Design of a Wrist and Gripping Mechanism for an Upper Limb Prosthesis
Specifically for the Game of Golf

by

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ABSTRACT

An upper limb prosthesis used for the game of golf was designed. More specifically, the
wrist and gripping mechanism was designed. The motivating factor behind his project
was to improve a player's ability to make a smooth, reliable golf swing. An improved
design was conceived that can overcome these limitations. Consideration was given to
their design in order to overcome its limitations, especially for amputees that have lost
their arm above the elbow. This project dealt primarily with only the gripping
mechanism of the prosthesis. The rest of the prosthesis was worked on by another
student. This project accomplished the primary goal of designing a simple device that
addresses various problems in existing prosthetic devices.

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1. Introduction

1.1 Background

The game of golf is a very difficult sport to play. That difficulty is further increased for a person with only one upper limb. While a person familiar with the game would be able to fairly accurately strike a golf ball. There will be a noticeable loss of power creating a lack of distance on full shots. In this project, the goal was to develop an upper-limb prosthesis for amputee golfers. There are currently devices that exist for golfers. However, these devices have their limitations due to the diverse requirements of the game of golf. An improved design was conceived that can overcome these limitations. Consideration was given to their design in order to overcome its limitations, especially for amputees that have lost their arm above the elbow. This project dealt primarily with only the gripping mechanism of the prosthesis. The rest of the prosthesis was worked on by another student.

1.2 Goal of the Project

The overall goal of the project was to develop a fundamental understanding of how the golf swing functions and use the acquired knowledge design a simple, cost effective prosthesis that helps upper-limb amputees achieve lower golf scores. In obtaining lower golf scores, hopefully one would find the game of golf to be much more fulfilling and enjoyable. The driving force behind developing the prosthesis was to make the game more enjoyable for people who already play golf and to possibly reach people who may otherwise had thought there was no hope of playing this great game.
2. The Golf Swing

2.1 Golf Swing Summary

In order to be able to design a suitable prosthetic device for a golfer, one must have a firm understanding of the game itself. The Royal and Ancient Golf Club of St Andrews (R&A) simply defines the game of golf as follows: The Game of Golf consists of playing a ball with a club from the teeing ground into the hole by a stroke or successive strokes in accordance with the Rules\(^1\). This definition is quite innocuous. However, golf is far more complicated than what its definition implies. Golf courses can total over 7,000 yards in length with individual holes stretching over 500 yards. A player is required to hit tee shots as far as possible in order to have the best chance of holing the ball in as few shots as possible. The following text will provide sufficient information in understanding the golf swing. From the information, one is able to better understand the requirements and restrictions that are imposed by the physics of the golf swing.

The golf swing can be difficult to describe in detail without visual aid. A sequence of numbered photos of a golf swing shown in Figure 1\(^2\) below will be used to describe points of importance. The golfer initially aligns his body to be parallel with his intended target line as shown at point 1. As can be seen in the photograph, the golfer’s arms are at full extension. One could draw a straight line from the golfer’s left shoulder, through the left arm and club shaft, to the clubhead. It is in this manner that nearly all golfers address the ball during a normal shot. The golfer begins his backswing at point 2 and continues through point 3. At these points the golfer’s arms are still nearly at full extension.

Another item to note is that both wrists begin the flex. It is at this point where the golfer
swing begins to store energy. By flexing the wrists, the arc created by the clubhead decreases in radius, thus increasing the centripetal acceleration. At point 4 the golfer reaches the top of his backswing. One can see the club shaft is then parallel to the ground at that point in time. At is at this point where the energy stored is at its maximum. The wrists are at their fully flexed position and the arc created by the club has nearly the same radius as the arc created by the hands in relation to the golfer’s shoulders. The golfer begins his downswing at point 5 and continues through point 6. It is important to note that through points 5 and 6, the wrists are still flexed and the left arm is still straight. There is still a tremendous amount of energy being stored in the golf swing. It is critical that the golfer releases the clubhead as late as possible. This maximizes clubhead velocity at the point of impact. Impact occurs at point 7 where the clubhead is then fully released and the golfer finishes with his follow through at points 8 and 9. From the photo sequence of the golf swing shown in Figure 1, it can be seen that a well designed prosthesis will allow a golfer to be able to control the amount of flex with his right wrist. This is a critical feature that must be included in any prosthesis for golf.
Figure 1 is a perfect example for what a typical golf swing should look like and can serve as a guide to design a device to enable an amputee golfer to recreate this swing. One very important item to note is the golfer's left arm throughout the swing. The left arm is nearly at full extension throughout the swing. The extended left arm throughout the swing enables the golfer to keep the clubhead on an even plane. Thus optimizing control at impact. A straight left arm also allows for the most power transfer through the club to the ball.

2.2 Physics of the Golf Swing

The golf swing is made up of a complex array of body movements. No person has ever truly modeled it to perfection. Even to this day, nearly 600 years since the game was invented, there is still great debate as to what makes a perfect swing. The simplest way
to model the interaction between the golfer’s arms, the club and the ball would be to model the system as a double pendulum. A simple figure of golf swing can be seen below in Figure 2.

![Figure 2: Block diagram of golfer setup](image)

From Figure 2, one can see how the golf swing can be approximated as a double pendulum. The arms can be approximated as the first pendulum that rotates about a fixed point halfway between the shoulders. The golf club can be approximated by the second pendulum which rotates about the end of the first pendulum. The golf ball can then simply be modeled as a point mass in which an impulse will be applied at impact. In Figure 3, the double pendulum system can be seen.
As shown in Figure 3 above, the arms and hands are modeled as $L_1$ with point mass $m_1$. The golf club is modeled as $L_2$ with point mass $m_2$. The golf ball can be modeled as point mass $m_3$. In reality, the golfer applies a torque at both the hub (shoulders) and the junction between $L_1$ and $L_2$ (wrists). This is a greatly simplified model of the actual swing. The golf swing is actually a three dimensional movement where there is a linear force provided by the body of the golfer that also influences clubhead speed. Gravity also influences the clubhead acceleration throughout the downswing. There is also a spring effect between the club and the ball at impact that actually cause the golf ball to leave the clubface at a higher velocity than expected if modeling the two with conservation of momentum. All of these occurrences affect the physics of the golf swing, but will be omitted for the sake of simplicity.
Now the golf swing is modeled in only one dimension, which greatly simplifies the equations of motion required to define the system. In only looking at the club-arm system, it is discovered that since there are two masses in the model, there are two degrees of freedom. For further simplicity, the two masses will be approximated as equal and evenly distributed throughout each element. The Lagrangian method will be used to find the two required equations of motion for the model. The Lagrangian for the system shown in Figure 3 is as follows:

\[
L = T - V = \frac{1}{2} m L^2 \left( \frac{4}{3} \dot{q}_1^2 + \frac{1}{3} \dot{q}_2^2 + \ddot{q}_1 \dot{q}_2 \cos(q_1 - q_2) \right) + \frac{mgL}{2} (3 \cos q_1 - \cos q_2) \tag{1}
\]

From the Lagrangian one can solve for the equations of motions which are as follows:

\[
\frac{4}{3} \ddot{q}_1 + \frac{\ddot{q}_2}{2} \cos(q_1 - q_2) + \frac{\dot{q}_2^2}{2} \sin(q_1 - q_2) + \frac{3g}{2L} \sin q_1 = 0 \tag{2}
\]

\[
\frac{\ddot{q}_2}{3} + \frac{\ddot{q}_1}{2} \cos(q_1 - q_2) - \frac{\dot{q}_1^2}{2} \sin(q_1 - q_2) - \frac{g}{2L} \sin q_2 = 0 \tag{3}
\]

The previous equations of motion represent an extremely simple model that does not include the torques applies at the shoulders and the wrists. However, the previous equations of motions at least give a general idea as to how the double pendulum behaves in relation to the actual golf swing.
As mentioned earlier, the cocking of the wrists is extremely important in the generation of clubhead speed. If one were to swing with the wrist completely straight, the swing would be highly inefficient. The main reason why the cocking of the wrists increases clubhead speed can be explained by knowledge of the centripetal acceleration of the clubhead about the center of rotation. The centripetal acceleration is defined as follows:

\[ a_c = -\frac{v^2}{r} \hat{r} \]  \hspace{1cm} (4)

One can see that by decreasing the arc that the club head makes around the body, the centripetal acceleration increases. This in turn increases the centripetal force that can be transmitted into the ball during impact. The centripetal force is defined as follows:

\[ F_c = -\frac{mv^2}{r} \hat{r} \]  \hspace{1cm} (5)

It also makes maximum clubhead velocity much more attainable. A golfer also must wait until as late as possible before impact to release his wrists in order to preserve the maximum clubhead speed. As seen in the previous section, being able to control the amount of flex in the wrists is important in achieving an efficient, powerful golf swing.

2.3 Examples of Golf Swings

In order to better explain the importance of the flexed wrists and late release, the following figures contain photos of golfers with perfect wrist action throughout the swing. The first of which is Byron Nelson in Figure 4\textsuperscript{3}. In the case of Byron Nelson,
the clubhead is not released until point 7 in the sequence when the hands are nearly at the identical position to impact. This delay in releasing the club ensures that the clubhead will be travelling at maximum velocity at impact with the ball.

Byron Nelson was not the only great professional golfer who had an extremely late clubhead release. Another good example is that of Ben Hogan which can be seen below in Figure 5[^3]. Ben Hogan also had an extremely late release. One can see the tremendous amount of torque that is being stored in the wrists when the hands are nearly at their impact position. One unique thing to note about this photo is that even when the clubhead is nearly at impact with the ball, the wrists are still slightly flexed. This further delay helps generate even more power through the impact. That is one major factor in the reason why Ben Hogan was, by far, the best ball striker in the history of the game of golf. Even today, there are no professional golfers that can replicate the swing and late club release of Ben Hogan. This is one reason why a suitable prosthesis that replicates the late swing release is so difficult to design and implement.
As stated throughout the previous section, the most important feature of the golf swing that must be recreated in a prosthetic device is the wrist action that is essential to have in a good golf swing. Without the aforementioned wrist movement, the golfer’s swing will be largely ineffective and inefficient. However, in designing a prosthetic arm for a golfer, one must note that even though a fairly large amount of wrist action is required, the golfer still must to have at least a fair amount of control of the wrist motion with his good arm. If the wrist movement in the prosthetic device is too difficult to control, the golfer will be faced with a far worse situation than if simply using one arm. This information is extremely important to make note of because the entire point of design a prosthetic arm for golf is to make the game easier and more enjoyable. In the following section, some prosthetic arms for golf that are presently out on the market will be looked at and analyzed taking into account all the fundamentals of the golf swing that were discussed in the previous section. In addition to using those basic fundamentals of the golf swing in analyzing the devices out on the market today, those same fundamentals will also be used in designing what is hopefully a slightly more efficient prosthetic arm that can be used by amputee golfers.
3. Existing Devices

There are many golf prostheses out on the market today. One of which can be seen below in Figure 6. The example is the prosthesis from Therapeutic Recreation Systems Incorporated (http://www.oandp.com/products/trs/). In order to fully describe how their prostheses work, a summary from the company’s website will be directly quoted in the following passage:

The Amputee Golf Grip is designed for persons missing either their left or right hand and requires gripping action from the remaining hand. Ideally the device should be used to replace the leading hand (left hand for the right handed swing/right hand for the left handed swing) otherwise a cross-handed grip is required. It can be positioned anywhere on the club grip and uses the “sound” hand’s gripping pressure to “lock” the device in place, preventing slippage and improving control.

The Golf Pro was primarily designed for persons missing their right hand who swing right handed or persons missing their left hand who swing left handed. The flexible coupling is specifically designed to improve bio-mechanical action in this swing scenario. The device slips over the shaft of the club and then “jams” in place on the grip when pulled up. The “sound” hand grasps the club normally. Plastic sizing rings can be enlarged to custom fit the user’s clubs. Uniform grip sizes on the clubs are recommended.

Both feature a unique, strong, flexible coupling, which duplicates the wrist action required for a smooth, controlled swing. The Amputee Golf Grip and Golf Pro are the only commercially manufactured golf devices available for person missing a hand(s). They are functional and reliable and will allow you to improve your drive distances and game in general. They enable you to be a two-handed golfer!\(^4\)

The gripping mechanism is quite simple in this particular case. It is made up of a semi-circular metal collar that slips over the shaft and locks into place via the larger diameter end of the grip. The inner surface of the collar is lined with two rubber rings to strengthen the grip on the club. While this design works, there are a number of things that can be improved upon. These improvements mainly deal with optimization for all
types of golf swings. Ideally, the prosthesis would work well for any situation that the
game requires. One problem that arises from this particular gripping mechanism is that
the device can become physically stuck on the shaft after a swing. At the very least, this
is an inconvenience. In order to dislodge the device, one risks damaging the grip or the
prosthesis itself. The golfer also risks injury to himself when trying to disengage the
device. What once was possibly a fairly inexpensive device could quickly drive up costs
in replacing club grips and repairs to the device. Even with those flaws, the simplicity of
the device makes it appealing and will serve as an outline in designing an improved
gripping mechanism. One way to fix this problem would be to simply increase the
contact area that the gripping device has with the grip on the club.

Figure 6: Existing model prosthesis

A few more models from Therapeutic Recreation Systems Incorporated can be seen
below in Figure 7.
There is one more issue that will be indirectly addressed in the improved prosthesis. That issue is the extreme amount of flex in the “lower arm” portion of the device. As addressed previously, the flexing of the wrists is a very important part of an effective golf swing. Without that the swing will be slow and ineffective. The amount of flexing that is created in the prosthesis shown in Figure 6 is sufficient in attained optimal clubhead speed. However, that amount of flexing will surely cause the leading arm to more or less try to whip through the ball at impact. This makes control far more difficult and could defeat the purpose of using the prosthesis as opposed to just swinging with one arm. After all, the whole point of golf is to keep the ball in play and score as low as possible. A low score will not be attainable if a golfer cannot control his shots. The examples shown above in Figure 7 are not serving as model examples for the design of the improved prosthesis. However, there are some features that may be of use for at least general ideas as to how to improve the prosthesis design.
4. Design

4.1 Simple Visual Sketch

The first step taken in the design of the prosthesis was to visualize a simple way to achieve the desired goals. The primary goals were to develop an improved gripping mechanism that addressed flaws in previous designs in an inexpensive yet effective manner. The initial sketch of the redesigned prosthesis is shown below in Figure 8. It consists of an inline ball joint that threads into the gripping mechanism. The redesigned gripping mechanism has a much larger contact area with the grip on the club. The larger contact area distributes the gripping force, lessening the chance of the prosthesis becoming stuck on the shaft. The large area also enables the right hand to control the grip pressure of the prosthesis. This will help control and also aid in preventing jamming on the shaft. The inline ball joint could eliminate the need for the large flexing section in the example device shown in Figure 6 above. It could accomplish this by being able to rotate fully about the z-axis and having the ability to swing about 30 degrees around both the y and z-axes. This will in effect simulate the straight left arm as described above in the introduction. The straight leading arm will enable the golfer to swing with more power and still have optimal control of the club.
4.2 Components

The ball joint, which acts as the wrist joint, is a very simple component that can be purchased from most major hardware catalogues. The particular inline ball joint described in the following text is from McMaster-Carr® Supply Company. A solid model of the preferred ball joint is shown in Figure 9 below.

Figure 8: Initial Sketch

Figure 9: Inline Ball Joint
The technical drawing from McMaster is shown below in Figure 10. This particular ball joint was chosen for its relative size in comparison to the rest of the prosthesis. With that in mind, the actual size of the ball joint depends on the particular golfer.

![Technical drawing of inline ball joint](image)

**Figure 10:** Technical drawing of inline ball joint

The gripping portion of the prosthesis is much more complicated. Its contour must match that of the typical club grip. The rules of golf state only that the grip must be of circular cross section and may have a taper along the length of the shaft. Therefore the gripping portion must also be customized for the best fit per individual golfer. The best way to build the gripping portion with the ability to firmly hold the club would be to make a mold from a standard club from the player’s own set of clubs. From that mold one could make a die and stamp 1/16” stainless steel into the desired shape. Steel of that thickness
will be flexible enough to be able to both engage and disengage the grip. The flex in the steel will also enable the golfer to control the grip pressure with his right hand. However, if this proves to actually be too flexible and compliant, the gripping mechanism could be cast. The resulting part would likely be much less compliant and would thus need another means of gripping onto the golf club. There are a few options in going about doing this particular design. One possible solution would be to line the inner surface with a material that is quite hard yet will still provide sufficient grip. One material that may work well would be a very hard cork lining. A cork lining would be soft enough to provide a firm gripping surface, yet rigid enough to prevent the gripping mechanism from becoming jammed on the club. Another material that may work would be nylon or a Teflon-like lining. In this case, while there will be a great deal of grip while the two surfaces are jammed together, it shouldn’t take much force to dislodge the prosthesis from the grip of the golf club. The hole in which the ball joint is threaded into will simply be welded onto the gripping portion at approximately 45 degrees. Again, this also depends on the particular golfer. Since golfers of varying heights have differing swing planes. Thus the angle between the golfer’s arms and club differ from one person to another. The inline ball could then mount directly to the rest of the prosthetic arm through (in this particular case) a 3/8" -24 tapped hole. A very crude solid model of the gripping mechanism of the prosthetic arm can be seen below in Figure 11.
5. Next Steps

Since the design process is finished, the next step would be to build a prototype of the gripping mechanism. A prototype would be useful in determining an appropriate length, radius and stiffness of the gripping mechanism. With only a solid model, sizes are arbitrary and must be customized for an individual. This is the only way that the prosthesis would effectively serve a golfer. Once the first prototype is completed, there would then be the need for thorough testing to verify whether or not the prosthesis addressed the problems experienced in products already in existence. As mentioned above, the gripping mechanism may be more flexible than desired if is made simply out
of stamped 1/16” steel. Alternatives such as casting may need to be explored as the design and prototyping process continues. Another area that may present a problem is the inline ball joint that serves as the wrist. The example shown above has a flexing range of approximately 35 degrees. This may prove to be not enough flex for some golfers. If that is the case, there may be other options for the ball joint. Ball joints that are made specifically to serve as joints are an obvious first choice. However, this will inevitably raise the cost of the final product for the consumer. With that possibly being the case, one must weigh the benefits versus the increased costs of the product. It may be worth the extra cost in order for the golfer to have an improved piece of equipment. The golfer will likely be much more pleased if he or she can lower his or her score by a few shots per round.

6. Conclusions

This project accomplished the primary goal of designing a simple device that addresses various problems in existing prosthetic devices. The possible elimination of the entire flexing section of the lower arm will greatly increase control while minimizing any possible loss in clubhead speed. This design will certainly help an amputee golfer increase his distance and quite possibly help with his control. With further breakthroughs in prosthetic technologies, maybe one day an amputee golfer can play as well as Tiger shown in Figure 12.
Figure 12: The Man himself Tiger Woods\cite{5}
Acknowledgements

I would like to thank Professor Dan Frey for putting up with me for the past two years. I would also like my family, especially my grandfather, who inspired me to pursue my passions.
References


[2] Figure from [http://www.swing-shots.com/images/GolfSwing3_copy_SMIX.jpg](http://www.swing-shots.com/images/GolfSwing3_copy_SMIX.jpg)


[5] Figure from [http://upload.wikimedia.org/wikipedia/en/7/7a/Woods_technique.jpg](http://upload.wikimedia.org/wikipedia/en/7/7a/Woods_technique.jpg)