An Assistive Device for Elevator Operation

by

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Abstract

Many disabled people who have the mobility in their arms and hands to operate powered wheelchairs do not have sufficient strength or the ability to extend their arms to operate the buttons of standard elevator control panels. This prototype allows these people to operate elevator controls using a remote controlled system to actuate the existing elevator buttons. While the prototype is dimensioned specifically for use on one of the two Beechwood Home elevator installations, the design concept can be applied for use on virtually any existing elevator control panel.

Analysis of the current situation was done to determine customer needs and the state of current technology in use to address similar problems. Design alternatives were examined to determine their ability to meet these customer needs and the Pugh Selection Method was used to arrive at the final design. Based on research, brainstorming, and a survey of ten potential users at Beechwood Home, it was determined that the prototype must enable users to actuate elevator controls without extending their arms and must not interfere with normal use of the wheelchair by users or by care-givers. It must allow operation without precise aiming of the control device, be adaptable to a variety of user needs and wheelchair designs, and provide for both remote and normal operation of the elevator controls.

This report documents the work performed in designing, fabricating, and testing the prototype. The design is based on the need to provide a force of between 1.0 and 4.0 pounds and button travel of between .125 and .200 inches. The major components of the prototype are the infrared remote control system and the electric solenoid actuation system. The infrared remote control system allows operation of elevator buttons without extension of the users' arms. The compact size of the remote transmitter allows mounting to a variety of wheelchair designs to meet a variety of user needs without interfering with normal use of the wheelchair. Final testing of the prototype at Beechwood Home proves that precise aiming is not required for proper system operation.

Successful testing proves that this prototype not only meets all identified requirements but also provides a basis for the development of a useful production system. Throughout the design process, many improvement possibilities have been identified to make a production system even easier for users to operate. Continued application of established design practices will result in successful evaluation and implementation of these improvements in a production system. The resulting product will meet all user needs and provide increased independent mobility and an improved quality of life for its users.

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Introduction

The Problem

While the electric powered wheelchair improves the lives of thousands of disabled people by giving them some degree of personal mobility, their inability to operate elevator buttons limits that mobility to a single floor of multi-story buildings. No practical, inexpensive device exists to allow these people to transfer limited hand motion to the proper location to activate elevator call and floor selection buttons.

Background

A staggering number of people in the United States alone are affected by this problem. Diseases such as cerebral palsy, multiple sclerosis, Parkinson's disease, arthritis, and stroke affect millions of Americans and in many cases result in permanent confinement to wheelchairs. According to the New York Online Access to Health (NOAH) [1], more than 1.8 million people in this country suffer from some degree of cerebral palsy, multiple sclerosis, and Parkinson's disease. Various forms of arthritis, many disabling, affect millions more in this country. In addition to disabling disease, the National Spinal Cord Injury Statistical Center (NSCISC) [2], estimates that there are currently between 183,000 and 230,000 Americans with permanent disabilities due to spinal cord injury. An additional 11,000 cases of spinal cord injury occur each year. This means that there are roughly 215,000 cases of quadriplegia resulting from injury in the United States and the number is rising by almost 6,000 each year. (For further information, refer to **Appendix A, Statistical Data on Spinal Cord Injury**) Clearly the number of people in the United States alone who are permanently confined to wheelchairs is in the millions.

Through a great deal of effort and physical therapy, many of these people have developed at least limited use of their hands, allowing them some degree of independence through the use of powered wheelchairs. There are limitations to this independence, however. Independent travel between floors of multi-floor facilities is nearly impossible. While nearly all modern buildings are equipped with elevators and a great majority of these elevators are handicapped accessible, most people requiring the use of powered wheelchairs are incapable of sufficient arm movement to reach the control buttons of accessible elevators. This is due not only to their physical limitations but also to the common placement of control panels in elevator cars. The size and mobility of the powered wheelchairs prevents these users from being able to maneuver close enough to the control panels to reach the buttons.

Beechwood Home of Cincinnati, Ohio is an 88 bed group home specializing in long-term care for the severely and permanently disabled. During a visit to Beechwood in August of 2001, the problem of elevator control accessibility was presented as a possible subject for a senior design project. According to Kay Barker [3] of the Beechwood

Home staff, this problem of independent mobility is not just a physical problem. If these patients could have some device to allow them to operate elevators on their own, they would experience an increased sense of independence. Anything that helps in this area is a major improvement to the quality of life for these people.

Scope of Project

There is a wide range of capabilities and physical limitations among patients confined to wheelchairs. The targeted customers for this project are those disabled people who have the mobility in their hands and arms to operate powered wheelchairs but lack sufficient strength or reach to extend their arms to operate elevator control buttons.

Additionally, a wide variety of elevator configurations exist as many buildings currently in use were constructed prior to legislation on accessibility for the handicapped. The location of elevator call buttons and control panels varies widely in such buildings. While the design concept resulting from this project may be applied to a wide variety of care facilities, the prototype built for this project is constructed specifically for the elevator system of Beechwood Home in Cincinnati, Ohio.

Product Performance

Based on first-hand observation of the problem and personal communication with Kay Barker [3] and Renee Loftspring [4] of Beechwood Home, a list of specific problem elements was developed. A customer survey was completed with ten residents of Beechwood Home to determine what design characteristics were most needed and what physical limitations were most common. See **Appendix B- User Survey, Results, and Analysis** for details of the survey. The following problem elements were identified during this process:

- Inability of patients to move their hands from the wheelchair armrests
- Difficulty in manipulating device controls
- Interference between wheelchair-mounted devices and walls, furniture, and other patient wheelchairs
- High likelihood of damage to any device mounted to the wheelchair
- High degree of variation in patient motor and cognitive skills
- High degree of variation in designs of wheelchairs
- Variation in elevator design
- Difficulty in mounting any device to any location on wheelchairs other than the back
- High cost of adaptive devices

Through analysis of this list of problem elements, the following design elements were identified as requirements in the prototype:

- The user is to be able to actuate elevator controls without extending his or her arms.
- The prototype must not interfere with normal use of the wheelchair by the patient or by caregivers.
- Precise aiming of the control device must not be required.
- The prototype must be adaptable to a wide variety of patient abilities and wheelchair designs.
- The prototype must provide for both remote and normal manual operation.

Project Management

Research and problem identification for this project began in August 2001 when the subject of elevator control accessibility was presented as a subject for a design project. The project was accepted in late December 2001 and design work began in early January 2002. The final design was presented and approved in March 2002. Once the design was approved, the required components were ordered and manufacturing began in mid-March. The prototype was completed by late April and ready for testing. Testing of the prototype was completed on April 27, 2002 and proof of the design was accomplished at Beechwood Home in Cincinnati, Ohio on May 1, 2002. All phases of the project were completed on schedule as detailed in **Appendix J-Project Schedule.**

Completion of the prototype was accomplished within the limits of the original budget. At the beginning of the design stage, $336 was allocated to the design and production of the prototype. Total cost of the project through completion of the prototype is $385, with the prototype materials costing just under $260. The additional $125 spent on the project were for tools and shop supplies. For budget details, see **Appendix K-Project Budget.** While the design and development of the prototype was self-funded by the student, additional costs associated with development of a production system are to be negotiated with the customer.

Conclusion

This prototype extends the independent mobility of many disabled people by giving them the ability to remotely actuate elevator controls. Through the use of an infrared remote control system and electric solenoid powered extension button assemblies, the system allows both remote and normal manual use of existing elevator controls. The prototype designed, built, and tested proves that an affordable production system can be developed to provide independent use of elevators for the identified customers.

Design Overview

Design Requirements

In addition to the customer defined design requirements, physical requirements for the prototype to perform the specific task of operating elevator control buttons were identified. Specific limits of force and displacement were established based on the need to overcome the spring force of the existing control buttons and to move the buttons the required distance to actuate the existing system.

Required force was measured on all the existing buttons of the Beechwood Home elevator system. This measurement was done using a spring scale calibrated in .1 lbf increments. Minimum and maximum required force was found to be .8 and .95 lb. respectively. Due to the possibility of damaging the existing buttons through the application of excessive force, testing was performed to determine what maximum force should be allowed. Using a 1/4 inch diameter steel rod, force was applied to one existing button beyond that required for activation. This force was increased to 8 lb. without damaging the button. This test was stopped at this point since 8 lb. was more than the anticipated maximum and to avoid any damage to the existing system.

Displacement was also measured on all existing buttons of the Beechwood elevator system. Using a scale and straightedge, each button was depressed to the point of activation. This distance was noted and the button was depressed until it bottomed out. This method provided a minimum and maximum displacement value for each button. Button activation occurred at a minimum and maximum displacement of .060 and .125 inches, respectively. Total button travel was found to average .200 inch.

Based on these measurements, it was determined that the design must apply a minimum force of 1 pound to reliably operate all the buttons of the Beechwood elevator system. A maximum force of 4 pounds was established to avoid any possibility of system damage. Minimum required displacement was established at .125 inch to assure that the system would be capable of actuating all buttons. While a maximum displacement was not required for system operation, it was determined that travel in excess of .200 inch could result in damage if a user applied excessive force manually. For this reason, .200 inch was established as the maximum displacement to be allowed. The following list summarizes all customer and design requirements to be met by the prototype. The prototype must:

- Allow operation of existing elevator controls from a wheelchair
- Remain as compact as possible
- Require no precise aiming of the control device
- Allow simple mounting of control device
- Allow operation by the identified customers and normal users
- Apply a minimum of 1 lb and a maximum of 4 lb force to existing buttons
- Displace existing buttons by at least .125 in and no more than .200 in

System Operation

The prototype allows simple remote and normal operation of existing elevator control buttons. For remote operation, the user presses a button on a wheelchair mounted remote control transmitter to select the desired function. The remote receiver senses the infrared signal and activates the corresponding relay of the receiver/relay board. When the relay contacts close, the solenoid circuit is completed and the solenoid plunger extends, providing the required force and stroke to depress the existing elevator button. The indicator light of the existing button provides feedback to the user, indicating when the correct button has been selected. Normal operation is possible simply by pressing the outer end of the extension button assembly which extends beyond the outer surface of the housing assembly. Each extension button is marked exactly as the existing buttons of the elevator control panel.

Users are able to operate both the hall call buttons and the in car floor selection buttons using a single remote transmitter. The transmitter for the prototype has buttons for up, down, floor 1, and floor 2 selections. As additional floors or functions are added, the number of buttons on the remote control transmitter will increase as needed.

Design Details

Introduction

Each component of the prototype is designed to address the identified customer needs and design requirements. From selection of the preferred design alternative through material selection, all design decisions are based on these requirements.

Control System

Due to the limited number of available similar products and the total lack of experience with any similar products by the identified customers, the Pugh Selection Method was used to select the control system for this prototype. The alternative designs were based on the use of either an RF (radio frequency) system or an IR (infrared) system using either push buttons or rocker switches for the user control. Each alternative was compared against the others using Pugh selection matrices. **(See Appendix B, Pugh Selection Matrices)** The design criteria used for control system selection were:

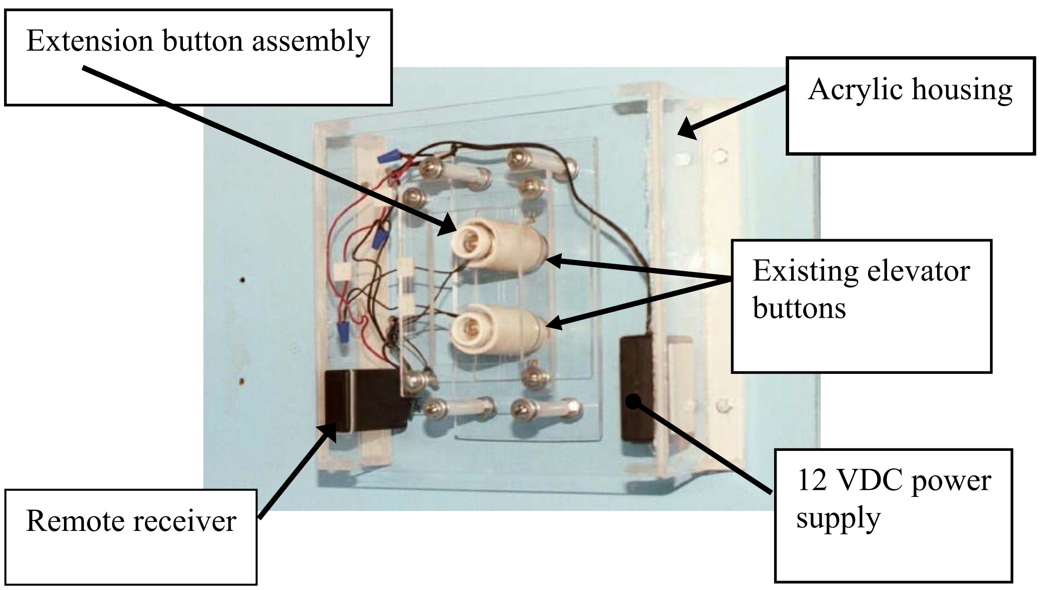
- Transmitter size
- Directional sensitivity
- Manufacturing cost
- Ease of operation
- Component availability

Based on the results of the Pugh Selection Method, an infrared remote with push button control was selected.

The selected system operates on 12 VDC, 100 mA input power. This system provides momentary relay-controlled output so the solenoid will be actuated only while the remote transmitter button is depressed. Only one relay can be actuated at a time, limiting the forces on the system to the output of a single solenoid. While only two output relays are required for this prototype, the selected system has four relays per receiver. This is not a design requirement but simply the result of selecting from a limited number of available systems. The selected receiver/relay board is quite compact, being only 1.9" x 2.95" by .75". The output relays are capable of carrying a 1 amp load, which is more than sufficient for the .5 amp load of the system solenoids. Each receiver is furnished with a transmitter and for this application, multiple receivers are programmed to operate using a single set of transmitter codes. This allows a single transmitter to operate both the hall call and in-car control systems. Additional transmitters can be added using the same codes to allow an unlimited number of users. For complete details of the selected infrared remote control system, see **Appendix C-Infrared Remote System**. The selected system, model # 4relay-01, was purchased from Custom Remote Systems, Inc., of Westbury, New York.

Housing Assemblies

The housing assemblies (Refer to Sketch 1) are designed to support and align the extension button assemblies and to provide the required space for mounting the remote control receiver and power supply systems. **See Appendix F, drawings 101-1 through 102-6** for housing assembly and detail drawings. Each housing assembly is constructed of clear acrylic sheet to allow the existing illuminated control buttons to be visible to the system user. .250 in. sheet has been selected to provide the required rigidity for this assembly. The housing supports the outer end of each extension button at the switch plate (item 2, drawing 101-2 and 102-2). The switch plate was added to the design to allow for replacement of extension buttons without removing the complete assembly from the wall.

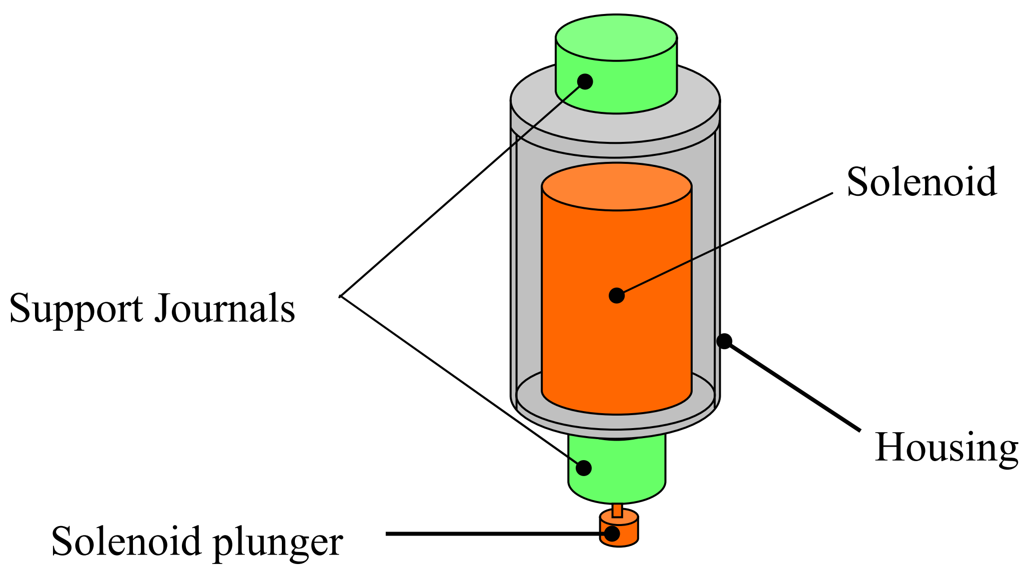


Sketch 1
Wall Mounted Assembly

This plate also provides a location for shimming to allow for adjustment of the system at assembly and final installation. By shimming this plate out from the housing, the extension button is moved out, away from the existing control button. This ability to adjust the system using shims is necessary due to variation in control buttons and to allow for manufacturing variation. The inner end of each extension button is supported by a guide plate (item 3, drawing 101-1 and 102-1). The extension button is captured between the existing elevator control button and the housing switch plate and slides freely through the housing guide plate. Ability to adjust the extension button into the existing control button is provided by shimming between the switch plate and outer shoulder of the extension button. (Refer to drawing 101-5 and 102-5 for shimming locations) The details of the housing assembly are assembled using glued joints for permanent assemblies and standard threaded fasteners for removable components. Drawing reference dimensions are determined by the final stack up requirements of the assemblies. For the hall call button assembly, a final clearance of .300" is required between the assembly to wall mounting surface and the inner end of the extension button assembly. This dimension is determined by measurements of the existing call buttons of the Beechwood system. For the floor selection assembly, this dimension is .125". The reference dimensions of the detail drawings are specified to provide these clearances. Variation in actual dimensions is acceptable providing that these final clearances are met.

Extension Button Assembly

The heart of the system is the extension button assembly. (Refer to Sketch 2) Design of this assembly was based on the force and displacement required to actuate the existing elevator buttons and on the need to provide for both remote and normal operation. The extension button assembly is a hollow cylinder with support journals at the inner and outer ends. This cylinder is positioned in the wall- mounted assembly with the inner end resting against the existing elevator button. Normal operation is made possible by the transfer of force and displacement through the cylinder to the existing button. Return force is provided by the spring force of the existing button. All of the extension buttons for both the hall call and floor selection assemblies are identical and one extension button assembly is required for each existing button to be operated.



Sketch 2
Extension Button Assembly

The extension button assembly is designed to provide sufficient space for mounting the electric solenoid and to provide for normal manual actuation of the existing elevator control button. **See Appendix F, drawing 103-1 through 103-3a** for design details. This assembly is constructed of standard PVC pipe and clear acrylic sheet, with detail components secured using contact cement. The contact cement selected for assembly is Plumber's Goop Contact Cement and Sealant. Determination of reference dimensions is based on mounting requirements for the solenoid and required displacement of the solenoid plunger. The outside diameter of this component is limited by the spacing of the existing elevator control buttons. With minimum center to center spacing of the existing buttons of 2.875 in., outside diameter must be less than 2.875 in. to provide clearance between adjacent extension buttons in the final assembly. The outer end of the assembly must protrude through the housing assembly to provide an operating button for manual operation. The diameter of this outer end is 1 in to match the diameter of the existing elevator control buttons. The housing body, item 4, sheet 103-2b is designed to allow for replacement of solenoids. The side of this cylinder is cut away to allow access for ease of solenoid replacement. The end plates of this assembly are slotted, again, to allow for solenoid replacement. The solenoid nut/plunger assembly, (refer to drawing 103-1 and 103-3a) is designed to capture the solenoid mounting nut and provide the required space to house the solenoid plunger in the retracted position. The solenoid nut is bonded to the housing using the same contact cement used for the overall assembly. Combining the solenoid nut with this plunger housing is necessary to provide for solenoid replacement. Diameter of the solenoid nut/plunger assembly is determined by the diameter of the existing elevator buttons. Each existing button has a 1.0 in diameter. The inboard end of the solenoid nut/plunger assembly has a .75 in diameter to allow for proper alignment of the assembly to the existing button. Due to variation in solenoid performance, the solenoid plungers are cut to the required length to provide necessary force and displacement. The plunger housing length is designed to allow for this variation in final length.

Mounted in the center of each extension button is an electric 12 VDC tubular solenoid. When the solenoid is actuated through its control relay, the solenoid plunger extends, providing the necessary force and displacement to depress the existing elevator button. The selected solenoid is a 12 VDC continuous duty cycle, 1inch diameter push type solenoid. This model provides the required force and displacement while remaining relatively compact. Solenoid selection was based on the following requirements:

- 12 VDC power requirement
- Minimum physical size
- Ability to provide 1 to 4 lbs force over a stroke of .125 to .200 in.
- Tubular design

Based on these requirements, a solenoid was selected using standard solenoid force curves. Electric solenoids apply higher force as they approach the closed or sealed position. The sealed force is the maximum force the solenoid can apply. The force curve is relatively flat at higher stroke ranges and climbs sharply as the stroke nears 0. A solenoid must be selected that can supply the minimum required force at the maximum required stroke or it will be incapable of overcoming the spring of the existing control button. A continuous duty cycle solenoid was selected based on advice from Tom Barnett [5] of Pontiac Coil, Inc., a manufacturer of tubular solenoids. The continuous duty cycle indicates that the solenoid is constructed to operate continuously without overheating the coil. This selection was made to avoid the possibility of solenoid damage and a possible fire hazard in the event the user depresses the remote transmitter button and fails to release it in a short time. Using typical solenoid force curves for 12 VDC, continuous duty cycle solenoids, a 1inch diameter by 2 inch length solenoid was selected. (See **Appendix E- Typical Solenoid Force Curve**) The selected solenoid, model number MSA 7163 / 0139, provides the required output force/displacement combination. The force curve is only an approximation of solenoid performance. As can be seen in the force curve in Appendix I, the selected solenoid could be expected to apply 165 oz. or 10.3 lbs of force in the sealed position. A sample of the selected solenoid was obtained and tested for output performance. It was found to apply a sealed force of 6 lbs. and 1.5 lbs over a .200-inch stroke. Predicted performance properties will vary somewhat between solenoids, requiring that each purchased solenoid be tested to allow for proper system setup of each individual unit. See **Appendix H-Solenoid Data Sheet** for complete details of the selected solenoid.

Conclusion

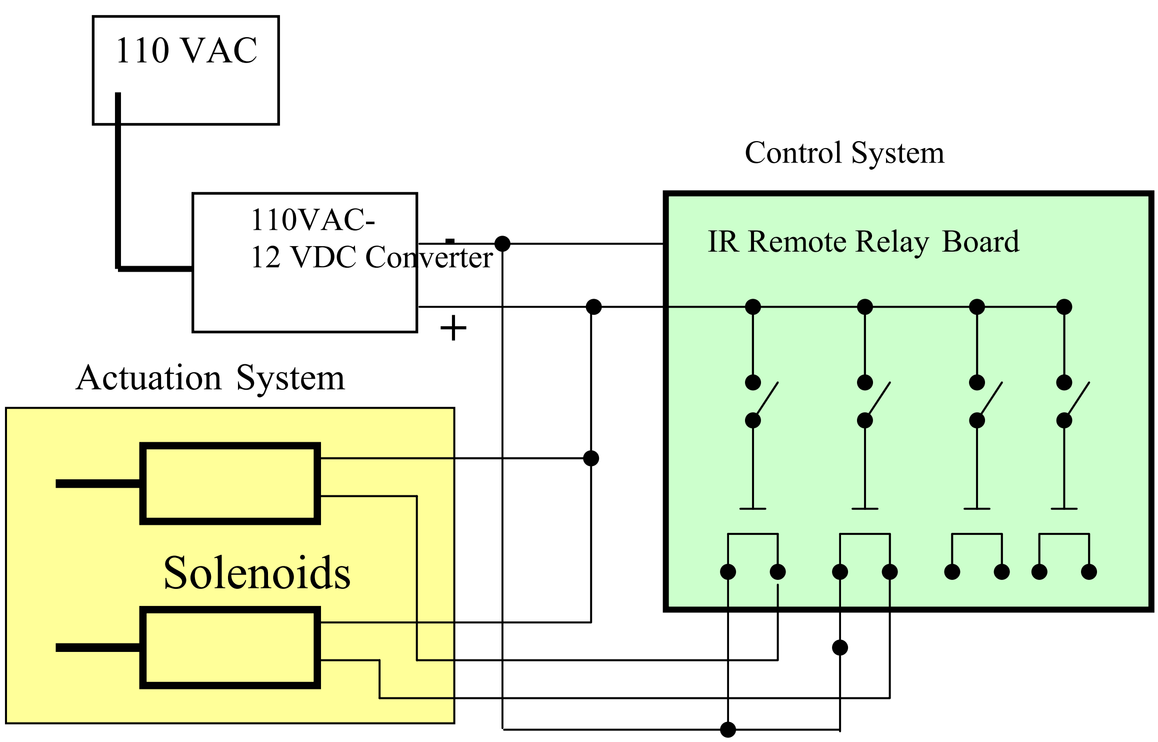
Due to the extremely low force values present in this system, the design was quite simple, requiring no calculation of loads for material selection and detail design. The suitability of the selected materials was, however, verified through testing. Through the use of a well-organized design process, the remaining steps in the project were clearly identified. Fabrication of the prototype was simplified by accurate design drawings. Since customer requirements and design considerations were clearly established from the start, product testing goals were well defined at the beginning of the final phase of this project

Final Product Development

Fabrication

All fabrication was completed using standard hand tools and all the work was completed in my home workshop. Housing panels were cut using handsaws and sanded to final dimensions as specified on the design drawings. Large diameter holes for extension button support journals were cut using standard sized hole saws and enlarged to final design dimensions using abrasive reamers.

Final Assembly of the remote receiver and power supply to each housing was accomplished using two-sided tape. Wiring was quite simple, as seen in Sketch 3-Wiring Diagram. Each housing assembly contains a single 110 VAC to 12 VDC converter to supply power for both the infrared remote receiver and the extension button solenoids. (See **Appendix I, Power Supply Data Sheet** for power supply specifications) This allows for easy connection of the assembly to a standard electrical outlet or for simple modifications to existing facility wiring for a production system.



Sketch 3
Wiring Diagram

Testing

All required tests were included in the detailed project schedule as milestone events and all were completed as scheduled. During fabrication of the housing panels, holes for the extension button assemblies were positioned as specified on the design drawings. Each panel was tested to verify hole location prior to assembly of the housings. This verification was done by trial fitting each panel to its respective control panel of the Beechwood Home elevator system. When fabrication was complete, each housing was tested for strength of the joints between panels. Due to the low forces in the overall system applied by the solenoid plungers against the existing elevator control buttons, these joints were only required to carry a maximum load of 4 lb. This testing was performed by securing the housing mounting flanges to a workbench and applying a force to pull the housing away from the workbench. A force of 20 lbs was applied with no damage to the housing or separation of joints. This test indicates that the housings will withstand a load of at least 5 times what they will experience in actual operation.

Prior to final assembly, each solenoid was tested for proper output force and displacement. Based on this testing, each solenoid plunger length was adjusted to provide the required force and stroke.

The infrared control system was tested prior to installation into the assembly to assure that it operated over the required range and to prove that precise aiming of the transmitter was not required. Through this testing, it was found that at distances of up to 8 feet, the transmitter could be positioned at any angle up to 90 degrees from the receiver and still function properly. At distances of from 8 to 15 feet, the transmitter must be aimed within an arc of 30 degrees in any direction from the receiver. At distances exceeding 15 feet, the transmitter must be aimed almost directly at the receiver, with the need for precise aiming increasing as the distance between transmitter and receiver increases. This testing proves that within the specified range, the control system does not require precise aiming to function properly.

Testing of the completed assemblies was performed for proper remote and normal operation. As a result of this testing, shimming was added as specified in the assembly drawings to assure reliable system operation. During the first test, extension buttons were positioned too close to the existing buttons and the required force was not applied. Shimming the assembly outboard from the existing buttons corrected this problem.

Final testing and product demonstration was completed according to the conditions of the Proof of Design agreement drafted during the design phase of the project. **(See Appendix G, Proof of Design Statement)**. Three residents of Beechwood Home volunteered for this testing. Each in turn used the remote control to successfully call both up and down elevators and to operate the elevator between the first and second floors of the Beechwood facility. Normal operation was also demonstrated at this time and found to be reliable. It was noted during this testing that some additional adjustment was required on the in-car floor selection assembly. This was due to the use of two-sided tape to temporarily secure the assembly to the elevator car wall. The thickness and pliability of the tape positioned the assembly slightly too far outboard for reliable operation. This was corrected by applying pressure against the housing to maintain the proper location. This would not be a problem in a production system, however, since the assembly would be shimmed to function in a permanently mounted position. Results of the Proof of Design testing were very positive. All of the residents participating in this test were impressed with the ease with which they were able to operate the elevator. During this test, the prototype performed as expected to meet all design requirements.

Production Considerations

The prototype constructed for this project is for operation of only one hall call button panel and for only two floor selection buttons in a single elevator car. A production system for a four floor two elevator system like Beechwood will require four hall call assemblies and two floor selection assemblies of six buttons each. The requirement for six floor selection buttons is based on the need to provide for operation of two emergency buttons in each car. The addition of these emergency buttons to the system will also make it necessary to use an 8-channel remote system. While the materials for the prototype cost only $260, these changes result in an estimated cost of nearly $1200 for the production system. Most of the cost of the system is in the electrical components, with less than 10% attributed to the materials for housing fabrication.

The estimated cost per unit to produce these systems does not decrease significantly with high volume production. Due to the variation in control panel design between different elevator models and installations, housings remain basically custom- built for each installation. High volume production of these units is not possible. Since these housing assemblies account for most of the labor in the overall assembly, the only cost advantage in the production of several systems lies in volume discounts on the purchase of electrical components. Assuming a volume discount of 20% on these components, the overall per unit cost could be reduced by only approximately $200.

Recommendations

Based on observations during fabrication of the prototype and on input from users during final testing, a number of recommendations have been identified for improvement of this design. These recommendations will each be evaluated for incorporation in a production system.

While the center section of the housing assemblies must remain clear to allow the user to see the existing lighted elevator control buttons, use of a smoked acrylic for the housing would help hide dirt, fingerprints, and internal system components. While the system users expressed the opinion that appearance of the prototype was of no concern to them, this improvement in the design should result in little added expense and no increase in manufacturing difficulty.

The users identified size and marking of the remote control buttons as a significant problem. This observation was expected since the remote control used for the prototype was not specifically designed for this specialized application. For a production system, the buttons of the control must be larger, spaced farther apart, and the button marking must be applied directly to each button.

For high volume production, it was suggested that the use of molded plastic housings could result in reduced manufacturing time and cost. If the housings could be standardized and molded rather than assembled from individually cut panels, approximately half the assembly time would be eliminated.

During Proof of Design testing at Beechwood Home, Mary Lee Kohl [6], a Customer Service representative of Tash, Inc. suggested that the use of a learning remote control could allow a much wider range of users to operate this system. Systems are currently available to convert a variety of user inputs to infrared signals. If the remote receiver used in the wall mounted unit could be taught to recognize these infrared signals, users could operate the elevator buttons using such input as voice control, eye blinks, head nods, or whatever other input they were using to operate their wheelchairs. The use of hands could be eliminated entirely, allowing anyone who can operate a powered wheelchair to operate the elevator controls. While this improvement might have a significant impact on product cost, the obvious benefits make this an exciting possibility.

Conclusion

Final testing proves that the prototype meets all identified customer and design requirements. Users can actuate elevator controls without extending their arms. They can operate the hall call buttons from almost any position in the lobby and can operate the floor selection buttons without maneuvering their wheelchairs to any particular position in the car. The compact size of the remote control unit allows the system to function without interfering with normal use of the wheelchair by the patient or by caregivers. Demonstration of the prototype by residents of Beechwood Home proves that precise aiming of the remote control is not required. Through the use of a universal mount, users can keep the remote control handy in whatever position they find most convenient for their particular disabilities and wheelchair designs. The extension button assembly used in the prototype allows both remote and normal operation of existing elevator control buttons.

The prototype meets all the identified design requirements while providing a simple system to allow elevator operation for those users unable to extend their arms to reach existing control buttons. While the prototype is custom made for the Beechwood Home facility, the design concept can be applied for use on virtually any existing elevator control panel and costs less than 1/5 what available systems cost. This design provides increased personal freedom, resulting in a significant improvement in the quality of life for its users.

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   On-line information inquiries, May 2002

2. The National Spinal Cord Injury Statistical Center (NSCISC), Board of Trustees,University of Alabama, 2001.
   On-line information inquiries, August 2001 through May 2002

3. K. Barker, Director of Physical Therapy, Beechwood Home, Cincinnati, Ohio, Personal Discussions, August and November, 2001.

4. R. Loftspring, Physical Therapist, Beechwood Home, Cincinnati, Ohio, Personal Discussions, November, 2001..

5. T. Barnett, Production Engineer, Pontiac Coil, Inc., Arkansas Center, Personal Discussion, February, 2002.

6. M. Kohl, Customer Service Representative, Tash International Inc., Ontario, Canada
   Personal Discussion, May 1, 2002

Annotated Bibliography

Access Board-A Federal Agency Committed to Accessible Design
1331 F Street, NW, Suite 1000, Washington, DC 20004-1111
http://www.access-board.gov/adaag/html/adaag.htm

- The Access Board is an independent Federal agency devoted to accessibility for people with disabilities. The three key responsibilities of this organization are the development of accessibility requirements, providing technical assistance in meeting these requirements, and enforcing accessibility standards in federally funded facilities.

Association of Ohio Philanthropic Homes, Housing and Services for the Aging (AOPHA) @www.aopha.org

- AOPHA is a nonprofit organization of not-for-profit retirement communities, housing facilities, and adult community services providers in Ohio.

Barker, Kay, Director of Physical Therapy, Beechwood Home, Cincinnati, Ohio
Personal communications, August and November, 2001

- Kay Barker has many years of experience in working with severely handicapped patients and in the application of adaptive technology.

Barnett, Thomas, Production Engineer, Pontiac Coil, Inc.
Telephone Communications, February, 2002

- Tom Barnett is a great source of information regarding electric solenoids, their applications, and limitations.

Custom Remote Systems, Inc. , Westbury, N.Y.
Telephone conversation with Chester, of engineering /sales

- Selected supplier for infrared remote control system

Dave, Janak, PhD , University of Cincinnati College of Applied Science
Project faculty advisor. Weekly communications, January -March, 2002

- Dr. Dave is an excellent source of information on the design process in general and has had a significant influence on the development of this project.

Dieter, George E. , Engineering Design, 3rd Edition, Copyright 2000

- Dieter's text offers a comprehensive study of the overall design process.

Jameco Electronics, Belmont, California
E-mail contact and catalog order

- Selected supplier for system power supply

Kohl, Mary Lee, Customer Service Representative, Tash International Inc., Ontario Canada

- As a Customer Service Representative for Tash Inc., Mary Lee has a great deal of experience in the application of a variety of products for improving accessibility for the disabled. Mary Lee was present at Proof of Design testing at Beechwood Home on May 1, 2002 and provided significant input on future improvements and possibilities for the prototype.

Loftspring, Renee, Physical Therapist, Beechwood Home, Cincinnati, Ohio
Interview, November, 2001

- Renee has a great deal of close contact with the patients at Beechwood and provides great insight into their specific needs and abilities as they relate to adaptive equipment.

Louis Calder Memorial Library @http://calder.med.miami.edu

- The world wide web site of the University of Miami's School of Medicine provides access to limitless links to educational materials in the fields of medicine and patient care.

McMaster-Carr Supply Company, Aurora, Ohio
E-mail contact and catalog purchase, February, 2002

- Selected supplier for system solenoid.

National Spinal Cord Injury Statistical Center (NSCISC)
@http://www.spinalcord.uab.edu/

- The National Spinal Cord Injury Statistical Center maintains and publishes a number of widely accepted statistical databases on spinal cord injury cases.

New York Online Access to Health (NOAH)
@http://www.noah-health.org/

- NOAH is an on-line service providing a great deal of information on a vast number of diseases and physical disabilities.

Paralyzed.Com @ www.paralyzed.com

- Paralyzed.Com offers free information about: paralysis, spinal cord injuries, physical disabilities, resources for the disabled, accessibility issues, wheelchair resources, personal stories, mobility issues, people who are ventilator dependent, and more.

Scipilot.com @ www.scipilot.com

- Scipilot (Spinal Cord Injury Peer Information Library On Technology) is"a resource describing the assistive technology experiences of individuals with quadriplegia from their own perspective." This organization offers advice to individuals with quadriplegia and provides an excellent resource in understanding the value and importance of assistive technology.

Southeast Iowa Technical Society (SEITS) @ http://www.seits.org

- SEITS is an organization of amateur radio operators dedicated to the advancement of amateur radio. Their monthly newsletter provides articles and technical information on a wide variety of topics in the electronics field.

Spinal Cord Injury Information Network @ www.spinalcord.uab.edu

- The Spinal Cord Injury Information Network is funded through grants to the UAB Rehabilitation Research and Training Center on Secondary Conditions of Spinal Cord Injury and the UAB Model SCI Center. This organization conducts research in the prevention and treatment of secondary conditions of spinal cord injury.

ThinkQuest @ http:// library.thinkquest.org

- ThinkQuest is a global organization dedicated to furthering youth-centered learning on the internet

Appendix A
Statistical Data on Spinal Cord Injury

This Fact Sheet is published by the National Spinal Cord Injury Statistical Center

Incidence: **It is estimated that the annual incidence of spinal cord injury (SCI), not including those who die at the scene of the accident, is approximately 40 cases per million population in the U. S., or approximately 11,000 new cases each year. Since there have not been any overall incidence studies of SCI in the U.S. since the 1970's it is not known if incidence has changed in recent years.**

Prevalence: The number of people in the United States who are alive today and who have SCI has been estimated to be between 721 and 906 per million population. This corresponds to between 183,000 and 230,000 persons. Note: Incidence and prevalence statistics are estimates obtained from several studies. These statistics are not derived from the National SCI Database.

The **National Spinal Cord Injury Database** has been in existence since 1973 and captures data from an estimated 13% of new SCI cases in the U.S. Since its inception, 24 federally funded Model SCI Care Systems have contributed data to the National SCI Database. As of September, 1999 the database contained information on more than 19,648 persons who sustained traumatic spinal cord injuries. All the remaining statistics on this sheet are derived from this database or from collaborative studies conducted by the Model Systems.

Detailed discussions of all topics on this sheet may be found in a special issue of the journal, *Archives of Physical Medicine and Rehabilitation,* published in November, 1999.

Age at injury: SCI primarily affects young adults. Fifty-five percent of SCIs occur among persons in the 16 to 30 year age group, and the average age at injury is 32.1 years. Since 1973 there has been an increase in the mean age at time of injury. Those who were injured before 1979 had a mean age of 28.6 while those injured after 1990 had a mean age of 35.3 years. Another trend is an increase in the proportion of those who were at least 61 years of age at injury. In the 1970's persons older than 60 years of age at injury comprised 4.7% of the database. Since 1990 this has increased to 10%. This trend is not surprising since the median age of the general population has increased from 27.9 years to 35.3 years during the same time period.

Gender: Overall, 81.6% of all persons in the national database are male. Although this four-to-one male to female ratio has varied little throughout the 25 years of the Model Systems data collection, since 1990, the percentage of males has decreased to 80.5% (from 81.8% in the 1970's).

Ethnic groups: A significant trend over time has been observed in the racial distribution of persons in the Model System database. Among persons injured between 1973 and 1978, 77.5% of persons in the database were Caucasian, 13.5% were African-American, 5.7% were Hispanic, 2% were American Indian and 0.8% were Asian. However, among those injured since 1990 only 59.1% were Caucasian, while 27.6% were African-American, 7.7% were Hispanic, 0.4% were American Indian, 2.1% were Asian (and 0.5% were unknown and 2.5% were unclassified).

Appendix B
User Survey, Results, and Analysis

The inability of quadriplegic residents to access elevator control buttons has been identified as a serious problem, severely limiting the independent mobility of these residents within the facility. I am working on the design of a system to allow these patients to operate elevator controls using a remote control device. The purpose of these survey questions is to gather information from prospective users of this system to help in selecting a design solution which will benefit the greatest number of users. Thank you for taking your time to respond to this survey.

1. On an average day, how often do you require the use of elevators?

a. 1 to 5 times

b. 6 to 10 times

c. More than 10 times

2. One proposed system would cause the elevator to stop at each floor rather than going directly to the selected floor. Please indicate the degree of inconvenience this would cause for you.

a. Not at all inconvenient

b. Somewhat inconvenient

c. Very inconvenient

3. For remote control of elevator buttons, which type of control device would be most useful for you?

a. Arm rest mounted multiple toggle switch control panel (switches requiring forward push and backward pull)

b. Arm rest mounted multiple button keypad

c. Other (please specify)____________________________________

4. In selecting a control device for this system, the range of motion of the user's hand is an important consideration. The following three questions are designed to determine the degree to which you are capable of moving the hand which would be used to operate the system control.

What is the range of motion you have forward and backward along the length of the arm rest?

a. No movement at all

b. 1-2 inches

c. 2-3 inches

d. 3-4 inches

5. What is the range of motion you have in the lateral direction, from side to side across the armrest?

a. No movement at all

b. 1-2 inches

c. 2-3 inches

d. 3-4 inches

6. What is the range of motion you have in the movement of your fingertips above the arm rest?

a. No movement at all

b. 1-2 inches

c. 2-3 inches

d. 3-4 inches

7. Costs vary widely among various remote control systems. At what price range would you NOT consider use of this product?

a. $25 to $50

b. $50 to $200

c. $200 to $500

d. Over $500

e. None of the above. Price is not an important factor.

User survey responses and analysis

1. Frequency of elevator use.

1 to 5 times daily	1
6 to 10 times daily	5
10+ times daily	4

2. Inconvenience level of a system stopping at every floor rather than only the selected floor

Not at all inconvenient	2
Somewhat inconvenient	6
Very inconvenient	2

3. Which type of control device is preferred?

Multiple toggle switches requiring forward/backward pressure	0
Multiple push button remote similar to that used on TV	10
Other	0

4. Hand range of motion-forward/backward along length of wheelchair armrest

No movement	0
1-2 inches	3
2-3 inches	6
3-4 inches	1

5. Hand range of motion-laterally, across the wheelchair armrest

No movement	0
1-2 inches	3
2-3 inches	6
3-4 inches	1

6. Hand range of motion up and down from wheelchair armrest

No movement	0
1-2 inches	1
2-3 inches	7
3-4 inches	2

7. Level at which cost becomes prohibitive

$25-$50	0
$50 to $200	1
$200 to $500	3
Over $500	5
Cost is not a factor	1

Analysis

Question 1- this question was intended to determine the frequency of use of the proposed system to determine the expected life of the system components. Responses indicate that estimating at least 100 uses per day is reasonable. It was also pointed out that if access were available, much more use might be expected.

Question 2-this question was intended to determine if a system which calls both up and down elevators and stops at every floor once activated was a reasonable consideration. Such a system would require a much simpler control and

actuation device. Survey results indicate that for the majority, this would be only somewhat inconvenient. Additional comments from respondents indicate that for some, this would be confusing and for others it would be an improvement. Some residents may only know when to exit the elevator car because the doors open. Others would find it more convenient if they had only one button to push but could then select the floor to exit based on the visual recognition of the floor when the doors open. Based on these responses, Reduction of the number of control buttons to reduce confusion remains a valid option.

Question 3 - this question was intended to directly determine the preference of the intended group of users. There was evidently still much confusion regarding the options. The fact that all respondents selected the push button option indicates that they may not have understood the toggle switch option. Additional comments, however, indicate that there is still a wide range of user preferences regarding the location of the control device on the wheelchair. It was suggested that the mounting system for the control be left very flexible, allowing for whatever placement of the device a particular user might prefer. For example, some users may require that the control unit be placed on a lap tray while others may want it on the left or right armrest and at varying locations on the armrest. This should be an easy need to meet by offering a simple mounting system secured with something like Velcro, allowing the control to be placed wherever it is desired.

Question 4-6 - these questions were intended to gather information about the best orientation of the control device. For instance, if using a pushbutton control with eight buttons, would 4 columns of 2 be preferred over 2 columns
of 4. The exact numbers offered in the responses were of little value. The results generally indicate that the use of a pushbutton control should be possible for most users. The individual differences between users was again pointed out as a major concern. If the mounting system is flexible, as suggested in question 3, then it can be adapted to the individual needs of many users.

Question 7 - this question was intended to determine at what price level users would be unable to afford the system. Confusion was noted as to whether the available responses were intended to be cost borne by the user or the overall cost of the system. Responses are weighted heavily toward the upper end of the scale and it was again noted that the problem being addressed by this project is very serious and any solution at any cost will offer a valuable improvement in the quality of life of the residents and productivity of the care-givers. From discussing this question with Kay Barker, it seems that around $500 would not be considered an unreasonable cost for this system but that spending the $5000-$6500 for the commercially available Infra-Link system would be out of the question. It was also noted that the expected cost would be strongly linked to the capabilities of the completed system.

Appendix C
Pugh Selection Matrices

CRITERIA	Pushbutton RF	Rocker RF	Pushbutton IR	Rocker IR
TRANSMITTER SIZE	+	S	+	**B**
RECEIVER SIZE	-	-	S	**A**
MANUFACTURING COST	-	-	S	**S**
DIRECTIONAL SENSITIVITY	+	+	S	**E**
EASE OF OPERATION	+	S	+	**L**
COMPONENT AVAILABILITY	S	+	+	**I**
SUM OF +	3	2	3	**N**
SUM OF -	2	2	0	**E**
SUM OF S	1	2	3	

CRITERIA	Pushbutton RF	Rocker RF	Pushbutton IR
TRANSMITTER SIZE	-	-	**B**
RECEIVER SIZE	-	S	**A**
MANUFACTURING COST	-	-	**S**
DIRECTIONAL SENSITIVITY	+	+	**E**
EASE OF OPERATION	S	-	**L**
COMPONENT AVAILABILITY	-	S	**I**
SUM OF +	1	1	**N**
SUM OF -	4	3	**E**
SUM OF S	1	2	

CRITERIA	Servo	Solenoid
IR CONTROL COMPATABILITY	S	**B**
EASE OF MANUFACTURING	+	**A**
OVERALL SYSTEM COST	-	**S**
RELIABILITY	S	**E**
COMPONENT OPERATING LIFE	-	**L**
NUMBER OF MOVING PARTS	-	**I**
COMPONENT SIZE	S	**N**
SUM OF +	1	**E**

Appendix D
Infrared Remote Control System

Model #4relay-01

Supplier: Custom Remote Systems, Inc., Westbury, N.Y.

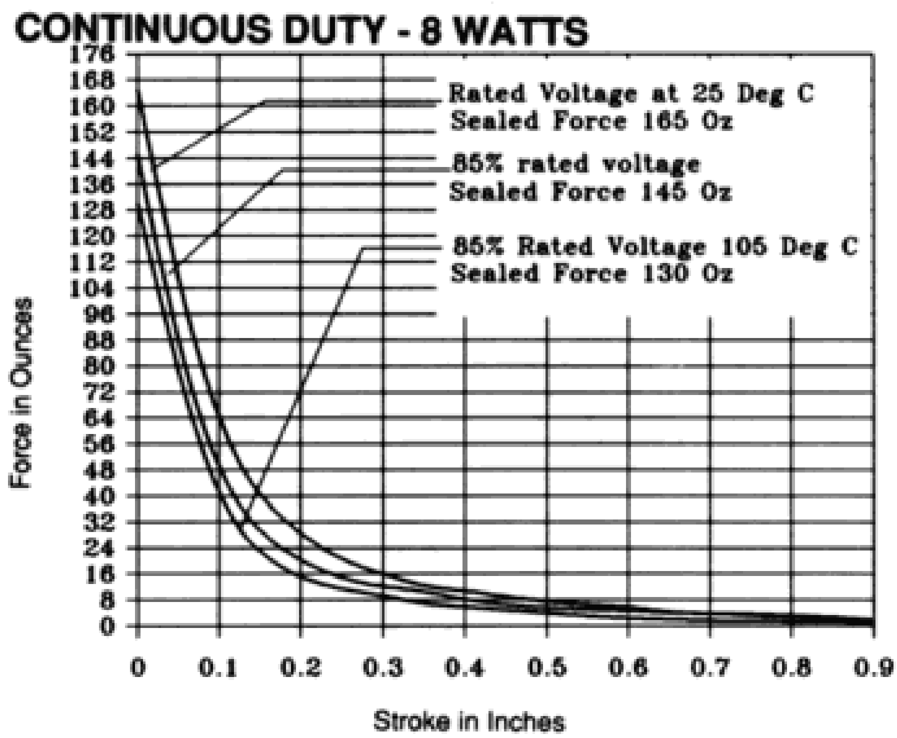
Features

1. Small footprint 1.9" X 2.95"
2. 4 normally open contacts
3. Powered: 9 to 12 volts DC 100 ma
4. Led Receive indicator
5. Contact rating: 1amp @125v AC
6. Available in ABS black and PC Bone
7. Rubber Feet or Stick on Tape for mounting
8. Available without case
9. Can be mounted in or on the controlled unit
10. Only one relay can be closed at the same time
11. All relays are momentary
12. Several hand remotes to choose from including the CIR2A2 series of remotes and NSD-038.
12. Can be special ordered for 5 volts DC operation.
13. Can also be special ordered with different relay codes which allows one 8 key NSD-038 transmitter to operate 2 different units

Also available are 8, 10, 13, and 16 relay versions.

Appendix E

Typical Solenoid Force Curve



Appendix F
Assembly and Detail Drawings

Appendix G
Proof of Design Statement

Proof of Design Statement

Proof of design is to be completed by demonstrating a prototype of the designed product on the elevator system of Beechwood Home. This demonstration will be performed in elevator car #4 and on one of two floors having both up and down hall call buttons. The prototype will be a system for one elevator car with a call button device for a floor with both up and down call buttons. The in-car floor selection device will have two floor capability. Once the design concept is proven through the successful demonstration of this prototype, Beechwood Home may elect to pay the cost of expanding the prototype to a fully operational system for that facility.

It is assumed that if this system were to be installed, 120 volt electric power would be supplied to the location of the hall call buttons and inside the elevator by the product user. The retrofit units will be equipped with a cord and plug for connection to this supply. For all in-car testing and proof of design, the system will be altered to be powered by 12VDC battery.

Proof of design of the completed product will be based on the capability of the prototype to perform as follows:

1. The prototype will allow actuation of both the up and down call buttons and two floor selection buttons.

2. The system will allow actuation of the selected buttons using a remote control transmitter mounted to a patient wheelchair with the wheelchair between 2 and 10 feet in front of the elevator control panels.

3. Operation of the system will be accomplished with no movement of the user's arms from the simulated wheelchair armrests.

4. The completed design will not interfere with normal elevator operations.

5. Proof of the button actuation system will be accomplished in the following four steps:

    a. With the hall call button actuation device temporarily held in the designed position over the existing call button panel, a quadriplegic resident of Beechwood will demonstrate the ability to call both an up and down elevator using the remote control system.
    b. With the hall call button actuation device temporarily held in the designed position over the existing call button panel, both up and down elevators will be called using manual control.
    c. With the remote transmitter secured to a wheelchair in the same position as for part a above and the in-car device temporarily held in the designed position over the existing floor selection panel, the device will be used to operate the elevator car between two floors using the remote control system. (Note: battery power will be required for this in-car demonstration)
    d. With the in-car device temporarily held in the designed position over the existing floor selection panel, the elevator car will be operated between two floors using manual control.

____________________________ _________________________________

James W. Henize, Student — Professor Janak Dave, Faculty Advisor

Appendix H
Solenoid Data Sheet

Model# MSA 7163 /0139

Voltage 12 VDC

Max. Stroke 7/8 in.

Force in oz. 22 @ .125 in. stroke

Mounting stud length 5/8 in.

Mounting hole diameter .800 in.

Diameter 1.0 in.

Length 2.0 in.

Mounting thread3/4-24

Plunger extended length 7/8 in.

Price $15.36 ea

Supplier: McMaster-Carr Supply Company

Appendix I
Power Supply Data Sheet

Model #	PSA15W-120
Input	120 VAC
Output	Regulated 12 VDC, 1.5 A, 18 W
Size	3.1 x 2.1 x 1.9 inch
Weight	1.5 pounds
Agency Approvals	UL
Price	$22.95

Supplier: Jameco Electronics

Appendix J
Project Schedule

Week Ending Dates

TASK	11/04/01	11/11/01	11/18/01	11/25/01	12/02/01	12/09/01	12/16/01	12/23/01	12/30/01	01/06/02	01/13/02	01/20/02	01/27/02	02/03/02	02/10/02	02/17/02	02/24/02	03/03/02	03/10/02	03/17/02	03/24/02	03/31/02	04/07/02	04/14/02	04/21/02	04/28/02	05/05/02	05/12/02	05/19/02	06/01/02
2ND DRAFT-PROPOSAL DUE	X																													
2ND MEETING @ BEECHWOOD	X																													
Final Proposal Due	x	x	x	x	x																									
3 Design Concepts Due										x																				
Proof of Design Statmnt Due											x																			
Procure Parts for Testing												x																		
Design Freeze																			x											
Oral Design Presentation																		x												
Interim Design Report Due																			x											
Order Electrical Pars																				x										
Begin Manufacturing																					x									
First system testing begins																								x						
Proof of Design Due																											x			
Oral Presentations Begin																												x		
Tech Expo-Product Complete																													x	
Final Project Report Due																														x

(green) = completed tasks (red) = overdue tasks

Appendix K
Project Budget

Item	Qty Req.	Est Cost $	Source	Est. Expense	Actual Cost
Remote Control System	2	$75.00	Commercially Available	$150.00	$130.00
Solenoid switches	4	$16.00	Commercially Available	$64.00	$54.00
Power supply	2	$14.00	Commercially Available	$28.00	$36.00
Battery- 12 VDC	1	$12.00	Commercially Available	$12.00	xx
PVC Pipe	2 ft.	$3.00	Commercially Available	$3.00	$3.00
Acrylic sheet	4 sq.ft.	$35.00	Commercially Available	$35.00	$18.00
Contact cement	1	$6.00	Commercially Available	$6.00	$4.00
Bushings	4	$1.00	Commercially Available	$1.00	xx
Wiring Supplies	A/R	$10.00	Commercially Available	$10.00	$6.00
2 Sided tape	A/R	$5.00	Commercially Available	$5.00	$3.00
Universal Wheelchair Mount	1	$22.00	Commercially Available	$22.00	xx
Total Product				$336.00	$254.00