ELEVATOR CONTROLLER FOR INDIVIDUAL WITH MS

Biomedical Engineering Design 201
University of Wisconsin - Madison

Michele Lorenz – Team Leader
Emily Maslonkowski – Communications
Sara Karle – BSAC
Ashley Matsick – BWIG

Client: John Fleming, MD
Department of Neurology, UW Medical School

Advisor: Naomi Chesler, PhD
Professor, Department of Biomedical Engineering

FEBRUARY 9, 2006

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. We drafted three designs to fulfill the requirements defined by the client and user, and focusing upon the ease of construction and accuracy of each proposed device, we have decided to pursue a combination of the spring-powered arm and crane designs.

CONTENTS

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, y, and z 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, 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:

<u>Elevator and hallway environments</u>

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 in which the device will be used. The first involves pressing the call buttons several feet from the hallway elevator door. The other situation requires pressing 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.

Once inside the elevator, however, the user has limited space and flexibility to move the wheelchair into a desirable position with respect to the elevator car's buttons. The current wheelchair position scenario is based off of what the user demonstrated as the typical manner in which he enters the elevator (Figure 1), as well as the maximum estimated width and length of the chair, 0.635 and 1.07 meters respectively (7). The angle of the chair does allow for good visibility of all buttons, but makes the distance from the chair's side to the buttons approximately 0.792 meters away. In the optimal situation, the user could rotate the chair so that it would be situated in a similar position (parallel to the wall) as in the hallway or lobby environments (Figure 2). This adjustment shortens the distance between the vertical plane of the side of the chair and the buttons to 0.191 meters.

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

Button function (floor)	Height (m)
Elevator up (1)	1.13
Elevator down (1)	0.997
Open automatic door	0.914
Elevator up (2)	1.14
Elevator down (2)	1.02

Table 2. The function and height for elevator cab buttons

Function	Height (m)
Help	0.521
Alarm	0.889
Open	0.943
Close	0.943
Basement	1.05
Floor 1	1.10
Floor 2	1.15
Floor 3	1.20

From the floor of the elevator, button heights range from 0.521 – 1.20 meters tall (Table 2). Depending upon the design chosen, the device will have to deal with these parameters differently: one based off of the floor will need a longer component in order to extend between the two height extremes, while a device based off of the wheelchair armrest will most likely have a smaller extension requirement in each direction.

Finally, the device must be capable of exerting a force sufficient enough to activate each button. When testing was performed in the apartment building, 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. Based on factory specifications for the approximate model of the user's wheelchair, the typical length and width of the chair are 1.07 and 0.635 meters respectively. 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 0.889 meters. This leaves 0.254 meters total of width within which we may add device components (Figures 1 and 2). The maximum height of the device will also be constrained by the original wheelchair structure since it will have to be attached. The user's power chair is customized to meet his individual needs, and as of yet we have not taken exact measurements of the armrest height and distance from the base/motor and wheel housing to the underside of the armrests.

Figure 1. Illustration of maximum dimension allowed on two sides of user's wheelchair to preserve normal maneuverability

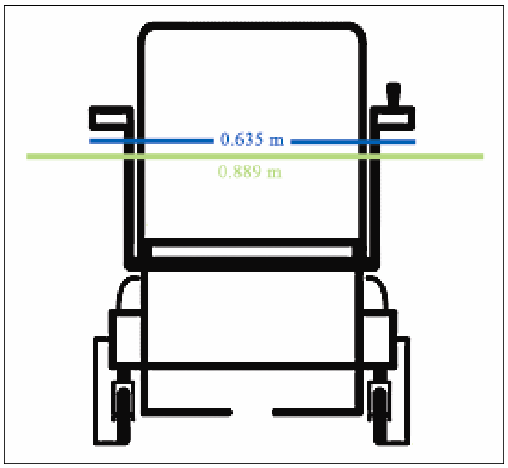
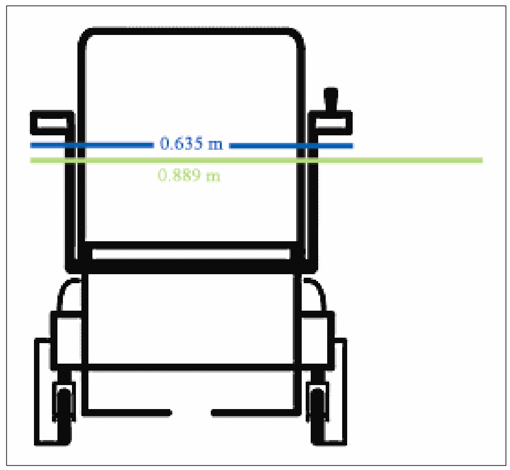


Figure 2. Illustration of maximum dimension allowed on one sides of user's wheelchair to preserve normal maneuverability



Design #1: The Robotic Car

This design incorporates aspects of several different products available today, each one slightly modified to adjust to our requirements (Figure 3). The theme behind this device is a remote-controlled car that the user operates and directs to the buttons. A telescoping rod extends out of the apex of the car and has a horizontal shaft mounted on the top of the rod. The telescoping rod lengthens or shortens as needed to reach the buttons. The horizontal piece lines up with the buttons and the car is driven slightly forward to push the desired button.

The main device is an electronic "car" which moves along the ground according to commands sent by the operator, dictating movement left, right, forward, and back. The car has three wheels instead of four to allow for a tighter turning radius and increased stability. The base of the car should be as small as possible, with an ideal diameter of 0.15-0.20 meters.

The telescoping rod is similar in design to telescoping car antennas, but must be stronger in order to withstand the 36 N pushing force required to push the elevator buttons. This rod moves up and down to reach the buttons under the direction of the user. A shaft parallel to the ground that has a rubber stopper at one end is located on the top of the telescoping rod. When the shaft and stopper are lined up with the button, the car is driven forward, and the stopper presses the elevator button.

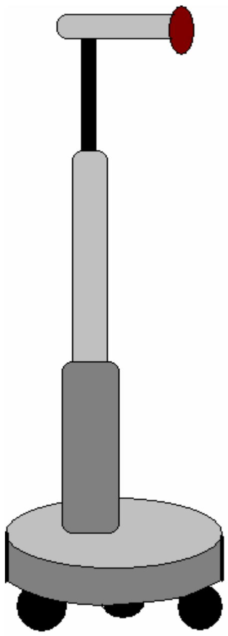


Figure 3: Car component of design #1, with a telescoping rod connected to a pushing shaft mounted on a three-wheeled robotic car.

When the device is not in use, it sits in a home base station, preferably located at the base of the wheelchair near the back. The station is connected to the wheelchair at two points (Figure 4). The base of the station is able to move slightly up and down to prevent damage during wheelchair movement. The rod has clamps mounted on it so when the device is sitting in the station, it is prevented from tipping over. A "return to home" command returns the device directly to the home base after pushing the elevator button.

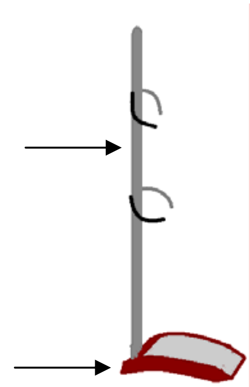


Figure 4: Proposed home base station houses the robotic car when not in use. Connection points are denoted by arrows.

This device would be relatively expensive to produce, including approximately $40.00 for the telescoping shaft (8), $100 to buy or build the robotic car and around $75.00 to build the home base. Despite the high price, this design is the most accurate and universal option of the three proposed thus far. The potential problems with this design stem from the complexity of building and directing the motion of the device. All of its parts deal with intricate electronic and mechanical applications and interactions, which will have to be controlled by either infrared signaling or a mouth control. A tremendous amount of future research and guidance from local experts in these areas will be necessary to properly construct this device.

Design #2) Spring-powered arm

This device involves a rotating arm installed on a vertical column which allows for motion along all three axes. Horizontal motion occurs when the arm (Figure 5) rotates parallel to the ground on a hinge based on a mounting plate used for attachment to the wheelchair frame. The force needed to press a button is 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 is achieved with the use of a releasable catch connecting the arm and mounting plate.

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.

Vertical adjustment to accommodate for different hallway environments and button choices within the elevator cab is performed by controlling a motor that will drive the arm up and down a vertical column. The present method proposed for this motion involves the construction of a rack-and-pinion system (Figure 6) to which the arm mounting plate is attached. Optimally, the combination of the three components (arm, mounting plate, vertical column) will not be wider than 0.10-0.15 meters while the arm is in its stored position.

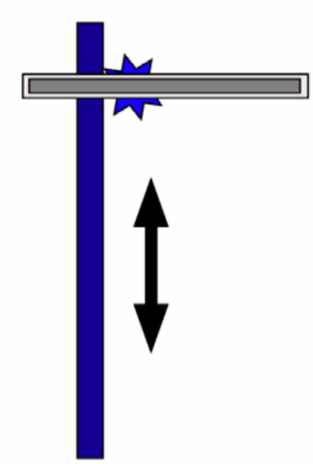


Figure 6. Side view of vertical column component of design 2, demonstrating the rack-and-pinion option for the desired motion.

While the structural components of this device could be produced with minimal expenditure, the motors involved with the vertical adjustment would make up the majority of the total cost. This is due to the possible need for wiring a motor to move bi-directionally to aid in the horizontal extension of the arm.

In comparison to the first design, this device involves a simpler construction process to manufacture the final product. There will most likely be a learning curve, however, for the user to properly control the arm and direct it to the appropriate buttons. In order to minimize this drawback, guides in both the elevator (such as markings for wheelchair position) and on the device (a simple pen laser mounted on the end of the arm) would be added to the final design.

Design #3) Crane

This device mimics the capabilities of a mechanical crane in that it uses a pulley system to raise an arm up and away from its supporting rod (Figure 7). Mounted to the back of the wheelchair armrest, the only possible movement of the supporting rod is a rotation of 360˚ around the z-axis. Another option for this component is to use a rod capable of producing a telescoping motion in order to reach a wider range of buttons. A second rod, approximately half the length of the first, attaches to it by means of a hinge, providing motion in a single plane.

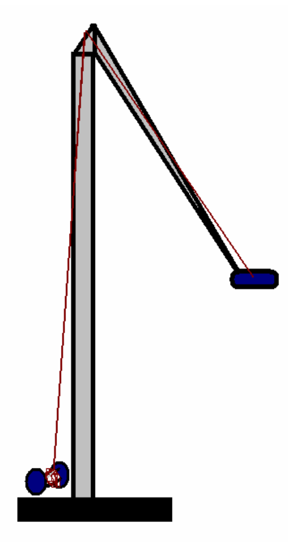


Figure 7: Side view of the crane proposed as design #3. The crank used to control cable tension and thus raise the pushing shaft towards the intended button is at the base of the longer rod.

A "pushing shaft" with a rubber stopper at one end is attached to the second rod, mounted parallel to the ground. A cable running from the base of the supporting rod to the end of the pushing shaft is directed up and over the hinge and controlled by a motorized crank. When the operator directs the crank to turn, the cable tightens, forcing the second rod and pushing shaft up and away from the wheelchair. The hinge holding the pushing shaft to the middle rod maintains the shaft in a position parallel to the ground in order to stay perpendicular to the button. When not in use, the crank can be loosened to allow the hinged arm to rest parallel to the first rotating rod. If the rods are made of metal 0.03-0.06 meters thick, this would add a maximum of 0.15 meters to the width of the wheelchair and thus offer minimal interference for maneuvering through doorways.

The average cost of this device would be around $85.00, including approximately $40.00 for the metal arms, $10.00 for the crank and $10.00 for the cable and rubber stopper (9). The price of the motor for this device may range from $20.00 to $50.00 depending on the power and the size required for optimal use (9).

The benefits of this design include its simplicity, low production costs, and compliance with client requirements. Construction would be relatively easy, considering the small number and minimal complexity of the moving parts. Problems may arise from adding height to the wheelchair (interfering with maneuverability) and having a limited range of vertical motion (unless the telescoping rod is utilized in the final design).

Proposed final design:

In order for us to assess each of our designs and choose one to proceed with, we decided to evaluate each of them in a number of different categories, based largely upon the client and user requirements. 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 push the desired button. The robotic car has 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 designs, as can be seen in Figure 8. The categories can be seen in the far left hand column with their weights 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 with their respective weights filling in the rest of the matrix.

	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

Figure 8. Matrix ranking important aspects of each proposed design.

The spring-loaded arm and the crane received a very similar total score (Figure 8), and for this reason we have decided to merge them into the final design. We will proceed with the design and construction of this final device to fulfill the requirements of the user and client.

Problems and possible resolutions:

The main problem encountered thus far in the design process has been the complexity of the solution, in which we must address three distinct, yet interrelated aspects of the project (Figure 9).

Mechanical construction → Signaling integration → Attachment to chair

Figure 9. Proposed design flow for the spring semester and summer (if necessary) demonstrating that construction of the mechanical solution to the problem will be the initial focus of the project.

First, the mechanical problem is that our device must successfully press the desired elevator buttons. Second, our device must be integrated with a controlling system using infrared signaling or movement generated at the neck and above. Lastly, our device must dock on the user's wheelchair and not be a hindrance to everyday movements. Regardless of the complexity of the device, we want it to have an uncomplicated user interface.

Each of the three portions of our design requires a thorough knowledge of a different field of engineering. As a team, we have a moderate background in mechanics, but very limited knowledge of circuitry or signaling. In order to overcome this challenge, we are relying upon outside sources and knowledgeable individuals for information and assistance. In addition, by dividing the problem into three manageable parts we have gained a more simplified view of the problem, and have chosen to focus first on the mechanical aspect. Throughout the design of the mechanical components, we will still consider the necessity of incorporating the control system and docking location, but will later on deal with these stages individually.

Many of the specific measurements that we need regarding the distance the device must travel and the area available for docking on the wheelchair are not easy to obtain. Gathering this information requires traveling to the apartment where D.P. lives and asking for his assistance in demonstrating his chair's maneuverability. In addition, the distance that the device needs to travel is variable based not only on the specific button being pressed, but also depending on the position of the wheelchair. To eliminate this variable, we are considering the possibility of placing marks on the floor of the elevator to ensure that the device operates from a consistent location. Similarly, the space available on the wheelchair for docking is variable based on the particular angle at which the chair is adjusted to. Allowing the wheelchair to maintain its full range of motion is essential, requiring us to work around this parameter rather than eliminate it.

Finally, testing our device will likely be a problem we encounter in the future. The environment in which the device must operate is comprised of the specific elevator and hallways of D.P.'s apartment complex. Testing our device in this environment will require traveling with our device to the apartment complex. In addition, although we are currently focusing on the mechanical aspect of the problem, we will need to incorporate a simple electrical circuit in order to test if the mechanics are working as desired.

References

(1) P., D. Personal interview. 31 Jan. 2006.

(2) *The National Multiple Sclerosis Society*. 2006. 29 Jan. 2006 <http://www.nationalmssociety.org>.

(3) Campbell, Neil A., and Jane B. Reece. Biology. 7th ed. San Francisco: Benjamin Cummings, 2005. 1012-1015.

(4) Dellegrazio, Phil. Telephone interview. 7 Feb. 2006.

(5) "Switches." NovitaTech Assistive Technology. Feb. 2006. Novita. 15 Feb. 2006 <http://www.novitatech.org.au/subcategory.asp?p=247&id=6>.

(6) "Sip-N-Puff, Mouth controlled Joysticks." AbilityHub. TGGWEB. 15 Feb. 2006 <http://www.abilityhub.com/mouse/joystick.htm>.

(7) “Invacare Product Catalog – 3G Ranger XWD.” 2006 Invacare Corporation. 1 February 2006 <http://www.invacare.com/product_files/00-315_LR.pdf>

(8) Audio Warehouse Express. 05 Feb. 2006 <http://www.audio-warehouse.com/web/mdl/PLNT90/detail.asp>.

(9) McMaster Carr. 14 Feb. 2006 <http://www.mcmaster.com/>

Appendix A: Product Design Specifications

Elevator Controller for Individual with Multiple Sclerosis

Product Design Specification

Team Members:
Michele Lorenz (Team Leader)
Emily Maslonkowski (Communicator)
Ashley Matsick (BWIG)
Sara Karle (BSAC)

Primary Contact:
John O. Fleming, MD
Professor, Vice Chair, Neurology
Professor, Medical Microbiology and Immunology
University of Wisconsin Medical School
Department of Neurology, H6/564 CSC
Phone: 608-263-5421
email: fleming@neurology.wisc.edu

Last update: January 31, 2006

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, y, and z 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 bystanders
   c) Accuracy & Reliability
      - The device should be able to move to a specific button based on the input of the user
      - The device should provide visual feedback about the position of the pushing component
   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
- Budget?
- Existing similar devices?
- Manufacturing/parts costs?
  - Dependent upon design choice: motorized retractable antennas = approx. 65-100 dollars, so whole project may be 100-300 total?

3) Miscellaneous

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