CHAPTER 6
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FOAM WARS II: SECOND ITERATION

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INTRODUCTION

Persons with disabilities sometimes feel limited when it comes to recreational opportunities; Foam Wars can provide wheelchair users with an outlet to interact and engage in a group setting. The game consists of various wheelchair attachments that pits two teams of five players against each other; where the objective is to score points by launching foam balls into stationary targets placed around a typical regulation basketball court (see Figure 6.1). The team collaborated with Kinesiology students to design a new game, and then built hardware to show a proof of concept. Project goals included creating a ball retrieval system, designing for maximum portability, using commercial off-the-shelf (COTS) products, and developing a simple yet engaging game.

SUMMARY OF IMPACT

During the school year, the Kinesiology Department helps the Special Olympics with the Friday Club. Athletes from San Luis Obispo gather to participate in various recreational activities, many of which use equipment designed and built by Cal Poly engineering students. The Foam Wars project is an attempt to create a fun, competitive game that provides the benefits of sport to athletes with disabilities. The Foam Wars II project made some substantial progress in meeting the needs of the Friday Club, but did not achieve all of its design goals. Only two prototypes were created, which means that eight additional devices would need to be manufactured to play the game.

TECHNICAL DESCRIPTION

The team worked with Kinesiology students and Special Olympics athletes to design a game that would include five different players – two Launchers, two Retrievers, and one Goalie. Five points are awarded when a Launcher shoots a ball through one of the three goals, and a point is awarded to the Goalie's team if he or she catches one of the launched balls in their goalie net. To facilitate this process, the students had to design the attachments for three different positions.

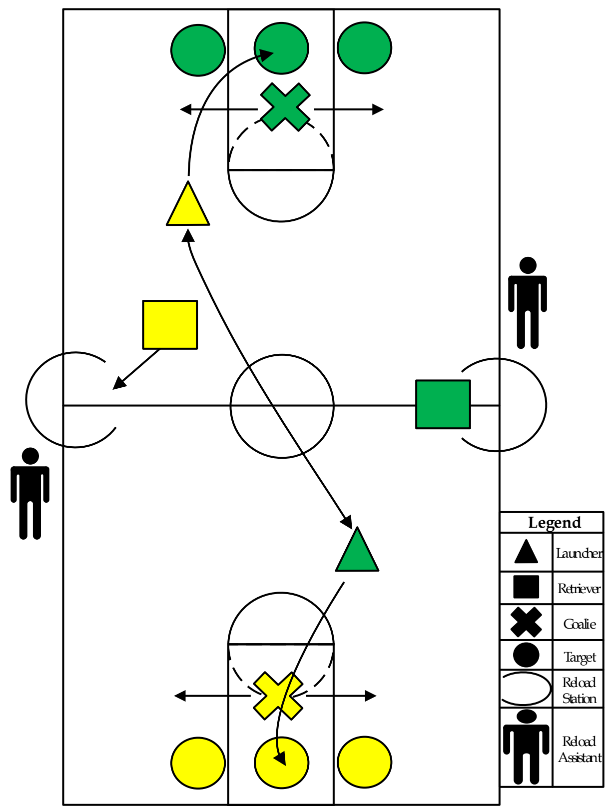

Fig. 6.1. Overhead view of the Foam Wars Game.

Fig. 6.2. Final design of the Launcher,

Fig. 6.3. Final design of the Goalie.

The student team developed a modular approach, where the Launcher, Retriever, and Goalie use the

Fig. 6.4. Final design of the Retriever.

same basic cage design. As seen in Figure 6.2, the launchers utilize a commercial pitching machine that can throw the foam balls at speeds up to 35 mph. The goalie uses an additional attachment (see Figure 6.3) to help them defend the three goals (the hoops in Figure 6.1). Finally, the ball retrievers (see Figure 6.4) use an attachment to collect the balls and return them to the launchers. The cage is attached to the wheelchair using bungee cords, which allows different styles of wheelchair users to use the device. Each of the vertical legs of the basic cages is made from 1¼ inch square aluminum tubing and cross pieces are constructed of 1¼ x ¼ inch aluminum bars. Bolts hold the base cart together. The launcher attachment table is made from Douglas fir to minimize weight and cost, and brackets attach the launcher to the base cage. The launcher is a commercial off-the-shelf pitching machine, which is controlled using a joystick, linear actuator, motor, L298N motor driver, 12 volt batter, and Arduino UNO microcontroller board. The Launcher can vary the up and down angle of the pitching machine and when to fire. The left-to-right aiming is accomplished using the athlete's wheelchair. The goalie attachment is made from ¾ inch PVC pipe, and the retriever is made from a commercial off-the-shelf acrylic bin. A 3 x 32 inch slot is cut into the bin and covered with angled acrylic flaps to capture the balls. Finally, all of the positions are covered with netting to protect the athletes.

The cost to produce the prototypes was $800 in materials. The estimated cost for a full five-on-five setup is $4500.

UNIVERSAL PLAY FRAME VI

Designers: Justin Bazant, Cullen Crackel & Anthony Franceschi
Client Coordinator: Michael Lara, Special Olympics, San Luis Obispo, CA
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INTRODUCTION

The Universal Play Frame (UPF) attaches to a wide range of wheelchairs and supports a variety of adaptive recreational devices (e.g., baseball, soccer, bowling, darts, and golf). It serves as a universal attachment point to allow athletes with mobility impairments to participate in various sports and activities. The goals of the UPF VI project are to decrease attachment time, increase stability and safety, improve all-terrain mobility, and decrease storage volume. Previous models were based on only two wheels and typically fit onto the front of different wheelchairs with clamps. They were sometimes difficult to attach and were often not as stable as necessary. The UPF VI team decided to design a frame that is self-supporting and attaches to the wheelchair using cargo straps.

Fig. 6.5. Previous version of the UPF.

Fig. 6.6. Current design of the UPF VI.

SUMMARY OF IMPACT

The UPF VI solves many of the problems associated with previous versions. Large, free-moving wheels allow maximum mobility and allow users to traverse more difficult terrain than previous versions. The rear portion of the UPF is easily removed, allowing the athletes to "roll into" the frame. The assistant can then reattach the back of the frame and use the cargo buckles to attach the frame to the wheelchair. This version of the UPF is the first to incorporate a frame that fully surrounds the athlete, providing for greater stability and easier attachment. The cargo buckles allow the chair to be easily attached to the frame, and the athlete is able to maneuver quite easily with the new design. Michael Lara, Coordinator from Special Olympics, stated that "this device exceeded expectations and adapts to all wheelchair types. This latest version has reduced the set up time to go from one wheelchair to another tremendously!"

TECHNICAL DESCRIPTION

Telescoping aluminum tubes (~1.25 inch diameter) are used for the primary vertical supports to allow some adjustability in the height of the attachment plate. The shorter vertical stabilizer (constant length) is made of 1 x ½ inch aluminum bar and is attached to the telescoping tube by a custom collar. The mechanism was designed so that the table top remains horizontal for any height the user chooses. The sides of the frame are also constructed from telescoping aluminum tubes to allow the length of the UPF to be adjustable, while the front and back are made of rectangular aluminum tubing. The project sponsor requested that the team change to 12 inch jogger wheels mid-design. These wheels use a magnetic mating system to insert into the frame, making assembly and breakdown easy. Their larger diameter does, however result in the attachment plate being too high for some of the users. This was fixed by a follow-on General Engineering senior design project (see next report).

The frame collapses easily for storage, and it is possible for the user to insert stationary legs into the wheel posts so that different users can simply wheel into the back of the frame and use the UPF for attachments that do not have to move with the athlete (the rear cross support is removable).

The CAD model for the UPF is shown in Figure 6.7, and a model of the device fully collapsed is shown in Figure 6.8.

The cost to produce the prototype was $1240 in materials.

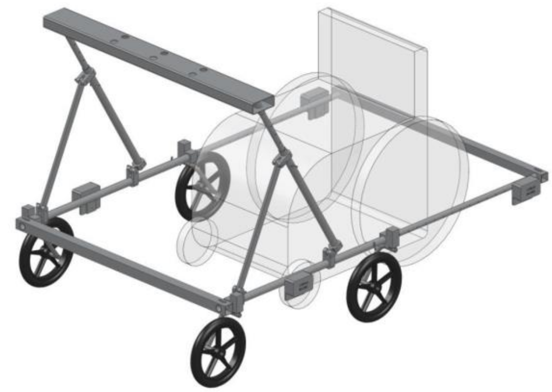

Fig. 6.7. Solid CAD model of deployed UPF VI .

Fig. 6.8. Solid CAD model of collapsed UPF VI.

UNIVERSAL PLAY FRAME VI.2

Designers: Ryan Westphal, with assistance from Mary Gentilucci (MECH), Marian Watson (KINE) & Tyler Holt (KINE)
Client Coordinator: Michael Lara, Special Olympics, San Luis Obispo, CA
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INTRODUCTION

As described in the previous project, the Universal Play Frame (UPF) is a device designed for the Friday Club by Mechanical Engineering and Kinesiology students at California Polytechnic State University, San Luis Obispo. In collaboration with Special Olympics, Friday Club is a Cal Poly Kinesiology organization in which students organize physical activities for athletes of all ages with varying disabilities. The UPF is designed to support several devices to allow athletes in all types of wheelchairs to participate in various sports and activities. There have been six different UPF models, each improving upon issues encountered by their predecessors.

The designers of the UPF VI did not meet all of the goals they originally set out to accomplish. The adjustable table where the devices attach rests higher off the ground than initially planned because the wheels were changed at the last minute by the sponsor. The increased height of the table causes the attachments to be at or above eye-level of the athletes, blocking their view and causing potential safety hazards. Also, the cargo buckles that attach the wheelchairs to the frame were not properly designed (one of the four buckles broke off the frame shortly after completion). The placement of the buckles could be altered in order to improve the response of the frame when maneuvering. The goals of the UPF VI.2 were 1) to lower the minimum table height to approximately 30” while maintaining a maximum height of approximately 40” and 2) to improve upon the cargo buckle system.

SUMMARY OF IMPACT

The UPF VI.2 appears to have finally met the needs of the Friday Club and Special Olympics. The team was able to change the height of the table to one that is more appropriate for the various attachments, and to permit optimal movement by choosing new attachment locations for the buckles. The

Fig. 6.9. Original geometry of the UPF VI.2

Fig. 6.10. Modified geometry of the UPF VI.2.

Kinesiology students who work with the Friday Club indicated that the modifications to the device greatly enhanced the ergonomics and maneuverability of the UPF.

TECHNICAL DESCRIPTION

The UPF VI.2 was a modification of the previous UPF version. The General Engineering Department often has individual senior design projects, and Ryan Westphal chose the modification of the UPF for his. Mary Gentilucci, a Mechanical Engineering student who received credit for one unit of independent study, helped Ryan design and manufacture the UPF VI.2. Two Kinesiology students, Marian Watson and Tyler Holt, worked with the team to determine user requirements and to provide initial design feedback.

The students came up with several options for modifying the length of the vertical support tubes, and performed stress analyses to make sure that their modified design would withstand the applied forces. Using an applied vertical load on the table of 100 lbs. (which is twice the weight of any current attachments), the calculated max pin shear stress was 1263.3 psi. This resulted in a factor of safety of 1.9. After the redesign, two welds on the slide joint were ground off and the support pieces shortened. The slide joint was then re-welded and the UPF was reassembled.

The original UPF VI team welded the cargo buckles to the frame. This was not strong enough, and it was difficult to securely weld the buckles onto the thin-walled aluminum tubes. The cargo buckle welds were ground off and were relocated to add support and maneuverability. The attachments were done with bolts to allow future alteration and easy replacement should one of the belts break.

Because the UPF VI.2 was simply a modification of the UPF VI, only the additional bolts for the cargo buckles needed to be purchased. The entire modification supply cost was only $10.

Fig. 6.11. Final UPF VI.2.

THE WIIBFIT

Designers: Seth Black, Craig Leitterman, Jamie Nease, Canh Sy, Mike Tran
Client Coordinator: Paul Mortola, Central Coast Assistive Technology Center, San Luis Obispo, CA
Supervising Professor: Dr. Chris Lupo
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INTRODUCTION

This project's primary intent is to develop a form of exercise for people with quadriplegia, using the Nintendo Wii system. Wii-B-Fit takes the Wii's engaging and fun game play and adapts it to meet user defined requirements. It is difficult for people with quadriplegia to participate in suitable forms of exercise. In addition to the lack of exercise options, people with quadriplegia also face very limited access to video games. Although Nintendo claims the Wii targets a broad demographic, the ingenuity of the Wii's remote actually alienates people with quadriplegia. The Wii requires players to have control of their arms and upper body to make full use of the accelerometer and infrared based remote system. In order to make exercise with the Wii possible, the ability to play the Wii must be an inherent property of the device. Thus, this project increases the accessibility of the Wii system to people with disabilities. This in turn provides those with quadriplegia the opportunity to enjoy the health benefits of physical exercise and play.

SUMMARY OF IMPACT

In general, it is very difficult for people with quadriplegia to find suitable forms of physical activity. Using the Wii and a customized Wiimote, the WiiBFit system makes the Wii accessible to people with quadriplegia and provides a fun form of exercise. The clear impact and potential of this system can be summarized by one user's blog entry (this user is shown in Figure 6.13 using the device).

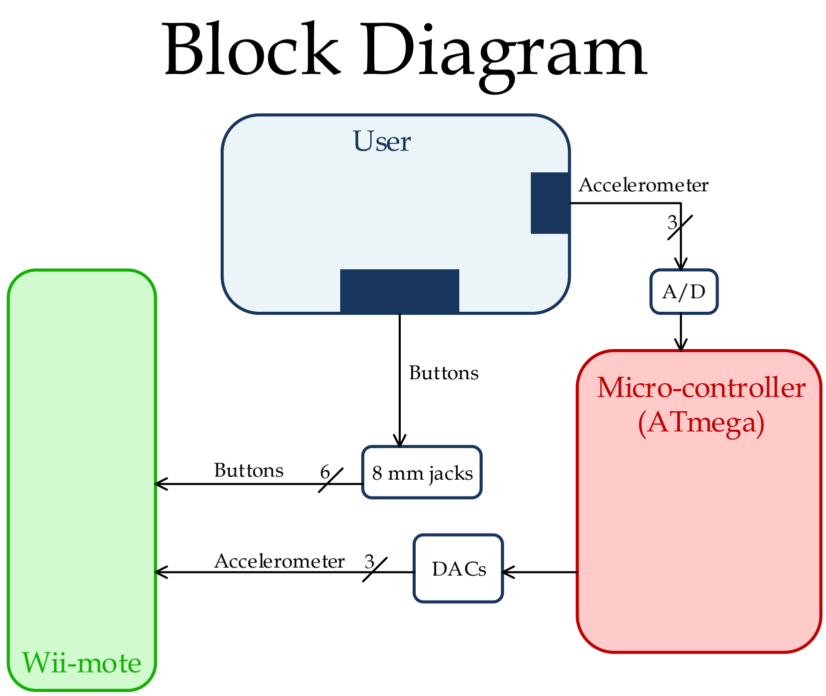

Fig. 6.12. Block Diagram of the WiiBfit.

Fig. 6.13. The client using the WiiBfit

"After my accident, I never expected to be able to play my Wii games. But now, despite my disability, I can play my Wii whenever I want. I can even use it as a physical therapy tool, which is great. It's nice to be able to have fun and exercise at the same time. Now, when I'm using it, I forget that I'm actually exercising."

TECHNICAL DESCRIPTION

The design objectives were to 1) allow the user to play at least two Wii games, 2) be lightweight and durable, 3) include hands-free operation, 4) be easy to learn and fun to use, 5) mimic functionally of Wii-mote, 6) incorporate exercise, 7) not limit head motion, and 8) not make the user feel self-conscious while playing.

The overall system design (shown in Figure 6.12) uses an ATMEGA1284P microcontroller to intercept the accelerometer readings, amplify them to sufficient values, and to output them back to the remote. The accelerometer is embedded in an ordinary baseball hat to allow user inputs to the system. The athlete uses a large push button and a puff sensor for the most commonly used buttons on the remote ('A' and 'B'). The team has also provided connections for adaptive buttons for each of the four D-Pad buttons. This way, the client may choose any switches they would like to be used for menu control and for directional control in games. There is also a flex switch and four push buttons so that the client has a variety of switches from which to choose.

The team successfully tested the system with both Wii Tennis and Wii Bowling. The system was lightweight, although additional packaging work will need to be done for full implementation. The software algorithm must be fine-tuned for each individual user, and some training for the athlete is necessary before they can play the game. Future iterations could include a sensitivity adjustment to allow different users to adjust "on the fly."

The cost to produce the prototype was $1,016 in materials.

ADAPTED BOCCE BALL

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Client Coordinator: Michael Lara, Special Olympics, San Luis Obispo, CA
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INTRODUCTION

It has been said more people play Bocce than any other sport besides soccer and golf. With roots back to 5000 B.C., Bocce is also the oldest know sport in world history. The game begins by throwing out the pallino, a 2.4″ diameter ball. The first player tries to throw his Bocce ball, which weighs about 2.2 lbs. and is about 4.25″ in diameter, as close to the pallino as possible. Successive players then try to get their Bocce ball closest to the pallino. Full rules and other information can be found at www.bocce.com. Currently this historic game is inaccessible to those with mobility impairments.

SUMMARY OF IMPACT

The Adapted Bocce Ball project allows people with disabilities to obtain the social and physical benefits of participating in the sport, and allows them to compete with other athletes with and without mobility impairments. Michael Lara, the regional sports director for Special Olympics, has stated that the device (shown in Figure 6.14) "met expectations and now allows wheelchair users to participate in the game of bocce. This also challenges the user to figure out the distances using the device, the same as one not using the device."

TECHNICAL DESCRIPTION

Design goals for the project were transportability (including electrical power), 60 ft. maximum range, lifetime of 20,000 cycles, maximum of 3 lbs. user input force, ability to create backspin on the bocce ball, and a reload time of 20 seconds. A full Solid Model of the system is shown in Figure 6.15.

The balls are launched using compressed air, which is supplied by two air tanks that are 1 foot long, have a diameter of 4 inches, and a total volume of 300 in3. The piping system has two PVC barrels, one for launching the pallino and another for the bocce ball. A three-way valve is used to select which of the

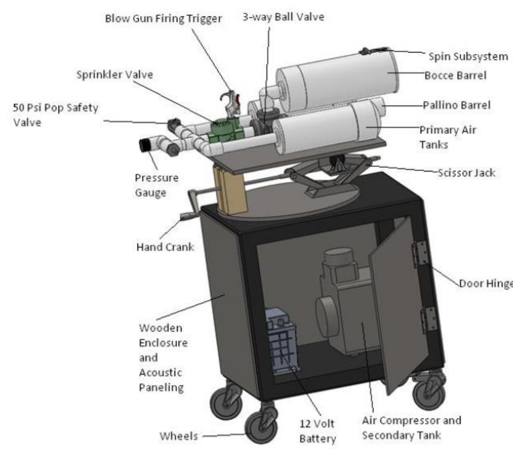

Fig. 6.14. Full solid model of the Adapted Bocce Ball Launcher.

barrels will be used. The bocce ball pipe, which requires much higher pressures, is modified because no standard pipe size is the exact diameter of the ball. Rubber inserts and metal flashing are used to create an adequate fit for the bocce ball. A deployable rubber wedge is placed in the top of the bocce pipe to allow the athlete to apply backspin to the ball. For safety, the piping system has a pop safety valve that will release pressure if the tanks exceed 50psi.

An air compressor is used to fill a 5 gallon secondary tank, which is connected to the piping subsystem. It is powered by a 12 Volt rechargeable battery, and the system can run for one hour continuously before needing to be recharged. In actual use, the compressor is used to fill the secondary tank intermittently. In testing, the device was used for three hours at the senior design expo without needing recharging. It is usually necessary to turn on the compressor every six or so launches to maintain the necessary pressure. The compressor sound level is slightly below 75 decibels at a distance of 2 feet, although again this does not run continuously.

The athlete controls the launch of the balls with three different control mechanisms. The first is the amount of pressure applied to the pipes. A calibrated pressure gage is provided to help the athlete determine how much pressure is stored in the secondary tank. The primary exercise for the athlete is in adjusting the scissor jack. The athlete must turn a hand crank to change the angle of the pipes, thus changing how high the ball will go. Finally, the entire launch system is on a turntable that can adjust the aim from side to side.

Fig. 6.15. The Adapted Bocce Ball Launcher demonstrated at the Senior Design Expo.

RECREATIONAL SIT SKI

Designers: Krystina Murrietta, Tom Silva, Allen Thrift & Dan Murray
Client: Mr. Jon Kreamelmeyer, Developmental Coach of the US Adaptive Ski Team, Colorado
Supervising Professor: Sarah Harding
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INTRODUCTION

Cross country skiing has been a part of the Winter Paralympic Games since the first Paralympic Games event in Sweden in 1976. There are many fans of the Paralympic Games who would like to recreationally use sit skis. Several companies (e.g., Spokes n' Motion, Sierra Sit Ski, and Teton) make sit skis that are either custom made or come in specific sizes, but to date there is not a suitable adjustable program ski that is adjustable for different sized athletes. Although Cal Poly teams have built recreational sit skis in the past, fairly broad adjustability requirements resulted in the devices being too heavy for most athletes.

Most skiers prefer one of two positions: 1) legs stretched out in front or 2) the teacup position, where the knees are pulled up close to the torso (see Figure 6.17). A few athletes have also been using a more upright, legs tucked under position. The goal of this project is to allow different sized recreational users to cross country ski and to choose which of the two most popular sitting positions they use.

SUMMARY OF IMPACT

An adjustable sit ski can be used in a number of cross country resorts where athletes with disabilities might want to try out cross country skiing. The ability to switch between the two positions allows people with different levels of spinal injury to participate in the sport, and the adjustability of the foot rest can accommodate athletes of different sizes. Additionally, the binding design allows the sit ski to attach to any ski with an NNN binding, allowing the athlete to switch to different skis quickly and easily. Jon Kreamelmeyer, a developmental coach with the Adapted Nordic Cross Country program, would like to use the sit ski when he travels to recruit different athletes for the Paralympic Team.

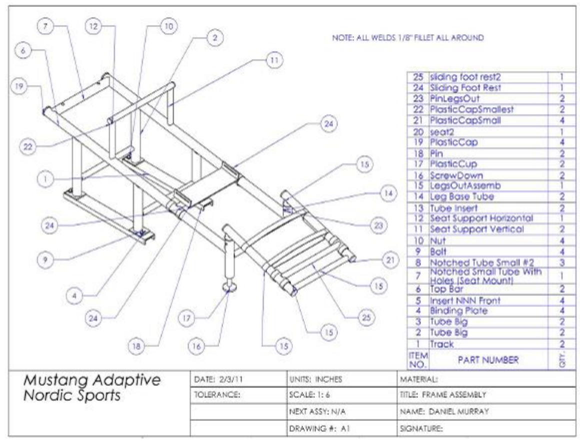

Fig. 6.16. Solid Model of Sit Ski.

Fig. 6.17. Skier in the teacup position.

TECHNICAL DESCRIPTION

The frame is made of 6063 T5 Aluminum tubes. The aluminum frame consists of eight 1inch diameter, 1/16 inch thickness tubes and seven 5/8″ diameter tubes. These tubes are welded together and plastic caps plug any open tubes. The four vertical "legs" of the frame are welded to small aluminum plates and are attached to the U-channel binding with hex screws and lock nuts. This hardware requires minimum tools and remains secure during use. A removable assembly consisting of an aluminum plate welded to a 5/8″ diameter tube and attached foot restraints is used for the teacup footrest. Turn-key hose clamps secure the footrest and allow the rider to adjust his or her feet for the teacup position. Polyester seat belt webbing and plastic buckles provide comfort and security for the rider's ankles.

The modular attachment slides into the vertical tubes of the frame and is secured by rounded retainer snap safety pins. These retainer pins make the attachment and removal quick and easy since no tools are required. The attachment consists of four 1″ diameter tubes and one 5/8″ diameter tube. The 5/8″ tube is a footrest for the legs-out position and an additional 5/8″ tube can be added to the attachment in order to accommodate petite riders. This removable footrest is also secured with turn-key hose clamps.

The ski bindings on the bottom of the frame are constructed using a U-channel and a set of plastic inserts. The inserts are modeled after the bottom of a NNN ski boot. These inserts are rapid-prototyped in ABS plastic and are press-fit into place. This design only required a single binding which allows the sit ski to easily fit into standard cross country ski bindings. The ski mounts are also able to slide side-to-side to adjust the track width. The free heel design works by snapping a pin on the front of the base into the binding, like a standard boot. These pins are machine screws held to the frame with lock nuts, making them easy to replace should they ever break. The front leg on the frame has a rubber stopper on the end that can screw in or out to hold the frame in place and prevent rocking.

Fig. 6.18. Skier with legs out front.

The large bucket seat is from Enabling Technologies. Abdomen and thigh restraints made of polyester webbing and plastic buckles are bolted to the seat. Closed-cell foam padding is used as cushioning and extra padding is provided should the rider need extra security, and can be used to raise the skier by a few inches if desired. The seat is secured to the aluminum tube with hex screws and lock nuts.

The material cost of the device, including powder coating, is $880.

COMPETITION SIT SKI

Designers: Kyle Martinez, Ben Woodward, and Vinay Clauson
Client: Andy Soule
Client Coordinator: Mr. Jon Kreamelmeyer, Developmental Coach of the US Adaptive Ski Team, Colorado
Supervising Professor: Sarah Harding
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INTRODUCTION

Andy Soule is a talented athlete who won a bronze medal in the 2010 Winter Paralympics. He has an above-knee double amputation, with full use of trunk and arm muscles. As with any elite athlete, Andy wants to have the lightest, most competitive sit ski possible to help him place even higher at future Olympic Games. The primary focus was in weight reduction, but the team also decided (based on input from Andy and his coach) that placing Andy upright with a forward lean might improve the biomechanics of Andy's poling.

SUMMARY OF IMPACT

The sit ski was designed to push the limits of current competitive sit skis. The final product (see Figure 6.19) weighs 3.02 lbs., a remarkable accomplishment. Andy will be testing the sit ski during the upcoming season to determine if the calculated 1.5 factor of safety will prove adequate for his racing needs.

TECHNICAL DESCRIPTION

The students developed the following design criteria:

1) The sit ski must weigh less than five pounds total.

2) The track width must be adjustable in order to conform to both American and European track widths.

3) Skis should connect/disconnect as easily as possible with nothing more than basic household tools.

4) The angle of the seat must be such that Andy feels comfortable and is able to exert maximum power during the arm stroke. A forward lean is advised.

5) Center of gravity must be kept low to provide excellent cornering ability and stability.

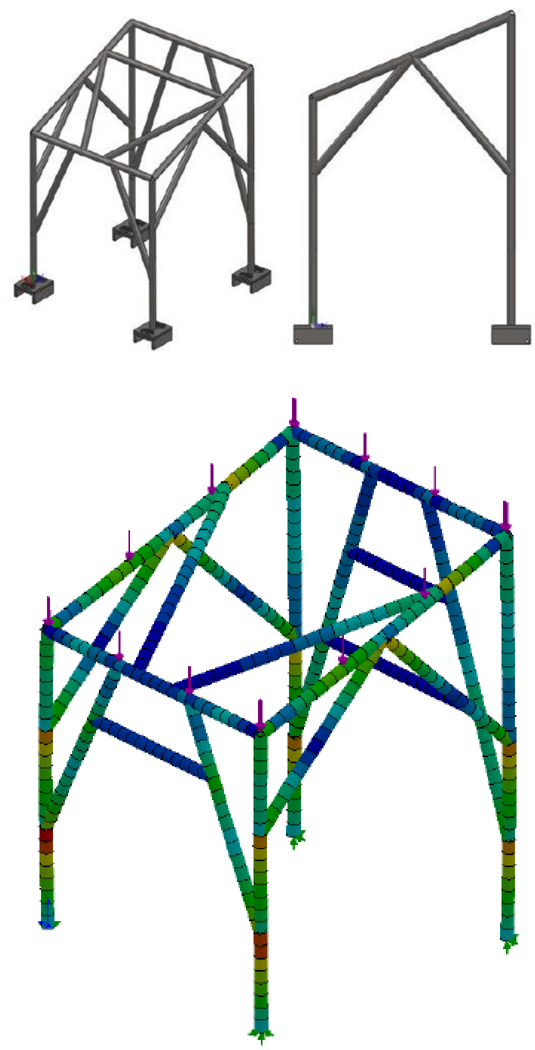

Fig. 6.19. Competition sit ski made from Titanium.

The sit ski was made from 0.375 x.019 inch Titanium tubing to maximize the strength to weight ratio. It was quite difficult to weld titanium, which requires an argon-rich environment and a welding chamber. The thin-walled tubes made welding even more difficult – the student team recommended that future designs may want to use slightly thicker wall dimensions. Despite these difficulties the student team decided to perform all of the welding themselves. Each tube was welded to 0.125 inch thick plates that were attached to aluminum U-channels with mechanical fasteners. The U-channels served as part of the binding system for the sit ski, and four short individual channels were used to reduce weight. Stainless steel mounting pins were placed in each of the U-channels to articulate with the bindings; one front and one back binding are mounted on each of the skis for easy attachment and removal of the sit ski. Special steel fixtures were constructed to ensure proper alignment of the sit ski frame.

The seat was constructed by carving a mold out of a single piece of high density foam using both wood chisels and sandpaper to acquire the desired shape. Four separate coats of epoxy resin were then applied to the foam mold to both eliminate its porous nature and to add rigidity. On top of the epoxy resin a layer of tool release agent was applied so that the carbon part would release from the mold cleanly. The seat was made from a pre-preg unidirectional carbon fiber utilizing an epoxy matrix that would cure at low temperature. In order to ensure that the seat would have adequate strength under the predicted loading conditions a 5-ply [90/0/90/0/90] layup was utilized.

A Solid model of the sit ski is shown in Figure 6.20. The sit ski had a safety factor of 3 when the seat was loaded with a downward distributed load of 200 lbs. The sit ski was also tested with 250 pounds placed in the seat, and with a 180 pound person in the seat leaning 45 degrees to the side. As mentioned, the final sit ski only weighed 3.02 pounds.

The total material costs for the frame, seat, molding material, and fixtures were $1300.

Fig. 6.20. Competition sit ski made from Titanium.

UNTETHERED RUNNING AID

Designers: Aaron Baldwin, Brian Berg, J.P. Charlesbois, Eric Cerney, J.C. Li
Clients: Students from the Santa Maria school district
Client Coordinator: Stephanie Cleary, Teacher, Santa Maria, CA
Supervising Professor: Dr. Lynne A. Slivovsky
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INTRODUCTION

The purpose of this project is to design a system that allows people who are blind or have low vision to run completely independently from a sighted runner. The traditional methods of solving this problem typically rely on sighted runners; a physical tether, either a rope or bungee system around the waist or finger tethers, or by running alongside a sighted runner and receiving audio cues from them. Counting steps may also be used to help the users cover well known distances relatively accurately.

Several other electronic travel aids (ETA) are available – some use ultrasonic signals to detect obstacles around the user and provide audio and vibratory feedback. Different types of camera technologies have also been used, but these types of solutions are quite expensive and over-complicated for the user needs. Ms. Stephanie Cleary runs after-school activities that include groups of student runners on a 400 meter track, so the system should allow multiple simultaneous users.

SUMMARY OF IMPACT

The student team worked on developing a wireless system consisting of (1) four sensors placed around the track, (2) a user belt (shown in Figure 6.23) consisting of wireless transmitters and tactile actuators to cue the runner, and (3) hardware and software to process the signals. A working system would provide the athletes with greater autonomy and less dependence on sighted runners. It might even be possible to have an athlete run for longer distances on the track without any other supervision. This first prototype attempted to provide navigational cues to allow the runner to stay on the track – they also recommend developing a method to allow the runners to detect and avoid other runners. Unfortunately the correlation between signal strength and distance was very weak and cannot be accurately relied upon for this system, and the team was not able to deliver a working prototype. The

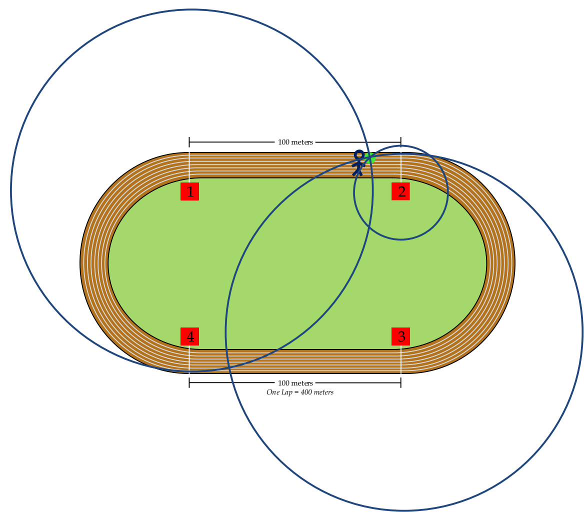

Fig. 6.21. Placement of track sensors to localize position of the runner(s).

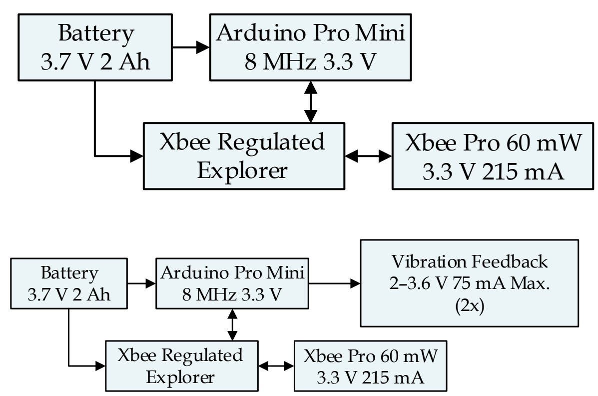

Fig. 6.22. Hardware diagrams for track sensor (top) and belt (bottom).

background research and progress made will be useful to a follow-on team next year.

TECHNICAL DESCRIPTION

The design objectives were to 1) allow user to run blind and untethered without the need for a sighted runner, 2) be usable by a wide variety of users, independent of vision level, 3) be small and lightweight, 4) have a long operating time, 5) have a small learning curve for users, 6) have high safety and reliability, 7) not impede normal running movement, 8) have signals to the user that are clear and independent of environment, 9) assist user in avoiding obstacles, and 10) be low cost. The system used four sensors placed around the track as shown in Figure 6.21 to try to triangulate the position of the runner(s).

The belt itself (schematic in Figure 6.22) is worn by the users, and contains an XBee Pro wireless board, an Arduino Pro Mini micro-controller, a vibration motor, and a battery pack. The wireless board allows the belt to transmit and receive signals from other belts and the track sensors. The signal then is passed to the micro-controller, which processes the signal and determines the current position of the user. The track sensor (schematic in Figure 6.22) is built around the XBee Pro 60 mW, a wireless communications board specifically designed for embedded systems. It has a range of approximately 1 mile.

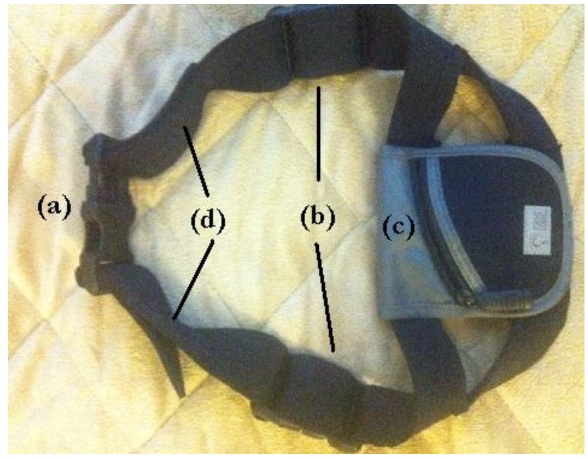

Fig. 6.23. Belt for runner, including (a) easy clipping component, (b) double adjustment straps to adjust size and location of vibration sensors, (c) pouch holding electrical components (d) location of vibration sensors.

The total cost for materials and components was $1160.

LOW COST PROSTHETIC TEST SOCKET

Designers: Erica Wong, Mackenzie Tageson & Karina Moraes
Client Coordinator: Matthew Robinson, Hanger Orthopedic Group, San Luis Obispo, CA
Supervising Professor: Lily Laiho
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INTRODUCTION

A test socket is a vital component of a prosthetic leg and is used to ensure the final prosthetic socket properly fits a patient. An incorrect fit can lead to patient pain and discomfort and may require a new socket to be constructed.

Typical steps in developing a test socket before final socket fitting in the U.S. include 1) Initial Evaluative Consultation, 2) Acquire Residual Limb Measurements and First Positive Plaster Mold, 3) Static Clear Test Socket Analysis, and 4) Dynamic Clear Test Socket Analysis. Vivak, Surlyn and polypropylene are often used for the test sockets. Vivak, a form of polyethylene terephthalate (PET), is a transparent semi-crystalline thermoplastic polymer widely used in the prosthetic industry. Surlyn is a thermoplastic copolymer made from polyethylene and methacrylic acid. Neither material, however, is readily available in Honduras and are both too expensive for use in the Clinic.

SUMMARY OF IMPACT

Due to the high cost, using a test socket is a complete luxury for developing countries such as Honduras. Without a test socket, the clinic has no way to locate any detrimental pressure points before the final socket is cast. A low-cost, easily manufactured test socket could prevent multiple fittings for patients. This is critical when many patients have to travel long distances to reach the clinic. The technicians in the clinic were impressed by the work that the team did, but right now this is still too cost prohibitive for them to implement. This is primarily due to the time involved, since they are paid an hourly wage and this would essentially double the time they spend on each prosthesis.

TECHNICAL DESCRIPTION

Design specifications were developed: 1) transparent, 2) less than 3 lbs., 3) bear a weight of 300 lbs., 4) fit to a tolerance of ±0.2", 5) be manufactured and cured within 12 hours, and 6) allow connection to pylon adapter using either glue or screws.

During a trip to Honduras by a second team (see later report on the Piernas de Vida project), students noticed a large number of plastic bottles in piles along the road. This could be a very inexpensive source of material for the test socket, and could help utilize an underused resource. After experimenting with milk bottle caps, banana leaves combined with plaster, wax and epoxy, seaweed and epoxy, and even shrinky dink, the test socket design team decided that using PET from two or three liter bottles was the best approach.

In general this process uses vacuum assistance, a heat gun, sections of 2L or 3L bottles, and epoxy to create a test socket. The vacuum ensures that a tight fit is created with the soda bottles and the heat gun, with digital controls, allows for specific degrees of heat to be applied throughout the process. Being able to control the temperature is a vital aspect of this process due to certain materials not being able to withstand certain temperatures. The 2L bottles must be cut, then placed in overlapping sections, and then tape and epoxy used to form the final test socket. If the plaster cast of the leg is small enough, then a single 3L bottle can be used in the process. The following figures show how to complete the process to complete the test socket for the 3L bottle. (a) Attach pylon adaptor to top of mold, (b) place 3L bottle over the mold, (c) put turkey oven bag over mold and bottle, (d) wrap tightly around tube on bottom and apply vacuum (around 28 in Hg), (e) apply vacuum to bag and use heat gun (at 350 degrees F) to shrink the plastic bottle around the mold, (f) repeat the process with two additional 3L bottles (cut off tops) around the first. (g) Finally, you will take out the second and third layers, cut off the first layer bottle top so that the adapter is exposed, and then epoxy the

Fig. 6.24. Placement of pylon adapter.

Fig. 6.25. Placement of bottle over mold.

Fig. 6.26. Placement of turkey bag over mold and bottle.

Fig. 6.27. Bag tightened around vacuum hose.

three different layers together for strength and stiffness.

Tensile tests were performed on seven specimen strips of heated and seven specimen strips of unheated PET from two liter bottles.

Compressive tests were also run on sockets made from 2L and 3L bottles. Both were able to hold 300 lbs. of force, although the 2L bottle socket did show some slight jumps in force (likely due to some delamination of the multiple cut sections).

The total cost for materials to develop the process was less than $250.

Fig. 6.28. Use of heat gun to melt plastic.

Fig. 6.29. Process is repeated for a total of three bottles.

Fig. 6.30. Final Test Socket.

ADAPTER FOR SURFING WITH A PROSTHESIS

Designers: Josh Cutts, Ben Friesem & Natasha Nelson
Clients: Members of AmpSurf on the Central Coast
Client Coordinator: Matthew Robinson, Hanger Orthopedic Group, San Luis Obispo, CA
Supervising Professor: Lily Laiho
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INTRODUCTION

Currently there are no specialized surfing prostheses to fulfill the need for amputees who desire to surf. Historically, amputees who surf use a normal prosthesis, occasionally with some modifications to compensate for common issues that occur with the use of a prosthesis created for everyday wear. These modifications are temporary fixes to problems encountered by the amputees while surfing on a normal prosthetic foot.

The first problem is corrosion from exposure to salt water and sunlight. Corrosion is mainly seen in connectors, such as screws, which are typically made of cheaper metals that are unable to resist the corrosive saltwater environment of surfing. The second problem is the limited ankle range of motion with normal prostheses. Ankle flexibility is extremely important in a dynamic sport such as surfing. The range of motion required is especially important for popping up, turning, and carving. The third major problem that amputee surfers experience is the lack of friction between their prosthetic foot and the surfboard; this contact is critical for allowing the surfers to pop up into a standing position and for controlling their board as they ride the wave. The most common methods to solve this friction problem are applying a material to the top of the surfboard such as a wax or a cutout foam pad, or by using a surfing boot with bottom traction.

SUMMARY OF IMPACT

AmpSurf (ampsurf.org) is a non-profit organization that is very active on the Central Coast. A device such as this could help improve the surfing experience of a large number of people with amputations in our local area, and help introduce the sport to others. Unfortunately this design team was unable to find someone to test their product, but the client coordinator, Matt Robinson, will be finding test

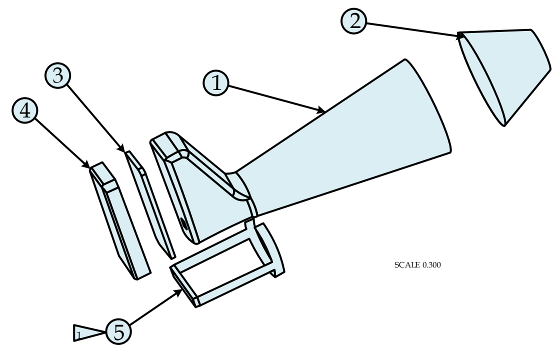

Fig. 6.31. Schematic of Surfer Boot: (1) Bilaminate leg from waders, (2) Latex neck gasket, (3) silicon insole, (4) Hyperflex sole, (5) Velcro strap.

Fig. 6.32. Surfer Boot prototype.

subjects this fall. A picture of the prototype is shown in Figure 6.32.

TECHNICAL DESCRIPTION

The student team developed the following design specifications: 1) prevent corrosion of the metal parts of a prosthetic. The design must remain watertight during 2 hours of salt water immersion, 2) include a surface area contact material providing a coefficient of friction of at least 0.4 between the prosthetic foot and a surfboard, 3) include an adaptation that allows a 10 degree inversion angle and a 5 degree eversion angle of the ankle from the surfboard's surface, 4) take less than 2 minutes to put on and take off, 5) have a lifetime use of 2000 hours of use without losing water resistance and grip, 6) be easily adapted to multiple users, 7) have a weight less than 2 lbs., and 8) cost less than $500.

Several off-the-shelf components were purchased for the prototype, including Cabella's Three Forks Stockingfoot Hip Waders, a Seamtite Latex neck gasket, and Hyperflex Access 3mm Round Toe Surf Boot Size 11. The leg section of the waders was made of a bilaminate of nylon denier and polyurethane; it was glued to the latex neck gasket. The sole was cut off of the Hyperflex Surf Boot, and a silicone gel insert was sewn onto the inside of the sole. This was done to help increase the amount of inversion and eversion that the surfer could achieve. Finally, the sole was glued to the neoprene foot section of the waders.

Cotol-240, a cleansing agent, and Aquaseal, an adhesive, were used to adhere the different parts of the device together. Great care had to be taken to ensure that all seals were watertight. A lip was sewn into the joint between the bilaminate of the hip wader and the neck gasket to serve as a handle when the surfer was putting on the boot. A heel support cup with Velcro fastener was also added to the sole to help hold the prosthesis firm while surfing.

During static testing of the device, a test subject performed minimal movements in the water for 30 minutes. This was followed by dynamic testing, where the subject moved his leg for five minutes. Both tests resulted in less than 1 ml leakage of water. Don/doff tests resulted in times of 80 seconds and 35 seconds, respectively.

The total cost for materials to develop the process was $365.

STRIDER – STANDING WHEELCHAIR

Designers: Matt Browning, Michael Flynn, Douglas Desfor, Mary Gentilucci
Client Coordinator: John Lee, San Luis Obispo, CA
Supervising Professor: Brian Self
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INTRODUCTION

For people who are restricted to a wheelchair for mobility, standing has many health benefits. Passive standing alone has the benefit of preventing pressure ulcers and improving circulation. Meanwhile, bearing weight on the legs increases lower body muscle and bone strength. Walking increases muscle strength, promotes joint mobility, and allows for a mild cardiovascular workout. Standing also has the benefit of allowing easier eye-to-eye contact and easier access to devices designed for a standing position.

There are several devices on the market which fulfill some of these requirements. Standers (e.g., the EasyStand Evolv, Permobil LifeStand Helium) allow users to transfer from a sitting to a standing position. They are generally not designed for the user to move around under his or her own power, but allow the user to gain the health benefits of passive standing. The GlideCycle PT Pro is a two-wheeled exercise device similar to a bicycle. The user sits in a seat suspended from a U-shaped frame between the two wheels. Since the device is two-wheeled it is difficult to set up autonomously by a person with limited use of their legs and is not appropriate for indoor use. The Rifton Pacer Gait and the LiteGait Mobility Device are well-designed mobility aids that fulfill the largest number of the design requirements. Unfortunately, the devices are too wide to fit through a door and do not provide a transfer seat for the user.

Fig. 6.33. Front (left) and rear (right) views of the strider.

SUMMARY OF IMPACT

The user, John Lee, provided a great amount of feedback on the device.

The Adult Strider is the type of walking aid that I've been wanting to develop for several years, ever since the injury that compromised my walking and left me relying on a wheelchair for my primary means of mobility. The Strider enables me to get out of my wheelchair for longer stretches of time to weight-bear and move around using my legs as my primary locomotion (instead of my arms). In addition to the weight-bearing benefits, the Strider helps me work on my standing balance, lower body strength, flexibility, posture, and endurance. Even in only 15-20 minutes, I get a good burn in my legs and lower back, as I exercise muscles that I normally under-utilize during an average day. Once I'm in the Strider, I feel very safe and secure as I move around. Thanks to the swing-away seat, I'm able to remain in the Strider for longer periods of time, as I can take breaks whenever I need to by simply perching on the seat. Merely sitting in the Strider while watching TV is better than sitting in my wheelchair, as I'm able to stretch my thigh muscles. It will take me some time to build up my endurance so that I can walk around in the Strider for longer stretches. It's worth the effort because I realize the many benefits that the Strider offers for my bone health, muscle health, even organ health. I believe that regular use of the Strider will ultimately help me maintain and hopefully even improve my physical functioning and quality of life. It feels great to be able to walk around again without fear of falling.

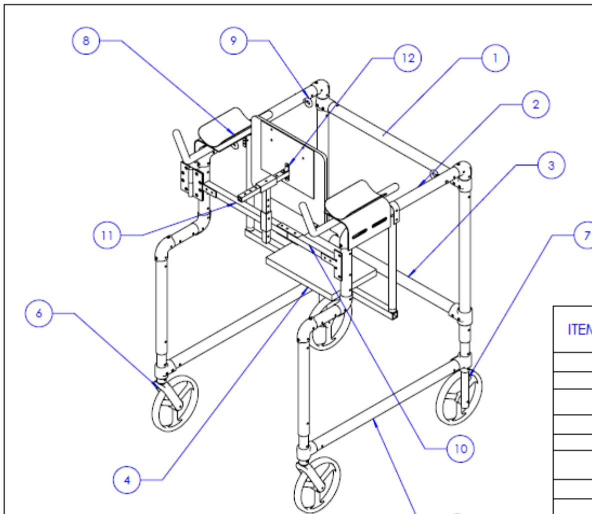
TECHNICAL DESCRIPTION

The student team developed the following user requirements: 1) independent use by user, 2) safe, 2) high mobility, 4) weight bearing adjustable, 5) adjustable for different users, 6) comfortable use for 2-3 hours, 7) light, quality materials, 8) transportable by van, 9) low maintenance, 10) little to no assembly, 11) aesthetically pleasing.

The frame was primarily made from 1.5" OD X 0.125" and 1-1/4" OD X .083" 6061-T6 Aluminum circular tubing. Aluminum slip-on rail fittings (Tee with through hole, 90 degree elbow) were used at the joints of the frame because pipe bending weakened the aluminum pipes. A transfer seat was also constructed to allow the user to position him or herself into the Strider, and also to provide a resting seat. The seat was commercial-off-the-shelf, and was supported by aluminum rails. A commercially-available walker was purchased, and several parts were scavenged from the device. The wheels and braking system were adapted for the Strider, and the seat was used for a chest pad. The user can lean against the chest pad to help propel the Strider forward; the entire front adjustable chest pad assembly can also be removed if desired. This torso support system is constructed of zinc-plated steel square tubing and corrosion-resistant aluminum.

A climbing harness (Black Diamond) was purchased to partially support the user during walking. The straps are adjustable, so the user can decide how much weight bearing he would like to have on any given day. The bottom legs are adjustable (telescoping tubes) to accommodate users of different heights. Hand brakes and arm rests are also fixed to the Strider. Almost none of the joints were welded to allow the user to take apart the device for transportability, and to allow for easy repair should any of the parts fail.

The material for the Strider cost just under $1300.



ITEM NO.	PART NUMBER	QTY.
1	Upper Crossmember ASSM	1
2	Frame side	2
3	Rear lower crossmember assm	1
4	Swing Seat Assm	1
5	Side Crossmember ASSM	2
6	Strider Front Wheel Assembly	2
7	Strider Rear Wheel Assembly	2
8	Armrest ASSM	2
9	Eyebolt	4
10	Left arm assm	1
11	Right arm assm	1
12	Chest pad H tele Assm	1

Fig. 6.34. Solid CAD model of the Strider.

ROCK-N-BOWL

Designers: Josh Grip, Travis Rodrigues, Richard Rozporka
Client: Mike Ward, San Luis Obispo, CA
Client Coordinator: Kevin Taylor, Kinesiology Department, Cal Poly, San Luis Obispo, CA
Supervising Professor: Brian Self
Mechanical Engineering Department
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INTRODUCTION

Bowling is a classic American pastime enjoyed by people of all ages, but this seemingly simple game has been difficult for people with disabilities. It is highly important to get the motion and strategy of bowling as close as possible to standard bowling. Using strategy and ball control allows people with a disability the opportunity to truly compete with a standard bowler. The Rock-N-Bowl needs to allow the athlete to curve the ball in for a strike, just like the professionals do. Also, the bowler needs to control the speed of the ball for optimal ball control.

There are several devices on the market which fulfill some of these requirements. Free-standing ramps are very simple, but do not provide spin to the ball, often move when the ball rolls down the ramp, and have limited speed variability. The IKAN Bowler is a well-designed device that has provided an enjoyable bowling experience to many bowlers with disabilities. It does not, however, allow the user to vary the spin on the ball a great deal. Spin is achieved by placing the holes of the ball to one side, limiting the options available to the user.

SUMMARY OF IMPACT

The Rock-N-Bowler has the potential to open up the world of bowling to several local athletes. One benefit of the device is that it can be either attached to the bowler's wheelchair to add to the forward speed of the ball, or it can be set up as a stand-alone device and allow different bowlers to wheel up to it. The spinning mechanism allows the athlete to experiment with different hooking speeds and add to the enjoyment of the game. Alternatively, the athlete can use the Rock-N-Bowler as a simple ramp bowler. Mike Ward, the customer, seemed quite happy with the device when he tested it at the Senior Design Expo. The Rock-N-Bowler will be kept at Mustang Lanes where anyone is free to use it.

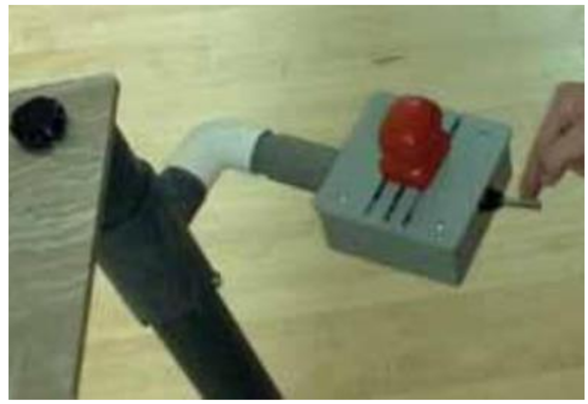

Fig. 6.35. Spin Controller.

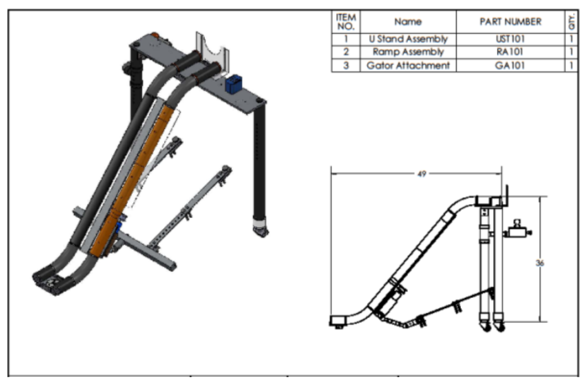

Fig. 6.36. Solid CAD model of the Rock-N-Bowler.

TECHNICAL DESCRIPTION

The student team determined the following user requirements: 1) the end product should be able to "throw" the ball close to the normal speed of a bowling ball, and it must curve the ball to enhance the bowling experience, 2) the user interface should be within a six inch range of motion around the customer's hand, 3) the device needs to easily attach to a wide variety of different wheelchair designs, and be easily adaptable to go from one chair to another, 4) a personal assistant must be able to install it unassisted, so the device cannot be too heavy or cumbersome to prevent a single person from installing it, 5) the device must be easily transportable so that it can be used at multiple bowling alleys; therefore, the device must come apart and fit in a car or truck.

The legs of the frame were constructed of PVC, and locking casters were attached to allow the device to act as a stationary bowler when desired. The top of the frame was constructed from aluminum and supported the controller and ball holder. The controller was made from a linear potentiometer, and simple circuitry was designed to allow the user to control the speed of the drill motor by moving the large handle shown in Figure 6.35

The curved portions of the ramp were also made of PVC. One of the rollers was made of Delrin to allow easy turning and low friction, while the powered roller was made of polyurethane. Steel rods attached to bearings and aluminum brackets provide structural support to each of the rollers. A drill motor and pulley were used to spin the roller; a small groove was machined into the polyurethane roller for the belt. A mechanism consisting of telescoping steel tubes and heavy duty pivot locking hinges was designed to attach the device to a variety of different wheelchairs. This attachment mechanism can be adjusted in height, width, and length to accommodate different users.

The material for the Rock-N-Bowler cost just under $1230.

Fig. 6.37. Team with completed Rock-N-Bowler.

THE QUADRICYCLE – HAND AND FOOT CYCLE

Designers: Marissa Chin, Parker Drennan, Spencer Nelson, Kevin Reidy
Client: Scott Davis, San Luis Obispo, CA
Client Coordinator: Kevin Taylor, Kinesiology Department, Cal Poly, San Luis Obispo, CA
Supervising Professor: Sarah Harding
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INTRODUCTION

Daily tasks can be a challenge for people with physical disabilities, and one of the most important of those is getting a sufficient amount of exercise. The senior design team was tasked with designing and manufacturing a hand and foot powered cycle to be used for exercise and mobility by Scott Davis of Atascadero, California. The main objective of the project is to build a cycle that Mr. Davis can power predominantly by hands and upper body strength, but also allow a cycling motion and some power input by foot in order to get a full body exercise.

Mr. Davis has a C5 level spinal cord injury which is approximately at the deltoid/bicep height. Due to the location of his injury, he had very limited use of his arms and legs. He spent several months at a program called Project Walk and through rigorous rehabilitation he was able to regain a significant amount of upper body and leg muscle control. In order to achieve an appropriate amount of daily exercise, a hand and foot powered cycle is ideal for Mr. Davis. While there are many companies who design and manufacture hand cycles and recumbent cycles, there are few that produce a product that meets Mr. Davis' needs. The two that are closest to his needs are the BerkelBike Pro and the All Body Workout (ABW) Trike. The main design feature that will differentiate the cycle from anything else on the market today is that it will allow parallel hand and foot power, adapted specifically to Mr. Davis' abilities.

SUMMARY OF IMPACT

Mr Davis is very happy with the final design of the bike, but has made a few small alterations after the product was delivered. It was very difficult for him to get in and out of the bike because of the positioning of the hand cranks, therefore one of our mechanical engineers made some modifications for him as part of an independent study course. These changes have allowed Mr. Davis to exercise his upper body, while providing some passive (and slight active) motion for his lower extremities.

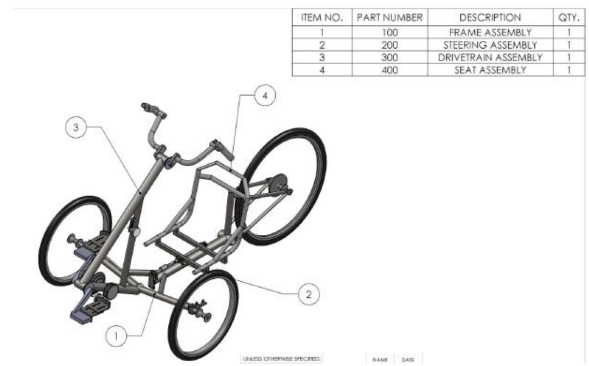

Fig. 6.38. CAD model of Quadricycle.

TECHNICAL DESCRIPTION

The student team determined the following user requirements: 1) powered mainly by hands, specifically in a circular, synchronized, prone pedaling motion; the feet must move in a cycling motion as well and allow for parallel cycle power, 2) gears should be similar to a normal bike, with a low underdrive gear for hills and starting out, 3) easy to (dis)assemble and able to fit in a car, 4) weigh less than 50 lbs., 5) turning radius of < 12 ft., 6) width < 25 inches.

The frame material is 4130 chromoly steel. This alloy is commonly used in bicycle and recumbent frames since it provides adequate stiffness and strength, while maintaining low manufacturing cost. All components such as cranksets, spindles, bottom brackets, chain, derailleurs, shifters, wheels, and hubs are off-the-shelf components and can be purchased at any bicycle retailer. The hand pedal material chosen was 6061 T-6 aluminum for its high strength to weight ratio and excellent weldability.

The seat frame material is made of T6-6061 Aluminum, and the seat was made of lightweight foam.

The front wheels are 20 inch TerraTrike replacement wheels and tires. Since the team is using TerraTrike hub mount replacement spindles, these wheels are an appropriate match. The rear wheel is a standard 26 inch mountain bike wheel; the 26 inch size provides additional high gearing to help attain a higher top speed. Any three-wheeled vehicle with two wheels in the front requires steering geometry compensation for maximum stability during turns. As the vehicle executes a turn, the inside wheel makes a smaller radius arc than the outer wheel and as a result the angles that the wheels make relative to the chassis are different. Compensation can be made to account for this and is commonly referred to as Ackerman compensation. For the Quadricycle, this compensation is performed by locating the tie rod mounting points appropriately.

The chain is routed from the hands to the feet on the left side through two chain rings of equal size. On the right side, the chain is routed from a 3 speed chain ring on the foot crank to an 8 speed cassette on the rear driving wheel. With the selected cassette and chain ring, the Quadricycle will be able to achieve a low gear ratio of 22:34 and a high gear ratio of 44:11. This means that in low gear, the user will be able to transmit approximately 130 ft-lb of torque if 150 lb. of force is given at the hand and foot pedals combined. In high gear, the user will be able to travel at a speed of approximately 28mph with a 90rpm cadence.

The total cost of the device was $2675.

Fig. 6.39. Client with the completed Quadricycle.

PIERNAS DE VIDA – DEVELOPING A LOW-COST PROSTHETIC FOOT

Designers: Jennifer Van Donk, Justin Lekos, Sarah Baker, Kevin Yamauchi, Adam Paicely
Client: Vida Nueva Clinic, Choluteca, Honduras
Client Coordinator: Matthew Robinson, Hanger Orthopedic Group, San Luis Obispo, CA
Supervising Professor: Brian Self
Mechanical Engineering Department
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INTRODUCTION

Walking is such a part of everyday life in the developing world that it is frequently taken for granted. Transportation is often limited, and it is not uncommon for people to walk several miles every day to get to and from work, the grocery store, etc. A growing number of people, however, have severe disabilities due to traumatic, dysvascular, and congenital defects. There are 300,000-400,000 known landmine-related amputees worldwide, of whom 20% are children. In total, it is estimated that there are up to 500,000 total amputees worldwide, and that 5,000-10,000 are added to this number each year. Many of the amputees in Honduras are working men that were injured in mine explosions or train accidents. These men are often the main provider for the family and after an amputation they lose work because they are unable to perform the tasks required for their jobs. Therefore, a prosthetic leg, that can allow them to earn a living, is critical. In addition to empowering individuals to continue working, a well-designed prosthetic leg can improve a patient's self-image. Dealing with persons with physical impairments in any culture can be uncomfortable for both the patient and those interacting with the patient. There are many cultural stigmas attached with those who have disabilities, including viewing them as inferior and incapable. Piernas de Vida (the senior design team) hopes to fight back against stigmas held against persons with physical impairments and design products that can help break social and cultural barriers.

SUMMARY OF IMPACT

Many clinics and organizations have been established in the developing world to attempt to treat those with lower limb impairments. One success story is the Vida Nueva clinic in Choluteca, Honduras, seen in

Fig. 6.40. The Vida Nueva Clinic in Choluteca, Honduras.

Fig. 6. 41. Different PolyStack prototypes.

Figure 6.40. Since it opened in 2003, the clinic has provided 369 new prostheses, 1278 orthoses, and performed 21 repairs. The clinic treats approximately 70 patients per year, including both children and adults. Vida Nueva prides itself on providing prostheses to patients who normally cannot pay. They also maintain close relationships with their patients to ensure proper fit and to provide follow-up care. However, because Vida Nueva is funded entirely by international aid organizations and other private donations, the clinic typically has to turn

away 10-20 people per year because they do not have funds for the necessary components. Currently Vida Nueva purchases most of its hardware from the US or Switzerland. Their typical costs are $550 for an above knee and $350 for a below knee prosthesis. Considering that the estimated per capita gross domestic product is $1829, the cost for these prostheses is beyond the reach of most Hondurans. If Vida Nueva could manufacture high quality, lower cost prostheses within the country it could potentially help them to serve a larger population base as well as spur on the local economy by allowing individuals with disabilities to return to the workforce.

TECHNICAL DESCRIPTION

During the Fall quarter, the entire team took a weekend trip to the clinic to perform a needs assessment and further develop relationships with the technicians (prosthetists), Walter and Roque, as well as several of the clinic's patients. They spent two days in the clinic and during this time had the opportunity to interview several patients who were receiving new prostheses or were in for regular adjustments. From these interviews, the team learned more about their stories and better understood their specific needs. They also observed Walter and Roque at work fitting patients with prostheses and discussed their thoughts about problems with the current designs. This trip was instrumental for all parties involved because it provided inspiration and enthusiasm. One teammate, Kevin, said that "Our trip to Honduras showed [him] how fortunate we are to have grown up in a country with bountiful resources" and he "left Honduras with a feeling of responsibility to use the knowledge [he] has gained in school to help others." Also, the trip provided the information about the needs, technical abilities, and available supplies at Vida Nueva that would have been extremely hard to attain otherwise.

Using information from this trip, the team developed the following user requirements: 1) manufacturable in house, 2) reproduce natural gait, 3) low cost, 4) minimal deterioration, 5) long replacement interval, 6) low weight, and 7) aesthetically pleasing.

The team brainstormed several different designs, and performed structural analysis on their top concepts. After testing different design concepts, the students decided that the PolyStack Foot was the best alternative. This foot, pictured in Figure 6.41, is composed of multiple layers of material fastened with a bolt that simultaneously acts as the ankle. A

Fig. 6.42 PolyStack being tested on the Instron machine.

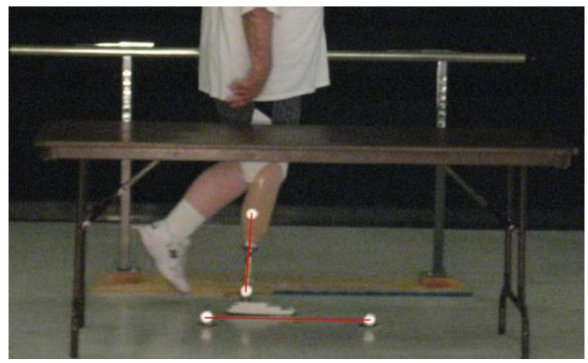

Fig. 6.43. Gait analysis on subject walking with the PolyStack.

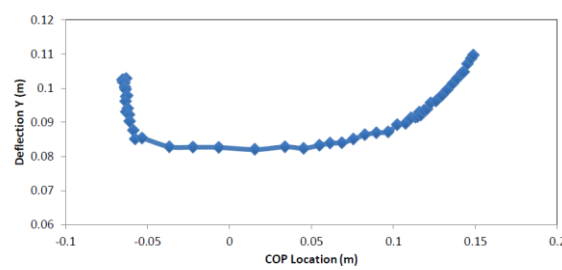

Fig. 6.44. Rollover shape from gait analysis.

second pin is inserted through the layers in front of the bolt to provide rotational stability. The layered design will allow for controlled flexion, and by joining the layers at different locations could provide a variety of gait responses. This also gives clinicians control over the foot behavior and allows them to vary the response according to individual patient needs.

Originally, the team was hoping to make the layers out of polyethylene terephthalate (PET) recycled from plastic bottles to form the layers. They noticed piles of bottles virtually everywhere in Honduras, so knew that it is a prevalent material and available at fairly low costs. However, the plastic must be melted into sheets, and this alone presents significant challenges.

Led by the Materials Engineer on the team, the students discussed and tested several viable options including compression molding (where plastic flakes are placed into a mold and compressed at high heat and high pressure into a flat sheet) and extruding (where flakes are placed into a machine that heats them and then compresses them out through a rectangular die to form films). The challenging task is to create these processes on a scale that can be replicated at clinics throughout the developing world. Unfortunately the team was unable to develop a suitable process for creating the recycled PET during the past school year, so they utilized their backup material, Delrin.

This material is an ideal alternative because it shares similar material properties to PET and is the same material used in the LeTourneau M1 knee. The greatest downside to Delrin is that it is not available in-country; however the layer foot would fulfill the low cost requirement. Similar to PET, Delrin is easy to work with. The construction process was as follows: 1) use a jig saw to cut out the pieces from the big sheet of Delrin, 2) measure out the locations for the holes using a square, center punched the hole, and then drill out the holes with a drill press (a hand drill can also be used), 3) insert the ankle bolt and install the pin with a mallet. The prototypes took approximately 2 ½ hours to build.

As can be seen in Figure 6.41, several different thicknesses (0.5 in, 0.375 in, and 0.25 in) were originally made for testing. The foot was placed in an Instron test machine and loaded to 4000 Newtons (see Figure 6.42). All of the feet were able to withstand the load, so the team then did human testing in San Luis Obispo.

Before each trial the patients were allowed to walk a few paces to become accustomed to the foot. They then walked across the force plate while both the force plate software and the video camera collected data. Each foot (0.5 inch, 0.375 inch, and 0.25 inch layer thickness) was tested with the force plate on

Fig. 6.45. One of the patients wearing the modified PolyStack.

two different patients three times for a total of 18 runs. Two runs of data were also collected for each patient on their standard prosthesis for comparison.

The testing equipment included a force plate from the Cal Poly Kinesiology Department and a long-zoom digital video camera. The force plate records the location of the Center of Pressure (COP) of the foot during gait as well as the magnitude and direction of the ground reaction force on the foot. Simultaneously, the video camera captures kinematic data from markers placed on the shank and on the ankle of the patient during gait. These two sets of data are then matched to produce an accurate rollover shape, as seen in Figure 6.46.

After each prototype foot the patients were asked a series of qualitative questions about their experience. Both patients had similar responses and helpful feedback. The following were questions asked in the survey: 1) Did you feel more or less balanced on this prosthesis when you were standing/walking? 2) Did you feel the foot turn inward or outward at all? 3) Was the foot heavier or lighter than your standard prosthesis?

Patient 1, because he was much heavier, felt most comfortable on the 0.5 inch foot. There was considerable deflection in the toe from this foot under his weight, however little to no deflection in the heel. Patient 2 responded best to the 0.375 in foot. Their comments alone made it clear that there was a

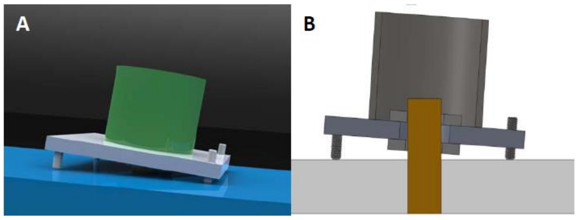

Fig. 6.46. A solid model [A] and section view [B] of the pylon cup adapter. The pylon is inserted into the cup and the four set screws allow two axes of rotations (inversion/eversion and flexion/extension).

correlation between weight and appropriate thickness. Patient 1 frequently commented that the foot "felt out of whack." It was clear that he was not accustomed to the foot, and did not find it particularly comfortable. Both patients felt that the heel strike was significantly too hard and there was little to no give. We observed the toe was too compliant on the thinner feet, so the patients felt as though they were "falling forward", "going downhill," or being "thrown forward."

The team was pleasantly surprised at how much flexing there was. They did not believe there would be much deflection, however all three feet showed considerable compliance, and some even exhibited too much deflection. From the results of the test, their primary suggestion was to shift the bottom layer back in order to improve deflection in the heel and reduce the deflection in the toe. Unfortunately, you can only shift the bottom layer out a few centimeters. If the heel protrudes too far behind the ankle it will not induce natural walking motion.

Three additional prototypes were constructed for testing at the Vida Nueva Clinic. 1) 0.375" modified: In this design the middle layer was shifted forward to be in line with the top layer. This was done to soften the heel and stiffen the toe. Each layer was 0.375 inches thick. 2) 0.25" modified: Same design as above but using 0.25 inch layers. 3) 0.1875" modified: Same design, but using 0.1875 inch layers. In Figure 6.47, one of these prototypes is shown on a Vida Nueva patient.

The prototypes were then taken to the Vida Nueva Clinic in Honduras, and a series of subjective tests were performed. Several of the lighter patients commented that even on the 0.1875" modified the toe was a bit stiff.

Walter, the Vida Nueva technician, made several suggestions, including cutting the toe a bit shorter or using an even thinner layer in the middle. Another concern was the overall length of the foot. Many of the patients were shorter and would not normally use a 26 cm foot. Their complaint was that they were unable to reach the toe flexion point in the foot in their natural gait because it was so far forward. The team has not yet tested out scaling the feet down, so it is unclear how the foot will perform if all of the layers are shortened.

One individual mentioned that he felt some energy return as he walked forward. A second patient stated that using the 0.1875 modified foot felt considerably smoother than the ICRC foot he had been using, even though it was a bit too long for his height. He felt very comfortable on this foot, and walked around with confidence, even testing out the hills and steps in the dirt area behind the clinic. He also brought in his bike and rode around a few laps with ease.

The technician Walter, who currently uses a Flex Foot, also tested out the 0.1875 inch PolyStack. He said he liked the feel of the foot, though the pylon was a little long so it was hard to get an accurate feel. He mentioned that the heel felt a little stiff and commented that it would be a good idea to potentially use a different material for the heel than the rest of the foot.

The total estimated cost for the foot is $17.70.

Two different trips to Honduras were paid by a generous grant from Boeing and funds from the Cal Poly chapter of the Engineering World Health Club. The team spent under $750 for materials and fixturing costs for the project.

Finally, the team also spent considerable time in developing an ankle adapter to help the clinic use different donated feet that they receive. Often these feet have different attachment mechanisms, and it can be difficult to fit them onto different pylons. The preliminary design is shown in Figure 6.45. Because the bolt from the PolyStack is attached directly to the current Vida Nueva pylons using their current adapters, this ankle adapter was not rigorously tested.

Perhaps the most beneficial outcome of the project is the strong relationship formed between the students and the Vida Nueva Clinic. The clinic personnel were warm, talented, and open to new designs and solutions to their design problems. The student team had various Skype video conferences to discuss their ideas and to get feedback from the technicians and clinic supervisor. The students went to Honduras on their own for the prototype testing, and brought an additional student who will continue the project next year.

Matt Robinson, a local certified Orthotist and Prosthetist, will continue to advise the project (he travelled with the team on the fact finding trip and is fluent in Spanish). Next year's team will be formed from students in the Cal Poly chapter of Engineering World Health. Many of the students involved in the club have expressed great interest in prosthesis design, and this momentum will contribute to the success of the project in future years. This interest and the continued strong design work by our students will help sustain our relationship with Vida Nueva.

Fig. 6.47. Cal Poly Piernas de Vida Senior Design Team and personnel at the Vida Nueva Clinic.