CHAPTER 21
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Sensory Feedback System for Gait Modification

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INTRODUCTION

The subject for this project is an eight year old boy from Gorman Public School. His primary condition is hemiplegic Cerebral palsy, affecting the right side of his body. He has a severely pronated right foot and therefore has trained himself to bear all his weight on his left side. Recently, he underwent a surgical tendon release and should now bear weight evenly on his right side. However, he is not doing so due to the decreased awareness in his right side, a phenomenon similar to that of stroke victims. He walks with an exaggerated limp so that he never has a significant portion of his weight supported by his right foot. When manually forced to bear more weight on his right side, he does not complain of any pain, but simply notes that it "feels funny." Chronic gait problems such as his have been shown to cause secondary complications of abnormal bone growth in the pelvis and lower extremities, which would then require surgical correction. To prevent this outcome, a device is needed to help train him to bear his weight evenly on both feet.

It is believed that a feedback system giving him positive reinforcement for placing more weight on his right foot would accomplish this goal. There are several ideal characteristics for this system. First, since the subject has some visual impairment, the feedback should be auditory in nature. The system should be portable so he can use it while walking as well as standing. It should allow for changes in the amount of weight shift needed to get the feedback so that, initially, he will get encouragement from very little progress and then the system can gradually be made more demanding. Finally, the platform force plate should be made so that it will not require special shoes and will not alter his gait in a way that would cause other complications.

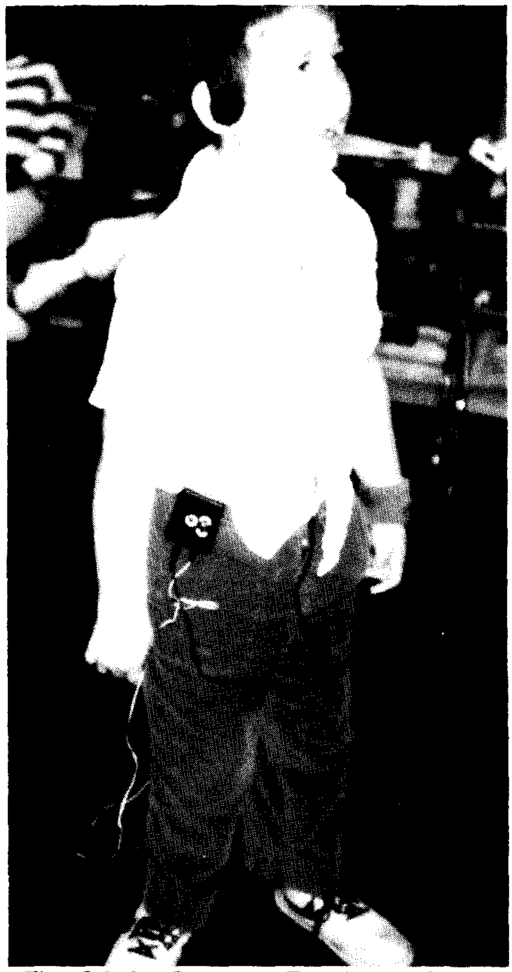

Fig. 21.1. Sensory Feedback System for Gait Modification.

SUMMARY OF IMPACT

After testing the final device on the subject, it was found that the gait modification system constitutes a very useful, safe, and relatively inexpensive training tool for those with gait problems. The effective solution to this problem will bring significant benefits to the student. As well as the psychological benefits of looking more "normal" when walking and being able to run and play better, there are serious medical complications that will be prevented.

TECHNICAL DESCRIPTION

This project is divided into three sections. First, the design of an unobstructive and efficient platform force plate is needed. Second, the electronics and software logic necessary to determine when feedback should occur needs to be defined. Finally, an optimum feedback method needs to be determined. The gait modification system itself will be physically divided into three parts. Almost the entire system will be located in the main project box, which will be adapted so the subject can wear it on his belt. The two devices that will not be installed within the box are the force plate (located in the right shoe) and the feedback device itself.

Optimum Platform Force plate - In the past, these devices were generally bulky, rigid, and very uncomfortable for the user. However, through the use of Force Sensing Resistors (FSRs), a shoe insert can be designed such that the subject won't even notice it is there. An FSR is a polymer thick device that exhibits a decreasing resistance with increasing force applied normal to the device surface. FSRs have a thickness between 0.008 and 0.030 inches so they will not contribute any significant bulk to the insert. The subject already has to wear an AFO brace on his right foot so the force plate can easily be attached to the bottom of this orthosis. A simplistic design, the FSRs are sandwiched between two Dr. Scholl's inserts allowing comfort and ease in removability. By using these FSRs the force plate will become a resistor that will have decreasing resistance when more pressure is applied. Therefore, if a constant voltage is applied to the force plate, the output will be a voltage that increases with increasing force applied to the force plate.

After evaluating a pressure profile across the foot from heel strike to toe-off, it was noted that the highest pressure was located at the heel during the heel strike. It would have therefore been optimal to place a single FSR beneath the center of the heel. However, the subject also had a tendency to be very unstable and did not consistently bear his weight over his heel. At times his balance would shift forward to the ball of his foot. It was therefore decided to place two FSRs within the insert, one located at the heel and the other at the most distal portion of his orthosis.

The final force plate design utilizes a 1/2" diameter FSR at the heel connected in parallel with a 3/8" diameter FSR at the ball of the foot. Measuring from the heel of the insert to the center of the FSR, they are located at 2 and 16 centimeters, respectively. The two FSRs are connected in parallel so that the resistor that is seeing the greatest pressure will dominate the total impedance of the force plate. If the two FSRs were in series, it is conceivable that as a large amount of weight was centered over just one of the FSRs, the other would still exhibit high impedance, thereby masking the decrease of the other.

Feedback Device - The other part of the system external to the main box is the feedback device. For an auditory mode of feedback, an earphone is preferable to a speaker so that it would not disturb bystanders. Since continuous wearing of an earphone could cause pressure sores or a hearing deficit from the physical occlusion of the auditory canal, other modes were explored. One possible mode is a small device worn close to the body that would buzz at low frequencies so that it would not be heard, but the vibrations would be felt by the subject. This would be comparable to wearing a beeper close to one's skin when at a loud party, such that the vibration would be felt, but the crowd noise would drown out the sound. However, due to the subject being extremely ticklish, it was decided to fall back upon the earphone idea. The final design utilizes lightweight Walkman headphones. They are less likely to fall off the subject's head, as well as being more comfortable. Also, the present foam design of the headphones allows external sound to pass to the auditory canal with little or no attenuation.

Electronic Circuitry - Figure 20.2 illustrates the first generation design for the gait modification system. Beginning with the force plate, there is a limiting resistor Rm. This resistor is necessary to limit the current flow through the FSRs. They will only tolerate 1 milliamp per square centimeter of surface area. The smallest FSR has a diameter of 3/8 inch, so it could only handle 0.71 mA. If we simplify the analysis by assuming that at high pressure one of the FSRs will be a short, and we want to limit the current to 500 mA, then for a 9V battery power supply Rm would have to be 18 KΩ. If we switch to a smaller power supply, Rm could be altered proportionately.

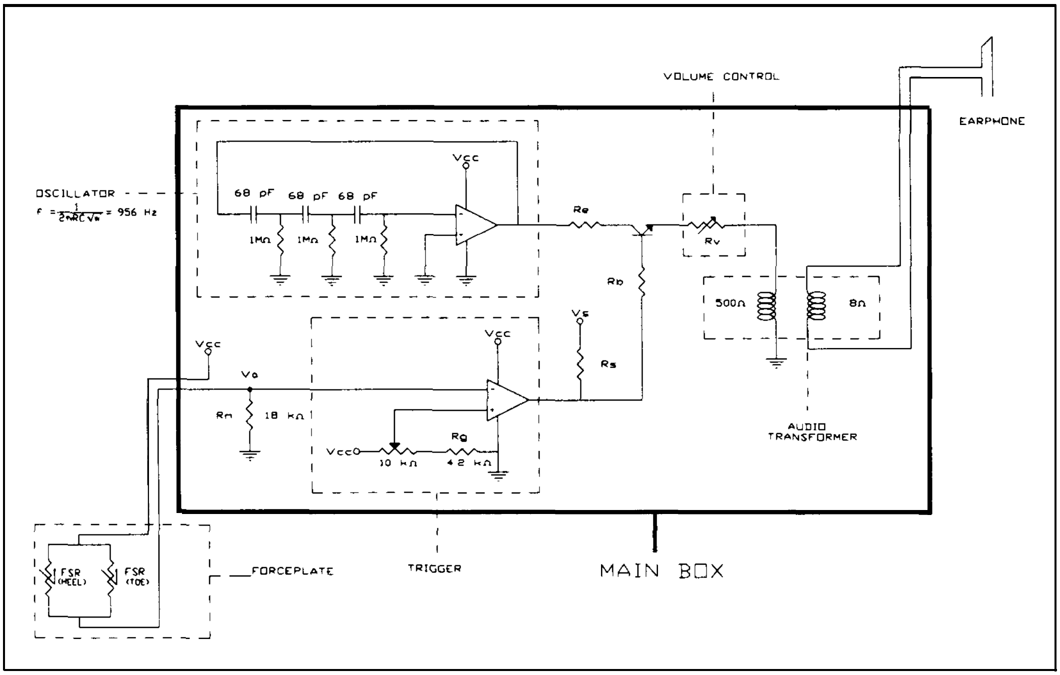

Fig. 21.2. Circuit for Gait Modification System.

In actual use, the resistance of the FSRs will only swing roughly between 2 KΩ under extreme pressure and 40 KΩ when not loaded.

Even though an FSR has infinite impedance under no load, there is enough pressure inside the shoe to reduce the resistance to the 40 KΩ mentioned above. Therefore the equivalent impedance of the force plate will vary from 1 KΩ to 40 KR. The voltage seen at the non-inverting input to the triggering op-amp (Va) will vary between 95% to 31% of Vcc. Thus, when using a 9 V battery Va will swing between 8.5 V to 2.8 V. The triggering voltage will be set using the 10 KΩ potentiometer at the inverting input. To give higher resolution to the 10 KΩ pot, a series resistor Rg is added between it and ground. Since when the pot is at its maximum, we only want it to drop 70% of Vcc, we choose Rg to be less than 3/7 of the potentiometer, or 4.2 KR. Normally, one might assume that a hysteresis resistor would be needed to give feedback between the output of the op-amp and the input. This would establish a linear range for the op-amp. However, no such linear range is desired for this application. We simply want the op-amp to turn on and off when the threshold voltage is crossed.

Next comes the transistor that will send the feedback signal to the output device (earphone). When the triggering op-amp flips high, the transistor will deliver the oscillator signal from the collector to the emitter and on to the output device. When the trigger flips low, it will be a sink and turn off the transistor. The resistor (Rb) at the base of the transistor is simply to limit the amount of current that is drawn from the op-amp, and is on the order of a few hundred ohms. A source voltage (Vs) is added in order to drive the transistor. When the triggering op-amp is low, it will sink this voltage, leaving the transistor off. When the trigger flips high, Vs will drive the transistor.

The oscillator is simply a phase-shift oscillator. It is always on as long as there is power supplied to the op-amp. The only negative aspect of this is that it will dram the most power from the battery. The oscillator is chosen in order to save space. It contains no bulky indicators and can be driven with the same type of op-amp as in the triggering mechanism. Therefore, one dual op-amp will be able to drive both sections of the circuit in only half the space. The frequency for the oscillator is determined using the equation shown in the circuit diagram. Using the 1 ML resistors with the 68 pF capacitors it will produce a signal at approximately 1 kHz.

The output section of the circuit is driven from the emitter of the transistor. It is a simple 500 L to 8 L audio transformer along with another potentiometer that is used as a volume control. The main box has two jacks: one to the earphone and the other to the force plate. It will also have two knobs for adjustment of the output volume and triggering voltage. Additionally, there is an on/off switch to cut the power from the battery to the rest of the circuit.

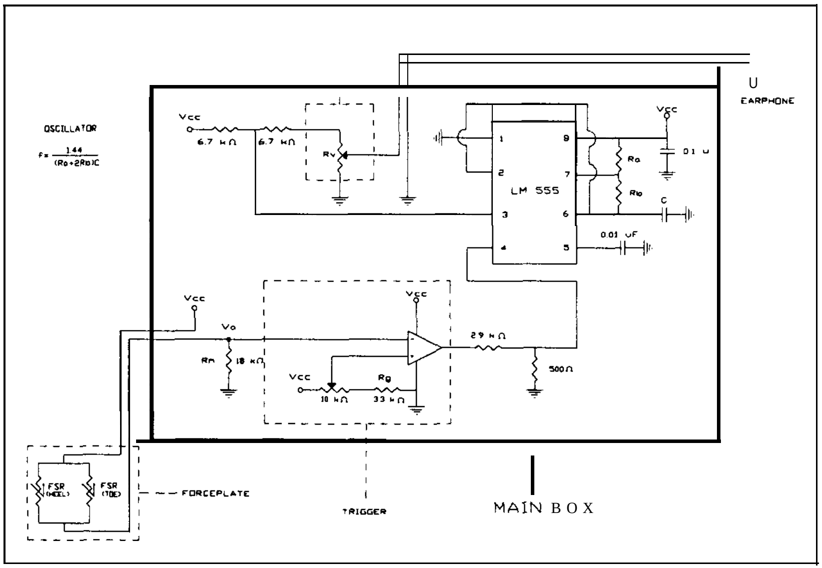

Fig. 21.3. An Improved Circuit for Gait Modification System.

However, a major design change came from the realization that an LM 555 timer chip can drive a headphone directly without a transformer. A circuit diagram using this chip is shown in Figure 20.3. The RC network at pins 6, 7, and 8 determine the frequency of oscillation of the output. Using an Ra of 18 KR, Rb of 100 KR, and a capacitor, C, of 0.01 mF, this produces a frequency of 660 Hz. This yields a pleasant signal as well as allowing for a low current being drawn from the power supply.

The voltage divider leading into pin 4 of the chip is necessary because the "off' voltage level coming from the comparator is more than 1.5 volts. To reset the chip, this voltage has to be reduced to below 1.0 volts. Two fixed resistors are used to balance pin 3 evenly between Vcc and ground, so that optimum sound quality is achieved. Since the headphone has an impedance of only 16 Ω, its resistance is insignificant. The 6.7 KΩ resistors were chosen to be as large as possible to limit current flow while still delivering sufficient voltage to the headphone to be audible.

The final major design change was due to the benefits of CMOS technology. An LMC 555 can be used in much the same way as the LM 555. However, it operates at much lower power so a single AA 1.5 V battery can be used as a power supply.

The reset current required at pin 4 is also several orders of magnitude smaller at pA levels. Therefore, the comparator was eliminated completely to save even more space. The final circuit design is shown in Figure 20.4. With a 1.5 V power supply the current limiting resistor, Rm, is reduced to 3 KΩ Since the force plate impedance can vary between 2.0 to 30 KΩ, the resistance between Vcc and pin 4 can vary between 5 to 33 KR. Since the reset voltage at pm 4 is 0.4 V, the maximum resistance needed between pin 4 and ground becomes 12 KΩ. To increase the resolution of the potentiometer this is broken up into the 2 KΩ fixed resistor and the 10 KΩ potentiometer shown in the circuit. The lower power supply also eliminates the need for a volume control. The balancing resistor at the output now matches the impedance of the headphone, 16 Ω.

Total cost for the final sensory feedback model was $350.

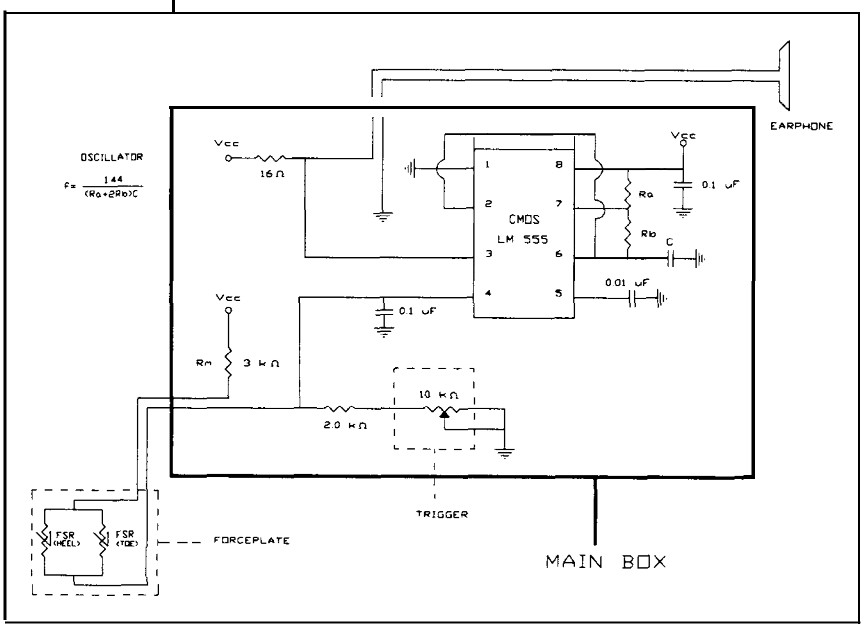

Fig. 21.4. Final Circuit Design for Gait Modification System.

Motorized Adjustable Height Table

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INTRODUCTION

This project was conceived with the idea to design a motorized adjustable height table that can be used by a student at Gorman Elementary School in Dayton, Ohio, with quadriplegic Cerebral palsy. The power wheelchair in which the child is bound to is higher than the chairs that the other students use, making him unable to access the classroom learning devices. To resolve this problem, the adjustable table smoothly raises and lowers to accommodate differing wheelchair and seating heights. This is accomplished by two switches, one for raising and one for lowering the table top. Since the student also has very limited movement of his arms, being able to use only his left elbow, this requires control of the table height to be reduced to either his left elbow or the back of his head.

SUMMARY OF IMPACT

Overall, all feedback given by the staff and students at Gorman School was clearly positive. The table was built not just with the individual child in mind, but for most of the present and future students at the elementary school as well. The controlling mechanism is compatible with most varieties of switches, allowing other students with different physical problems to utilize the table. With this added to the table's range of height, the project turned out to be quite a success.

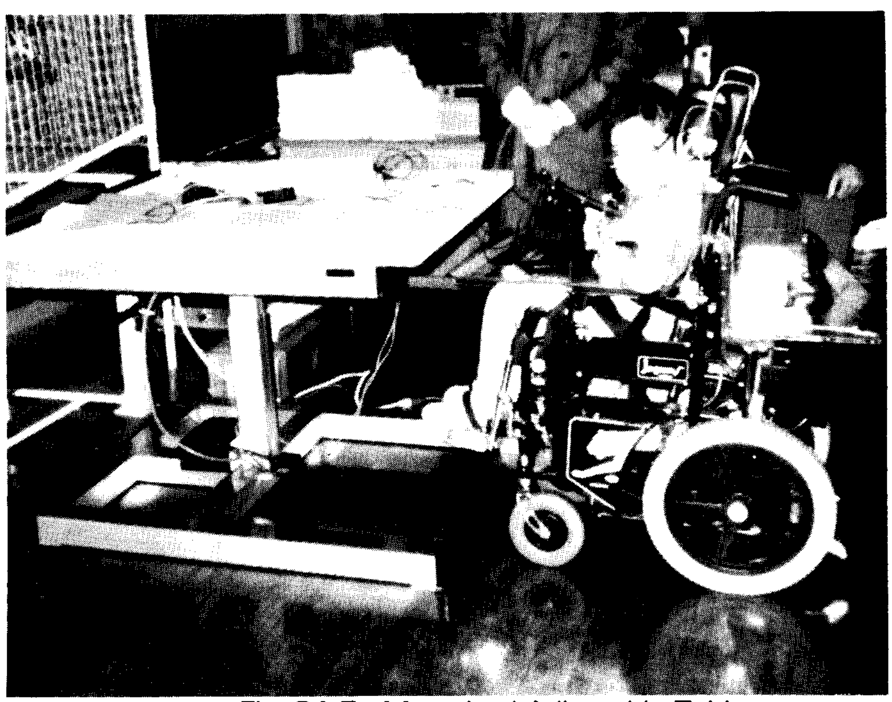

Fig. 21.5. Motorized Adjustable Table.

TECHNICAL DESCRIPTION

A motorized adjustable height table can be designed and represented by an open loop linear control system. This consists of two switches, an actuator (motor), a 6 V battery (transformer), two relays, a cantilever beam (mounting base), a table base and a table top. Plywood (3.5' x 3.0') with a covering of Formica is used as the table top. The aluminum cantilever beam (36" x 27.5" x 1.5") is attached directly to the bottom of the table top within 27.5" from the back of the table top. This allows for perfect balance of the table regardless of the weight distributed over the table. This also allows the motor to be located at a point other than the center of the table, therefore creating more room for the wheelchair under the table.

The motor is an electro-mechanical system that receives an actuating signal (110 V, 60 Hz) through a system of two relays that are controlled by switches attached to the student's wheelchair. The relays also help avoid electrical shock since a high current associated with the 110 ac voltage is applied through the system. To further avoid electrical shock, all electrical components are stored in a metal box that is grounded.

The switching system consists of two cup switches. Each switch operates as an ON/OFF switch. If the upward switch is pressed ON, it causes the table to move upward. By releasing the switch, the system is turned OFF and the table stops. Similarly, if the downward switch is pressed ON, it causes the table to move downward. By releasing the switch, the system is turned OFF and the table stops. The switches can be replaced by any kind of switch without any additional wiring simply by inserting another switch into the phono jack where the original switches are hooked.

All told, the table has a range in height from 21" to 33". Since the majority of the table is constructed of hollow aluminum squared tubing, it is fairly lightweight at 86.6 pounds and can easily be moved by an able-bodied individual. Total cost of the final model is $1,370.

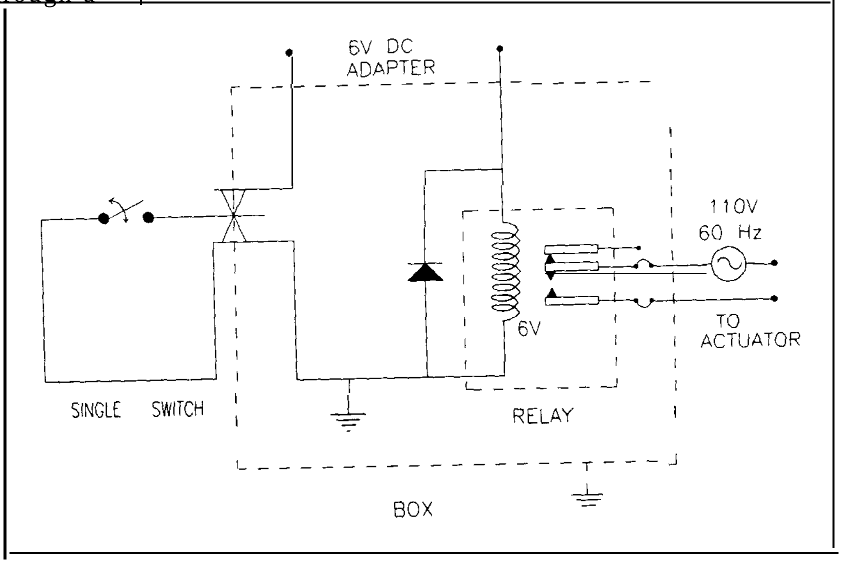

Fig. 21.7. Circuit Diagram for Motorized Adjustable Table.

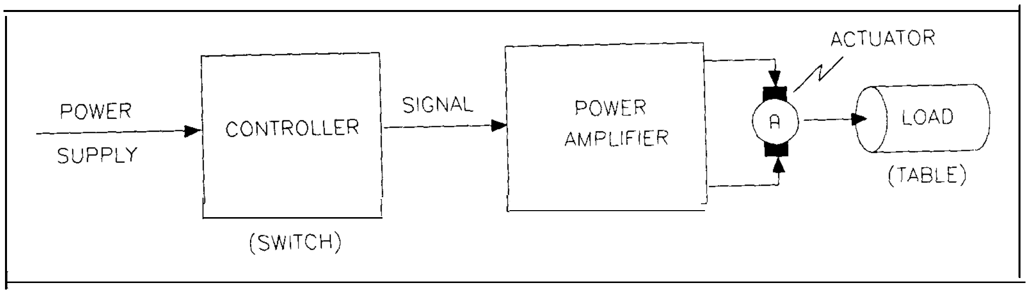

Fig. 2 1.6. Control System for Motorized Adjustable Table.

Portable Device to Highlight Individual Reading Lines

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INTRODUCTION

The subject for this project is a child who suffers from Cerebral palsy, a motor disturbance attributable to a cerebral disorder of early life. Such a disorder can result in severe paralysis of voluntary movements that will inhibit processes like mobility, facial expressions, and various other muscle control. The child has a limitation with his visual tracking skills. He can read words or phrases along a line of text but cannot maintain focus upon the reading line. Therefore, a device that will highlight individual reading lines is necessary.

The new device (Figure 21.8) is equipped not only with a magnified g ual line of text, but also a simple method of shifting which allows the child to shift their focus smoothly from one line to the next. This creates an increased attention span for the child.

SUMMARY OF IMPACT

After testing was done with the child, the device was found to be quite useful. As a result of its utilization, the child was able to concentrate more upon the material he was reading, thus increasing his productivity levels. The device simultaneously promoted a more positive self-image through a realization of increased capabilities.

Fig. 21.8. Portable Device to Highlight Individual Reading Lines.

TECHNICAL DESCRIPTION

The main components of this device are the book supports, the magnified guide, and the leverage system to adjust the position of the book. All three attach to a Victor Line-A-Time II which in turn attaches to a 16" x 16" sheet metal base. Figure 21.9 illustrates where placement of the three components should occur in relation to the Victor Line-A-Time.

When a book is placed on the adjustable reading device, it is supported in two places; at the top via a torsion bar which presses the book firmly to the front plate of the Victor Line-A-Time, and at the bottom via an L-shaped sheet metal plate (6" x 10" bent to 4" x 10" x 2"). The supporting metal plate has three notches that interact with three screws that can be untightened/tightened to adjust for varying book sizes.

The magnified guide is held stationary by supporting metal rods that attach to the immobile section of the Victor Line-A-Time.

The actuating lever attaches to the lifting mechanism within the Victor Line-A-Time. The lever consists of a 17" x 1" metal bar specifically twisted so as to permit insertion of several screws and other mechanisms. Its fulcrum is positioned approximately 4 " from the Victor Line-A-Time and, by pressing down on the lever arm, the book will raise anywhere from 1/16" to 1/2" depending on the setting. Through calculations, it was found that the force required to press down on the lever arm is equal to one pound plus the weight of the book used. Pushing the arm up causes the inner mechanism to be released, thus dropping the book to its original position.

Total cost of the completed adjustable reading device was $410.

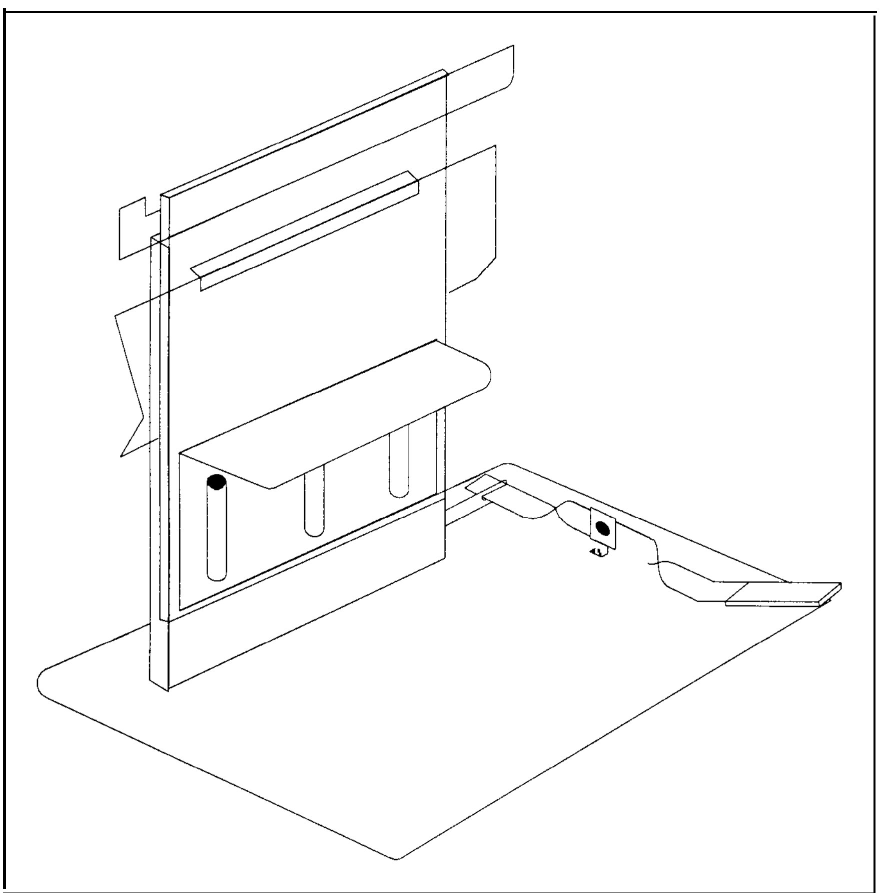

Fig. 21.9. Mechanical Drawing of the Portable Device to Highlight Individual Reading Lines.

Robotic Arm

Designers: Ken Luke, Diane Ney
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INTRODUCTION

This project involved the design of a robotic arm for a 12 year old child, Nathan. Nathan is confined to a manual wheelchair, having significantly limited motor skills and a limited range of movement due to Cerebral palsy. His most controlled movements are found within the head and neck region and degenerate from that point down. With the limitations described, the afflicted child has problems in doing simple things such as playing with toys or picking up objects. With the help of a robotic arm, Nathan may have some way to interact with his environment.

SUMMARY OF IMPACT

The feeling of independence to people who suffer from various types of physical disabilities is always a very important factor in rehabilitation. The robotic arm allows Nathan the chance to play amongst his friends or to just simply pick up an object without the assistance of the staff at Gorman School, therefore decreasing the amount of staff time needed during the day while increasing his happiness. In addition to this, the final utilization of a chin-controlled joystick is slowly improving his coordination. Since Nathan is currently waiting for a power wheelchair, which coincidentally is also controlled via a chin joystick, this device becomes excellent practice for him before his new chair arrives.

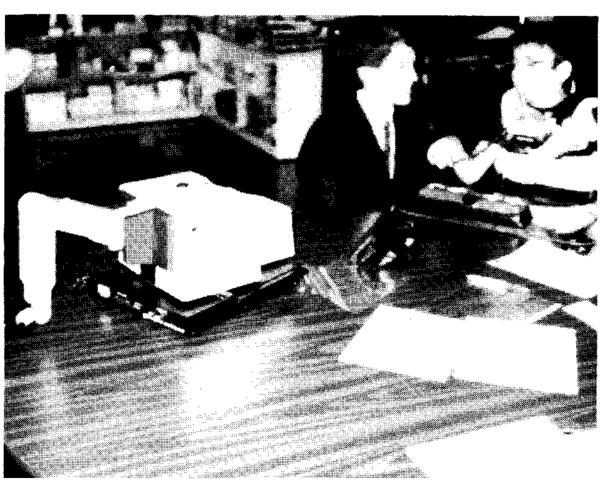

Fig. 12.10. Robotic Arm.

Fig. 12.11. Another View of the Robotic Arm.

TECHNICAL DESCRIPTION

There were three obstacles that needed to be conquered in order for this project to succeed. First, a robotic arm that could perform the necessary functions needed to be found and purchased. Such functions included a full range of movement, having the capability to pick up objects of varying size and shape, and be user-friendly. Second, a controller needed to be designed that was electronically compatible with the chosen robotic arm. Third, the same controller needed to be designed so that it was physically compatible with the child.

The robotic arm that was chosen was a Zenith Hero 2000 Robotic Arm that is controlled by a programmable central processing unit. The arm had a solid structure, was within a reasonable price range, and was capable of the following functions:

- 360 degree left and right rotation about its base
- Arm extension of slightly over 2 feet
- 180 degree wrist rotation to left or right
- Controllable claws for grasping objects
- Can completely shut down with the push of a button.

From observing Nathan's chin control, it was decided to design the control of the robotic arm through the CPU via a chin-controlled joystick. Problems occurred while trying to control the arm through the CPU; therefore, a different plan of attack was devised. By connecting the joystick directly to the six 12 V DC motors (by-passing the CPU completely) control was regained. These motors change direction by reversal of polarity across the motor, thus a joystick that can make positive and negative contacts was necessary. In its final design, the joystick had two sections of polarity on it, one positive and one negative. If the joystick was pushed to one side, each section of polarity touched contacts that were set within the base of the joystick. The negative contact sent a signal to the motor that halted any motion in a counter clockwise motion while the positive contact initiated motion in the clockwise direction. When contact was interrupted, all motion stopped. Figure 21.12 illustrates the joystick-motor connection and how an actuating signal can be sent.

The joystick was placed in a lightweight, water resistant baseplate. Two cup switches were added to control the claw movement on the robotic arm. By pressing the CLOSE switch, the claws will slowly close together until the switch is released, at which point motion stops. Similarly, by pressing the OPEN switch, the claws will slowly withdraw from one another until the switch is released, at which point motion ends.

Expenses for this project can vary. If one is willing to construct the model robotic arm, labor costs can be avoided, which was the case for this project. The purchase of the Zenith Hero 2000 Robotic Arm, the joystick and its various attachments, and miscellaneous supplies came to $1,140.

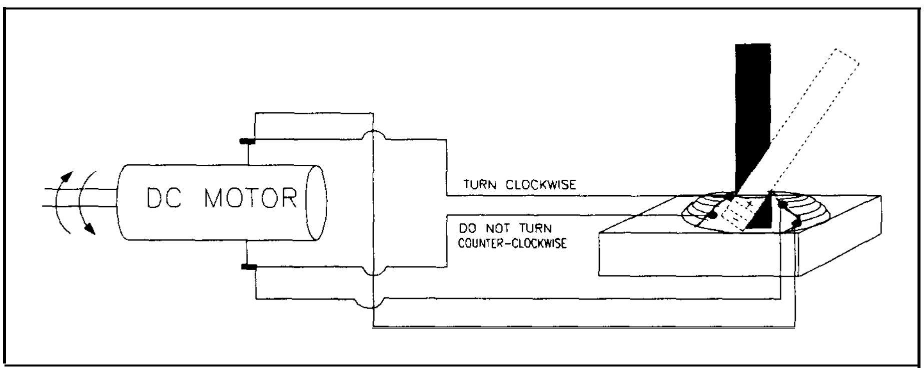

Fig. 2 1.12. Diagram of the Joystick and DC Motor.

Electronic Timer for a Muscle Stimulator

Designer: Faisal Shajira
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INTRODUCTION

The 555 timer circuit was designed for a quadriplegic with poor muscle control of finger movement. Due to this poor muscle control, a circuit had to be developed that would accept minimal external triggering. The circuit was therefore designed to function as an edge-triggered, monostable, one-shot. It is turned on by simply pressing a push button switch and this seems relatively simple even for an individual with limited muscle control. The timer will be used in conjunction with a muscle stimulator in order to provide controlled muscle stimulation for muscle conditioning. The finished product can be seen in Figure 21.13 (attached to a TTG Selectrode System and an NTRON neuromuscular stimulator).

SUMMARY OF IMPACT

Overall this project was quite successful. The subject was able to turn the stimulator on for a mechanically set period of time and, therefore, condition his own muscles without the help of an attendant. This project is also quite useful in that it can be used for anyone. The circuit has a dial that can control the duration of the stimulating pulse and can be set anywhere between 0.2 seconds and 1.5 seconds. This allows for greater versatility in implementation.

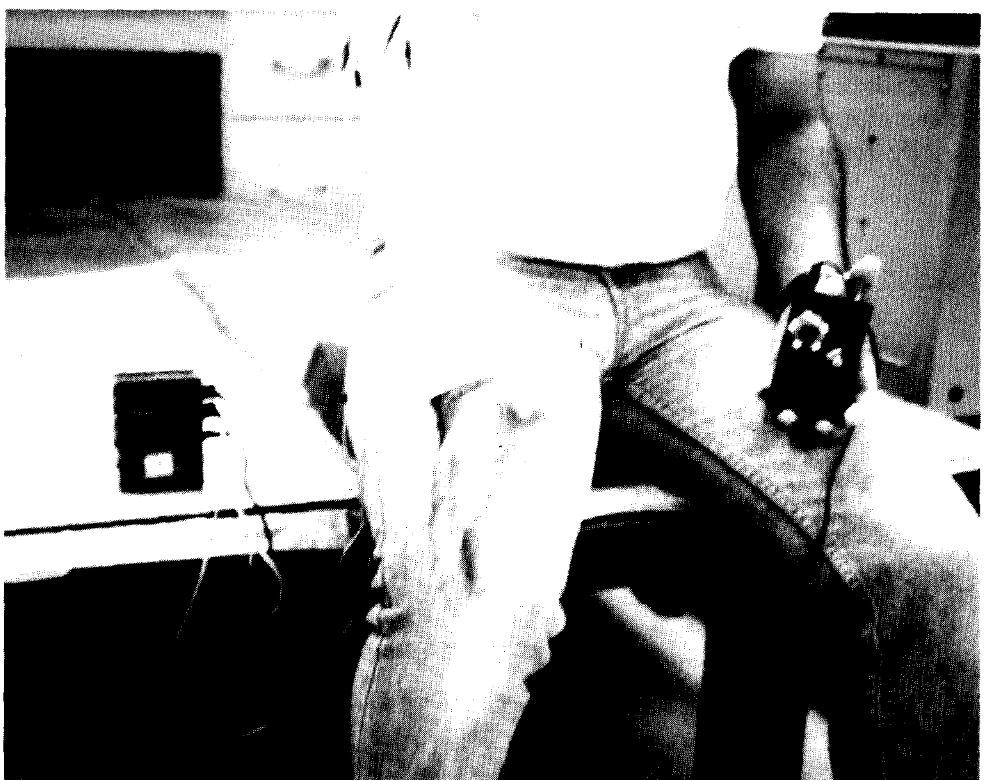

Fig. 21.13. Electronic Timer for a Muscle Stimulator.

TECHNICAL DESCRIPTION

As seen in the schematic drawing (Figure 21.14), the duration of the output pulse is determined by the time constant of the capacitor and resistors on pins 6 and 7. The time constant was designed to vary between 0.2 seconds and 1.5 seconds. Using the following equations, a minimum and maximum value of resistance was calculated assuming that C_1 = 1.5 µf. The width of the output is determined by the time required for the capacitor to charge from 0 to 2/3 V_{CC}. For our purposes, V_{CC} = 9 V was chosen. Thus we have

$$V(t) = A(1-e^{-t/RC})$$

and with

$$2/3V_{CC} = V_{CC}(1-e^{-t/RC})$$

it follows that

$$2/3 = 1-e^{-t/RC}$$

$$e^{-t/RC} = 1/3$$

$$-t/RC = \ln(1/3)$$

$$t/RC = 1.099$$

This equation can be rewritten to directly determine the values of the variable resister.

$$t(\text{pulse width}) - 1.099\ R_tC_1$$

Assuming C_1 = 1.5 µf, as mentioned above, and the duration of the pulse width varies between 0.2 and 1.5 seconds, Rt is found to vary between 122 KΩ and 917 KΩ. The physical values for Rt are obtamed with a 120 KΩ fixed resistor and an 800 KΩ variable resistor. The output from pin 3 travels through a relay system in order to trigger a mechanical switch attached to the muscle stimulator. The triggered pulse from the relay is transmitted through a phono-jack output. Finally, an extra resistor, capacitor and diode were added to pin 2 as seen in the schematic drawing to cause the circuit to behave as an edge-triggered system. The total cost for the production of this system shown in Figure 21.13 is approximately $680.

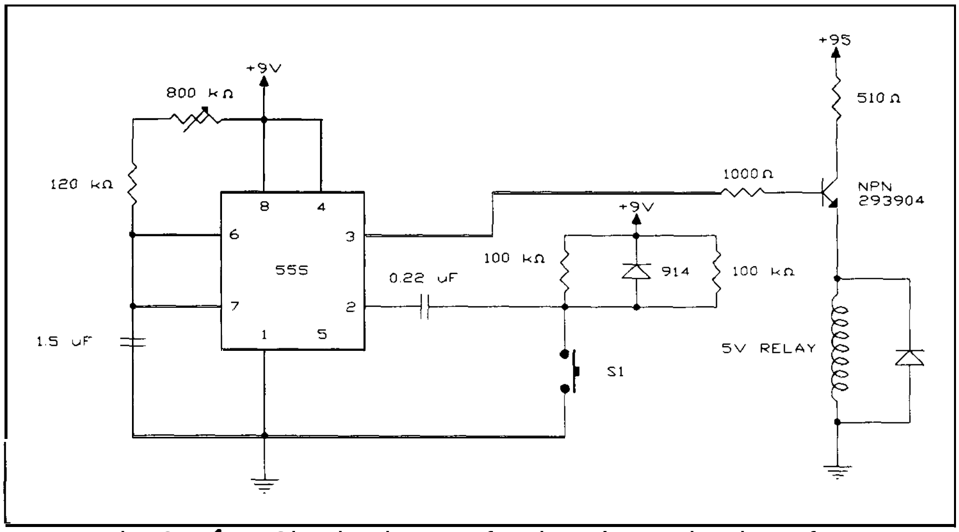

Fig. 21 .1 4. Circuit Diagram for the Electronic Timer for a Muscle Stimulator.