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Assistive Device to Augment Strength in the Weak Hand of a Stroke Patient

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Final Report

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Title: Assistive device to augment strength in the weak hand of a stroke patient

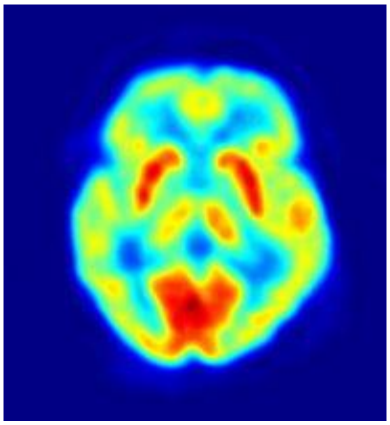
Contents

Abstract

More than 700,000 Americans suffer strokes annually, causing more serious long-term disabilities than any other disease. It is imperative that rehabilitation of stroke patients is efficient and successful. A common characteristic of post-stroke disability is loss of strength and sensation in the hand. It is hypothesized that robotics can be used to effectively augment this movement as well as improve the speed of recovery. In order to create such a device, there are a variety of approaches including the mechanical and electrical approach used in this design. The device is designed to move the hand in one movement as if it were hinged only at the knuckles. In order to take into account the amount of force a patient wants to apply with his or her hand, it is necessary to create a device that bases its movements off of varying pressure. This device includes a bladder that senses pressure and sends the signal to a microcontroller that determines the output for the stepper motor. The stepper motor moves the robotic hand. In the future, work will be done to improve mobility and mechanics, motor output, and the compactness of the device.

Background

Stroke is the third leading cause of death in the country (Figure 2). Stroke causes more serious long-term disabilities than any other disease (Robotic Therapy Helps Restore Hand Use After Stroke). The amount of damage done to the brain varies among stroke victims, and consequently the physical debilities do as well. Patients can experience effects ranging from complete inability to move muscles, to a mild deficit in the mobility of muscles. Commonly, stroke patients incur damage to one hemisphere of the brain. This damage leaves them physically impaired on the side of the body opposite the brain damage (Jensen).



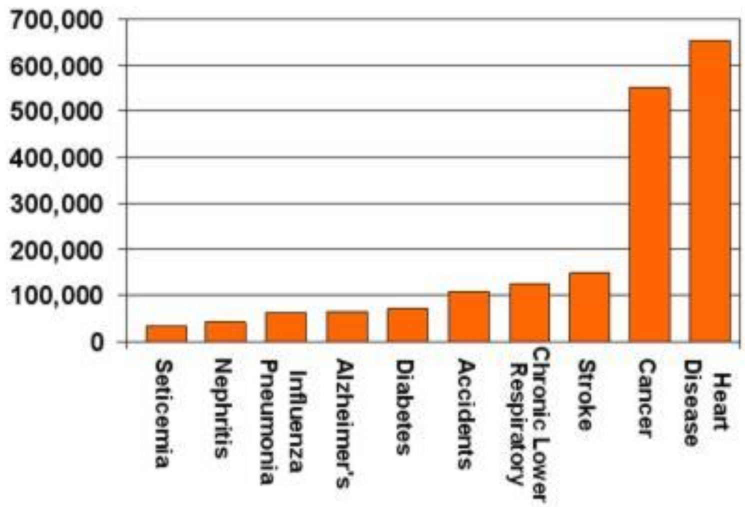


Figure 1, PET scan of the human brain (High Resolution Images)

Figure 2, Graph of leading causes of disease in the United States (Leading and Actual Causes of Death)

Studies have found that the brain is capable of recovering from trauma due to stroke. Scans such as the PET and MRI have been developed to detect the flow of blood in certain areas of the brain (Figure 1). Using this technology, researchers have found that when a person completes a physical task, blood flow increases in the area of the brain responsible for that task. Also, it has been found that an ability of the brain is to transfer the responsibility of a function from the trauma hemisphere to the healthy hemisphere. The brain will undergo rewiring rather than regrowth. Just as a car with a flat tire, a "spare tire" is needed to make up for the loss of function, although, similar to the spare tire on the car, the function is never completely regained. The majority of improvement in function occurs within the first three months after stroke (Robotic Therapy Helps Restore Hand Use After Stroke). Patient therapy during this post-stroke time could be extremely valuable.

Key characteristics of post-stroke hand mobility show the majority of patients have more difficulty extending rather than gripping. Also, studies have shown that grip force and extension force are variable, depending upon the openness of the hand (Oh and Radwin). These trends in hand strength add complexity to hand therapy and will consequently be important components to the development of our device.

Design Problem

After stroke, most patients regain partial strength of the hand. There are groups working on robotic devices that sense and augment movement. This helps the movement itself, and is hypothesized to improve recovery of strength and or dexterity. The device should be a glove or mitten design that can sense and augment finger movements in stroke patients.

Client Requirements

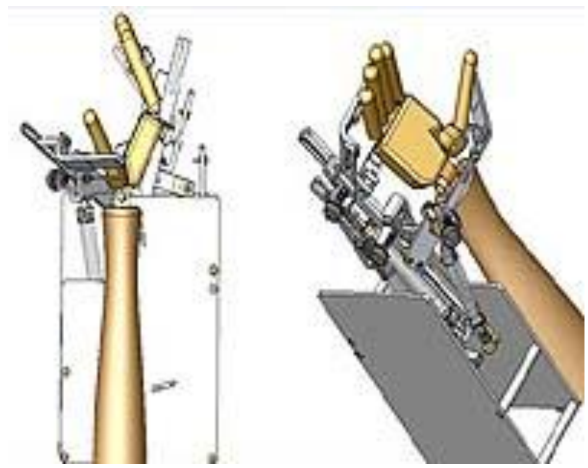
Dr. Matt Jensen, M.D., would like to develop a glove or mitten that is able to augment finger movements in stroke patients. This device should include the following items:

- Sense when the patient is opening or closing his or her hand and augment this movement based on pressure.
- Be able to be removed from the hand with little to no work involved.
- A safety feature so the patient's fingers are not broken.
- Be affordable and convenient for all stroke patients.

Similar Products

Researchers and therapists alike have been working hard for many years to accomplish a therapeutic device not only for the hand, but for other "hinged" joints such as knees and arms. Although there are not many products on the market today that mimic our proposed design, there is one in particular that seems to work towards the same goal. This product is called the HOWARD device (Hand-Wrist Assisting Robotic Device). The HOWARD is a robotic device that attaches to the hand using Velcro straps and augments the movement of the patient's hand. The device helps that patient move his or her hand when it is moved at least 1/10 of an inch. The HOWARD device strives to significantly improve grasping and releasing ability, manual dexterity, and range of hand and wrist motion (Robotic Device Helps Stroke Patients Regain Hand Use.").

Figure 3, HOWARD device (Robotic Therapy Helps Restore Hand Use After Stroke).



Figure, The HOWARD therapeutic device 4 (Robotic Device Helps Stroke Patients Regain Hand Use).

Product Uniqueness

Our device will be very similar to the HOWARD but will deviate from it by allowing patients to not only use the device for therapy, but also for everyday use, which the HOWARD is not currently capable of doing. This way, patients will obtain practice accomplishing day-to-day tasks they may not do in therapy.

Design Alternatives

On the most basic level, amplifying a stroke patient's grip force is about transmission of energy. Given a relatively small exertion from the user, the device must use an outside power source to add to the power generated by the user. In the design process, three fundamental systems of transmitting energy from one place to another were considered: mechanical, electrical, and hydraulic systems. Each of these systems was considered for the energy transmission system upon which the device would be based.

Since safety, both of the user and of the people whom the user would interact with in everyday life, was of paramount concern in designing this amplification device, precision of control was the major evaluative criteria in consideration of each of these systems. The system must be able to deliver a precise amount of force for any given force input, without fail, to avoid generation of dangerous levels of force. Size and weight of the system was also considered as a major criterion for the most viable candidate. Because the device's ability to be used in everyday life is the central point of difference between this device and similar apparatus already on the market, it must be small and light. If it is too heavy or unwieldy, it will discourage patients from using the device in regular activity. Also, if the device is heavy, repeated use could cause other musculo-skeletal debilities due to the abnormal load at the hand, especially in an already weakened stroke patient. By the same token, ease of use was also considered carefully in selection. Ease of use includes both functions during use and while idle, as well as the level and frequency of maintenance required for the system.

Factors that were considered, but on a more minor scale were the level of augmentation each system could supply, the aesthetic appeal each system would allow, and the overall cost. On average, human grip strength is around 250 N. Each system, given the correct selection of elements, is able to output this amount of force, albeit with different numbers and sizes of constitutive elements. As such, selection of the system that minimized energy consumption while generating this force was deemed to be less of a priority at this stage of the design process than selection based on other factors. Similarly in the case of aesthetic appeal, this attribute is secondary to the actual functioning of the device at this stage of the project, but must be considered in the future in order to encourage users to wear the device. The cost of the device was also secondary to the ultimate functionality of the device, but will obviously be minimized as the design process proceeds. In order to choose the appropriate system, one must examine each system in depth.

Hydraulic Systems

Hydraulic systems function based on a few basic properties of liquids: shapelessness, incompressibility, and equal distribution of force in the liquid in all directions (Hydraulic systems). These properties lead to the application of Pascal's Law which states that pressure in a fluid acts equally in all directions. Hydraulic systems harness the consequences of this law to generate large amounts of force via controlled transmission of liquid through a network of hoses and reservoirs to pistons of varying sizes. Of the three energy transfer systems, this one can generate the greatest amount of force. It also generates very smooth motion, which is desirable in order to minimize vibrational discomfort the device inflicts on a user.

Unfortunately, this system tends to require a large number of constituent parts. At minimum, it requires reservoir to store the fluid. It requires a pressure source like a pump, as well as a pressure user which generates either linear or rotary motion. In order to control flow, it requires a large network of valves, filters, and hoses to generate the correct outputs for given inputs. Finally, the system requires a transmission fluid. This causes further problems compounding that of the system's already excessive size. The fluid can leak, meaning the system may require regular maintenance.

Mechanical Systems

Mechanical systems use gear ratios to transfer energy via tradeoffs between speed of rotation and torque generated. Ultimately, these systems are the most intuitive to understand as they consist of a number of "real" mechanical elements such as gears, levers, belts, springs, and other elements which allow you to see the flow of energy. Unfortunately, because of these elements, mechanical systems tend to be large. Furthermore, in our particular case, the control logic will be particularly complex because grip strength varies with the degree of openness of the hand. As such, a mechanical system would require the ability to switch between multiple gear ratios to provide the desired amplification. This will add to the size of this type of system, as well as decreasing the level of control that designers have overall. The need to shift gear ratios will also interfere with the system's ability to operate smoothly on the scale of the hand, and may introduce undue stress upon the user's musculo-skeletal system. The speed of system response will also be hindered due to this necessity in the control logic.

Electrical System

Electrical systems provide a number of control and size advantages over either purely hydraulic or mechanical systems. As shown in Figure 5, a complex system of springs, pistons, and masses can be replaced by an equivalent network of sources, resistors, inductors, capacitors, and transistors. These discrete components which serve as the basic components of an electrical system will usually be contained within larger constitutive parts of such a system, such as operational amplifiers, analog to digital converters, and microcontrollers. These higher level components allow for higher level design of the overall system.

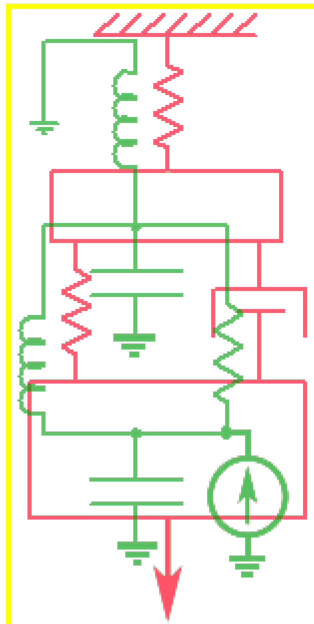


Figure 5, Equivalent mechanical (red) and electrical systems (green). The mechanical system will most likely consist of elements much larger than those of the electrical system, especially when dealing with the controling and output force ranges encountered by this device (Fraser).

This network of electrical elements can be shrunk down and printed onto a very small chip if necessary. This size reduction allows for very complicated logical controls to be applied in a very small amount of space and mass. Furthermore, the ability to use a microprocessor to apply complex decision-making logic based on a wide range of inputs (the equivalent to shifting gear ratios) will reduce the excess vibrational stress introduced to the user and decrease the reaction time of the system. If contained properly, this type of system would also require little maintenance, as moving parts are minimized reducing the need for regular oiling and care. Finally, using this type of system as a basis for control will allow incorporation of mechanical and hydraulic components (e.g. actuators and rotational motors) as may be necessary to generate forces of the required magnitudes. Table 1 summarizes the evaluations that were made for each system and demonstrates the major reasons for our selection of an electrically based system.

Design Criteria (Points out of 100)	Electronic	Mechanical	Hydraulic
Accuracy and Precision (30)	**30**	**10**	**10**
Size/Weight (20)	**20**	**15**	**10**
Ease of Use (20)	**15**	**15**	**10**
Maximum Force Generation (15)	**10**	**10**	**15**
Aesthetics (10)	**10**	**10**	**5**
Cost (5)	**5**	**5**	**0**
Total	**90**	**65**	**50**

Table 1, Design matrix for selection of a basic control system for the device.

Prototype Design

The current prototype design combines the stepper motor, microcontroller and pressure sensor into one device. The cuff of the blood pressure sensor will be attached to the user's hand and can sense the amount of pressure the person applies to it. When pressure is sensed, this signal is sent to the manometer which reads it and outputs an electrical signal to the microcontroller. The microcontroller is programmed to process the signal and send a new signal to the stepper motor instructing it to move in the appropriate way (To see a full diagram of the electrical configuration, see Appendix B). It is programmed for different speeds and different angles depending on how much the user inputs. Although not completed, a sensor on the back of the hand will allow this process to be reversed opening the user's hand. The following sections are key components used in the final prototype design in the respective order: Sensor, microcontroller, stepper motor, worm gear, hand mount. See appendix C for photos of the final design.

Sensor

For the prototype, a noninvasive sensor was used to output analog signals processed by the microcontroller. The sensor used was a blood pressure sensor. These are regularly used in hospitals and clinics all around the world for accurate measuring of arterial pressure. For the project, arterial pressure was not needed, but the same basic concept was used to measure the amount of force exerted by the user of the prototype, which is then translated into movement by the device.

Figure 6, Blood Pressure Cuff

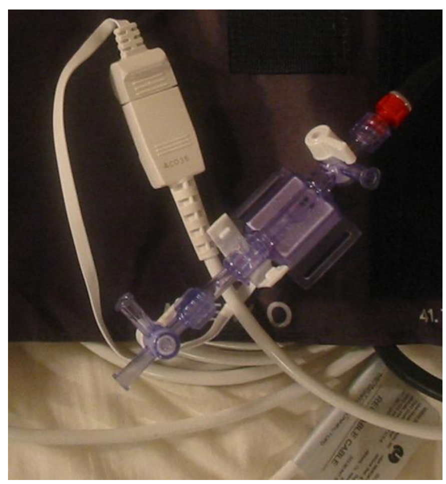


Figure 7, Blood Pressure Sensor

Blood pressure sensors operate by an inflatable cuff (Figure 6) placed around the upper arm of the patient. This cuff is attached to a manometer (Figure 7) which accurately measures arterial pressure without need for calibration. When vibrations or pressure is sensed on the cuff, the signal is transferred into a transducer in the monitor that converts the measurements into electrical signals. These electrical signals are then transferred into systolic and diastolic arterial pressure (How Sensors Work). In the prototype an Op-amp was needed to increase the signal from the sensor to the microcontroller.

In this device, the cuff of the sensor is wrapped around the patient's hand so to fit comfortably, yet securely. This allows the user to be able to grasp objects with his or her hand. When the user wishes to move his or her hand, he or she will put slight pressure on the cuff. This translates to the manometer which will give an electrical output signal. Instead of giving readings in systolic and diastolic pressure, however, these signals are transferred to the microcontroller which will then further processes it.

Advantages

The blood pressure sensor is a noninvasive sensor that provides quick and simple oscillometric measurements which can easily be converted to output signals with the microcontroller (How Sensors Work). They are easy to use, affix to the hand, and are very reliable with virtually no complications. Also, there is little discomfort or pain to the user. Blood pressure sensors are fairly common devices found in many places and are relatively inexpensive (Vernier).

Disadvantages

The blood pressure sensor has many advantages; however, there are some hindrances in its design as well. This type of sensor may provide less accurate readings than other more precise sensors (Vernier). Also, since the design uses an inflatable cuff, this may obtrude the palm and the user will have difficulty picking up objects. When objects are picked up and grasped in the palm, there may be some pressure on the cuff, which will cause the device to continue closing the hand. This is a major problem and will be corrected in the future. More advanced sensors along with proper sensor positioning and the correct programming algorithms will be used to solve this problem.

Microcontroller

Microcontrollers are small computers used in a variety of applications such as remote controls, automobiles, and cell phones. They are specific purpose computers designed to do one task, which means they can come in a variety of forms. They are a single integrated circuit with many features in common with normal computers. They consume very low power, usually 50 milliwatts or less, and are usually small and inexpensive (Brain). They operate at low speeds, usually only a few MHz, but this is adequate for many typical applications. Stepper motors can work in many types of environments and can be implanted or embedded into many types of devices. Because they are imbedded they do not have the typical human interface of normal computers. This means they must be connected to an external source that will provide directions.

In many cases this external source is a typical computer connected via a USB cable, which was used in the prototype (Brain).

When used in conjunction with the stepper motor, the microcontroller also serves as the indexer and is the pulse source for the motor. This can be programmed to produce the steps of the motor by providing the power to energize specific electromagnets which move the rotor. The number and rate of pulses determines the speed, direction of rotation and the amount of rotation of the motor output shaft. The input of these variables can be controlled by an external analog sensor, which for this project will be the amount of force the user will supply with his or her hand (Micro Tutorial 1: Understanding DC Electrical Characteristics of Microcontrollers).

The microcontroller that was used for the project is called the BASIC Stamp Discovery Kit (BS2-IC) provided by parallax. It includes a BASIC program to get started and only requires a 9V power source (BASIC Stamp Discovery Kit). Since the program only runs on the BASIC programming language, there were limitations in the usage of the device. However, for this project, a simple program was enough to move the device the desired amount, for the exact program see appendix E.

Stepper Motor

Stepper motors are common types of motors used in a wide array of settings such as in floppy disc drives, scanners, and printers. They are mass produced and relatively small, cheap, and quiet compared with other types of motors. They have excellent response to acceleration and deceleration commands and operate in an open loop system with no positive feedback required (How Stepper Motors Work).

A stepper motor is a type of electric motor that partitions the rotation into multiple steps. It contains a rotating shaft, called the rotor, and electromagnets on the fixed portion that surrounds the motor, called the stator (Fraser). The rotor is surrounded by a gear-like device that is able to align with the electromagnets. When one of the electromagnets is activated, usually by an external control circuit such as a microcontroller, the gear aligns with the first electromagnet and is slightly offset from the second electromagnet. To move the motor one step, the first electromagnet is turned off and the second is powered on. The gear then aligns with the second electromagnet, causing the gear to move (How Stepper Motors Work). The more electromagnets the motor has .the more precise each step can be. Frequent movements like these allow the motor to precisely "step" to a new angle. The angle that the motor achieves can vary widely by application. Typical motors run at an angle from about 1 to 5 degrees per step (Shinano). The process can then be reversed with the second electromagnet shutting off and the first electromagnet being powered on. This results in a movement in the opposite direction. A mechanism for this movement is shown in the figure below (Figure 8).

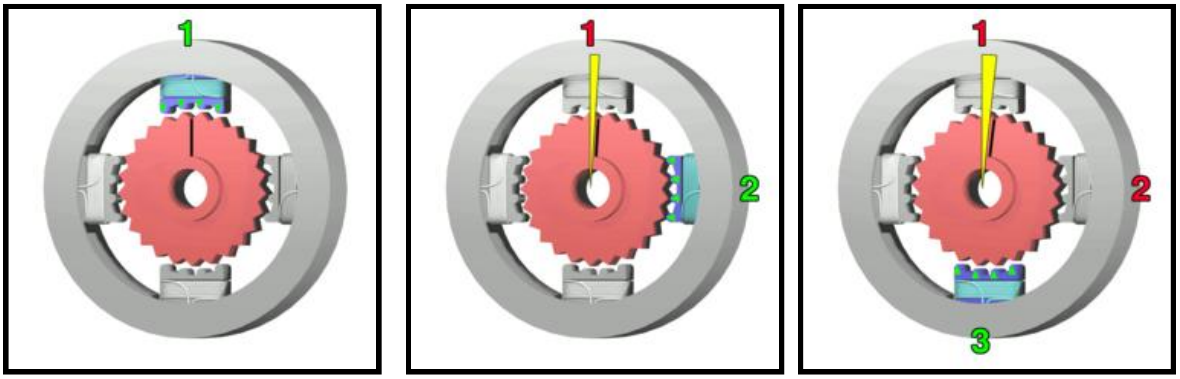


Figure 8, The first electromagnet (labeled 1) is activated first. Then, to move one step, the first one is deactivated and the second electromagnet is activated, which aligns the gear with the second one to move one step. To move another step the process is repeated with the next electromagnet (How Stepper Motors Work).

The motor used for the project has very precise control over movement angle at approximately 1.8° per step, which equates to 200 rotor teeth in the gear. It was easily controlled with a microcontroller and a simple circuit. It could also have been powered by a small battery or other power source.

The stepper motor model used in the prototype operates with a 10V supply and draws .85 Amperes per phase of current. Since the stepper motor was the major consumer of energy in this design, its energy data were used to approximate the energy usage of the prototype. Assuming use for 8 consecutive hours in a day, the device would consume 68 watt-hours. For this type of energy usage, a nickel-metal hydride rechargeable battery has characteristics that would make it an affordable and compact option for portable power. Appendix D shows various types of rechargeable batteries and the corresponding price and size of each type that would be required to power the prototype for 8 consecutive hours. This pricing and sizing information is an indication of the minimum specifications for a battery, and the actual choice of a battery would depend on the pricing and sizing of batteries available on the market. The motor used on the prototype, however, may not be powerful enough for use in a final design. Therefore, a lithium-ion battery may be the more viable option for a final design, given its high specific energy density (128 Wh/kg) and relatively high volumetric energy density (230 Wh/L).

Advantages

Stepper motors are generally low cost, efficient motors that continuously provide precise angles with each step (Shinano). Stepper motors also have high reliability. They perpetually create exact angle measures without need for recalibration (Shinano). When implementing this design on our device, the fact that there can be precise angles directly associated with it was a major advantage because it allowed the user's hand to move to the exact position he or she wished. Also, they are very durable and can work in most environments. At a low speed, which is the condition our device operated under, it provides a high torque (How Stepper Motors Work).

Disadvantages

Although the design offers promise in several areas, there are also a few obstacles to its implementation. Stepper motors in general produce a vibration called resonance that is more vigorous than other types of motors. This is caused by the rapid movement of the gear clicking from one position to the other because the motor must accelerate and decelerate in a short period of time (How Stepper Motors Work). This could lead to an uncomfortable sensation to the user unless proper casing is applied. Also, the motors experience decreasing torque at increasing speeds. However, this is only a minor issue because the device mainly operated at low speeds.

Stepper motors are also more complicated than typical DC motors because they need the precise amount of electricity to the exact place and time and usually have many wires integrated in the circuit (How Stepper Motors Work).

Worm Gear

In order to move the device in the proper direction, it was necessary to use a worm gear (Figure 9). The gear was attached to a hinge, which was in turn connected to two Plexiglas sheets that fit on the fingers and the forearm respectively. The worm was attached to the motor, and when in contact with the gear, moved the device in the proper direction.

Figure 9, Worm gear and hinge

Hand Mount

The current design although simple, provided a good starting point for the final goal of a complex, highly functional rehabilitation device. The device consisted of two bi-layer plexi-glass sheets approximately 4.5 x 6 inches each. Each sheet had a layer of 1 inch soft foam adhered to its underside along with Velcro straps for attachment to the user. These sheets were joined to each other at their ends by a metal hinge. Each bilayer plate was fastened with 3 rivets to the hinge. The half of the hinge attached to the forward plexi glass plate, which was strapped to the user's fingers, was fixed to the hinge pin. Additionally, a gear was fixed to the hinge pin at its center.

The rear plexi-glass plate, which was strapped onto the user's wrist, has a stepper motor attached by a forward opening hinge approximately at its center. This stepper motor had its drive shaft extended and directed towards the hinge. An aluminum coupling along with a brass rod cut to length were used to extend the motors drive shaft. At the end of the motors drive shaft was a worm gear, which was engaged to the gear on the hinge. A plastic wedge in the motors mounting hinge kept the worm gear and hinge gear engaged.

Safety and Ethical Concerns

Given the complex design of the final prototype, there are many safety concerns that need to be considered when putting the device into actual use. The delicate nature of stroke patients is highly concerning, and therefore, first and foremost, the device needs to assist them instead of causing more difficulty. One of the main concerns with the safety of the patient is that the device will move only when the patient wishes. If the device continues to either open or close when the patient wishes it to stop, the patient's hand may be forced into an unnatural or potentially harmful position. The hinge on the back of the device acts as a safe guard to make sure the device does not open too much. However, there is no safe guard to prevent the device from closing too much and therefore crushing the patient's hand. A future design will take this into consideration and correct this problem.

Another concern for the patient is that the device may be too heavy. Many stroke patients are already in a weakened state and may not be able to lift heavier objects. The goal of this design is to make the device as lightweight as possible so the patient will not become fatigued throughout the duration of use. Currently, the device weighs approximately 3.5 lbs. Future designs would significantly reduce this weight to ideally make it under one pound. Currently, smaller and lighter motors are too expensive and beyond the scope of this project.

Also, if the wire is too small for the current it is supposed to carry, it will heat up and could potentially cause a fire (Electrical Safety). To prevent overloading, a fuse will be incorporated in the device to protect both the user and electrical components in the case of overloading. The wiring used in this design minimizes these risks by using correct size wiring and minimizing the exposure of the wires, and therefore the potential for electrical shock.

One final concern that has been a goal of this project from the start is that this device will only assist patients in movement and not be used as a necessary replacement. When a stroke patient moves his or her hands, the neurons in the brain are activated and repeating these movements strengthens them. This device is meant to strengthen those neurons instead of replacing them. The sensor attached to the device adequately prevents this situation because the patient needs to move at least slightly to activate the device.

Budget

The following is an approximate list of prototype development expenses. At this time it isn't possible to predict an approximate cost of a final design.

Item	Cost ($)
Microcontroller	160
Plexi-Glass	2
Hinge Large	5
Hinge Small	4
Fasteners	7.5
Adhesives	15
Plastic Motor Wedge	3
Foam	4.5
Velcro Straps	5
Parallax Steplper Motor	11
Vexta Stepper Motor	150
Parallax Stepper Motor Driver Chip	3
Vexta Stepper Motor Driver Chip	6
Analog to Digital Converter	6
AC/DC 9-Volt Power Supply	15
9-Volt Batteries	5
Total	**402**

Table 2, The total budget for the semester.

Future Work

In the future, there are many parts of the device that need to be enhanced. Improvements will be made in steps to make sure all corrections will function properly with the current device. The main development areas include: improved mobility and mechanics, improved sensory input and output, and a more compact size.

The current design is limiting to the hands' range of motion; in the future, enhancements to the design are required to better match the mechanics of the human hand. This will be accomplished by increasing the number of joints and mechanical complexity of the device to account for all the different movements a patient may want to make with his or her hand. For example, the current focus is on the movement of the four fingers simultaneously. In the future, it will focus on allowing each finger to move individually via its own mechanism. This improved mobility will allow for a more effective rehabilitation.

The sensitivity of input of the device is crucial to its function. Sensors will be incorporated that accept input in a way that can easily be detected and translated into the proper mechanical movement. Currently, a blood pressure sensor is being used for the purpose of setting up a temporary system of pressure input and mechanical output. Unfortunately, the blood pressure sensor being used is bulky and makes small changes in pressure difficult to interpret. Electrical sensors will be integrated that are sensitive and easy to calibrate. These sensors will be incorporated with the hope of increasing the ease of use for the patient. As far as mechanical output, a motor and gear system will be implemented that allows for a smooth and rapid response to input.

In the future, improved computing power will allow for more complex mechanical functions. These more complex functions include multiple fingers moving at the same time and an overall smoother function of the device. Currently, the output from the stepper motor is rough because of necessary computing delays in the processing of signals from the sensor. With higher computing power, i.e. an operating system, it will be possible to run multiple programs simultaneously and eliminate any delays, causing for a more fluid movement. As for safety, programming and guards will be incorporated to protect against possible over-extension or compression of the hand and possible pinching.

Finally, the design will be recreated with smaller and more efficient and practical components. One of the main purposes of this device is to be user friendly and portable. To accomplish this, a smaller control unit will be integrated as well as a smaller battery and mechanism. Although the design proposal represents a significant challenge, success with such a device would be well worth the effort as a rehabilitation device to the thousands of people who are victims to strokes.

A

Appendix

Product Design Specifications

PRODUCT DESIGN SPECIFICATIONS

February 3, 2008

Title: Assistive device to augment strength in the weak hand of a stroke patient

Team:
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Brad Rogers-BSAC
Tyler Vovos-BWIG
Mark Reagan-Communicator

Function: After stroke some patients suffer complete loss of mobility in the affected body part; however, most regain a certain degree of their original mobility and strength. There are groups working on robotic devices that sense and augment movement - this helps patient mobility, and is hypothesized to improve recovery of strength and or dexterity. The device should be glove or mitten design that could sense and augment finger movements in stroke patients.

Client requirements: Our client, Dr. Matt Jensen, would like our team to develop a glove or mitten that is able to augment finger movements in stroke patients. This device should be able to sense when a patient is opening or closing his/her hand and augment their movement based on the pressure being applied on the glove. The device should also be able to be removed from the hand with little work involved. Important areas of focus include efficiency of the design, safety regarding glove movements, and the ability to be affordable and convenient for all stroke patients. This project may involve electric, hydraulic, and various other mechanical approaches.

Design Requirements:

1. **Physical and Operational Characteristics**

   a. *Performance Requirements*

   The product should be able to improve the mobility of a stroke patient's hand while being comfortable and safe for the patient. It should be unobtrusive and be able to be worn only when the user wishes. The device must be portable and capable of being attached and worn by a patient in a home setting. It should have a significant battery life so the user can wear it for long periods of time. To add to its practicality, the device should be able to achieve average hand strength assistance, approximately 279 N.

a. *Safety*

If electrical power is used, electrical safety is the main concern and the device should have proper guidelines on use. Electrical components should be encased in a protective material to reduce the risk of electrical shock. If other power sources are used, proper safety should be taken and proper instruction on use of the device should be given. Device should be tested to ensure its efficiency over time. Minimal user training should be required.

b. Accuracy and Reliability

The device should be able to withstand prolonged use and be readily available whenever the user would like to use it. It should have lengthened battery life for continual use. It should accurately sense the amount of force the user wishes to exert and assist in the sought movement.

c. Life In Service

The product would ideally have a power source that would last all day, approximately 6-12 hours. Additionally, it will be capable of recharging during night, approximately 6-12 hours. The product itself should last the lifetime of the user to reduce costs for patients.

d. *Shelf Life*

If batteries or another degradable power source is used, proper storage should be noted and labeled on the device. Electrical wires and other mechanics should have proper encasing so they don't degrade over time. It should be able to be stored in a home environment so it can be near the patient.

e. *Operating Environment*

The device will have to be robust enough to function in a number of different environments. Wearers may use it in a number of different temperature and humidity environments, including the possibility of total liquid immersion (as in the case of the user spilling a glass of water on the device). The device will most likely be subject to dirty and dusty conditions. The device must withstand shock loads, as objects could be dropped on the device during daily use. Electrical interference may be encountered due to the variety of household appliances, which radiate electromagnetically.

f. *Ergonomics*

Since the product will be worn on the user's hand and potentially be used in interaction with other humans, force restrictions must be established to protect both the user and other parties who might interact with the user. In the case that the user was to shake another party's hand, for example, the device must have a force feedback mechanism in order to avoid crushing the hand. Range of motion must also be restricted to avoid hyperextension or hyper-flexion of the fingers. Also, the fingers have no ability to rotate about the long axis, so torsion forces must be minimized or eliminated. Furthermore, the device must be comfortable enough to wear for extended periods of time.

g. *Size*

The device will be worn on the hand and must not be excessively large so as to be unwieldy in daily use.

h. *Weight*

The device must not add significant weight to the user's arm. Such excessive weighting could cause stress injuries to the user over extended periods of use. Ideally the device will weigh less than 1 lb.

i. *Materials*

Materials which will come in direct contact with the skin (i.e. the glove material itself) must be non-allergenic, and also non-irritating. Mechanical materials must be strong enough to withstand shock loading. Electrical components must be protected from liquid, dirt, and dust via some protective material.

j. *Aesthetics, Appearance, and Finish*

The device must mimic the shape of the human hand. It must be stylish and aesthetically pleasing so that the user is not discouraged from using the device in public.

2. Production Characteristics

a. *Quantity*

One prototype is needed at the current time, however product be designed for possible mass production in the future.

b. *Target Product Cost*

The price for production of the prototype must not exceed $1000. The mass produced final design should be affordable to all stroke patients.

3. Miscellaneous

a. *Standards and Specifications*

FDA approval will be necessary. IRB approval will be necessary before any testing is done. Product must be able to be easily translated into mass production. Product must be proved beneficial to the recovery of stroke patients.

b. Customer

Stroke patients with loss of mobility in the hand. The range of patient mobility can vary from low to high, as long as some mobility is present.

c. Patient-related concerns

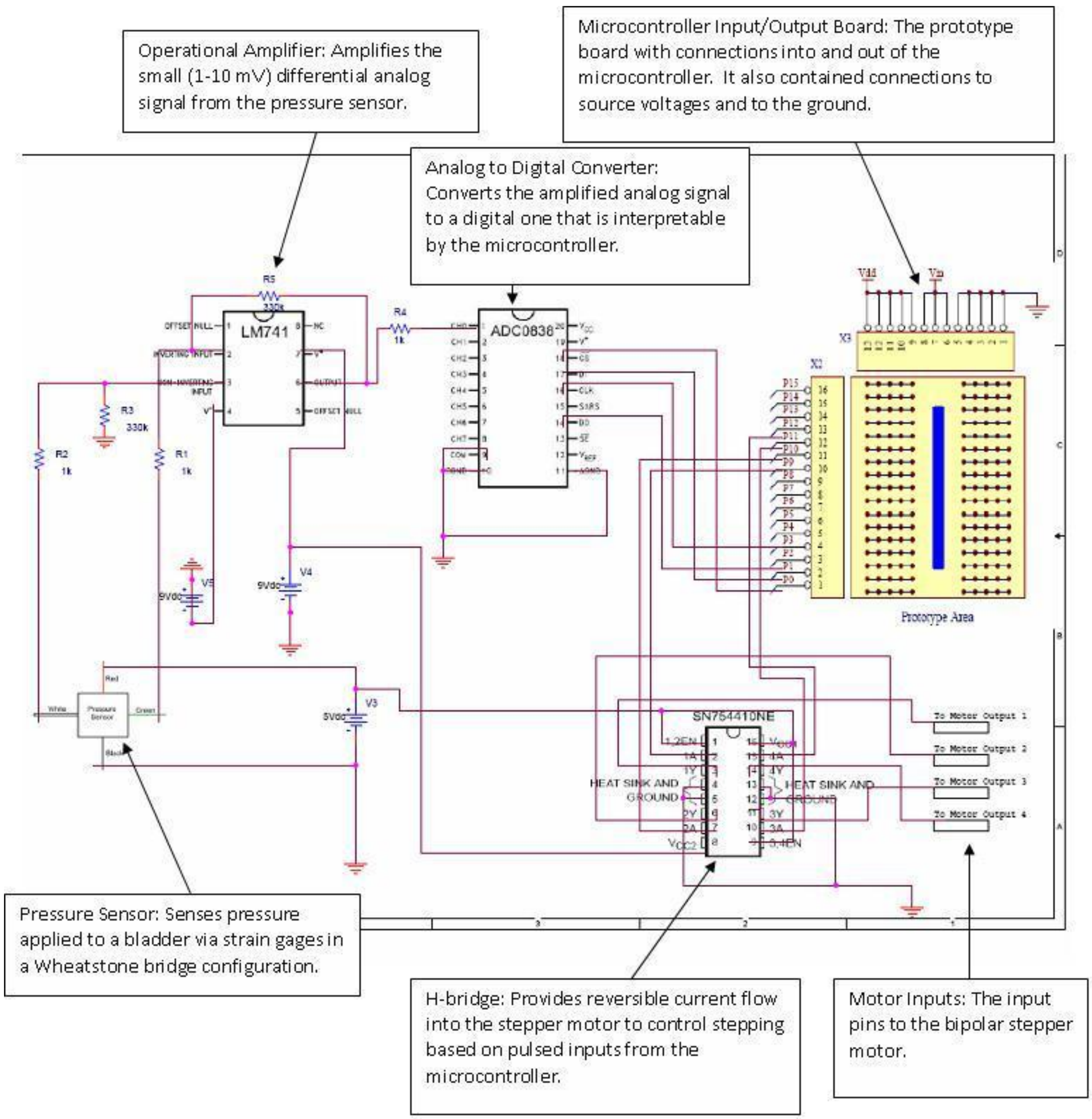
The product will have to undergo rigorous testing to ensure that it is safe for all patients under all circumstances. It must not have the potential to cause injury to the hand.

d. Competition

The concept of assistive movement stroke recovery therapy is new but widely known. Other devices for a wide array of body parts have been designed to assist the movement of stroke patients. To our knowledge and to the knowledge of our client no other “removable” devices have been made for the hand.

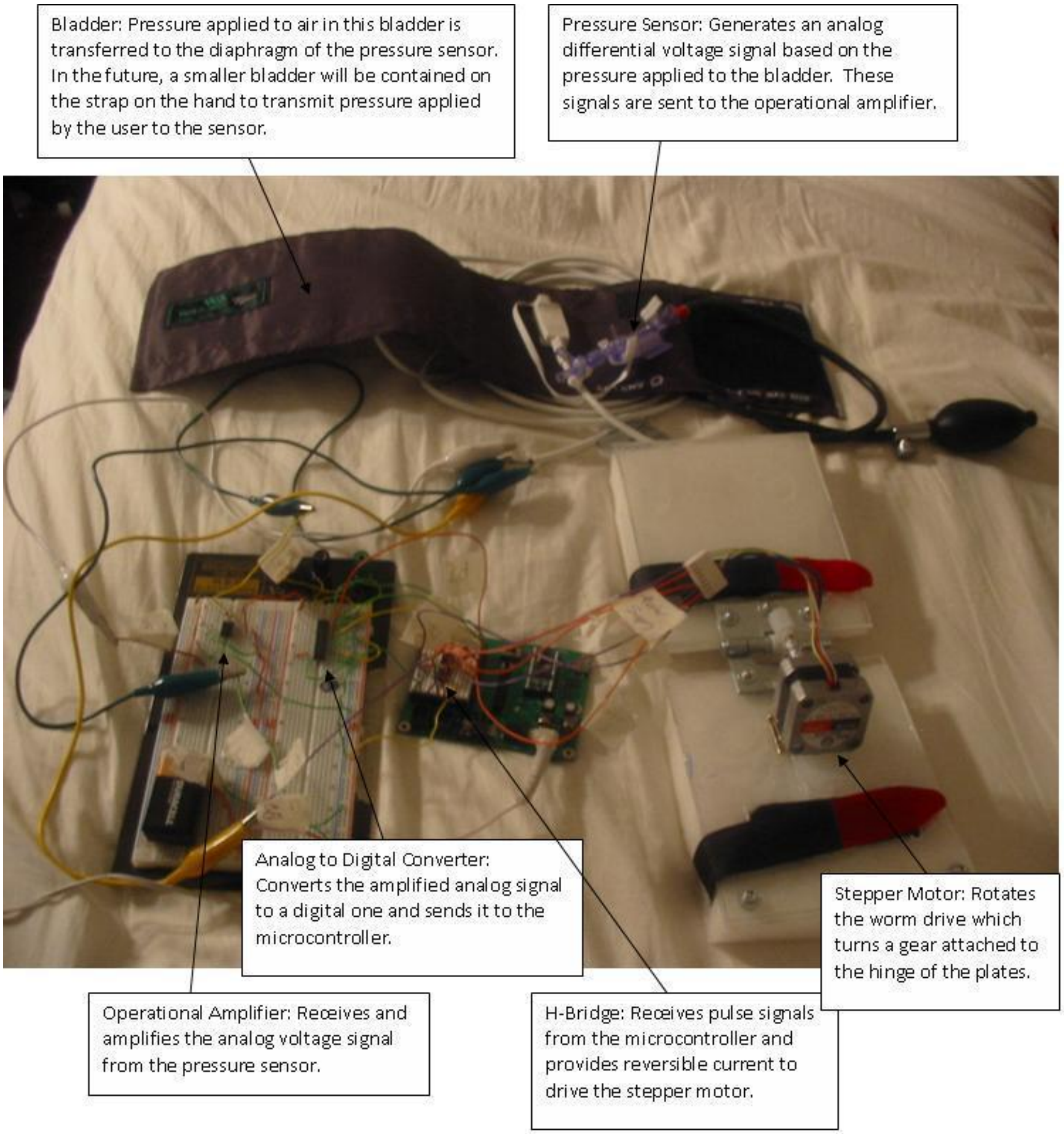
B

Electronic Configuration of Final Design



C

Final Design



D

Stepper motor energy consumption and characteristics of various rechargeable battery options

All Data from (Battery Energy)

Motor	**Voltage Rating (V)**	**Current per Phase (A)**	**Energy (J/s = watt)**	**Watt-hours (8 hours of use)**	**Price ($)**	**Weight (kg)**	**Weight (lb.)**	**Volume (L)**
Vexta PK244PA	10	0.85	8.5	68				
Battery Type	**Cost per Watt ($)**	**Energy Density (Wh/kg)**	**Energy Density (J/kg)**	**Energy Density (Wh/L)**				
Lead-acid	0.17	41	146000	100	11.56	1.6585	3.6571	0.6800
Alkaline long-life	0.19	110	400000	320	12.92	0.6181	1.3630	0.2125
Carbon-zinc	0.31	36	130000	92	21.08	1.8888	4.1650	0.7391
NiMH	0.99	95	340000	300	67.32	0.7157	1.5783	0.2267
NiCad	1.50	39	140000	140	102	1.7435	3.8446	0.4857
Lithium-ion	4.27	128	460000	230	290.36	0.5312	1.1714	0.2957

E

Microcontroller Program

```
'{$STAMP BS2}

' Program: ADC0838.BS2
' This program selects and reads each channel of the National Semiconductor
' ADC0838 8-Channel, 8-bit analog-to-digital converter.  Single/MSB First
' mode is used.  Connections to the ADC are shown below.

'                 -------U-------
'            -> --| 1      20 |-- Vcc  (to +5)
'            -> --| 2      19 |-- N/C
'            -> --| 3      18 |-- CS*  (to I/O pin 0 of Stamp II)
'  0 to 5 Volt    -> --| 4  ADC   17 |-- DI   (to I/O pin 1 of Stamp II)
'  analog inputs  -> --| 5  0838  16 |-- CLK  (to I/O pin 3 of Stamp II)
'            -> --| 6      15 |-- N/C
'            -> --| 7      14 |-- DO   (to I/O pin 2 of Stamp II)
'            -> --| 8      13 |-- SE*  (to +5)
'   (to ground)  Com --| 9       12 |-- Vref (to +5)
'   (to ground) DGnd --| 10      11 |-- AGnd (to ground)
'                 ---------------
'  * indicates an active low pin

ADCRes    VAR  Byte  ' A-to-D result: one byte.
CS    CON  0  ' Chip select is pin 0.
ADCIn    CON  1  ' Data input to ADC is pin 1.
ADCOut    CON  2  ' Data output from ADC is pin 2.
CLK    CON  3  ' Clock is pin 3.

Channel    VAR  Byte  ' Number of the channel we want to measure
InitBits  VAR  Byte    ' Sequence of bits for initialization
```

```
ChInput VAR    Byte
' set variables:
x           VAR    Byte
stepper       VAR    Nib
steps          VAR    Word
pauseTime VAR    Byte

' set pins 8 - 10 as outputs, using DIRS to do so:
DIRS.HIGHBYTE = %00001111

OUTA = %0001  ' Set Chip Select High to deselect ADC
DIRA = %1011  ' Set direction bits properly



steps = 100

main:
   GOSUB Again
   ChInput = ADCRes

   DEBUG "ChInput Test:", DEC ChInput

   IF (ChInput >= 0) & (ChInput < 10) THEN Again
   IF (ChInput >= 10) & (ChInput < 50) THEN torqueLow
   IF (ChInput >= 50) & (ChInput < 100) THEN torqueMid
   IF (ChInput >=100) THEN torqueHigh

   turn:
   'GOSUB clockStep
   'PAUSE 1000
   GOSUB counterClockStep
   'PAUSE 1000
```

```
GOTO main

torqueLow:
  pauseTime = 50
GOTO turn

torqueMid:
  pauseTime = 10
GOTO turn

torqueHigh:
  pauseTime = 5
GOTO turn

clockStep:
    DEBUG "counter" , CR
    FOR x = 0 TO steps
        LOOKUP x//4, [%0011, %0110, %1100, %1001], stepper
        OUTS.HIGHBYTE.LOWNIB = stepper
        PAUSE pauseTime
    NEXT
RETURN

counterclockStep:
    DEBUG "clockwise", CR
    FOR x = 0 TO steps
        LOOKUP x//4, [%0110,%0101,%1001,%1010], stepper
        OUTS.HIGHBYTE.LOWNIB = stepper
        PAUSE pauseTime
    NEXT
RETURN

Again:
```

```
DEBUG HOME
Channel = 0 ' Go through channel 1
  LOW CS    ' Activate the ADC0838.

  'Calculate initialization bits.  Bit definitions are as follows:
  'Bits 7..5 = all 0's (will be ignored by the ADC)
  'Bit 4 = 1 (Start bit)
  'Bit 3 = 1 (Single mode)
  'Bit 2 = Odd channel selector (bit 0 of channel #)
  'Bit 1 = Channel selector (bit 2 of channel #)
  'Bit 0 = Channel selector (bit 1 of channel #)
  InitBits = %11000 | ((Channel & %001) << 2) | ((Channel & %110) >> 1)

  'Shift out the initialization bits
  SHIFTOUT ADCIn,CLK,MSBFIRST,[InitBits\8]

  'Shift in the 8-bit data
  SHIFTIN ADCOut,CLK,MSBPOST,[ADCRes\8]

  HIGH CS    ' Deactivate the ADC0838.

  ' Show us the conversion result.
  DEBUG "Channel ",DEC Channel, ": ",DEC ADCRes,CR
  PAUSE 0    ' Wait a second.
'NEXT      ' Select next channel
RETURN
```

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