Creating adaptive technology to play the piano

Final Report

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Client

Vicki Janisch

Mary

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Abstract

AgrAbility of Wisconsin (AAW) supports Wisconsin farmers and their families by accommodating disability in agriculture and promoting disability awareness [1]. Our client is Vicki Janisch who is an outreach coordinator for AAW. Her long time client is Mary, a Wisconsin farmer who has rheumatoid arthritis and as a result has had a below-the-knee amputation of her right leg in addition to bilateral knee replacements and left ankle fusion.

Mary's passion is playing the piano. Both of her ankles have little to no flexion, which prevents her from using the damper pedal that is necessary to create a rich, full sound. Some current adaptive devices exist, but are not ideally suited to our client's greatest need of portability. Our device features a simple design that utilizes a wedge to actuate the pedal. Through modification, we were ultimately able to achieve a compact, low profile, lightweight device that is portable and is easy to use.

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Background

Client Description

Our client is Vicki Janisch, an Outreach Specialist for AgrAbility of Wisconsin (AAW). Established in 1991, AgrAbility of Wisconsin is a partnership between the University of Wisconsin Cooperative Extension and Easter Seals Wisconsin. It supports Wisconsin farmers and their families by accommodating disabilities in agriculture and promoting disability awareness [1].

Ms. Janisch has known a specific client of hers, Mary, for quite a while. Mary has rheumatoid arthritis and has turned to AgrAbility before to enable her to continue farming even with this disease. Vicki, along with AgrAbility, have helped Mary before by providing adaptive equipment [2], and now she wants to help Mary some more. Vicki has requested an adaptive technology device that would enable her client, Mary, to return to playing the piano, a lost passion of hers since the onset of rheumatoid arthritis.

Current Devices

Currently, there are a few different kinds of piano adaptation devices for people with disabilities; however, most of these devices are very specialized for the unique individual. Two devices were found that most similarly matched this project's design requirements.

The first adaptive device to play the piano found was developed at Duke University for a client who had a bilateral amputation. The apparatus, shown in Figure 1, created involves a wedge anchoring system and a series of levers. The device functions by lateral motion of the user's thigh. This motion pushes a mechanical lever horizontally which activates a series of levers that eventually converts the lateral movement into vertical movement and presses the pedal [3]. The user is able to control the amount of force applied by varying the amount of lateral motion. When the client moves the leg medially back to resting position, the pedal is released. This device proves to be portable and adaptable to any piano since it can be placed under any pedal and attaches using a simple clamp.

Figure 1: Thigh-controlled piano adaptation device created by Duke University [3].

The second device found was created for a comparable situation, and was designed by Michiel van Loon(www.pianoman.nl), who specializes in making piano pedals for clients with disabilities. His most recent device uses a pipette to control the force applied to activate the pedal. Figure 2 displays other components in this design [4]. This device is used specifically for clients who do not have control of their lower body. The pipette is placed in the mouth of the user, shown in Figure 3, and the act of squeezing the pipette activates the pedal. This action triggers a switch which activates the solenoid. As the solenoid moves, it actuates the pedal rod, which engages the pedal. Although this device can be easily controlled, its main disadvantage is that it lacks portability.

Figure 2: Components involved in the pipette design created by Michiel van Loom include a solenoid, control board, power unit, and pedal rods [4].

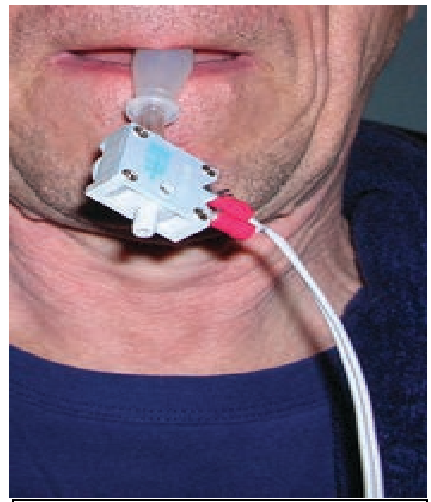


Figure 3: User presses down on pipette with their mouth to activate piano pedal [4].

Regardless of their restrictions, both devices enable clients with lower-body limitations to play the piano. Two important aspects of these designs include minimal force application and incremental control. These features will be taken into consideration throughout the design process of the adaptive device for Mary.

Problem Motivation

Mary is a Wisconsin farmer who raises bull calves. She has been a client of AAW since 1993 [2] as a result of physical limitations due to rheumatoid arthritis (RA). According to the Center for Disease Control (CDC), an estimated 1.5 million people have rheumatoid arthritis [5], [6]. Unlike the more common, osteoarthritis, which is due to wear and tear, rheumatoid arthritis is a chronic, systemic, inflammatory disorder. The exact cause has not yet been determined, but once the inflammatory process begins, an autoimmune reaction perpetuates this chronic condition [7]. Figure 4 depicts a joint lesion and some commonly affected joints. The joints are warm, swollen, painful, and especially stiff after a period of inactivity, making simple daily activities excruciatingly painful [8]. To date there is no cure for this debilitating disease.

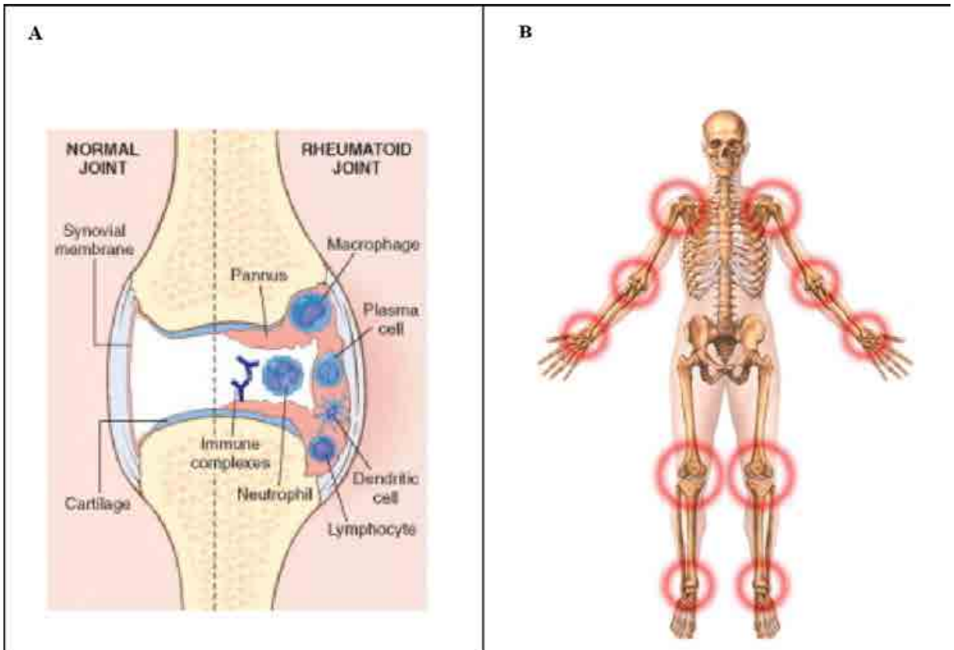


Figure 4. Rheumatoid Arthritis and Affected Joints. (A) In this figure, the left side of the joint is normal while the right side illustrates a joint lesion that resulted from the body's immune system attacking itself [7]. (B) While variable, the pattern of joint involvement in RA is typically symmetrical, with smaller joints being affected before larger ones [8].

Rheumatoid arthritis has greatly altered Mary's life, and makes her passion of playing the piano exceptionally difficult. This disease has resulted in two knee replacement surgeries, a below-the-knee amputation of her right leg, and a completely fused left ankle. Mary has been fitted with a prosthetic right leg which restores her ambulatory ability, but does not provide a natural range of motion. The lack of flexion in either ankle proves to be the most significant problem for Mary when attempting to play the piano because she is unable to apply the adequate force to the piano pedal. The goal of this design project is to provide Mary a device that enables her to play the piano again.

Design Requirements

The design requirements outlined in the Product Design Specifications in the Appendix are explained in detail here. Requirements for this design revolve around three main focuses: client requirements, patient comfort, and safety.

The client requests a device that will allow Mary to play the piano damper pedal with her prosthetic foot. Due to limited range of motion, the device should not require the flexion of her ankle to operate. Within the physical and operational requirements, it was determined that the device needs to apply a minimum force of 3.63 kg (8 lbs) in order to depress the piano pedal. The device should be durable and able to withstand repetitive use (about 20 times per minute over an approximate five minute increment) and allow for varying force application. The height of the device should be low enough to allow placement of Mary's leg beneath the piano keyboard while accommodating varying pedal dimensions to satisfy the requirement of adaptability set forth by the client.

Patient comfort is another main concern in the design as Mary has limited range and types of motion that can be utilized to activate the piano pedals. The user should be able to easily activate the device with a controlled motion which will, in turn, depress the pedal. It should also not require much effort by the user in resting position, therefore the foot should be able to rest comfortably between pedal activation. The device should also be lightweight, less than 10 lbs, and compact to optimize portability since Mary will need to move the device herself.

Safety is the third and final focus of our product design specifications. The device will be used by Mary directly, and should therefore pose no danger to her. The device will be in contact with the client's prosthetic limb, and should not affect its mobility or function. Additionally, the device should not contain any sharp edges or constricting pieces that may cause the user harm while using or transporting from place to place.

Design Alternatives

Prior to building and testing, three design alternatives were conceptualized and evaluated based upon criteria set in the design matrix. All three designs were developed for the user to utilize the device in a seated position facing the keys of the piano.

Wedge and Lever System

The first design incorporates a wedge and lever system placed at the foot of the user, as shown in Figure 5. The wedge component houses the foot of the user and is attached to a gliding mechanism similar to that of a drawer. The gliding mechanism will provide ease of motion in the anterior and posterior directions. This motion consists of flexion and extension of the knee joint, which is a motion easily conducted and controlled by the user. Forward gliding of the wedge causes the wheels at the near end of the lever to roll up the wedge, and thus causes rotation about the pivot point at the end of the platform. At the far end of the lever, a crossbar will be attached to the piano pedal to prevent slipping. The forward motion of the wedge activates the lever motion downward, and applies the necessary force to depress the pedal. A strap around the ankle of the client will enable her to pull the wedge back, which would lead to the wheel rolling back down the ramp, and ultimately releasing the pedal.

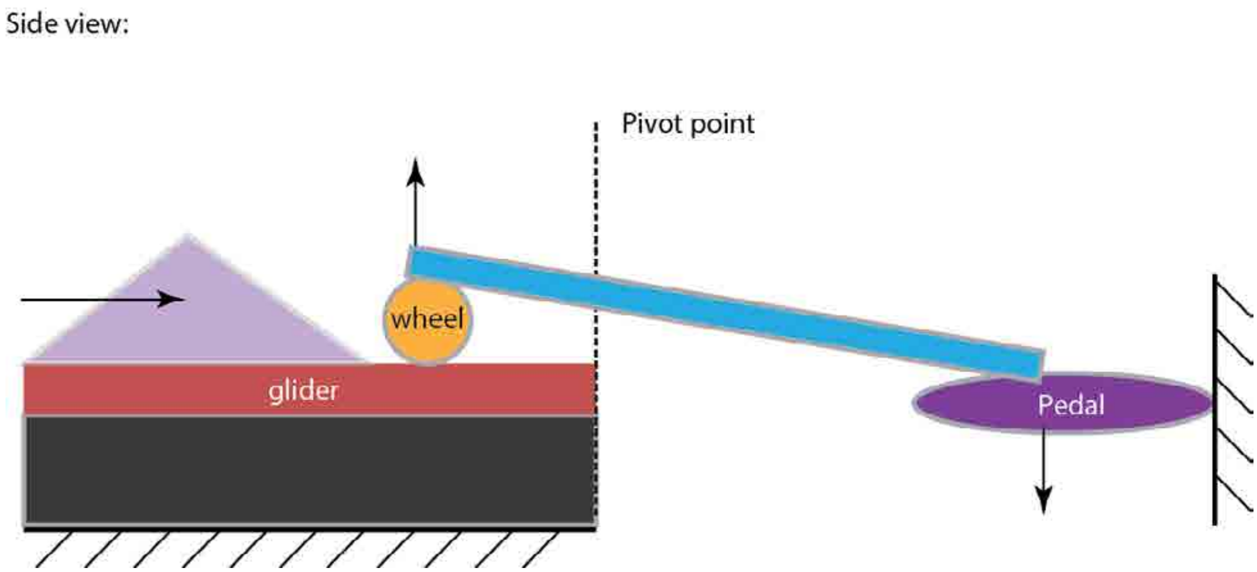


Figure 5: Wedge and Lever Design Alternative. The device consists of a gliding mechanism, a wheel, and a lever with rotation about a pivot point (shown above).

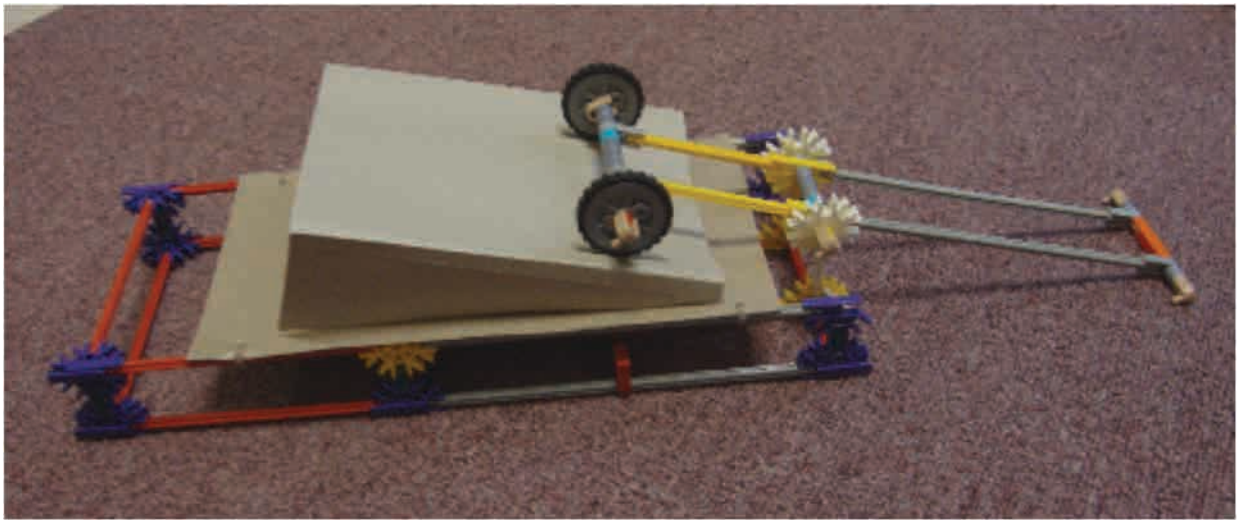


Figure 6: Wedge and Lever Design rough model of prototype.

Free Weight and Pulley System

The free weight and pulley design utilizes anterior and posterior motion in the sagittal plane to activate the pedal. This device incorporates a soft weight to depress the pedal. A fibrous cable is connected to the weight and then wraps around the user's leg. Mounted pulleys are used to guide the cable, change the direction of motion, and reduce the amount of force required to raise the weight. Figure 7 illustrates the layout and function of the device.

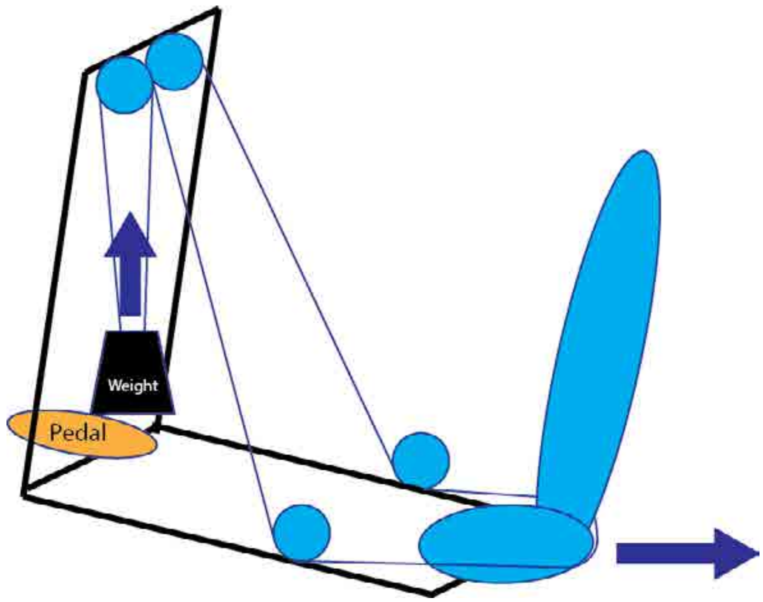


Figure 7: Free Weight and Pulley System. The device consists of a soft weight and multiple pulleys as well as a strap wrapped around the heel of the user. Posterior movement will raise the weight and release the pedal which deactivates the sustain function.

Translating System

The third design alternative is a mechanical system of levers and a wheel that will change the force's line of action from lateral to rotational and ultimately vertical. Shown in Figure 8, the red lever pivots at the connected bar when the user applies lateral pressure with the thigh. This motion will create a horizontal force onto the long gray lever, moving it medially along its axis. This pushes the small attachment on the wheel, turning the wheel and causing downward movement of the attachment on the opposite side that is used to activate the pedal. The system will return to an unloaded position due to a torsional spring attached to the pivoting lever when the user ceases lateral pressure application.

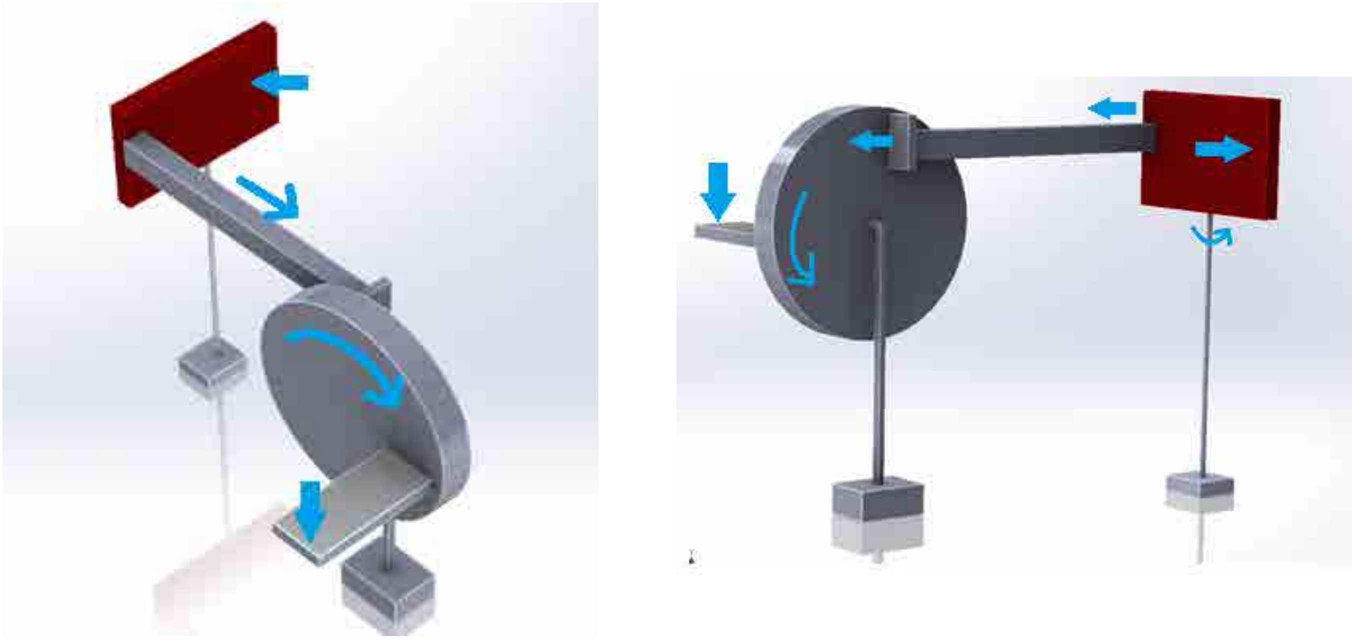


Figure 8: Translating System. The device consists of multiple levers, a wheel, and a spring-loaded (red) lever.

Gliding Platform and Wedge System

The fourth design's main components are a wedge and a drawer slider. Shown in figure 9, the inverted wedge in the system allows the pedal to be depressed as the wedge is moved forward using anterior and posterior motion of the leg. The ball-bearing drawer slides will enhance the movement of the system as it allows the device to glide easily back and forth.

Figure 9: Gliding Wedge System

Design Matrix

Each preliminary design has its own strengths and weaknesses. To effectively evaluate the individual points of all three designs, a design matrix was constructed and used to analyze each design alternative.

The four piano adaptation devices were rated on a variety of design criteria. These aspects included effectiveness, patient comfort, portability, cost, safety, and durability. It was determined that effectiveness and patient comfort were the most significant criteria, and were therefore awarded the greatest weights of 30 and 20 points respectively. Each design alternative was awarded a score for each category. These scores were added up to give a total score out of 100, as shown in Table 1. Based on the point distribution, the drawer sliding system received the largest allotment of points and is therefore the design we have chosen.

Criteria	Weight	Wedge and Lever	Free Weight	Translating System	Gliding Wedge System
Effectiveness	30	25	28	25	29
Patient Comfort	20	19	14	18	19
Portability	15	13	5	11	14
Cost	15	8	7	8	8
Safety	10	8	5	7	7
Durability	10	8	6	5	7
Total	100	81	65	74	**84**

Table 1: Design Matrix

The maximum point values are indicated in the second column from the left, labeled “Weight”. The point allotment will be discussed in the following sections.

Design Matrix Criteria

Effectiveness

The category of effectiveness, or how well the device performs the desired task of applying different levels of force, is the most important category, as the device needs to function properly. It was assigned the highest value, 30 points. While all four designs work fairly well in accomplishing the task at hand, the gliding wedge system was deemed the most effective with a score of 29 out of 30. Utilization of the wedge transfers the direction of the force from horizontal to a force that is normal to the bottom surface of the wedge, which is in direct contact with the pedal. The free weight design was slightly less effective with 28 out of 30. This device has an ability to convert the force directly to the pedal without much energy loss. The wedge and lever device scored 25 out of 30, as the lever decreases the effectiveness of the force application. The translating system also had a slight deficit on its effectiveness with 25 out of 30 due to the many components making it the least efficient.

Patient Comfort

Patient comfort is an important factor to consider while constructing the device, and was thus given a weight of 20 points in the design matrix. The wedge design and the gliding wedge system were given the highest point scores of 19 since both the devices use the forward-backward motion which is an easy motion for the user to perform. The free weight design received a lower score of 14 points since the design would require energy from the user and could lead to fatigue. Finally, the translating system scored just below the wedge and lever system with 18 out of 20. While the lateral motion is easy for the client, it does not mimic the typical motion used to actuate a pedal.

Portability

Portability is also an important factor, and received a value of 15 points in the design matrix. The device will be used in multiple locations, and it should therefore be simple and easy for the user to handle. The gliding wedge system scored the highest, receiving 14 points due to its compactness and lightweight design. The wedge system scored 13 out of 15 since it also had compactness but the lever part of the design constricts portability when compared to that of the gliding wedge system. The translating system received a lower score of 11 points due to its many components and its complicated set up. The free weight system scored the lowest, receiving 5 points out of 15, which can be attributed to its lack of rigidity and its greater weight.

Safety

The safety component had a weight of 10 points in the design matrix as there are relatively few safety risks while using this device. The wedge and lever system received the highest value of 8 points because its design lacks dangerous components. The translating system and the gliding wedge systems both scored 7 points. The gliding wedge system poses a potential hazard due to ball-bearing tracks. The translating system is less safe than the wedge and lever system due to the difficulty of transportation and set-up. The free-weight system scored lowest with a point value of 5, due to weight concerns.

Durability

Durability is of lesser importance compared to the other aspects, receiving a value of 10 points because it will not be subjected to a harsh environment. The optimal lifespan of this device is estimated at five years based on overall cost and expected wear-and-tear. The free weight system and translating system both received low scores of 6 and 5 respectively. The free weight system was determined to have parts that need replacement often such as the cable and soft weight. The translating system scored low due to the greater potential for mechanical failure of the multiple moving parts. In contrast, the wedge and lever system scored 8 out of 10 points since it has a simple design with components less likely to need replacement. The gliding system scored slightly less with a 7 due to the wearing of the wedge from the friction against the pedal.

Final Design

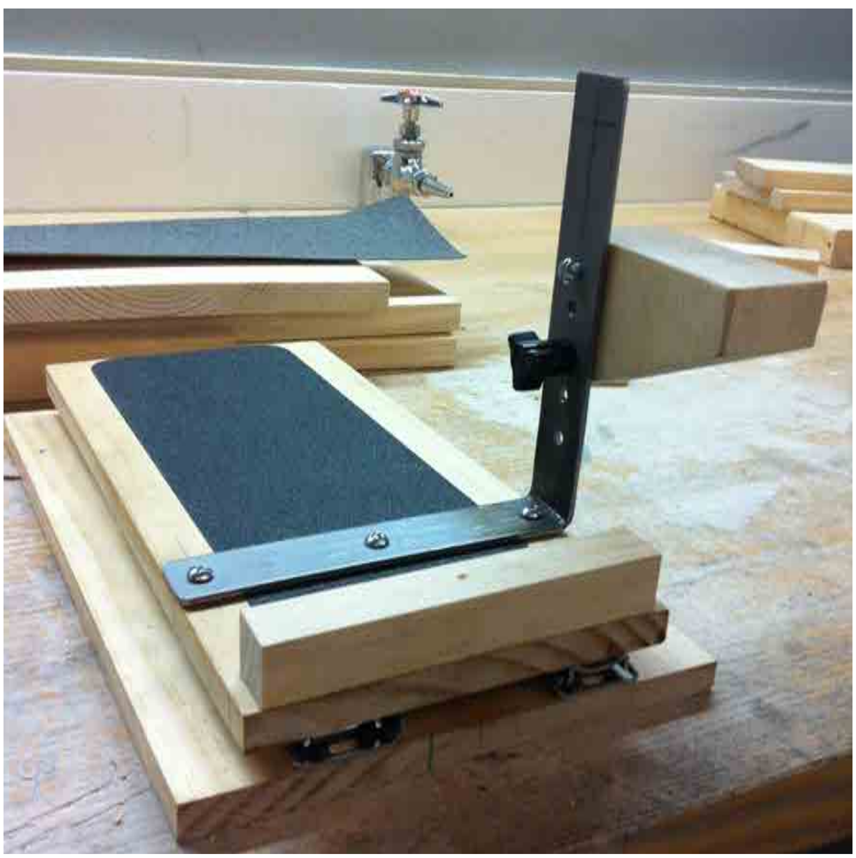
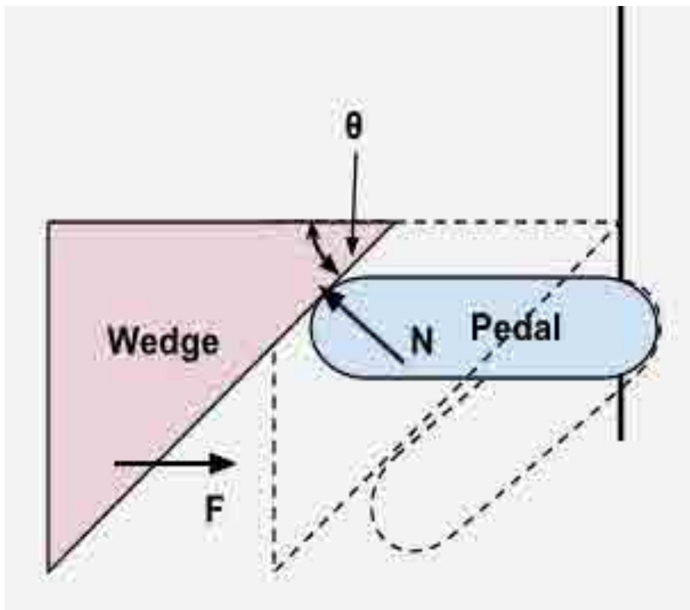


Figure 10: Final design. Gliding wedge system with adjustable height wedge.

The gliding wedge system offers maximum adjustability and portability. To minimize cost, we chose to build our design out of wood. We utilized two center mount drawer slides with 35-pound load capacities to provide the gliding action. For adjustability, we used a steel bar with precisely drilled holes allowing the wedge to be bolted to the bar at different heights which can be seen in Figure 10.

Force Analysis



$$F_{downward} = F \cos\theta$$

Figure 11: Analysis of forces transferred from wedge to piano.

We modeled the force transmitted to the wedge as a force normal to the surface of the hypotenuse of the wedge. To balance the amount of force required in the anterior direction while maintaining gradual pedal depression we calculated theta to be optimal at 25 degrees.

Testing

Pre-testing examination included SolidWorks modeling as well as force and pressure dispersion analysis. The initial prototype shown in figure 9 was delivered to Mary. Her initial feedback was that although the device worked, the platform was too high which did not allow her knee to fit under the piano keyboard. Additionally, when Mary flexed her knee to pull back the platform, the angle was too small and therefore uncomfortable. Modifications were made with lowered the platform height by about 2 inches. A second prototype was constructed and then tested. Even with the reduced platform height, Mary's knee still had trouble clearing the underside of the keyboard. We determined that the best solution was to place the wedge to the side of the platform with the front edge flush with the front edge of the platform. This would prevent Mary from having to flex her knee past 90 degrees, see figure 11.

Figure 11: Prototype testing. The left side depicts the placement of the device and Mary's foot, which resulted in discomfort for the user. The right side shows the ideal placement of the device and users foot.

Cost

We have a defined budget of $100-$200 to produce the final device. Our costs are listed in Table 2. We were able to stay within our budget by using low cost materials and performing all the work ourselves.

Description	Amount
Lumber	$20.13
Drawer Slides	$16.15
Hardware	$10.41
Accessories/Other	$21.95
Total	$68.64

Table 2: Cost Summary

Future Work

Our device is constructed from pine, which is a soft wood. There are concerns about its durability. Another adaptive device was also constructed with wood for a patient with bilateral mid-thigh amputations. It allows him to utilize the pedals on a drum set. The authors' recommendation was to use hardwood [10]. We also explored utilizing metal or plastic to build the device. We would recommend building a final device with one of these sturdy materials. Although we have designed an effective solution for using the damper pedal, we were unable to focus on the other piano pedals or the great and swell pedals of the organ.

Timeline

The following table shows our timeline with goals outlined from this semester. As you can see, filled boxes are our projected timeline and the checks are the actual progression. So far this semester, our team has stayed on track.

Tasks	**September**				**October**				**November**					**Dec**
	7	14	21	28	5	12	19	26	2	9	16	23	30	7
Meetings														
Advisor	X	X	X	X	X				X	X	X	X	X	
Client		X							X				X	X
Team	X	X	X	X	X	X	X		X	X	X	X	X	
Product Development														
Research	X	X	X	X										
Brainstorming		X	X	X	X	X								
Design Matrix				X	X	X	X							
Design Prototype						X	X	X	X	X				
Order Materials									X	X				
Fabricate Prototype										X	X	X		

Testing											X	X	X	
Deliverables														
Progress Reports	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PDS			X											
Mid-Semester PPT							X							
Mid-Semester Report							X							
Final Report													X	
Final Poster														X
Website Updates	X	X	X	X	X	X	X	X	X	X	X	X	X	X

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Appendix

Adaptive technology to play the piano (piano adaptation)

Product Design Specifications
09/21/2012

Group Members: Taylor Lamberty, Myranda Schmitt, Jolene Enge, Ugeun Choi

Advisor: Dr. Willis Tompkins

Function: Mary loves to play the piano and the organ at her local church and in her community; however, Mary suffers from rheumatoid arthritis (RA). RA is a long-term disease that leads to inflammation of the joints and surrounding tissues. With the amputation of her right foot, a knee replacement, and a fused left ankle, there is a significant barrier for her to operate the three pedals on the piano. This device will apply a necessary force (8-12 lbs) to the piano pedal mechanically to enable Mary to play the piano despite the effects of rheumatoid arthritis.

Client Requirements:

- A device to enable piano playing without flexion in the ankle
- Easily set up and removed, portable
- Must be compatible with client's prosthetic leg
- Compatible with multiple piano models

1. Physical and Operational Characteristics

A. **Performance Requirements:** The device must be able to withstand repetitive use with the ability to provide varying degrees of force. It will likely be used continuously for five-minute increments, multiple times over the span of an hour. It must be operable with a minimum amount of 8 lbs of force applied.

B. **Safety:** The device should not have any sharp edges or constricting pieces since it will be utilized on the client directly. It must be able to withstand excess force to avoid failure and damaging the client's prosthetic leg.

C. **Accuracy and Reliability:** The client should be able to control the amount of force applied to the pedal over a force gradient of 8 to 12 pounds (3.6 to 5.4 kg). The device should apply a consistent level of force each time it is activated.

D. **Life in Service:** The product should maintain function for at least 5 years.

E. **Shelf life:** Since the device is to be portable, it may be stored in a vehicle and be exposed to varying temperature extremes.

F. **Operating Environment:** Primary use of the device will be indoors with room temperate of 20-25 C. It will be transported to multiple locations and therefore will be exposed to a wide range of temperature and humidity. It will be placed on the floor and may be exposed to dirty surfaces.

G. **Ergonomics:** The device will interface with a prosthetic leg and should be positioned to allow the client to sit comfortably with minimal leg movement.

H. **Size:** The product must be portable as it will be used in multiple locations. The size will also be limited by the amount of space available underneath the piano, between the pedals, and between the piano and the user.

I. **Weight:** The device should be light weight so that it is portable because the client will need to move it independently. Ideally, the device will weigh no more than 15 lbs.

J. **Materials:** The device should be constructed so that it is durable, but not heavy. It should also be made with materials that are not harmful to the client since some parts of it will have direct contact with the prostheses and/or clothing.

K. **Aesthetics, Appearance and Finish:** The finished product should be aesthetically pleasing given that it will be utilized in public. It should also be as inconspicuous as possible.

2. Production Characteristics

A. **Quantity:** We will be constructing one device.

B. **Target Product cost:** The target product cost will be between $100 and $200.

3. Miscellaneous

A. **Standards and Specifications:** The device should comply with applicable ADA regulations.

B. **Competition:** There are two known current devices for consumers with limited mobility in the lower body. One uses lateral movement of the leg to press the pedal, and the other uses a wireless device to sense the movement of the mouth which in turn, applied force to the pedal.