ways we could improve these designs. The issue with these were they focused more on the club's path than what the golfer needed to feel. They didn’t show the golfer a key fundamental which was that the arms and shoulders needed to move in unison, they just showed a generalized path the club needed to take. By December we ultimately settled on trying to build our own one-piece takeaway tool. We thought of ways we could incorporate various parts purchased from department stores in order to save money. The geometry within the swing was more complicated than we initially anticipated, and we couldn’t find specific parts to suit our device needs. Besides using a telescoping shower curtain rod to make it more adjustable, we designed most of the parts in SolidWorks. By March 2020 we had our first prototype printed and assembled, but the first prototype needed modification for use with both left- and right-hand players. It also had problems with the material cracking, configuration issues, as well as tolerance issues. We went back to SolidWorks and took elements that we liked from the first prototype and implemented them into a newer second prototype. These newer elements included a rotating twist lock forearm assembly to account for right and left-handed golfers.

This new and improved design could still use more refinement, seeing as it's only the second prototype made of a device like this. These improvements would alter the twist locking forearm base, because when transferred from right arm to left, the connection is thrown off by a few degrees.

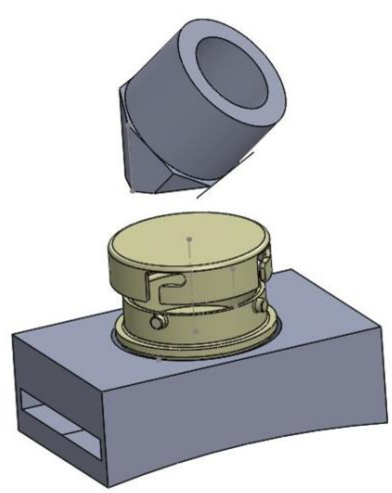

Figure 3.3.1: Forearm Connection Assembly

Also, the shoulder mount is not long enough along its base, so when a load is applied to it, the connection digs into the shoulder instead of applying consistent pressure along the base.

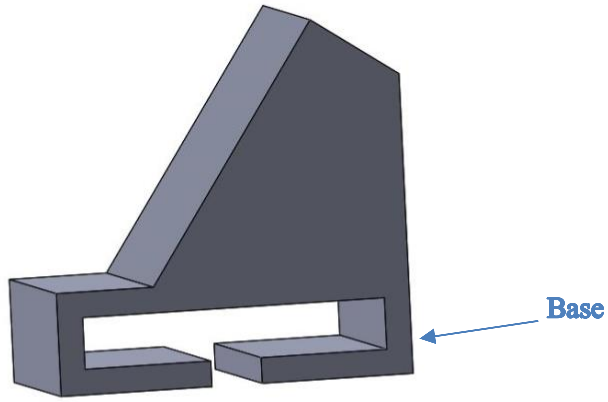

Figure 3.3.2: Shoulder Mount

If we had access to more custom materials as well as more experience with SolidWorks, I'm confident a product like this could help many golfers improve their backswing. A device like this helps golfers feel for themselves what the takeaway should be instead of just feeling how the club should move.

3.4 SLIDING FOOT BOARD

One of the goals of this project was to create a tool that would help a golfer obtain the feeling of the momentum shift throughout the golf swing. The idea of the design was that during the backswing, the golfer would slide their back leg in conjunction with a one-piece takeaway. Then to initiate the downswing, the golfer would slide their forward leg in the direction intended to propel the golf ball. It was decided that the golfer would stand on 2 separate movable boards, one for each foot. It was also required that these boards be able to offset from the neutral swing axis for draw and fade applications. Below is the initial design created as a proof of concept.

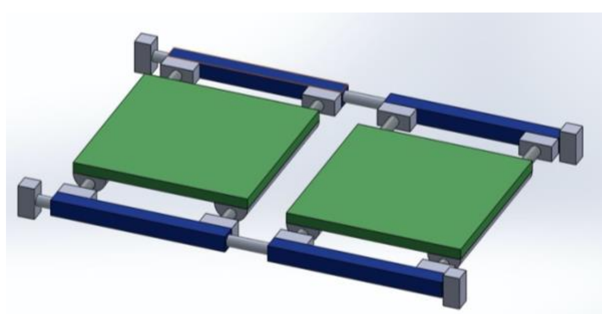

Figure 3.4.1: Slide Board Initial Design

As it can be seen in **Figure 3.4.1,** the golfer would stand on each board, and they would have the ability to slide in any direction completely independent of one another. Again, this design was simply a proof of concept. The next iteration planned was to create the footboard using existing components such as bearings and mounts. This next iteration of the design can be seen below in **Figure 3.4.2.**

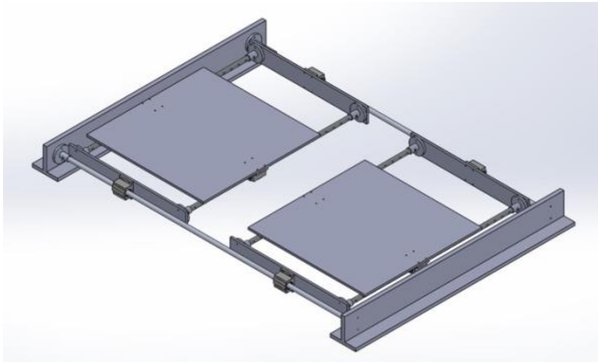

Figure 3.4.2: Slide Board Iteration 1

This iteration had the intent of being built as the final product. Parts such as bearings and rod brackets were downloaded from McMaster-Carr. Holes would also be drilled into the rods so that the footboards could be pinned down if needed. However, this design turned out to be troublesome. After talking with a machinist and running stress analysis tests, it was discovered that the rods, which were 0.5 inches in diameter, that supported the foot boards would need to be at least twice as thick in order to support the weight of a person. This meant the bearings also had to be twice as large and made the estimated cost of manufacturing over $2,000. This was well over budget which meant a new design would be needed. The new design can be seen below in **Figure 3.4.3.**

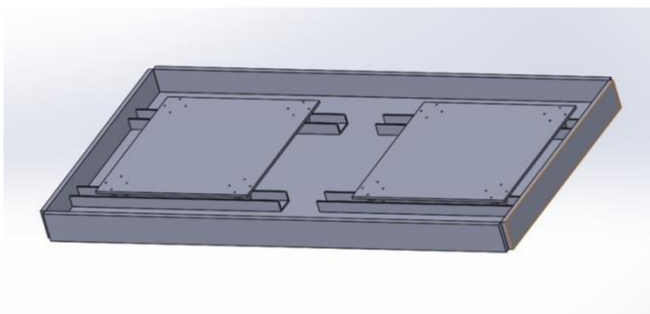

Figure 3.4.3: Slide Board Iteration 2

As it can be seen, the idea of the boards being supported on rails was abandoned. Instead, the foot boards were mounted onto ball transfer bearings and sat in U channels. These U channels, which sat inside the box shown above, were free to be placed anywhere. This allowed the user to have full freedom regarding where the foot boards could be placed. This was the design that was pushed forward to production. Fabrication was halted due to the COVID-19 pandemic in the U.S. so unfortunately, a final product is in process.

3.5 MOTION CAPTURE EQUIPMENT

Some of the many tools golf instructors use today are video cameras and motion capture equipment. The use of video cameras gives both the instructor and student the ability to replay golf swings at normal speeds and slow motion to analyze parts of the student's golf swing. Typically, these videos record two different views, a front view and a side view. The front view comes from recording the golfer from a viewpoint that is perpendicular to the stance, this enables the swing analysis to focus on aspects such as body positioning and weight distribution. The side view comes from recording a point behind the golfer facing the direction of the swing, this enables the swing analysis to focus on aspects such as body rotation and club path. An aspect of this project is to provide research and recommendations on equipment that would provide more information for golf swing analysis. This is where motion capture equipment comes into play.

Motion capture equipment is similar to video recording in the aspect that it is able to provide visuals for analysis however, motion capture goes further and has the ability to also provide 360° views, 3D models, and even numerical data for velocity, acceleration, and force in some cases. Motion capture equipment can be classified into two categories, one category utilizes cameras and the other utilizes motion sensors. 5 different products in both of these categories were explored, a ranking of these products can be seen in **Table 3.5.1**.

Table 3.5.1: Motion Capture Rankings

	Mobility	Ease of use	Software compatability	Data acquisition		Timing to square face	Swing Plane	Alignment	L/R side activity	Hip Motion
Kinect	2	4	5	2		3	1	5	5	4
Trio	2	2	3	4		3	1	5	5	4
Flex-3	1	2	3	5		5	5	5	5	5
Xsens	5	4	2	4		2	1	5	5	5
Notch	5	5	2	4		4	3	5	5	5

The ranking system follows 1- Not Great and 5 – Great. The parameters on the left side of the chart (Mobility, Ease of use, Software Compatibility, and Data acquisition) focusses on the capability of the equipment and the quantity of data it can provide. The parameters on the right (Timing, Swing plane, Alignment, L/R Side activity, and Hip Motion) focusses on key analysis parts and the quality of the data each product can provide.

The Kinect sensor is a motion capture camera originally developed for Xbox 360 and Xbox One games but is capable of being used with a computer to capture the motions of a golf swing for analysis. It is a valuable tool as it is cheap, mobile, and easy to use. It has the capability to capture motion and display it as a skeleton of the body for a deeper analysis of the golf swing. However, it is only capable of doing so as a 2D model, therefore it is only slightly more useful than a regular video camera.

The OptiTrack Trio is a high-end device similar to the Kinect sensor, it utilizes 3 cameras together to acquire more accurate data than the Kinect sensor. Though, it still will only be able to provide a 2D model and will require the use of IR reflectors to actually track the motion. These IR reflectors are the cause of the higher quality data but can easily become obstructed throughout the motion of a golf swing since its viewpoint is only 2 dimensional. This device also has a very high price point and will require more technical knowledge in order to use the software package it comes with.

In the same family as the Trio, the OptiTrack Flex-3 is another high-end motion capture device that utilizes 8 cameras capable of acquiring 3D models of the golf swing. This device, like the Trio, also requires the use of IR reflectors, but since it utilizes 8 cameras that can surround a subject of interest the chance of obstructing the reflectors is greatly reduced. The Flex-3 is the device with the highest price point of all, but it could be well worth it since it is also by far one of the most capable devices in the motion capture market.

The Xsens MVN-analyze is a system that uses wearable sensors to capture motion. This system is highly mobile and provides accurate data that can be used to create a 3D model of a golf swing. The system itself is also its own greatest flaw, since it is comprised of multiple wearable sensors it can be uncomfortable to wear and also may obstruct the motion of the golf swing depending on where the sensors are placed on the body. This system comes with its own software package and records its data straight to a computer.

The Notch sensors are identical to the Xsens sensors as they are wearable systems. However, the Notch system proves to be easier to use and records its data to a mobile app instead of a computer. Because of this, this device is the only one that can be taken to and used on a golf course instead of just being restricted to a facility with power, space, and a computer connection. Like the Xsens, the system being a wearable system is its greatest flaw.

3.6 SHAFT SPECIFICATION ANALYSIS

Golf shafts are typically made of either steel or graphite. The steel golf shaft replaced hickory shafts in the 1930s while the graphite golf shaft was first introduced in the 1970s. These two materials differ in weight, distance, feel, and price.

The typical graphite shaft is significantly lighter than a corresponding steel shaft. This translates to a faster swing speed. A typical steel driver shaft weighs between 115 to 125 grams while a typical graphite driver shaft weighs between 65 to 70 grams. There are, however, lightweight steel shafts that weigh less than the heaviest graphite shafts.

All else being equal, the increased club head speed generated by a lighter graphite shaft will translate into greater distance on your shots. A Golf Digest experiment using a robot that hit two 5-irons differing only in shaft material demonstrated that the iron with the graphite shaft averaged 4 to 5 extra yards of distance. However, the steel-shafted club's performance was more consistent, meaning there was less variation in distance when hitting multiple shots with the steel-shafted club.

Graphite shafts absorb vibrations better than steel shafts. However, some golfers prefer the feedback they receive from a steel-shafted club, particularly pros or low-handicap golfers who can tell the difference between the feel of a ball that hits the club's sweet spot and one that's slightly mishit. Also, steel costs less to manufacture than graphite, so steel-shafted clubs will cost less than their graphite counterparts.

Golf club shafts are available in five flexes and may be made of steel or graphite. These include extra stiff (X), stiff (S), regular (R), senior (A), and ladies (L). As shown in figure 1.7.1, the clubhead speed determines the flex the golfer needs.

Table 3.6.1: Golf Shaft Flex Chart

Swing Speed	Ball Speed	Flex
53-62	<100	L
63-76	100-110	A
77-92	110-139	R
93-107	140-160	S
108+	160+	X

Extra stiff shafts (X) are recommended for golfers who routinely drive the ball 260 yards or more and have a swing speed of 108 mph or higher. Extra stiff shafts are usually made of steel and are recommended for professional golfers, or golfers with unusually high clubhead speed.

Stiff shafts (S) are recommended for golfers who regularly drive the ball 240 to 260 yards and have a swing speed 93 to 107 mph. Stiff shafts are appropriate for men with single-digit handicaps as well as some with handicaps 10 to 15 who have high clubhead speed. Stiff flex is available in graphite or steel.

The most common flex, regular (R), is recommended for golfers who regularly drive the ball 210 to 240 yards and have a swing speed between 77 and 92 mph. Steel and graphite shafts are available in regular flex, which is appropriate for men with mid to high handicaps.

Shafts with senior flex (A) are recommended for golfers who regularly drive the ball between 180 and 210 yards and have a swing speed of between 60 and 75 mph. Older male golfers and some women with unusually high swing speeds should use this flex. Clubs with senior flex are usually made of graphite.

Recommended for the slowest swinging golfers, the ladies flex is designated as "L" on the flex chart. Golfers who routinely drive the ball less than 180 yards and have a swing speed of 60 mph or less should use the ladies flex. This flex is an appropriate choice for slow-swinging older male golfers and women, who generate less clubhead speed than men. Ladies flex is most commonly available on graphite shafts.

Another aspect that is directly related to the flex point is the torque on a golf shaft. Torque is the measure of how much the shaft twists during the gold swing. It also describes its ability to resist the twisting forces placed upon it by the golf swing. This twisting force exists due to the clubhead weight. When shafts are manufactured, torque, like the flex point, is taken into account for the design, as shafts are designed with specific torques.

Torque is measured in degrees and typically ranges from 1 to 8 degrees depending on the shaft material, with 1 degree for very little and 8 or even more for a lot of twisting. Steel shafts have less torque, normally 3 to 4 degrees, because it is a very solid piece of material compared to another common material, graphite. Graphite is not a solid piece of material; therefore, it will have more torque, typically 7 to 8 degrees.

The degree of torque for a golf shaft will impact the trajectory and accuracy of a golf shot. It has been observed that less torque for a golf shaft will yield a straighter shot, but with a stiffer feel. When the clubhead twists to make a square impact on the ball, it can vary whether the clubhead is more open or closed by a degree of 1 or 2; therefore, less torque is needed when a straighter ball flight is desired.

Consequently, it has also been observed that more torque for a golf shaft yields less accurate shot, but with further distance and a nice soft feel. Because of the greater torque, there will be a greater twisting force which can result in a not-so-square impact on the ball yielding the trajectory path to be more slightly left or right of the target. However, the distance of the shot will be increased due to the greater torque and the resulting twisting forces simply because of the increased speed

3.7 HIP ROTATION LOCKING MECHANISM

The motion of the lower body is an important aspect of the golf swing, influencing the balance, energy generation, and timing of the overall swing. As discussed in previous sections, the distribution of weight from the trailing to leading foot during the down swing affects the efficiency of the swing and thus the energy transferred from player to golf ball. Furthermore, the position of the player’s weight along the axis of toe to heel is important; a player that puts too much weight on the toes or heels creates problems with balance that adversely affect the efficiency of the swing. The challenge to perfecting this aspect of the swing, though, is that desired motion is not necessarily intuitive and difficult to explain. Footage of professional players, as well as animations from instructional content creators such as Athletic Motion Golf (AMG), demonstrates the complexity of the motion.

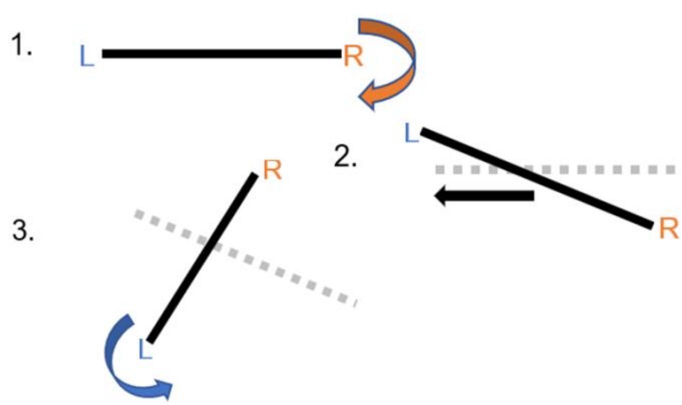

Figure 3.7.1: Diagram of Hip Motion during Golf Swing

Figure 3.7.1 diagrams some of this motion; in stage 1, the player is facing the ball with hips square and then rotates his right hip backwards, roughly 20 to 30 degrees depending on his conformation, while taking the backswing. As he begins the downswing in stage 2, he shifts his weight onto the leading foot which causes a slight shift in the center of the hips as well. Finally, stage three occurs just before contact with the ball; the hips are rotated back square at contact and then continue to rotate as the player follows through the swing.

Several design iterations were considered to demonstrate this motion to a golfing student. The firsthand sketches, shown in **Figure 3.7.2,** considered the possibility of using a track in metal plate or a combination of electromagnets to replicate the motion. However, the difficulties and costs in creating a manufacturable prototype of these designs kept them from progressing beyond the rough sketch phase.

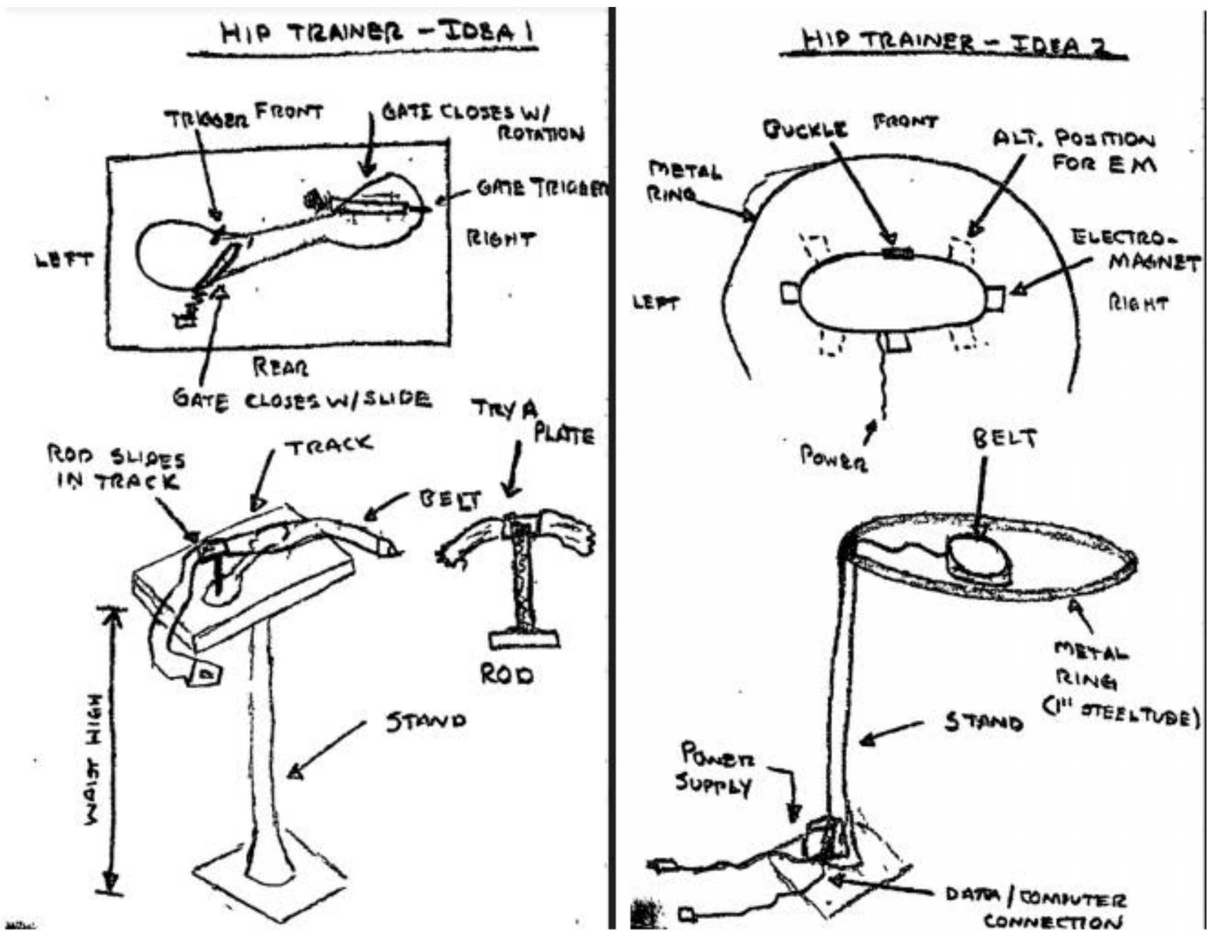

Figure 3.7.2: Hand Sketches of Initial Idea for Hip Rotation Mechanism

All of the designs after these two sketches are based on the concept of rotating some object attached to the player's body about a central shaft. The first iteration, shown in **Figure 3.7.3,** features a 1-inch diameter tube attached to the player's right hip; the player pushes this back until it locks on the light blue bar behind it; this locking feature was a request from the sponsoring golf professional since he noted a common fault among students was rotating through the right hip rather than the left hip in order to remain balanced along the toe-heel axis.

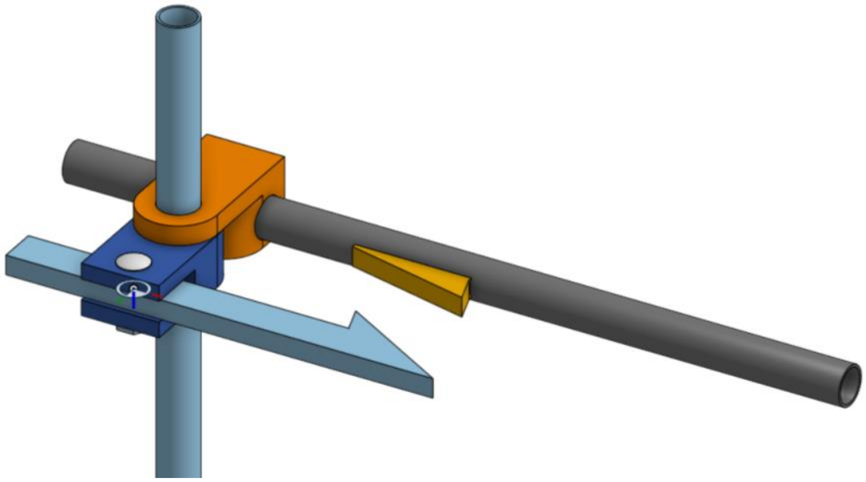

Figure 3.7.3: First Iteration of Hip Rotation Mechanism (Viewed with Player's Right Hip on Right)

Iteration two of this design, illustrated in **Figure 3.7.4**, improved on this request, introducing a more robust locking mechanism, similar in design to a seat belt buckle, held in place with springs (not modeled) that allow for the lock to be released by a lever mechanism that the player pushes with his left hip, thus freeing the hips to rotate for the follow through.

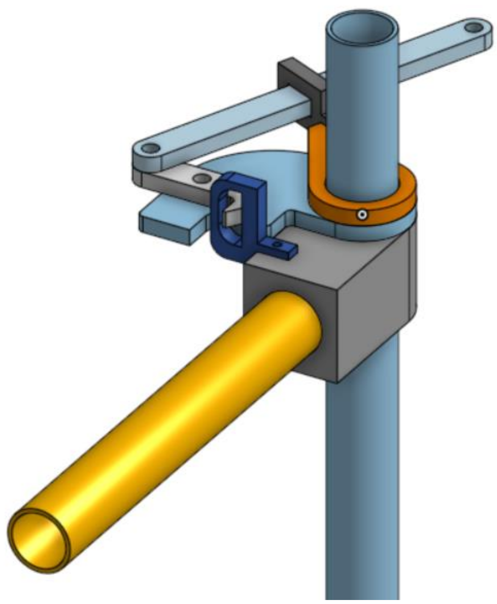

Figure 3.7.4: Second Iteration of Hip Rotation Mechanism (Viewed with Right Hip in Left Corner)

The locking components were intended to be made using a water jet cutter on quarter-inch thick aluminum or steel plate. This design still required refinement of the geometry to facilitate the locking mechanism's function; improvements were considered, including the replacement of the custom mechanism design with ready-made parts available from a vendor such as McMaster-Carr. Eventually, though, progress on these series of designs was halted in favor of the simplicity of using the capabilities of a Wii balance board paired with software, discussed in the succeeding sections. Furthermore, the rotation of the hips can be considered a by-product of the proper distribution of weight during the swing as well as the movement of the upper body; therefore, correction of these two areas should also lead to correction of the hips. The primary area of concern, as expressed by the golf professional, is the balance of the player along the toe-heel and leading-trailing axes, both of which are addressed by the Wii balance board. The limitations imposed by COVID-19 during the final months of design also led to the decision to move forward with the Wii balance board instead of the hip rotation locking mechanism.

3.8 WII BALANCE BOARD ASSEMBLY

The Wii Balance Board, manufactured by Nintendo for use with their Wii video game console, is essentially a wireless game controller that consists of four load sensors placed at each corner of a plastic covered steel frame. The board is roughly 20 inches long by 12 inches wide and 2 inches thick; isometric and side views are provided in **Figures 3.8.1** and **3.8.2**.

Figure 3.8.1: Wii Balance Board Isometric View

The board's circuitry is basic but does feature standard Bluetooth connectivity that allows the board to interface with a computer. This feature, combined with the low cost (less than $50.00 for a used board), makes the board a desirable platform on which to design solutions that can tackle the problems of teaching students' aspects of the golf swing.

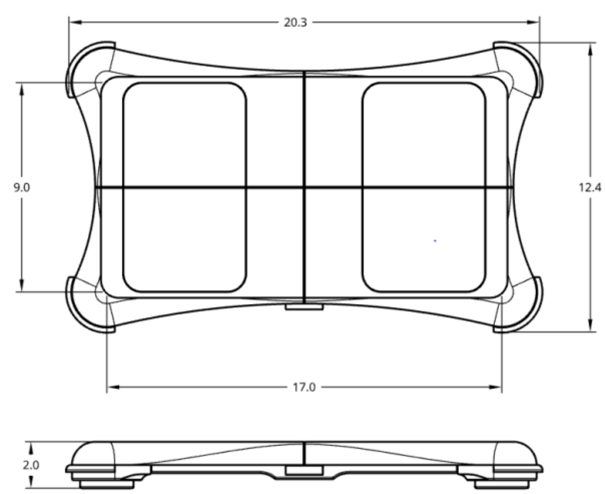

Figure 3.8.2: Wii Balance Board Critical Dimensions

The assembly involves minor modifications to the board and a computer with Bluetooth capability to connect to. The board itself is modified with the addition of a plywood platform fastened to the top of board to allow for the variation in a player's stance which can sometimes go beyond the 20 inches the board provides. A CAD representation is in **Figure 3.8.3**. 4 rubber stoppers are attached the corners of the platform to prevent the plywood from over flexing and thus failing with a player on it. The board can also be converted from battery power to a constant AC power source such as a wall outlet by replacing the batteries with any variety of commercially available battery charging assemblies.

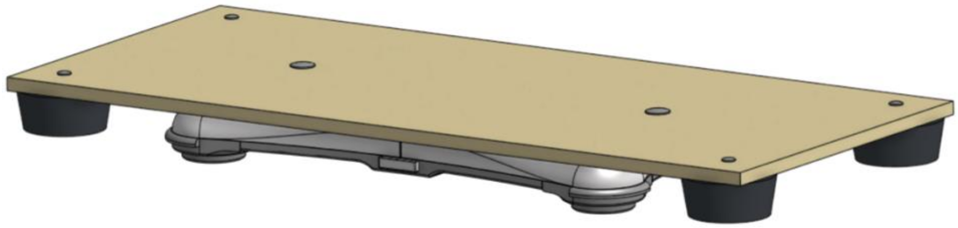

Figure 3.8.3: Wii Balance Board Modifications

The primary area of interest for using this board is to record and analyze how a player uses his weight during a golf swing. The board is able to do this by sending reports of the value of load on each of the four sensors to the computer, which in turn reads it similar to how it would read the inputs of a game controller or other human interface device (HID). Several third-party software applications exist that are able to understand and interpret these raw reports in a user-friendly way. One such application is known as BrainBLOX (Brain and Biomechanics Lab in a Box) which was developed by a team at the University of Colorado Boulder. The software is able to connect to a board, provided it has already been paired to the computer, and display real-time information about the center of pressure and total weight on the board; **Figure 3.8.4** shows a screenshot of the software.

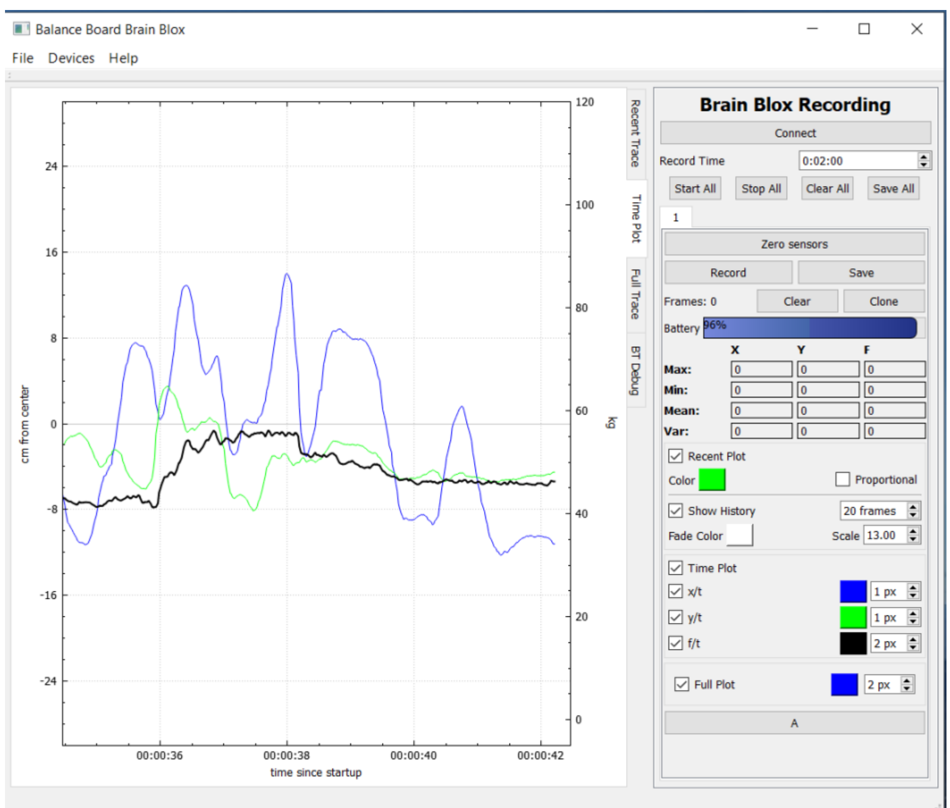

Figure 3.8.4: BrainBLOX Software Interface

The program also has the capability to record the data and then export that to other file formats, including text and csv files. These files can then be imported into another program, such as Excel, for golf specific analysis and post-processing. A concept Microsoft Excel document was created for this project to demonstrate what this post-processing might look like. The file utilizes custom macros programmed in Visual Basic for applications; a screenshot of the file is provided in **Figure 3.8.5**.

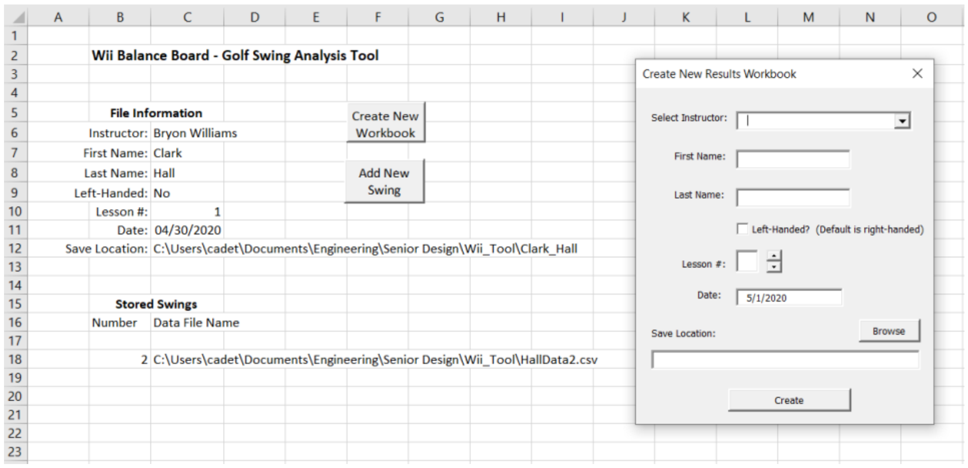

Figure 3.8.5: Golf Swing Analysis Tool - Microsoft Excel Concept

The program begins by asking the user for information via a user form about the golf student whose swings are being recorded; this data is then saved into a new workbook. The next step is for the user to add new swing results to the workbook by locating the raw date file and then clicking a command button that generates the results on a new worksheet. The results in the current build of the program are displayed as two charts that plot the center of gravity in the x and y dimensions and the weight on the left and right foot over time. A screenshot is shown in **Figure 3.8.6**.

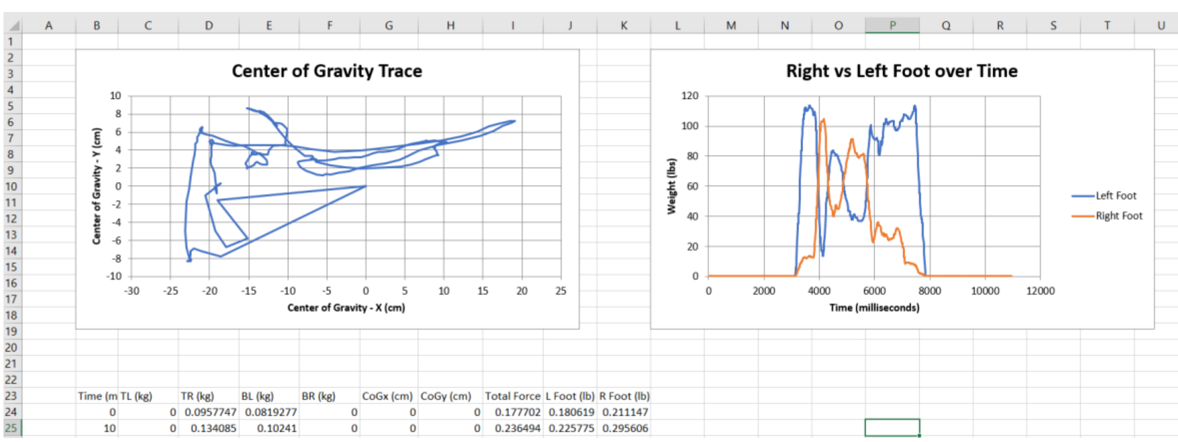

Figure 3.8.6: Golf Swing Analysis Tool – Results Concept

The main difficulties in full implementation of this concept are the difficulty in establishing a consistent initial connection between the board and the computer and the intuitive presentation of results which a golf professional or student can use to improve their swing. The first difficulty is largely dependent on how the user connects the board and what equipment they are using. Most trials using a Windows 10 PC were successful, but significant issues were encountered when trying to connect to a MacOS computer running Windows 10 in a parallel configuration. Several potential solutions exist that could remedy this problem involving additional third-party software such as WiiPair, an open source program that permanently pairs the board to a computer, or custom libraries such as one written for C#. There are also hardware modifications, such as the Raspberry Pi 3 microcontroller or other method of directly accessing the signals from the load sensors, that can work around the Bluetooth connectivity issues, eliminate the middle-step of using BrainBLOX, and also give more flexibility to design a customizable solution. Such a solution could then be designed from the concept written in the Excel file and developed in any number of programming languages, including Python and C# among others.

4. EXPENDITURES

Wii Balance Board Assembly

Wii Fit Game with Balance Board	QTY: 3	$198.00
Aluminum Plate 3003H14 0.250	QTY: 1 @ 36 x 48 IN	$193.87
Aluminum Plate 3003H14 0.250	QTY: 1 @ 48 x 72 IN	$ 433.74
Flange-Mount Ball Transfer, 1" Diameter Steel Ball and Housing Round Flange, 135 lbs. Capacity	QTY: 10	$ 92.20
Expandable Tapered Plug, Trade Size 7, for 1-3/16" to 1-29/64" ID	QTY: 10	$56.00
Zinc Yellow-Chromate Plated Hex Head Screw, Grade 8 Steel, 4-40 Thread Size, 1/2" Long, Packs of 25	QTY: 2 PACKS	$31.00
18-8 Stainless Steel Hex Nut, 4-40 Thread Size, Packs of 100	QTY: 1 PACK	$3.02
Multipurpose Neoprene Rubber Strip, Adhesive-Back, with Certificate, 1/16" Thick, 60A Durometer, 2" x 36"	QTY: 5	$75.15

Lead Forearm Connection

Holt Flexible Tiller Joint by Holt	QTY: 2	$6.61
Shipping	Variable Cost	$7.42
		TOTAL: $1,103.62

Future Purchases

Raspberry Pi 3* with a SD card and Power Supply	QTY: 1	$42.99
Wii Fit Game with Balance Board	QTY: 1	$110.00
Wii Fit Rechargeable Battery Pack with USB Cable	QTY: 1	$13.99
SoftTouch 4729595N Self-Stick Small Felt Pads Protect your Hard Surfaces from Scratches, 84 Pieces, Brown	QTY: 1 PACK	$7.28
		TOTAL: $174.26

5. CONCLUSIONS

The goal of this Senior Design Capstone project was to create golf swing training aid to consistently replicate the hip slide occurring on the downswing of a student receiving lessons. To achieve this, ideas were generated ranging from a sliding foot board to video equipment to mechanical devices that the player could wear. Ultimately, these ideas culminated in repurposing a Wii Balance Board to measure force and pressure distribution in real time as the student is receiving lessons. The Wii Balance Board was interfaced with the BrainBLOX program to output graphs of these distributions that Mr. Williams can use to highlight the student's strengths and weaknesses.

Due to COVID-19, our team was unable to assemble a full apparatus to test our equipment. We were instructed to remain at a distance after Spring Break although we still had much of our project to complete. Thankfully the Wii Balance Boards that were purchased were split among members of the team before we left for break, and we were able to continue testing pieces of the project individually. This was not ideal, and it certainly produced its own challenges. However, one member of our team has a complete apparatus, and we will attempt to deliver it to Mr. Williams when everyone is comfortable meeting.

Future research will utilize the publications by McNally and Okuda to experimentally validate the data collected and output by the Wii Balance Board. Additionally, the shaft specification analysis will be used in the future to better understand how different players execute their swings with different types of clubs and different club specifications. The video equipment ended up being out of the current scope of the project, but now that the information has been collected and consolidated it can be used in the future as the project grows. Finally, any student who is available over the summer will continue to communicate with Mr. Williams and Dr. Miller to make sure the product is working as designed and that expectations were met.

6. REFERENCES

[1] T. P. Jorgensen, *The Physics of golf*. New York, NY: Springer, 1999.
[2] W. McNally and J. J. McPhee, “Forward dynamic simulation of a golf drive: optimization of golfer biomechanics and equipment,” thesis, 2018.
[3] I. Okuda, P. Gribble and C. Armstrong, "Trunk rotation and weight transfer patterns between skilled and low skilled golfers," *Journal of Sports Science and Medicine,* vol. 9, pp. 127-133, 2010.
[4] S.-Y. Huang, K.-P. Kuo, and Y.-H. Lin, “A golf swing analysis system using Wii balance board and kinect sensors for novice players,” *Multimedia Tools and Applications*, vol. 74, no. 23, pp. 10679–10696, 2014.

APPENDIX A. PERSONAL REFLECTION

Brooks M. Leftwich

APPENDIX A. PERSONAL REFLECTION

My father was a golf course superintendent throughout my childhood, so I grew up playing golf from the time I could walk. I played competitively throughout my junior years all the way until I graduated high school, and I look back on those days fondly. Those years were spent becoming intimately familiar with the golf swing, even playing scratch golf as a Junior in high school, but I never thought about the physics of the golf swing in depth until I joined this Senior Design Team. I was absolutely elated when I saw a Senior Design Capstone project would be focusing on the golf swing, and I knew that I wanted to be a part of the team working on this project.

For my portion of this group project, I took the lead on reconstructing the two-dimensional equations of motion that describe the simplified golf swing. Having completed classes that focus on Newtonian Physics and Differential Equations, I knew how these equations functioned. However, these equations are complex with many variables that need to be collected from various pieces of equipment. My challenge was to clarify the important variables in these equations and see how they could be analyzed in a software package like MATLAB or Python. Unfortunately, after continued conversations with Mr. Williams, we realized that coding languages are out of the scope of the current project. Mr. Williams is hesitant to overwhelm students with lots of technology when so much of golf is about feeling comfortable with each unique swing.

As much as I wanted to implement high level coding languages to track and monitor different aspects of the swing, I learned that listening to the customer is critical in design projects. Even though the customer may not be able to form the ideas in an "engineering" language, they know exactly what they are looking for out of the final product. Mr. Williams was confident that too much technology use during his lessons would hinder his students rather than helping them. We thought the technology we were talking about could help some players, but he knew what his students needed more than we did. Once this sunk in, we knew that it was up to us to create a product that met and exceeded his stated objectives. This type of compromise was very similar to my experiences at my cooperative educational assignment at the Nissan Smyrna Vehicle Assembly Plant and my internship at I.C. Thomasson Associates, Inc. At each of these companies, it was vital to listen to the needs of the customer and use my engineering background to create a product that meets their wants and needs.

As with nearly everything else across the world, our project was substantially interrupted by the COVID-19 virus following our Spring Break. We were just starting to make a breakthrough in the Nintendo Wii Balance Board connectivity issues we were experiencing when we were asked to no longer hold in-person meetings and cease all on-campus design and construction. This put a considerable damper on the project and the pace at which we could work, but I think it was still a valuable experience. The COVID-19 virus taught our team how to be productive even when working remotely and how to maintain accountability even when we were not able to meet in-person. What really helped is how understanding Mr. Williams was with the whole situation. Of course, he wanted a deliverable by the end of the year when this project began, but he worked closely with our team throughout the year and during social distancing to make sure that we were still meeting his altered expectations given the circumstances.

What made this project worthwhile for me is that I knew the feeling that Mr. Williams was seeking to teach his students because of my years spent playing golf. This gave me a unique perspective on the team because I could filter the design ideas before pitching them to Mr. Williams. I could give the team insight into how a golfer would receive a specific design and whether it would hinder portions of the swing or be a useful tool for improving the golf swing. For these reasons, this Senior Design Capstone project was a fantastic way to end my time in the Tickle College of Engineering at the University of Tennessee, Knoxville. This project stretched my understanding of applied engineering principles while also providing me with the opportunity to translate these rigorous ideas into a tangible device that helps students better learn the concept of a one-piece backswing, and consistently replicate the hip slide occurring on the downswing of a student striking the golf ball.