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Universal Personal Transfer

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BMACT INDUSTRIAL

SIT-TO-STAND PERSONAL TRANSFER DEVICE

DESIGNED FOR LINDSAY LEE

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Executive Summary

The Universal Personal Transfer Device is a mechanical lift designed to provide assisted transfer to a person of limited mobility. The device will allow for transition to or from a wheelchair, bed, toilet, shower, and standard furniture. This device will eliminate the current need for outside assistance during most transitions, and allow an individual to experience more independence and privacy in everyday life. The design incorporates a solo-operated control mechanism, complete with mounted controllers. This device will be independently mobile, and powered by a rechargeable electric drive system. The current design provides horizontal and vertical lift required for transfer from one position to another. Safety has been a top priority throughout the design process. The base has been redesigned for additional stability, and the drivetrain linear actuator acts as a natural safe guard against sudden lift failure. Mechanical structures are not large or cumbersome, and an elbow lift joint efficiently provides the motion required for safe personnel transfer. This design will remain very mobile and compact, insuring compatibility with various environments.

Innovative features of this device include a simple yet effective structural design that makes it possible to lift a user up to 200 lb. with efficiency and ease. Qualification protocol tests demonstrated that:

- Battery and motor system can adequately transport a 150 lb. user for a more than desired distance
- Linear actuator is adequately able to lift and lower a user of 150 lbs efficiently
- Battery provides adequate power
- Device is stable and safe

Background

The primary client, Lindsay Lee, is an undergraduate student at the University of Tennessee. Ms. Lee has a particular form of muscular dystrophy, which limits her muscular strength. She requires assistance when moving from her primary electric wheelchair to any number of essential locations. Family, friends, or medical personnel have provided this assistance in the past. Lindsay has expressed interest in a mechanical device to replace the current function provided by an outside assistant. She has emphasized how such a device would dramatically impact her daily independence. Successful solution of this problem would reduce Lindsay's dependence on outside assistance and provide her a greater degree of privacy.

After surveying the current device market, it became clear that there was not a product that specifically met Lindsay's needs. Many existing products were crane-basket lift configurations. These devices often performed the needed translational motion, but were very bulky or immobile. Basket lifts also required use of an inconvenient basket harness and an assistant to operate the lifting device. Existing powered products allowed solo operation, but were not designed to be compatible with an individual of limited muscular strength. These designs often required extensive physical interaction or adjustment when operating. Lindsay also provided the design team with additional needed or desired device characteristics.

Problem Definition

The Universal Personal Transfer Device will provide fundamentally required lift and translational motion while allowing solo operation. The design process will be open for review by Ms. Lee and instructor stakeholders. Successful completion of this project involves presentation and review of an interim conceptual design, assembly of a prototype, and final manufacture of Lindsay's customized device.

Ms. Lee provided the design group with a specific problem description. In addition to the fundamental motion required by the device, Lindsay expressed her desire for a number of required design traits. Above all, the device must safely provide the range of motion required. The structure must remain stable and upright during lift and movement. This design must also be solo operated, and may not require any regular assistance outside of Ms. Lee's personal capabilities. The device must also have a rechargeable electric drive system with reasonable battery life. Ergonomic qualities are also important, as the device would become a regular feature in Ms. Lee's daily life. Structural and control system components must be waterproof, to allow transfer to locations in the bathroom. Structural components must also be compatible with Lindsay's electric wheelchair, bed, toilet, and other seating areas. The device must also provide adequate underarm, foot, and anterior knee support. Problem characteristics have been broken up into "Needed" and "Desired" groups based upon their importance and feasibility. These factors may be viewed in the following tables.

Needs:

Function	Required Feature or Characteristic	Target
Underarm/Knee Support	Ergonomic supports in proper location	Client Approval
Solo-Operation	Wireless and mounted controls/ Reliable, powered device mechanisms	Successful completion of all intended device motions/ Client approval
Splash-proof	Use of waterproof components/Waterproof housing material	Successful testing in shower or bathroom
Rechargeable	Rechargeable electric battery with reasonable charge time and life	Complete client description of a full day's use on single battery charge
Stability	Square shaped base with adequate dimensions	Safety Factor > 2.2
Mobility	Minimize size and dimensions of structural components	Successful navigation of test environments/Client approval

Additional Targets:

Desired Function	Required Feature of Characteristic	Target
Portable	Incorporate collapsible or modular structural components	Collapse the device to fit within a large suitcase
Easy Access Recharge Port	Include retractable cord easily within operator reach	Client Approval
Zero Turn Radius	Independently driven wheels paired with freely rotating wheels	Successful rotation

The design process thus far has incorporated several different concepts and equipment orientations. The design team will provide a presentation of both the design history and the most current conceptual direction to Ms. Lee and the instructor stakeholders. Ms. Lee frequently provides input and review of design concepts, helping to steer the project in the proper direction. The design team has followed pre-established timelines and aims to provide an interim conceptual design for review this December. Notes and input from review of the interim design will be implemented to manufacture a device prototype in the spring.

Conceptual Development

The BMACT Industrial Group was asked to create a personal transfer device that was capable of providing assistance with sit-to-stand transfers for a person with limited mobility. Instructors and advisors initially provided a brief overview of the output requirements for this project. The device was to be tailored for Lindsay Lee, an undergraduate student at the University of Tennessee with muscular dystrophy who depends on caregivers for assistance with these maneuvers.

After interpretation of the goals and descriptions provided, team meetings were set up to employ a preliminary round of brainstorming to reach an initial direction for conceptual development for the design of the project. To address the preliminary problem definition, the design team first defined solutions on very broad terms. It was decided that the device needed to be one of three options. It could either be a whole new wheelchair with transfer abilities, an attachment to the client's existing wheelchair that would provide transfer abilities, or a separate independent device that would transfer the client. A new wheelchair would directly solve the problem without the hindrance of another wheelchair, but would require extensive engineering ideation and analysis that undergraduate students could not meet in one school year. An attachment device would be compact, but might not be able to generate enough power to lift a person. Moreover, compatibility with the existing wheelchair would have to be engineered and analyzed, possibly altering the structure of the wheelchair to provide compatibility. Finally, a separate stand-alone device would easily provide power and would be the most stable of options, but would require space analysis as well as mobile control analysis. The figure below shows one of the initial design concepts generated by the design team.

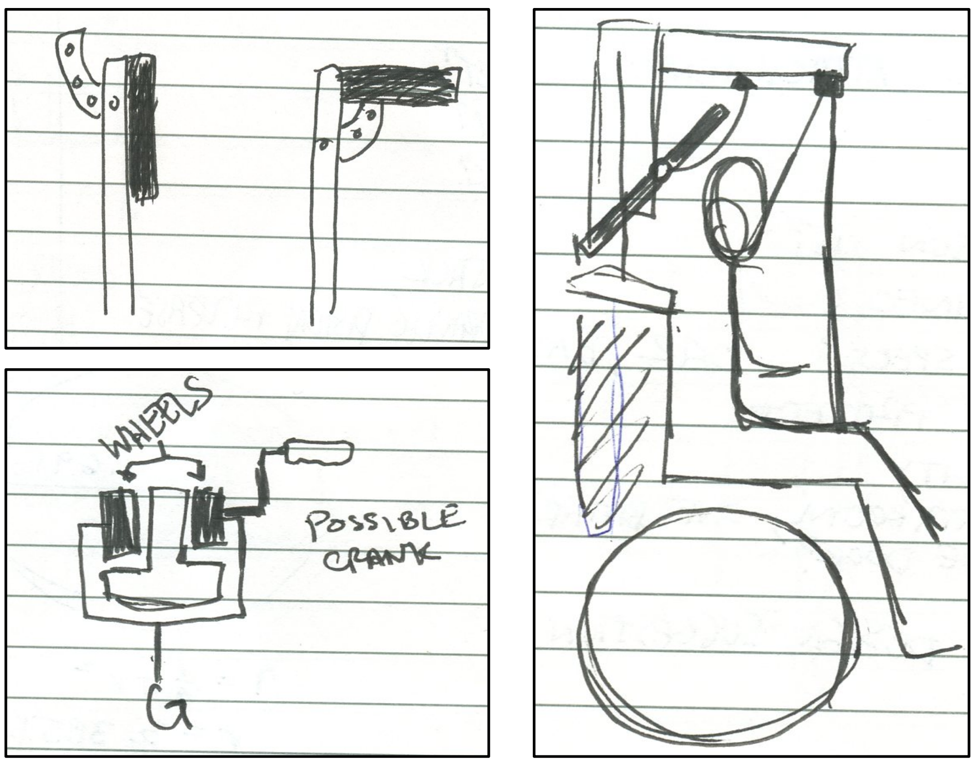


Figure 1: Sketch of wheel chair attachment design concept generated during preliminary brainstorming.

After making contact with Lindsay Lee, the client and primary stakeholder, a new direction for conceptual development determined. Lindsay desired a stand-alone lift, entirely separate from her primary electric chair. She also vocalized the exact situational lifts that would benefit her the most. This conversation also yielded exact chair dimensions, mobility requirements, and video displaying the required transfer motion. The figure below shows a sketch of one of the initial design concepts the team had developed for a standalone transfer device.

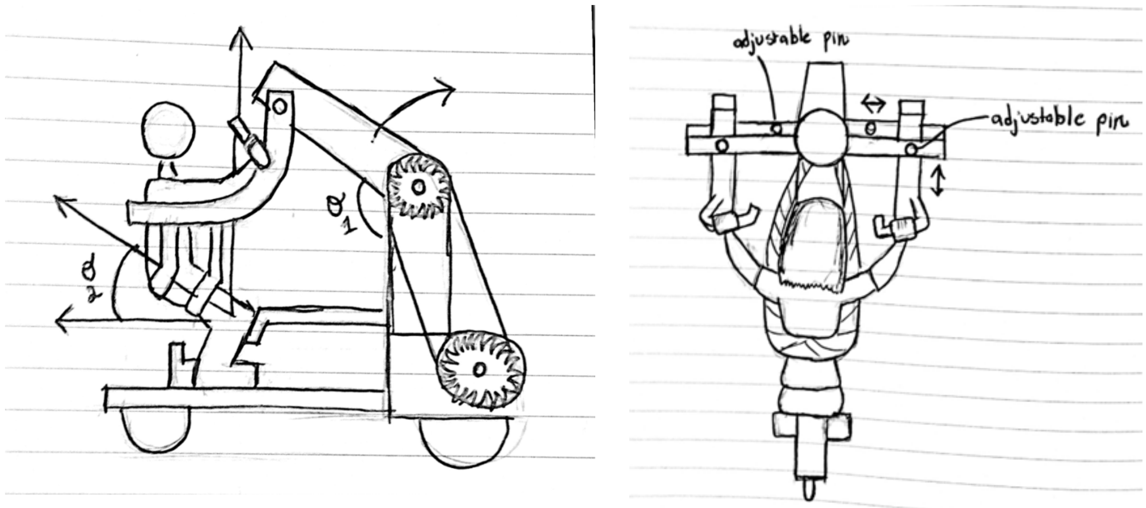
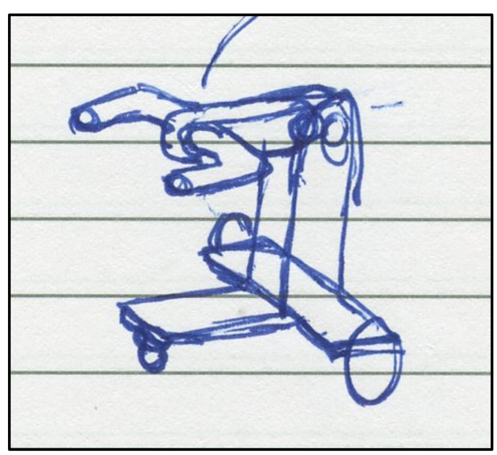


Figure 2: Sketch of standalone design concept for transfer device.

Considering concepts for the base of the design yielded many designs. The main constraint to keep in mind for the design was the size of the device. The device had to be portable, so the ability to fit through doorways was paramount to deciding a proper shape for the base.

The design team established that a square base would be a favorable choice, because it would provide adequate stability and would be simple to manufacture. However, a square base might interfere with mobility and use. Another shape choice for the base was a T-base shape like the one illustrated in the design shown below.

Figure 3: sketch of T- Base design concept.



This base shape would greatly increase mobility and maneuverability. This shape would allow the base to get closer to the client because the long base arm would reach further under the wheelchair. This would increase stability in the sense that the client's center of gravity would be inside the stable area of the device. But this would come at a cost of stability in the sense that with a T-base, the stable center is now a triangle, and would lessen the safety of the device.

To gain more ideas of design concepts for the base shape, the design team looked to pre-existing medical equipment similar to what we were trying to design. The team explored how hospital trays are constructed. The U-base of hospital trays offers superior stability because the stable center for the U-base is the same of that in a square base. The U-base would have almost as much maneuverability as the T-base and would have the added safe stability.

The design team also needed to determine how the device would interact with the user. Exploring the competitive landscape yielded many possibilities, but we had to narrow these down for the specific purpose. A harness that the client would wear would allow her to be secured and lifted up via cables or other connections. However, this device would only be used for transferring from one seat to another, so it would only be used a few times a day. Having to wear a harness all day or put it on when needed, then take it off when not needed, would be inconvenient and troublesome. Wearing a vest would provide similar benefits, as she could be hoisted comfortably from her midsection via clips on the waist and underarms of the vest. But a vest would have the same downside of inconvenience and hindrance.

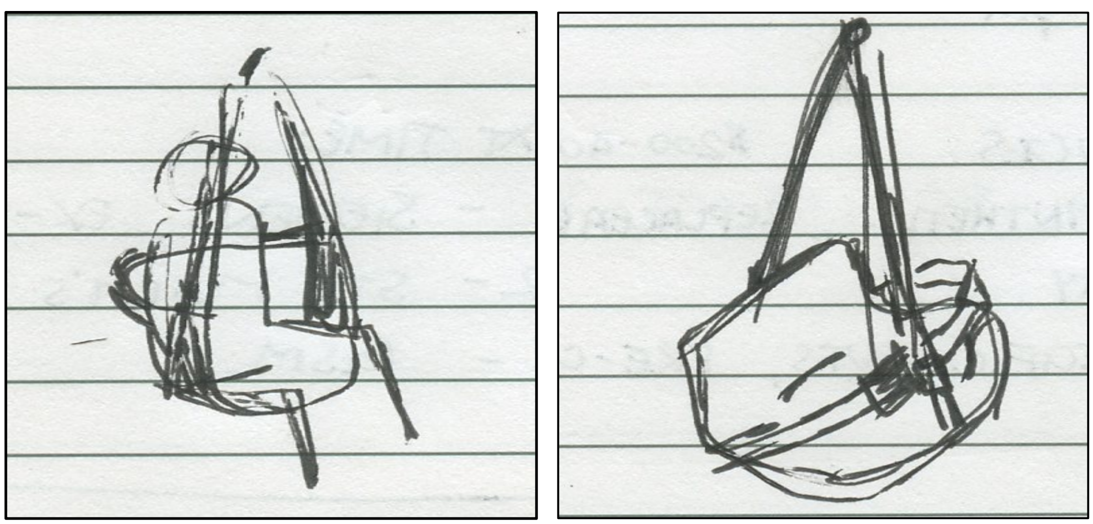


Figure 4: Sketches of possible concepts for harness or hoist.

The get a better idea of the approach needed for the design concept, the design team set up a meeting with Lindsay, in order to gain a better understanding of how she was physically transferred from one location to another by here caregiver. This yielded the ultimate design concept needed for the device. The main concept of this device is to imitate the motion of the client's existing way of transfer, i.e. an assistant lifting her up by the underarms. So an underarm lifting interface was conceptualized. A U-shaped body, with each leg of the “U,” would be placed under the client’s underarms. This would mimic an assistant’s interaction with the client very closely. This avoids the inconvenience of the vest or harness, as the U-body can easily slip in and out of the client’s underarms. However, this design, compared to the security of a vest or harness, would be less safe, as slipping off of it would be a greater concern. Obviously, safety measures would have to be put in place to implement this system.

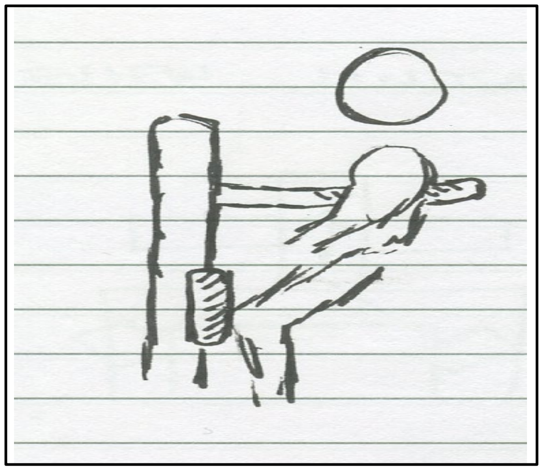


Figure 5: Sketch of ultimate design concept for the device**.**

The manner in which the device would perform the lifting was the next issue the design team had to address. A simple vertical beam on which the user-device interface would slide up and down was considered. The interface would be belt-driven or chain driven, with a motor attached to the base of the device. This would be relatively simple to engineer, but upon further inspection, would not cater well to the needs of the client. The motion required for the client is a curved path of movement; this concept would only provide linear, vertical movement.

Since mimicry of the existing familiar motion of the client was to be of utmost importance, it was decided that whatever lifted the client needed to move in an arced path. Exploring ways to accomplish this, the design team arrived at a concept that involved a geared elbow joint. A main vertical support beam would house, at the top, a gear, that was chain or belt-driven by a motor and worm gear at the bottom of this vertical beam. The top gear would be connected to an adjacent gear that would lift the “forearm” of the elbow, giving the power for the radial motion that would be required. This concept would be simple and manageable. However, the power required to generate the torque needed to move this arm would be very large and would necessitate a powerful and expensive motor.

Another concept for lifting radially was to incorporate a screw jack and cylinder attached via pins at the base of the device and along the “forearm” of the same elbow joint and vertical support described above. The screw jack would provide an inherent locking ability, locking the position of the screw when not powered. Also, the top connection along the top part of the elbow coupled with the inherent mechanical advantage of the screw resulted in a much smaller force to create the required motion. However, this arrangement would take up more space, having a bar in the inside of the joint.

In terms of mobilization, there were many concepts we conceptualized. Like an automobile, wheels could be arranged in a way that had one set of wheels turn synchronously while another set of wheels were driven by a motor. This concept would be simple to set up, but would require a turning mechanism in the wheels to be fabricated and controlled. Also, like an automobile, lateral motion is very difficult and would require much space to perform.

Another mobilization scheme ideated was one in which fthe wheels were used, and they all were powered and synchronously controlled. This would provide us with the maximum maneuverability and control. Translation and rotation would be very easily performed. However, fthe driven, synchronized wheels would be extremely complicated to organize and create.

Another mobilization method considered fthe wheels, two of which would be independently driven. These wheels would be the rear wheels which would provide rear drive capabilities. The two front wheels would be rollers and simply swivel. This “shopping cart” design would give us rotation and translation with relative ease. This has the potential to provide a zero turn radius, needing much less space to optimally orient itself in accordance with the user. This was the ultimate design concept that the design team chose for the design.

To control this device, deviation from the standard controls for such a device that would offer more benefits were hard to find. The options thought of were a joystick that would be on the device, controlling the front-back motion, as well as the rotation motion. Another scheme had two two-way switches. One switch controlled forward and backward motion and the other switch controlled clockwise and counterclockwise rotation

Product Description

The purpose of this section is to provide a detailed description of the design for the Universal Personal Transfer Device. In summary the Universal Personal Transfer Device has been designed as mechanical lift designed to provide assisted transfer to a person of limited mobility. The device allows for transition to or from a wheelchair, bed, toilet, shower, standard furniture etc.

This device is intended to eliminate the current need for outside assistance during most transitions, and allow handicapped individuals to experience more independence and privacy in everyday life. The design incorporates a solo-operated control mechanism with mounted controllers. The device is independently mobile, and powered by a rechargeable electric drive system. The current design provides the simultaneous horizontal and vertical lift motion required for transfer from one position to another. The base is designed for stability, and the drive train screw-jack mechanism used for lift acts as a natural safe guard against sudden lift failure. Mechanical structures are not large or cumbersome, and an elbow lift joint efficiently provides the motion required for safe personnel transfer. Overall, this design is mobile, compact, user friendly, and ensures compatibility with various environments.

The framework for the base of the device was constructed general-purpose low carbon steel for the tubing. **Figure 1** below shows the approximate size and dimensions for the framework of the base. The back tubing (1005 carbon) is $2'' \, x \, 2''$ with a thickness of $\frac{1}{4}$" and the front and side tubing (1026 carbon) is $\frac{1}{2}'' \, x \, \frac{1}{2}''$ with a thickness of $\frac{1}{8}$". The design team chose to bracket the tubing together in order to make the design more modular in order to fit the needs of the stakeholder. After testing the device, some welding will have to be employed however to make the device more structurally sound. Specifically the side tubing will have to be welded to the back tubing.

Weight (Framework): 26.3 lbs.

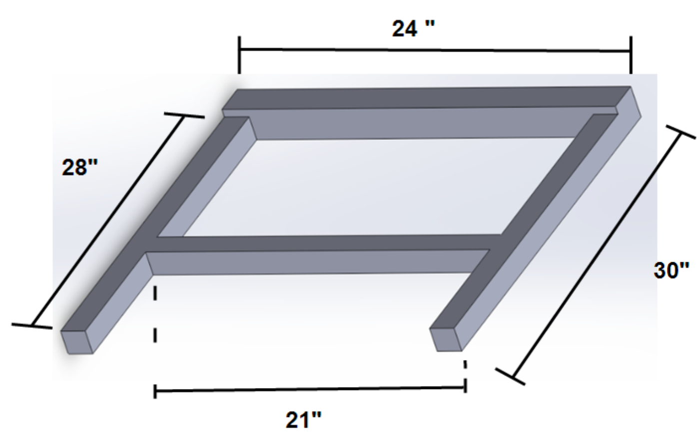


Figure 1: Dimensions for steel framework of tubing used for the base.

The base plating for the device is made from general-purpose low carbon steel (1018 carbon). This plating has yield strength of roughly 36,000 psi and a thickness of .125", and was screwed into the framework.

Weight (Plating): 11.037 lbs.

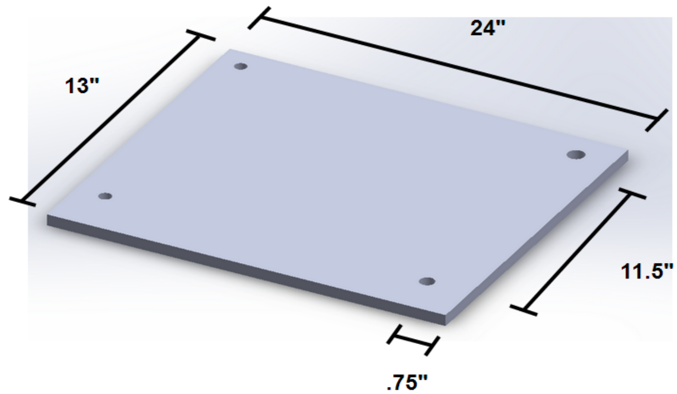


Figure 2: Base plating with dimensions.

The vertical beam used for the device was also made from general-purpose low carbon 1005-1026 steel. The tubing size is 2" x 2" with a thickness of .188" and the overall height for this beam measured approximately 32" from where it is attached to the base via fillet welding to the top of the beam. The vertical beam contains notches where two vertical forearm beams are attached via 316 stainless steel reversible clevis pins. These forearms are used as connecting members, which attach the vertical beam to the underarm supports.

Weight: 9.95 lbs.

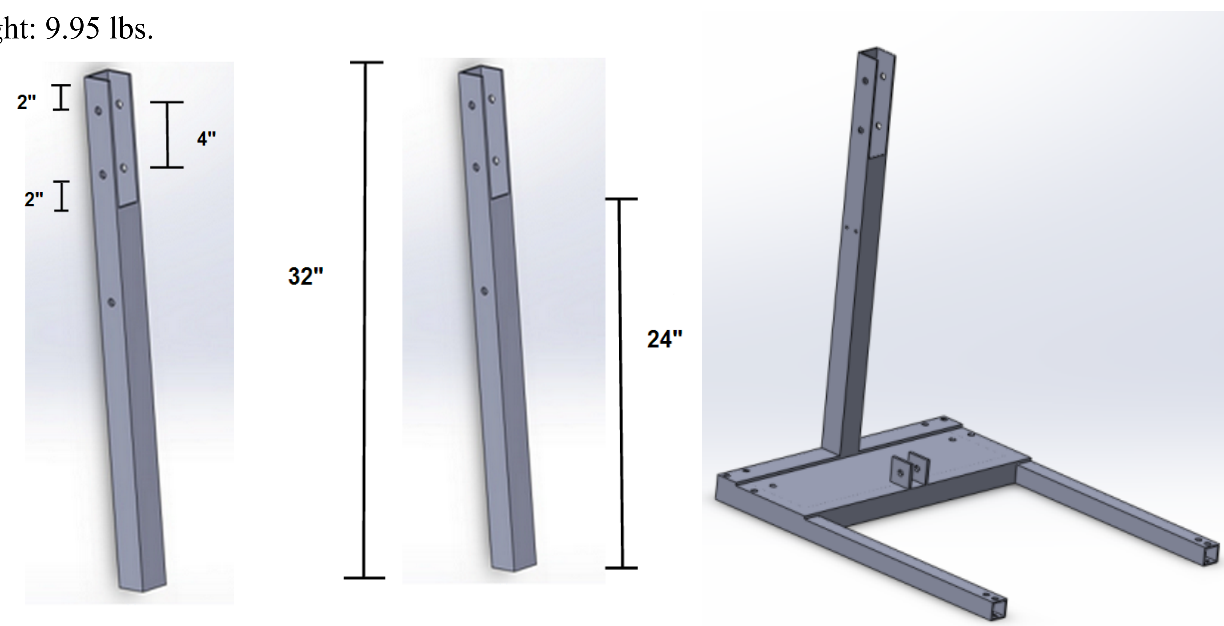


Figure 3: Dimensions for vertical beam

The connecting forearms for the device are attached to the vertical beam via reversible clevis pins as mentioned above. 6061 Aluminum steel was used for the top forearm to minimize the overall weight of the device. The dimensions for the top member are 1” x 2” with a thickness of $\frac{1}{8}$”.

The bottom forearm beam connects to the linear actuator and supports a heaver load than the top member. It is for this reason that the design team decided to use mill steel whose yield strength is higher than the aluminum support. Its yield strength is approximately 75,000 psi. The dimensions for the top member are 1” x 2” with a thickness of .65”.

Weight (Top forearm beam): 1.88 lbs.

Weight (Bottom forearm beam): 3.22 lbs.

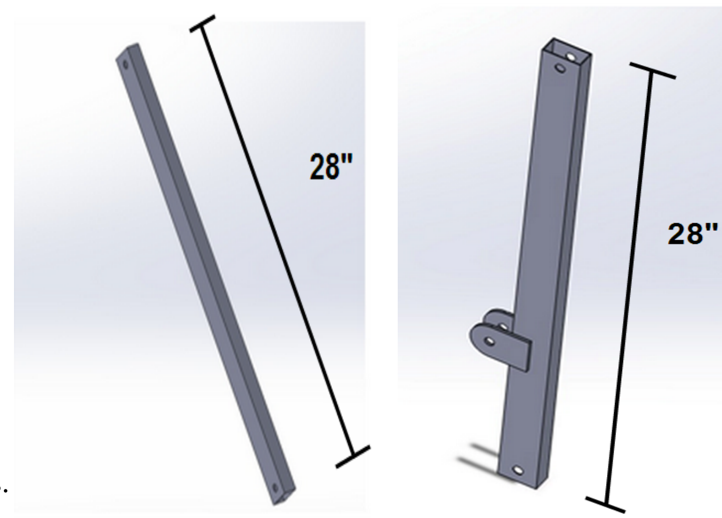


Figure 4: Forearm beams and dimensions.

The underarm support consists of essentially three main components. These include the following:

- A 9” long aluminum rectangular tube ($1\frac{3}{4}" \, x \, 1\frac{3}{4}"$) casing used for adjustability (Ultra Corrosion Resistant Architectural Aluminum Alloy 6063) that has a thickness of $\frac{1}{8}"$
- 2 Multipurpose Aluminum Alloy 6061 rectangular bars ($1.5" \, x \, 1.5$”) that have a thickness of $\frac{1}{8}"$
- A $5" \, x \, 5"$ Multipurpose Aluminum Alloy 6061 sheet with fthe connecting brackets

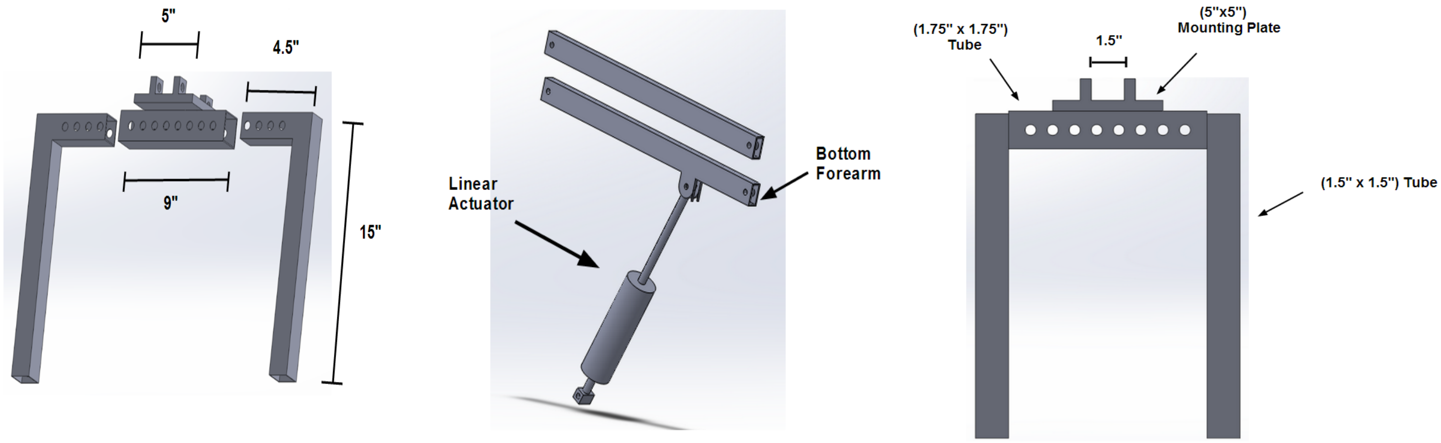


Figure 5: Illustration of underarm supports.

The underarm supports are attached to the forearm linkages via 316 reversible stainless steel clevis pins which slide through the mounting brackets welded on to the back of the (5 x 5") mounting plate.

Figure 6: Left: Clevis Pin Right: Underarm support attachment.

The device uses a thrust linear 12V actuator to provide lift needed during performace of the device. The linear actuator weighs aproximately 186.7 oz. and has an extended length of 38.78”. Its dynamic thrust capability is around 1010 lbs and its current drain is 3 Amps. The actuator is interfaced to the device through brackets located at the base (bottom of actuator) and at the bottom of the lower forearm beam (top of linear actuator).

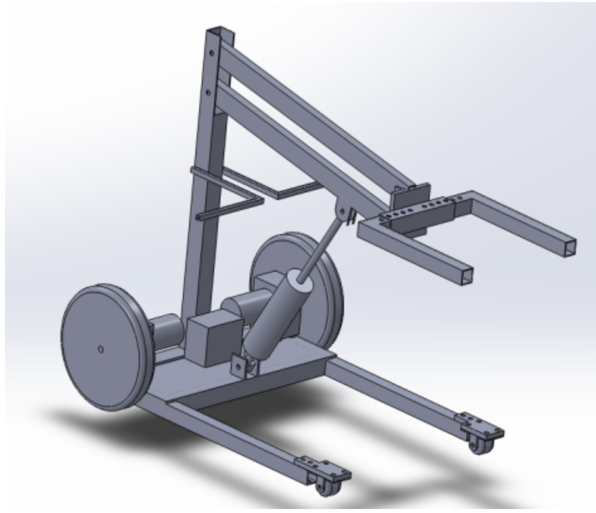


Figure 7: Illustration of the interfacing for the linear actuator.

The rear drive motors for the device were purchased from Grainger Inc., one of the several suppliers. The motors were mounted onto the base and provided a max torque of 278 in-lbs at 22 RPM. The motors had a very high to low gear ration in order to proved maximum torque while sacrificing speed which is ideal for the intended scenario of the device application.

The caster interfacing had to be changed because the placement where the motors were mounted onto the device was changed from the original design. The casters are now connected to the device via metal plates that sit on top of spacing between the caster and the caster housing plate. These plates are screwed into both the metal tubing and the spacing/caster. The wheels for the front roller are made of neoprene rubber and provide a capacity load of 300 lbs each.

2nd linkage – After testing the device, it was found that the structural integrity of the forearm linkages was lacking. The design team therefore decided to add another linkage to the forearm linkages in order to keep the spacing between the two members even.

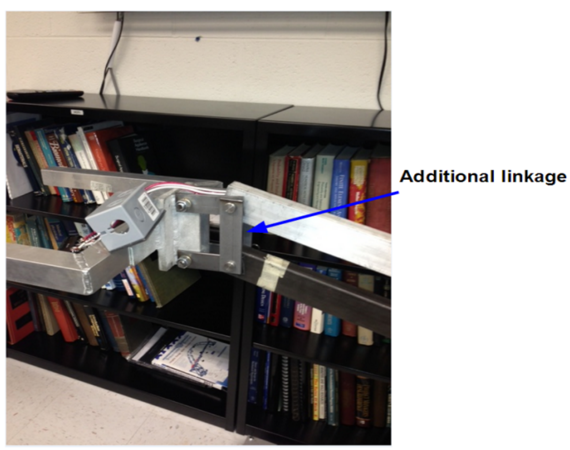


Figure 8: Additional linkage added for extra support.

The device was user operable by means of three double pole double throw switches that controlled the mobility and lift of the device.

Figure 9 shows the type of DPDT that the design team chose for the device based on economic restheces, costs, etc.

Figure 9: DPDT Switch illustration

These switches are costs effective, and they provide a quality control mechanism that allows the user to interface and control the device in a comfortable and easy way. The figure below shows a schematic of the circuit for the wired control of the device.

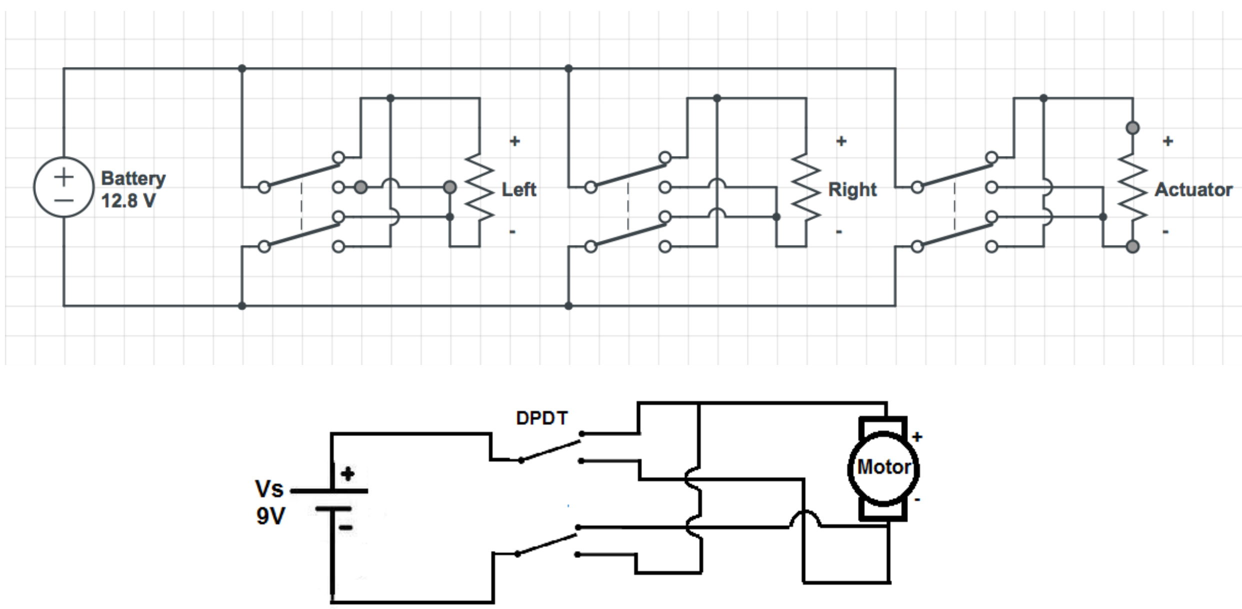


Figure 10: Top: Wired actuator control; Bottom: Wired motor control

Design Evaluation

In this section, the initial universal transfer prototype designed and constructed by BMACT for the use of Lindsay Lee will be evaluated based on the needs descriptions located in the Problem Definition section of this report. Many of the needs stated by the client require qualitative measurements, rather than quantitative. With this being said, evaluations of the device will be supported less from product testing and more from analyses of the product provided by both the client and the instructors. The needs analyzed on the device are as follows: underarm/ knee support, solo-operation, splash proof, rechargeable, stability, mobility, portability, easy access recharge port, and zero turn radius. Each need will receive a surveyed rating of completion (1-10) based on the opinions of team members and the feedback of requirements given by the client and instructors.

Underarm/ Knee Supports (5/10)

The underarm supports of the device were set as the primary user/device interface. With this being said, the safety, support, and comfort provided by the underarm supports were essential. The padding and covering over the arms of the transfer device provide maximum comfort, safety, and support throughout the entire motion of the prototype. The adjustable arm widths allow the perfect fit for various user body types. However, the knee supports could not be designed and constructed in time for the final presentation and evaluation by the instructors. With proper knee supports, the quality of the underarm/knee supports could easily reach an 8-9/10.

Solo-Operation (5/10)

The current prototype design allows the device to be fully self-operable while the user is on the device. The switches used for movement of the device are located in a comfortable position that will allow the user to remain in full control. Unfortunately, the wireless remote control for the device could not be included within the prototype. This prevents the prototype from being self-operable while the device is not within arm's reach of the user. Also, the next prototype design will include handle switches that can adjust the speed of the two wheel motors, giving the user more control with more comfortable, intuitive control switches.

Splash-Proof (8/10)

The electrical housing of the device resists a majority of water and moisture that may cause the device to malfunction. To better improve this factor, the control switches need to be housed in a waterproof container. Also, some of the wiring is not fully hidden from outside forces, which increases the chance of water and moisture from invading the device and shorting some of the electrical components.

Rechargeable (9/10)

The rechargeable battery selected for the device provides a charge strong enough to power the device through hours of use. Removal of the battery is a simple process. The battery only requires one hour on a wall station to become fully charged. While the battery is currently effective for the purpose of the prototype, stronger batteries that recharge faster are always sought to be more useful.

Stability (7/10)

The current prototype is able to lift just over 150 lbs. This does not meet the goal of 200-250 lbs. Most of this loss of stability comes from the bracketing of the base supports to one another. While the initial design asked for these pieces to be welded, time restraints forced the team to use single screw brackets to attach the base supports to one another. This results in the load bearing vertical beam creating a moment on the bottom, back support beam. This moment is fully countered by the screws located in the brackets and thus provides a failure point not originally figured in the design. Changing the support beam connections to double screw brackets or simply welding the beams together should resolve this stability issue.

Mobility (8/10)

The device is fully mobile and able to produce all the motions that were suggested by the client and instructor. Ways to improve the mobility of the device would be to add a potentiometer to the motors, allowing a more steady acceleration while the device is initially set into motion. Also, the prototype is slightly wider than initially designed, and thus provides more difficult entry through doorways and narrow halls.

Portability (5/10)

The current prototype is not able to collapse into a large suitcase the way that the client had suggested. While some pieces on the device are able to collapse or be removed, the wide base and the vertical beam are permanently attached to one another, making the device much more difficult to transport. Also, the weight of the device could be reduced by changing the material that many of the load-bearing supports are made from.

Easy-Access Recharge Port (9/10)

The battery housing the device is easy to access; being located that the foot of the device. However, the client had initially asked us to keep the recharge port at a level high enough for the user to reach without bending over. This can be solved by housing a recharge station within the device, and simply running a wire up to waist height so that the device may be plugged into the wall.

Zero-Turn Radius (8/10)

The device has a minimal turn radius with one wheel moving forward, while the other is moved backwards. This turn could be made easier by creating a switch that allows this movement to be made with one switch rather than attempting to press two switches simultaneously.

Recommendations and Future Work

This device has the potential to carve out a significant niche in the home healthcare market. The function offered by this device is previously unaddressed in the healthcare field, and being so, the need for human assistance when transferring seats could be drastically minimized, if not completely eradicated. Being the only device that serves this function on the market, the advantages conferred from this device has the potential to allow many people who would otherwise need assisted living to live independently. It could save others from the need to hire and utilize a living assistant and caretaker.

Continued development of this device would be to reevaluate the building materials and needs and select lighter, use-specific materials to build the device from. For instance, the overly robust character of the vertical beam is not needed - a lighter more portable thickness of vertical beam would have been adequate. Also, the power of the motor may have been more than what was needed. The features of knee supports and stable footrests should be installed to augment the already secure safety of use. Lastly, a more concerted effort on the electronics, such as an ergonomic control box, limit switches for the actuator, and a graded response for the motors should be exerted.

Continued effort for marketing and development would require approximately $2500 for each individual device, with cost expected to fall with increased volume. Because no such device with this function is on the market, there is no market research as to an appropriate price for such a device, but the suggested retail would be $6500.

Mass production of this product would require a large concerted effort and relatively large means of fabrication. A large amount of investment has to be contributed in order to make this product marketable.