ELEVATOR CONTROLLER FOR INDIVIDUAL WITH MS

Biomedical Engineering Design 201
University of Wisconsin - Madison

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Abstract: The goal of this project is to create a device that will enable an individual with limited mobility to press elevator call buttons in multiple hallways, as well as the internal elevator control buttons. Design constraints are defined by the environment in which the device must operate as well as the user's physical capabilities. The mechanical components of this project are the main focus of this semester, with signal integration and attachment to the wheelchair as secondary stages we plan on developing in the future. While we drafted three designs to fulfill the initial requirements defined by the client and user, subsequent alterations to the constraints dictated the development of a completely novel final design, a 6-bar mechanism attached to a vertically telescoping arm.

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Problem Statement

Our project involves the design of a device capable of covering the distance from a wheelchair to an elevator call button in the x and y directions. It must then exert a horizontal force sufficient to successfully push the call buttons in both the standard elevator car and the corresponding hallway. The mechanism must either be directed by infrared signals (to be later integrated into a voice-controlled adaptive technology system) or be controlled by another stimulus generated by movement no lower than the user's neck.

Motivation

Our client, Dr. Fleming, currently treats a patient with multiple sclerosis (MS). This patient, who shall be referred to as D.P., was fully mobile earlier in life, but has since been diagnosed with MS. The early stages of the disease consisted of attacks followed by partial recovery, but now MS has progressed and left him nearly paralyzed from the neck down. D.P. retained minimal use of his right hand for some time, but lack of use has led to atrophy of this last appendage. He lives independently in a second-floor apartment by making use of infrared technology produced by SiCare; this system allows him to operate many household appliances with his voice alone. D.P. can control his lights, fan, TV, DVD player, and change the channels and volume on the latter devices by speaking the appropriate command. Similarly, D.P. can nudge a switch mounted on his wheelchair to open the main apartment door.

When D.P. leaves his apartment, he travels around using the Madison Metro bus service, and is thus very mobile. The rate-limiting step, however, is his inability to press the elevator buttons in his apartment complex to move between his apartment and the building exit. He is dependent on others to press the elevator call button in the hallway as well as the appropriate floor button in the elevator. When no one is available in the apartment to assist D.P., he is unable to travel between his home and any exterior environments (1). Our device aims to provide D.P. with a means by which he can press the elevator buttons and thus get around independently.

Background Information: Multiple Sclerosis

Multiple sclerosis is an autoimmune disease currently affecting over 400,000 Americans. Individuals with MS sustain damage to the central nervous system, which includes the brain, spinal cord, and optic nerves. A protective layer of myelin, a fatty tissue, normally covers the nerves of the central nervous system and helps relay electrical impulses (neural messages) to and from the brain (3). In individuals with MS, myelin is lost in many areas of the brain and spinal cord leaving sclerosis, or the hardening of tissue. In some cases, loss of myelin also leads to the damage of axons and complete loss of brain tissue. These anatomical changes all impair the ability of the central nervous system to conduct electrical impulses (2).

MS is most common among northern Europeans and their ancestors, and it is two to three times more common in women than in men. Studies show that genetics may make some individuals more susceptible to the disease, though it does not appear to be inherited directly. Aside from genetics and gender, environment may also play a role in causing the immune system to attack myelin (2).

Attacks on myelin are random, and cause what are known as relapses. In relapsing-remitting MS, the most common form of the disease at diagnosis, individuals experience clearly defined periods of neurological worsening, followed by partial or total recovery. These attacks usually occur during early to middle adulthood, so most individuals with MS are diagnosed between the ages of 20 and 50. About half of the individuals that initially have relapsing-remitting MS develop the secondary-progressive form of the disease within 10 years, characterized by a steady worsening of symptoms (2).

MS produces unpredictable symptoms that vary both from person to person and throughout the course of the disease. The most common symptoms include fatigue, trouble walking and balancing, bowel and bladder dysfunction, vision problems, abnormal sensations such as numbness, changes in cognitive function, pain, depression, and mood swings. All of these symptoms are a direct result of demyelination, and although no cure is known to date, many treatment options are available. Physical therapy and cognitive rehabilitation can be beneficial to individuals living with MS, as well as prescription of a “disease-modifying drug” which can slow the progression of the disease (2).

Background Information: Available Controls

Due to D.P.’s physical limitations, any movement required for the control of our device must be limited to that generated at and above the neck. The voice activation technology developed by SiCare works by transmitting a specific infrared signal to a device which has been programmed to receive that signal. A particular voice command sends out the appropriate signal, which is received only by the intended device. Appliances such as the television are already equipped with infrared receptors since television remote controls use infrared technology. Devices such as a lamp that do not contain an infrared receptor, however, must be plugged into a module which is subsequently plugged into a 110 volt AC outlet. The module receives the infrared signal and translates it into X10 radio waves, which in turn closes the circuit (4). If infrared is to be used in controlling the movements of our device, an infrared receptor must be present on the device since an AC outlet is not available in the elevator environment. D.P. already has the infrared transmitter mounted on his chair, so incorporation of the infrared technology would make use of the unused signals that his transmitter can produce.

Another option for controlling the device is a mouth joystick. Such joysticks are currently used to control wheelchairs and other devices such as computers. In the case of a computer, the mouth joystick acts as a mouse to move the cursor about the computer screen. Head motions dictate the position of the cursor, and a sipping or puffing breath acts as a mouse click (6). Similarly, some wheelchair controllers are available that use a sip or puff of air to control the direction. In the simplest cases, a sip/puff switch can be responsible for a single function. In our device, a sip/puff switch may be used to close the circuit and cause the device to move in a particular direction. Also, simple touch switches may be used to serve the same purpose. For example, membrane switches require a touch but no pressure to send an electric signal. These switches are relatively inexpensive (as low as $46.00) and could be mounted on the headrest of D.P.'s chair (5). A specific head movement could bring the cheek or ear in contact with the switch and thus cause the device to move.

Design Constraints:

Elevator and hallway environments

In order to ensure full functionality of the device, all spatial limitations in the user's environment must be taken into account, but due to this project's specificity, these are relatively few in number. After an initial meeting with the patient in his apartment building, we determined that the four major constraining variables were the multiple button heights, limited maneuverability of the wheelchair, limited space within the elevator, and the minimum force needed to push a button in any of the environments.

Within the hallway environments on the first and second floors, there are only two situations where the user will employ the device; he will either need to press the call buttons several feet from the hallway elevator door or press the automatic door button in the main first-floor lobby to exit the building. The hallway and lobby environments as a whole do not pose any maneuverability issues as the user can easily align the wheelchair parallel to the wall, creating a 90° angle between the side of the chair and the line of force necessary to push the button. The vertical extension component of the device is specifically constrained by the various button heights, which range from 20.51 – 47.24 inches above the floor in the elevator environment, and 35.98 to 44.88 inches above the floor in any of the hallway environments (Tables 1 and 2).

Table 1. The function and height for first floor lobby/hallway and second floor hallway buttons (floor indicated in parentheses)

Button function (floor)	Height (in)
Elevator up (1)	44.25
Elevator down (1)	39.25
Open automatic door (1)	36.00
Elevator up (2)	45.00
Elevator down (2)	40.00

Table 2. The function and height (from the floor to the center of each button) of all necessary elevator cab buttons.

Function	Height (in)
Help	20.50
Alarm	35.00
Open door	37.125 (left of center)
Close door	37.125 (right of center)
Basement	41.125
Floor 1	43.125
Floor 2	45.125
Floor 3	47.125

The final constraint requires the device to be able to exert a force sufficient to activate each button. When testing was performed in the apartment building, the maximum force for the entire set of buttons (other than the "Help" and "Alarm" buttons which we will assume fall under the same requirements as the others) was 4.45 – 8.90 N (1-2 pounds). We plan on incorporating a safety factor of four with this parameter since it is a crucial component for effective operation of the device. A minimum force of approximately 36 N is therefore required of the pushing part of the device.

Interface between device and existing wheelchair structure

In order to ensure that the addition of this device to the user's wheelchair will not interfere with normal operation and maneuverability, we must determine the maximum possible dimensions we can add to its structure. The length of the user's chair, from the footrests to the back handles, is 48 inches; the distance between the user's elbows on the armrests is 28 inches. From measurements taken in the user's apartment building, we concluded that to maintain easy maneuverability through doorways, the wheelchair may have a total width of no more than 35 inches. This leaves a width of 7 inches total within which we may add device components (Figure 1). The maximum height of the device will also be constrained by the original wheelchair structure since it will have to be attached. The most feasible location for mounting the device appears to be on the "knee curve" of the chair (Figure 2), a component that is not removable and thus should not pose any problems with chair use or maintenance. When the user was asked to position his wheelchair parallel to the button wall of the elevator, his left-hand side was five inches away from the wall surface (Figure 3), necessitating only two dimensions of movement in the design (vertically depending on the desired floor or elevator function and horizontally to engage the target button).

Figure 1. Illustration of maximum dimension allowed on one side of user's wheelchair to preserve normal maneuverability through standard doorways (width of 35 in).

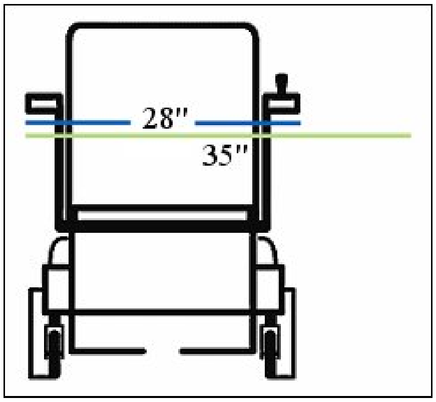


Figure 2. Knee curve component of user's wheelchair (A) lined up with the elevator buttons in the user's apartment.

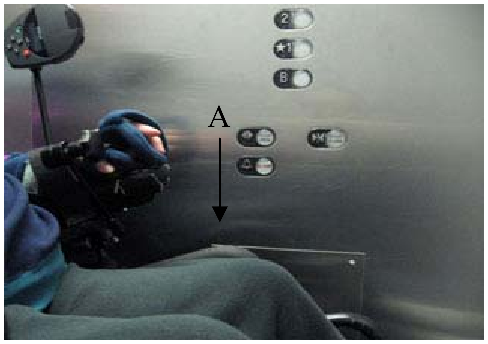


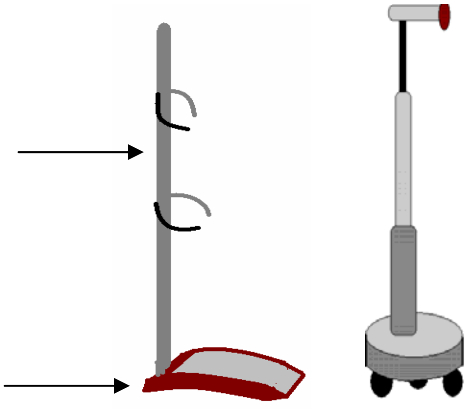
Figure 3. User's wheelchair in optimal position parallel to the elevator wall containing the buttons.

Early Design Ideas

Design #1: Robotic Car

This design incorporated aspects of several different products available today, each one slightly modified to adjust to our requirements. The theme behind this device was a remote-controlled car that the user operates and directs to the buttons (Figure 4). Vertical and horizontal motion was to be accomplished by raising or lowering a telescoping rod, then driving the robotic car towards the wall to engage the desired button. A docking station was also proposed to house the device while not in use and would be the component attached to the wheelchair (Figure 4). Disadvantages of this design were the high expected cost and degree of complexity in drafting and construction. If feasible, however, the device would have provided a very accurate means of pressing the elevator buttons.

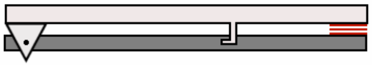
Figure 4. Three-wheeled robotic car with a telescoping rod connected to a pushing shaft and the docking station for device storage. Connection points are denoted by arrows.



Design #2: Spring-powered arm

Our second proposed design consisted of a rotating arm installed on a vertical column which allows for motion along all three axes. Horizontal motion would be generated by rotation of the arm (Figure 5) while vertical adjustment would be performed by a rack-and-pinion system (Figure 6). The force needed to press a button would be produced either by means of a spring located at the end of the arm opposite the hinge or by a simple motor. In either case, storage of the arm when not in use would be achieved with the use of a releasable catch connecting the arm and mounting plate. While this device would have had simpler components than the robotic car, the motors needed for both vertical and horizontal motion may have been expensive.

Figure 5. Top view of arm component of design 2. Spring option is shown at the right of the figure in red. Releasable catch is shown in the center of the arm.



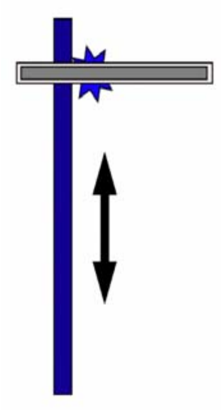


Figure 6. Side view of vertical column component, demonstrating the rack-and-pinion option for the desired motion.

Design #3: Crane

The third device was designed to mimic the capabilities of a mechanical crane by using a pulley system to raise an arm up and away from its supporting rod (Figure 7). Further vertical adjustment could have been accomplished by incorporating a telescoping rod into the device. Engaging a button would be accomplished by pulling the cable that runs the length of all included rods, causing a pushing shaft to swing forward and up to cover the horizontal distance necessary. Benefits of this design would have been its relative simplicity and low production costs, while disadvantages included its large size and questionable range of motion in the vertical direction.

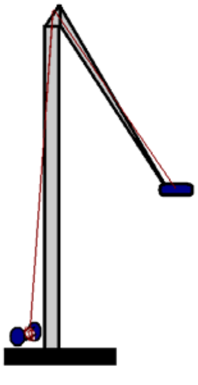


Figure 7. Side view of the crane proposed as design #3. The crank used to control cable tension and thus raise the pushing shaft towards the intended button is at the base of the longer rod.

Evaluation of early designs

An early assessment of our design ideas included several important categories, which may also be applied to the final design. Accuracy, ease of operation, durability, ease of construction and part replacement, estimated cost, and size were all characteristics that warranted discussion when choosing a direction for the prototype.

One of the most important aspects of the design is accuracy; if the user picks a button that he wants to push, the device must line up with and activate the target button. The robotic car had a significant advantage over the spring-powered arm and the crane in terms of accuracy due to the car's ability to easily make small, precise movements.

Another important consideration is ease of operation for the user. The device must be simple for the user to control with the least amount of interference to his routine. The number of individual parts that the user must learn to operate is a large contributing factor in the scoring of this category. A design such as the crane would be more difficult for the user to operate based on the complexity of directing multiple motors.

We included several other categories in the scoring of our first three designs, as can be seen in Table 3. The categories listed in the far left hand column are weighted out of 100 on the next column to the right. Since accuracy and ease of operation were the two most important conditions, they received the highest weight, with durability, ease of construction/part replacement, estimated cost, and size filling in the rest of the matrix.

Table 3. Matrix ranking important aspects of each proposed design.

	Weight	Robotic Car	Spring-loaded Arm	The Crane
Accuracy	25	20	15	15
Ease of operation	25	20	20	18
Durability	15	7	10	10
Ease of construction/part replacement	15	4	8	10
Estimated Cost	10	3	7	7
Size	10	7	9	8
TOTAL	100	61	69	68

Final Design

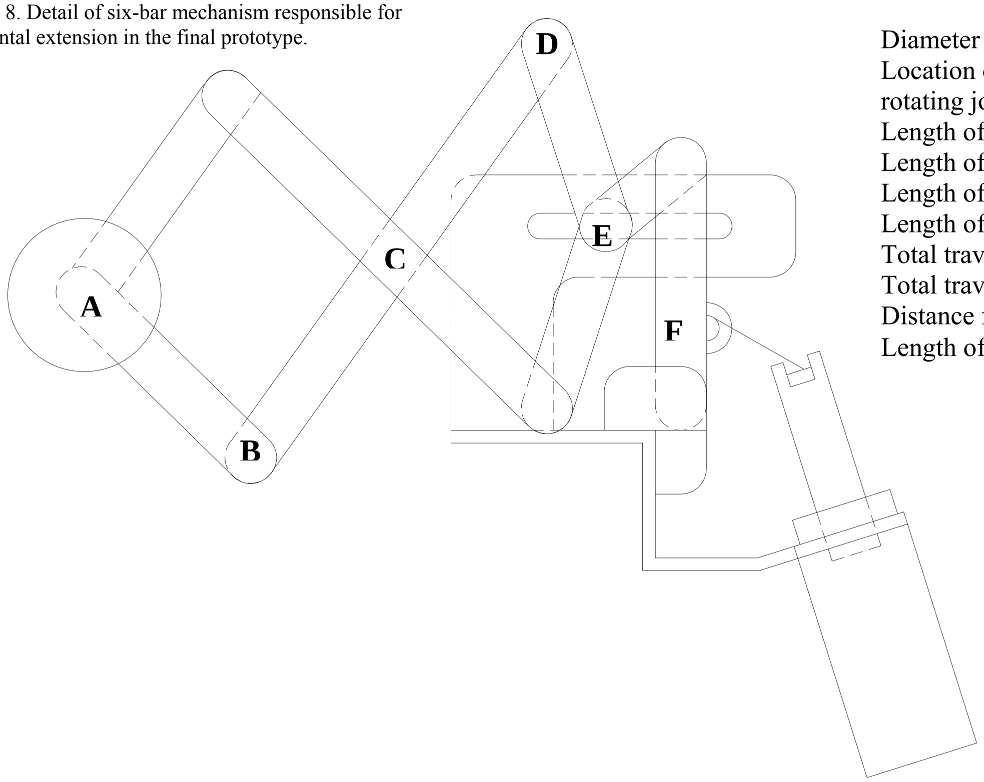
Our final design deviates from the three early designs due to updated constraints we obtained in the middle of the semester and further guidance from faculty on campus. The device is comprised of a six-bar pushing mechanism controlled by a solenoid, all of which is mounted on a platform on top of a linear actuator (Appendix C). We purchased a linear actuator with a 12" stroke to travel the vertical distance between the elevator buttons. This actuator is controlled by a toggle switch, in which the neutral position disconnects the circuit, while moving the switch left or right corresponds to moving the actuator up or down. We enclosed the base of the actuator in a rectangular metal box for protection and mounting purposes. Upon running the device, we discovered that as the actuator rod moves up and down, it also rotates slightly. This rotation is unnecessary for the extension of the device, and would cause the platform mounted on top of it to rotate as well. To eliminate this problem, we welded a hollow rod into the casing of the linear actuator, parallel to the direction of extension. A smaller rod is welded to the bottom of the platform, and runs inside the hollow rod, thereby acting as a guide to prevent rotation.

The pushing mechanism atop the linear actuator is constructed from six steel bars connected by a smaller bar to a hinged lever arm. After considering several designs that involved pushing mechanism rotating about a hinge, we decided on this design because it offers the advantage of purely horizontal motion. Since this device travels perpendicularly to the plane of the buttons, it will be easy for the user to line up properly, thereby increasing ease of use and accuracy. The six bars of the pushing mechanism are connected by bolts in a scissors pattern creating two deformable squares (Figure 8). Pulling the outermost bolt (joint A) away from the mounting platform causes the device to extend horizontally. Bolt E, located the farthest from the elevator buttons, is positioned inside a horizontal track to prevent the entire mechanism from rotating about the central mounted bolt (C). The metal plate containing the track is welded perpendicularly on top of the mounting platform.

The motion of the pushing mechanism is generated by a pull solenoid with a 1” stroke which is activated by a momentary contact switch. Pressing the switch sends a current through the solenoid, causing its central rod to retract into the encompassing cylinder a maximum distance of 1 inch. When the solenoid is not activated, the central rod is suspended approximately 1 inch above the bottom of the cylinder by a small wire which is attached to the lever arm of the pushing mechanism. The wire is connected to the lever arm at a distance of 1” from the hinge, and when the solenoid generates 1” of rotational motion, the top of the lever arm initiates movement of the bolt at joint E along the guide groove such that E travels 1.8” away from joint A. All of the bars are connected by nuts and bolts that allow the bars to rotate freely relative to one another. When the guided bolt is pulled towards the solenoid, the six-bar mechanism extends horizontally away from the solenoid a distance of 3 inches. At the tip of the six-bar mechanism opposite the solenoid (joint A), a rubber cylinder is attached to either side of the bolt. These two rubber cylinders protrude farther than the metal parts, thereby providing a surface to make contact with the buttons and prevent the device from damaging them. After the momentary contact switch is released, the solenoid is inactivated, allowing the lever arm to return to its original position. A spring attaching the six-bar mechanism to the mounting platform generates the force needed to pull the mechanism back into its fully retracted position.

The pushing components of the device, including the six-bar mechanism and the two bars connecting it to the solenoid, are mounted on a steel platform. The platform is designed so that the central bolt of the six-bar mechanism and the horizontal guide are mounted on the outermost horizontal surface. The lever arm is mounted at the location where the platform is bent downward into a right angle, and the platform angles upward where the solenoid is attached. This positions the solenoid so that it is pointing at the base of the lever arm to which it is attached. This setup was designed to maximize the use of the 1” stroke that the solenoid is capable of producing.

Figure 8. Detail of six-bar mechanism responsible for horizontal extension in the final prototype.



Diameter of stopper at **A**: 1.5”
Location of eyehole at **F** above rotating joint: 1”
Length of **B** to **D**: 4”
Length of **D** to **E**: 1.5”
Length of **A** to **B**: 2.5”
Length of guide groove: 2.2”
Total travel of stopper **A**: 3”
Total travel of bolt at **E**: 1.8”
Distance from **E** to bar **F**: 1.5”
Length of bar **F**: 2.5”

Prototype Testing

Initial testing consisted of mounting the device with an angled plate a distance of 5 inches away from a wall and activating the actuator and solenoid to hit drawn buttons. When tested on the elevator buttons at the Engineering Centers Building, we had found that our device exerts enough force to push and thereby engage a button, but the difficulties of operating the device lie in the fact that the device occasionally “binds” and will not retract completely into its storage position. We would still like to test the ability of the device to activate the elevator buttons at the patient's place of residence; however, a meeting could not be arranged so this will have to be postponed to a later time.

For the actual testing of our device, we performed three separate trials of 20 pushes each. We counted the number of times that the device hit the button and then recorded how far back it retracted. For the initial trial (Table 4), nothing was done to alter the device from how it has been stored since construction. Trial #2 (Table 5) differed in that adjustments were made to the tightness of two nut/bolt combinations and a small amount of the lubricant WD-40 was applied to the adjusted joints. Trial #3 (Table 6) was performed with a small amount of WD-40 applied to the guide slot through which the bolt at joint E travels. These adjustments are comparable to proper maintenance of the device.

Prototype Testing: Results

Table 4. Results from testing trial #1 of the device in which no adjustments or lubrication was performed on the upper six-bar mechanism.

Test/Push Number	**Fully Retracted**	**Mostly Retracted (40-75%)**	**No Retraction-Stuck**	**Hits Target**
1	X			X
2	X			X
3	X			X
4	X			X
5	X			X
6	X			X
7	X			X
8	X			X
9	X			X
10	X			X
11			X	X
12	X			X
13	X			X
14	X			X
15	X			X
16		X		X
17	X			X
18		X		X
19		X		X
20	X			X

Results: 16/20 fully retracted
3/20 mostly retracted
1/20 no retraction

Prototype Testing: Results continued

Table 5. Trial with joint adjustments and center slide lubrication

Test/Push Number	Fully retracted	Mostly Retracted (40-75%)	No Retraction - Stuck	Hits Target
1	X			X
2		X		X
3	X			X
4	X			X
5	X			X
6		X		X
7		X		X
8			X	X
9		X		X
10		X		X
11		X		X
12	X			X
13		X		X
14	X			X
15	X			X
16	X			X
17	X			X
18	X			X
19	X			X
20	X			X

Results: 12/20 fully retracted
7/20 mostly retracted
1/20 stuck

Table 6. Trial with center slide lubrication only

Test/Push Number	Fully Retracted	Mostly Retracted (40-75%)	No Retraction- Stuck	Hits Target
1	X			X
2	X			X
3	X			X
4	X			X
5	X			X
6	X			X
7	X			X
8	X			X
9	X			X
10	X			X
11	X			X
12	X			X
13	X			X
14		X		X
15	X			X
16	X			X
17	X			X
18	X			X
19	X			X
20	X			X

Results: 19/20 fully retracted
1/20 mostly retracted
0/20 no retraction

Table 7. Summary of trials demonstrating the effect of lubrication and joint adjustment on the ability of the six-bar mechanism to fully retract into its storage position.

	Percent Fully Retracted	Percent Mostly Retracted	Percent No Retraction
Trial 1	60.0%	35.0%	5.0%
Trial 2	80.0%	15.0%	5.0%
Trial 3	95.0%	5.0%	0.0%
Overall	78.3%	18.3%	3.3%
Trials 2 and 3	87.5%	10.0%	2.5%

Combining all trials, our device retracted fully 78.3% of the time (Table 7). With proper maintenance such as frequent application of WD-40, however, the device could be operated without major problems 87.5% of the time (Table 7). Simple maintenance performed by the patient's aid several times per week may be sufficient, but the optimal frequency of maintenance needs to be determined by long-term testing.

Lastly, while testing in the user's elevator is a definite necessity before any further development of the device is performed, we also feel that testing after mounting or determining user-friendly controlling is also necessary. Mounting the device will provide stability for operation of the prototype and establish a defined range of vertical motion which the device must cover. We would like to develop a test in the future that can accurately measure the amount of force that the device is exerting rather than simply testing its effect on a variety of buttons. Such a test would also tell us if the force exerted is too strong and has the potential of breaking weaker elevator buttons, a situation we have not yet encountered in testing the prototype.

Problems and Possible Resolutions

Though the mechanical aspects of our device are nearly completed, several issues remained unresolved. As of now, one of the main problems is that the principal actuator used for vertical motion does not extend the full, advertised 12 inches. With a rise of only 7.5 inches, the actuator currently does not cover the full distance between the elevator buttons. The actuator seems to provide a sufficient length of housing material to extend the full amount, so we are hoping to resolve this issue by finding someone who knows more about electronics and determine if the problem exists in the wiring.

Another issue that we would like to resolve is that we were not able to set up a meeting with the patient to test our device on the elevator buttons in his apartment. Testing at the Engineering Centers Building demonstrated that the device is accurate enough to activate a targeted button every time it is lined up properly; results also showed that some issues exist with regards to smooth operation of the extension and retraction motions. While this initial phase of testing confirms the feasibility of our design, it will be important to not only test the device independent of the wheelchair in the user's apartment, but also once it is mounted correctly.

Ideally, the device will be almost entirely weatherproof, a characteristic we have begun to develop by enclosing the actuator itself in a metal case; in the future, containment of the upper 6-bar component may be necessary. We have chosen to postpone this step in order to have free access to the mechanical parts of the device during early testing stages this spring and for any possible development in future semesters.

We did accomplish our goal of completing the mechanical aspects of this project, but work still needs to be done regarding the integration of a user-friendly control mechanism that uses either infrared signaling or no-pressure touch buttons. Mounting the device to the wheelchair and helping the patient integrate it into his life are also issues to be dealt with in the future.

Conclusion:

Overall, we have designed a device that will enable an individual with limited mobility to gain further independence in his daily life. When our device is incorporated onto his wheelchair, the user will be able to enter and leave his apartment without the human assistance he currently relies on. It is important that we test our device in the user's apartment to ensure that it is both accurate and reliable before it is mounted onto his chair. Similarly, after mounting, further testing needs to be done to ensure that the device will not fail and require the user to again depend on others for assistance. Finally, our device has the potential to be customized and implemented on the wheelchairs of other individuals with restricted mobility for similar purposes.

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Appendix A: Product Design Specifications

Elevator Controller with Individual with Multiple Sclerosis
Product Design Specifications

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Problem Statement/Function:
Our project involves the design of a device capable of covering the distance from a wheelchair to an elevator call button in the x and y directions, then exerting a horizontal force sufficient to successfully push the call buttons in both the standard elevator car and the corresponding hallway. The mechanism must either be directed by infrared signals (to be later integrated into a voice-controlled adaptive technology system) or be controlled by another stimulus generated by movement no lower than the user's neck.

Client Requirements:
- Device must be able to push normal elevator buttons both inside and outside of the elevator, including the help/alarm buttons
- Optimally, this device will be integrated into the patient's voice-activation technology to minimize the necessity of muscle involvement (cannot make use of any limbs)
- Device does not need to be universal with respect to the elevator controls in other buildings

Design Requirements:
1) Physical and Operational Characteristics
    a) Performance
    - Used multiple times daily
    - Ability of pushing component to exert a minimum force of 2 lbs, preferably 4-5 lbs
    b) Safety
    - Can't alter normal wheelchair or elevator operations
    - Forces exerted by moving parts should not endanger the user or bystander
    - Device should be capable of pressing help button in case of emergency
    - Device controls should not compromise ease of use of current wheelchair controls

c) Accuracy & Reliability
- Should be able to move to a specific button based on the input of the user
- Should provide visual feedback about the position of the pushing component
- Should operate in the vertical direction at a speed conducive to making small adjustments

d) Life in Service
- 10 years or until upgraded parts are available
- Individual parts should be easily serviceable as needed (including batteries)
- Each individual part should withstand use at least 5 times per day

e) Operating Environment
- Weatherproof: temperature ranges from 20-90 degrees Fahrenheit, humidity and rain
- Must withstand vibrations and dust upheaval caused by wheelchair motion, especially over uneven/bumpy terrain

f) Ergonomics
- Should not require physical interaction, with the exception of head/mouth movement

g) Size
- Total width of chair and device may not exceed 35" and should be significantly less to avoid unnecessary maneuvering by the patient
- Height of device should be minimized while in storage
- Additional dimensions of device should not cause unnecessary adjustments to normal movement (turning corners, etc.)

h) Weight
- Device should not compromise the existing stability of the wheelchair

i) Materials/Aesthetics & Appearance
- Exterior materials should be weatherproof
- Simple user interface
- Uncluttered components

2) Production Characteristics

a) Quantity
- One unit needed for individual client

b) Target Product Cost
- Minimize overall cost, preferably under $200
- Manufacturing/parts costs
  (1) Linear actuator - $100
  (2) Solenoid - $10-30
  (3) Miscellaneous - $20
  (4) Metal – free scrap + $30

3) Miscellaneous

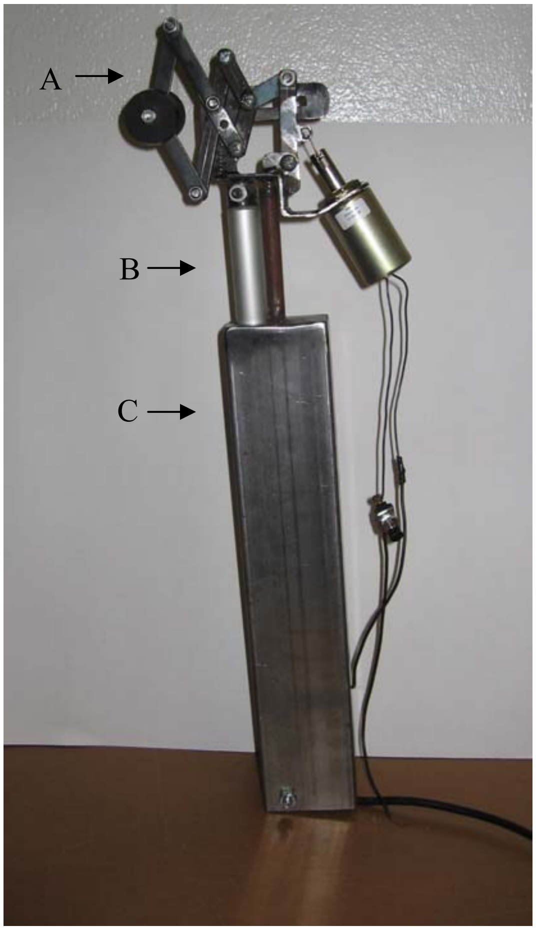
a) Competition
- Patent searches returned no similar devices (but components may be individually patented)

b) User Preferences—Control
- User prefers device be controlled using preexisting infrared signaling so voice commands can be used

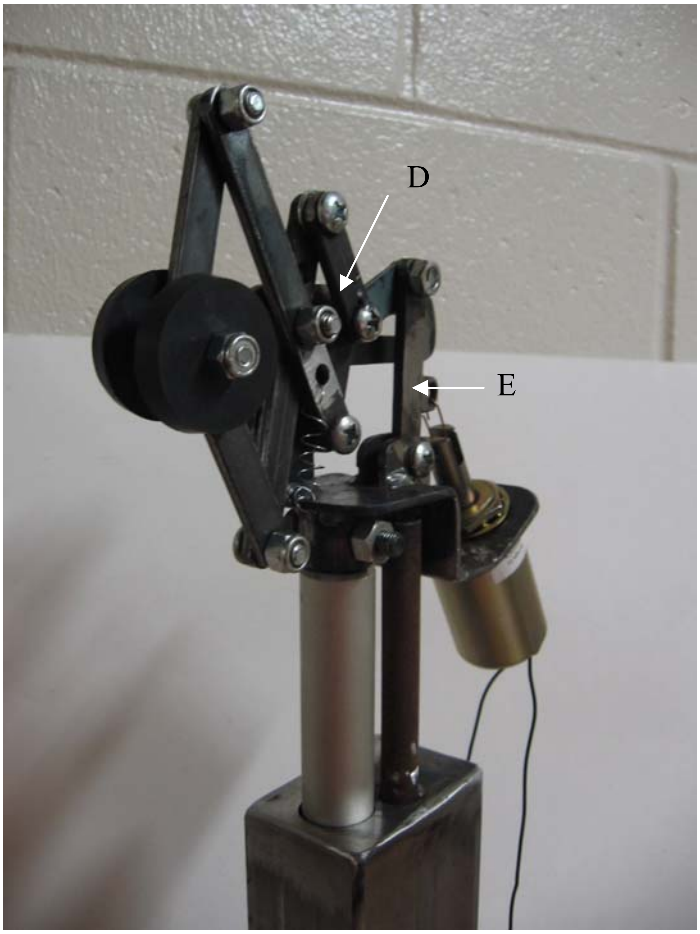
Appendix B: Expenses

DATE	ITEM	COST	COMMENTS
04.01.2006	Linear actuator	$102.00	12” stroke, ~ 30 seconds for full extension, 20” retracted length * price included shipping
04.11.2006	Platform and button-pressing bars	Donated	Available material donated by the Matsick family; steel platform approximately 3” x 2” x 0.25”, bars made of aluminum – vary in length, ¼” thick
04.13.2006	12 V battery	$35.17	For testing and demonstration purposes
04.13.2006	Flanged cap	*	≥ 18.32 mm interior diameter, intended for mounting bar platform to top of linear actuator – handmade, metal
04.13.2006	Extension spring	*	Used to pull bar back up to its vertical position after the 1” solenoid completes its motion.
04.13.2006	Rubber stoppers (2)	*	To minimize damage of buttons – ¼” thick, attached to outermost joint of 6-bar mechanism
04.13.2006	Hinge for button-pressing bar	*	Chest hinge: max. width of 3”, “stopper” plate used to prevent unwanted rotation, bar should be held vertically while not engaged * *Note: not used in final prototype*
04.13.2006	Cord	*	35 lb load limit * *Note: not used in final prototype*
Total cost of (*) items = $47.02			
04.22.2006	Pull solenoid	Donated (actual cost = $22.15)	1” stroke, used to pull bar to initiate horizontal motion in 6-bar mechanism, obtained from McMaster Carr, part #69905K7
04.23.2006	Washers (2)	**	
04.23.2006	Bolts (3)	**	¼” x 1.5” and 5/16” x 2.5”(bolts for horizontal slide groove (1) and mounting the actuator inside the metal case (2), respectively)
04.23.2006	Wire clamps (6)	**	Used for connecting wires during testing
04.23.2006	Extension spring (3)	**	Varying strengths to test force needed to retract mechanism while allowing free horizontal motion while solenoid is engaged
04.23.2006	Momentary contact switch	**	Used to activate pull solenoid
04.23.2006	Toggle switch	**	Used to control up and down motion of linear actuator
Total cost of (**) items = $23.17			
Total cost to date:		$207.36	

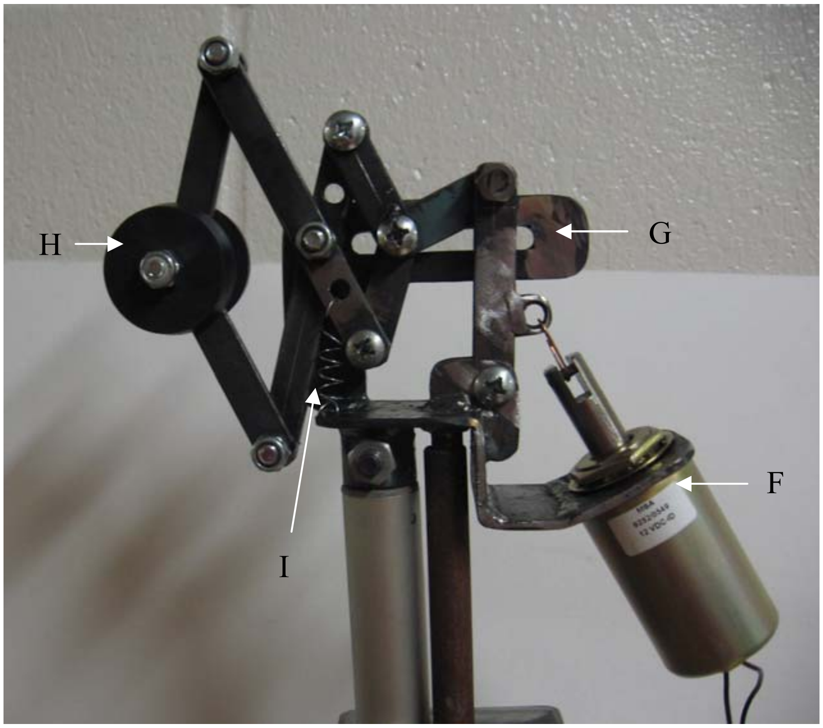
Appendix C: Prototype Detail



Final prototype consisting of six-bar mechanism (A) atop a platform mounted to linear actuator (B) housed in metal case (C)



Close up view of the six-bar mechanism detailing the mounted bolt (D) and lever arm (E).



Close up view of the six-bar mechanism detailing solenoid (F), horizontal guide (G) rubber cylinders (H), and retraction spring (I).