ADVANCED TECHNOLOGICAL AIDS FOR THE HANDICAPPED

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I wish to thank my husband, Ricky, for all his assistance on this project. Without his love and support I would never have been able to complete it.

CHAPTER 1

INTRODUCTION

Twenty times a day an American, usually young and healthy, is involved in an accident which will leave him partially paralyzed for the rest of his life. Of the approximate seven thousand victims of spinal cord injuries per year, one thousand are rendered quadriplegic. Roughly twenty-five to thirty-five million people in the United States, ten to fifteen percent of the entire population, are considered permanently disabled. Of these, one third have impairments severe enough to curtail normal activity. The disabilities may be caused by congenital defects, accidents, war, degenerative nerve and muscle diseases and numerous other reasons. But, in spite of the cause, the need to restore independence, functionality and self-respect to these handicapped individuals is apparent. The advent of the microprocessor has the potential of solving many of the problems faced by the disabled community.

1.1 Evaluating The Need.

This author believes that the importance of advanced technological aids for the handicapped could not be better expressed than by an individual in need of them. The following article was written by a man with amyotrophic lateral sclerosis, better known as Lou Gehrig's disease.

> Among the catalog of terrifying diseases one learns of at medical school, none frightened me more than amyotrophic lateral sclerosis. I have often asked myself why during the four years since I developed the illness.
>
> Was it the picture of that first patient etched indelibly in my memory? We had gathered in one of those awful, gloomy basement lecture rooms that used to be an indispensable part of the architecture of teaching hospitals - rows of stark benches rising steeply from the "well", more appropriately the pit, which sported a blackboard, a lectern and one

medieval chair. That chair was occupied by a seemingly elderly man stripped to the waist. Perhaps it would be more accurate to say that the chair occupied the man, so small, so cachectic, so vulnerable, so insignificant. He was reduced to flesh and bone, and what remained of his muscle was engaged in a macabre dance of death - the dreaded fasciculations of ALS.

His voice was all but gone, and to this day, I wonder what private hell he silently endured during that hour as the neurologist detailed the myriad physical signs on his broken body. The booming voice of the neurologist rendered the prognosis: "Hopeless! This is creeping paralysis! He will be demeaned, isolated, frustrated, unable to communicate, and probably will be dead in six months."

Today, I am the man in the wheelchair. However, I do not feel demeaned. I have combated isolation by speaking out to those of my colleagues who still retain the obsolete views of my neurologist "teacher" and as a family we have tried to divert our frustrations into creative energy - all of which require the ability to communicate. I lost the use of my hands more than two years ago, and as I faced a tracheotomy, my worse nightmare was whether this would finally turn me into a nonperson - every sensory perception intact but strictly one-way traffic.

Fortunately, miraculously, none of this would prove correct. On the day after my tracheotomy, I received a letter from a fellow physician who also has ALS telling me what countless prior inquiries had failed to elicit, that a computer was available that could be operated with a single switch. Not "on the drawing board," not "just around the corner," but with specifications on hardware and software, a purchase price and a delivery date.

The significance of the single switch is that it can be operated by anyone, however physically handicapped, who retains the function of one muscle group. For me, my eyebrow muscle is strong enough to depress a very light switch and thereby gives me access to the full power of the computer. Other patients have a functioning finger or toe. The first person to use a similar computer program had a switch fitted to her mouth and bit down.

The screen presents the alphabet to me. A pointer ("cursor") moves at a speed that I select, and I press the switch when the pointer is next to the letter I want. This opens an electronic dictionary to a page of words beginning with the desired letter. The process is repeated, and with the aid of the pointer, a word is selected. It takes longer to explain than to do!

What has the computer, in conjunction with a printer and voice synthesizer, afforded me? I talk to my family - that is most wonderful. I can make conversation with friends - the jokes take a little longer, but they don't seem to mind. I can work independently again - write papers, review manuscripts, cooperate by mail with other scientists - and I am able to interact with the persons in my laboratory. I write out my ideas before we meet and sum up afterward. Because of the loyalty and devotion of this group - and for me the indispensable ability to communicate - our research continues to be original and productive.

After 27 years of marriage and total sharing, Pauline and I have discovered the joy and satisfaction of writing together. Topics come from the news, from books we read, from our own experiences and from the human comedy all around. Ideas seem to be generated simultaneously, one of us prepares a draft - I, of course, use the computer - and then we enjoy a dialogue whereby we attempt without haste to use the rich textures of the English language.

A computer program such as mine, operating from a diskette no bigger than a 45-rpm record, can change the lives of hundreds of patients who retain cognitive function but are unable to communicate. While it was originally developed for a patient with ALS, its application in selected patients with stroke and other neurologic-syndromes, and in individuals who have lost their vocal cords, should be equally helpful. The main problem appears to be a dearth of information among health-care professionals about the medical applications of the computer. Advertisements for a variety of communication programs designed to meet the needs of the handicapped have appeared in the Summer 1983 issue of *Communication Outlook*, a publication of the International Society for Augmentation and Alternative Communication. However, this publication is not likely to reach the desk of many physicians.

Coping with ALS is a grim ordeal - but it is not hopeless. Every patient needs an infrastructure of love and support. Now, for those of us who could no longer communicate, the computer provides ALS patients with an Alternative Life Style [MCWI84].

This article was written by Dr. David Rabin, a professor of obstetrics and gynecology at Vanderbilt University's School of Medicine. Dr. Rabin was able to write this thoughtful essay through the use of computer technology and the movements of one eyebrow. This is just an example of the hope offered to the disabled by the power, versatility and speed of the computer.

Apart from the well-intentioned reasons, it makes good economical sense to restore independence to the disabled. In 1980, it was estimated that the average cost of spinal cord injuries was $319,777 per year (forty-four percent direct medical costs, and fifty-six percent indirect income loss). Given that most spinal cord injuries occur when the victim is between eighteen and twenty-two years of age, the lifetime cost of the injury could accumulate to over fifteen million dollars if the individual should live to he sixty-five. Multiply this hy the numher of people with spinal cord lesions and the figures hecome astronomical [LEIF81]. The utilization of suitable technological aids could considerahly reduce health care costs and even facilitate the handicapped individual's reintroduction into the joh market.

1.2 Report Organization.

This document is concerned with computer aids for the handicapped. It is divided into five chapters. Chapter 2 is a review of the literature. It includes descriptions of hoth existing and potential aids, distinguishing between those which reduce the handicap and those which attempt to replace the impaired function. A review of wheelchairs, both manual and motorized, is presented in Chapter 3. This chapter also documents the history of the wheelchair and presents an explanation for the lack of innovation in its design. Chapter 4 proposes the specifications and design of an autonomous wheelchair. Chapter 5 concludes the report with a summary of the entire document. It also suggests prohlems with current methodologies and possihilities for future development. Finally, the appendix contains a glossary of terms.

CHAPTER 2

COMPUTER AIDS FOR THE HANDICAPPED

2.1 Introduction.

Terminology has been established by the World Health Organization to distinguish between three often misused expressions concerning the handicapped. An 'impairment' is a physiological deficiency, a 'disability' is the loss of function due to the impairment, and a 'handicap' is the social or economic cost of the disability [HAGG83]. For example, damage to the spinal cord is an impairment, where paralysis resulting from the injury is the disability. Lack of mobility, reduction of employment potential, and loss of independence are a few of the consequent handicaps. This chapter presents an overview of technological aids for the handicapped, distinguishing between those which reduce the handicap or disability, and those which attempt to replace the lost function.

2.2 Reduction of Handicap.

The computer has long been considered a potential aid for the handicapped, but until the advent of the microprocessor it was too large and expensive to be a viable alternative. When the microprocessor did become available to society, many bioengineers and rehabilitation experts recognized the vast opportunities afforded to disabled individuals. In the ensuing years, an extensive number of systems have been developed which serve to lessen the impediments of the handicapped person. An attempt to compile an intensive survey of all of these aids would produce an unwieldy document which could not do justice to the amount of time and effort spent developing the devices. This section, therefore, will present an overview of aids for the handicapped which should provide the reader with an overall view of the types of aids available and the handicaps they serve to overcome.

2.2.1 Vision Impairment.

Individuals suffering from vision impairments must face obstacles daily that sighted persons can not begin to appreciate. Deprivation of sight may well affect every aspect of a person's life. Simple things like taking a walk, reading a book, or attending a class can become difficult or even dangerous without benefit of vision. Rehabilitation experts have recognized that the microprocessor can alleviate many of the hardships faced by the blind. Aids have been developed which may assist the blind person in traversing a route, orienting himself with his surroundings, and even comprehending the printed word. The following sections highlight a few of these systems.

2.2.1.1 Mobility Aids.

One of the most difficult challenges for a blind person is simply getting from one place to another. Travelling unfamiliar routes can be a frightening and dangerous experience to the unsighted. Even frequently travelled routes, which may be navigated from memory, can become hazardous due to transitory obstacles. The blind have found it necessary to rely on long canes, guide dogs and their other senses when travelling alone. These are all invaluable, but do little to warn a person of obstacles at or near head height not originating from the ground, such as overhanging branches. Studies have shown that a blind person travelling alone has a slower walking speed, must stop more often to orient himself with his surroundings, and has a higher heart rate than if he were travelling with a sighted companion [HEYE83a]. Scientists are currently developing instruments which should complement the established aids in supplying a blind person with enough information ahout his environment to allow him to progress with more confidence.

One such aid is the "Sonic Pathfinder," a mobility aid which utilizes ultrasound to warn the blind individual of obstacles in his path. Tbe device evolved from a hand-held system, which utilized ultrasound transducers to detect ohstructions and played a series of musical notes to alert the user to them. Because ultrasound can not recognize drop-offs such as curbs or holes, the aid bad to be used in conjunction with a long cane or guide dog. In order to alleviate tbe individual from using hoth hands for navigation, the developers of the "sonic pathfinder" chose to mount the ultrasonic transducers on eyeglass frames. Ultrasonic receivers mounted on the rigbt and left of the frames alert the individual to obstacles to his right or left, respectively, hy signalling with a series of descending musical notes in tbe corresponding ear piece. A center mounted receiver warns of an obstruction directly in the user's patb by signalling in both ear pieces simultaneously. Once the device has detected an obstruction in its direct patb, it will focus only on that ohject until the user has navigated around it. This prevents the masking of a central obstruction hy one to the right or left of the user. Tbe design also allows the individual to utilize shore-line information so tbat he may maintain a constant distance from continuous barriers sucb as walls or hedges. A major concern during the design of this aid was tbat, because the user would need to his process additional information, bis pace would actually be decreased. However, prototype tests bave shown that the output is so easily understood that the user may maintain his normal pace while enjoying the increased confidence provided by the aid [HEYE83h].

Computer vision systems have heen the hasis for other mohility aids for the hlind. Representative aids typically process a picture of the environment and present it to the user through tactile stimulation. Several systems have heen designed which essentially draw a two dimensional picture of the environment on the user's ahdomen through the use of vihrators [COLL84], [KIRS85]. A microprocessor is utilized to examine the picture, extract key elements, and create appropriate signals to he delivered to the vihrators. It is left to the user to recognize ohjects through the stimulation and to take the proper action. Many experts helieve, however, that this type of device may actually hinder the user. They feel that the skin in the area of the ahdomen is not sensitive enough to he ahle to handle the vast amount of information required. Another concern is that the user would need to concentrate so intently on the stimulation, that he would he impervious to other signals from the environment such as the sound of a car engine. To remedy these prohlems, another aid is heing developed which places the hurden of ohject recognition on the computer. This device incorporates a pattern recognition system to isolate ohstacles from the environment and alert the user to their presence through a speech synthesizer. The direction and proximity of each ohstacle is presented to the user hy tactile stimulation. In this case, stimulation is applied to the forehead through sixteen vihrators mounted on a headhand. When an ohstruction is first sensed hy the device, it is discretely reported to the user through earphones. The forehead stimulator most closely representing the alignment of the ohject is activated to convey direction, and its proximity is communicated hy the frequency of the stimuli. Due to the nature of computer-vision, mohility aids, real time processing is essential. Prototype systems have heen developed which work well in limited test environments; however, state-of-the-art technology has not yet produced a device small and fast enough to be realistic in an everyday environment [COLL84].

Another type of mobility aid for the blind allows the user to locate or orient himself with respect to specific areas. The Sonic Orientation and Navigational Aid (SONA) consists of a transmitter which is carried by the user and receivers mounted at locations of interest such as building entrances, exits, and restrooms. The transmitter features a keypad which allows the user to specify certain codes indicating the desired area. For instance, 911 might be the code for an emergency exit. If a signal is transmitted within seventy-five feet of a corresponding receiver, the receiver emits a musical tone, indicating the direction and proximity of the desired area. Popular acceptance of this device could provide a relatively simple and inexpensive method for blind individuals to find their way even in unfamiliar surroundings [KELL84].

The final mobility aid to be discussed here is a portable navigation device which basically helps a person remember long or seldom travelled routes. The device allows the user to record the number of steps taken in various directions so that he will not be forced to memorize such details. The aid operates in two modes. In the record mode, a pedometer counts the number of steps taken until the user indicates that he is changing direction by pressing the key associated with that change. At this point, the aid will record the turn, and the number of steps taken prior to that turn. When the user has reached his destination, he may store the entire route and associate it with a number for subsequent playback. Once a route is stored, it may be utilized in the playback mode to enable the user to once again travel that route. The device counts the number of strides taken by the user and emits specific tones to signify changes in direction. The playback mode may be used to either assist the user in travelling to a particular destination or to retrace his steps hack to the original starting position. In addition to turns, the user may record or be alerted to cross roads, pedestrian crossings and staircases [FREE84].

2.2.1.2 Reading and Writing Aids.

Perhaps the most difficult ohstacle faced hy the hlind individual is isolation from the printed word. Many everyday rituals require the ahility to read or write and this is especially true for vocational opportunities. It would he foolish to helieve tbat the hlind could rely on hraille for all tbeir written communication needs. A 1976 survey revealed that only twenty-one percent of the visually impaired students enrolled in hoth schools for the hlind and customary schools were proficient in hraille [HORO81]. Many hooks have never been translated to hraille and those that have are more expensive and much more voluminous than print. It has been estimated that the hraille cell, together with its necessary encircling space, requires forty times the amount of space as ordinary print. This together with the thick paper needed for braille and the elevation of the dots themselves could make a dictionary large enough to fill an entire bookcase [SULL81].

Advances in technology have served to alleviate many of the written communication needs faced by the visually impaired. A variety of devices have heen developed which give tbe blind person access to computers, ordinary print, and braille stored on tape. Cost, finger sensitivity, and user motivation are tbe major factors in determining which device is hest suited for an individual.

2.2.1.2.1 Reading Machines.

The Kurzweil reading machine incorporates optical character recognition software and a speech synthesizer to give visually impaired or dyslexic persons access to ordinary print. The user simply places the printed page face down on the camera unit, and the device automatically scans and vocalizes its content. The device is excellent for lihrary use hecause the user requires very little training, hut its relatively high cost makes it impractical for home use [KURZ81].

The Optacon, OPtical to TActile CONverter, is a device which discerns ordinary print and conveys it to the user through the sense of touch. The aid employs a hand held camera unit which the hlind user must guide along the printed page. An array of vihrating pins under the index finger of the user's other hand mirrors the print image appearing before the camera lens. Utilization of the Optacon requires intensive training due to the natural difficulty a hlind person would encounter attempting to scan something he can not see. It also demands an adequate degree of fingertip sensitivity so that the user may identify the images presented to him. Tests have heen developed which serve to ascertain an individual's ahility to use the device. Given the proper conditions and a substantial degree of user motivation, however, the Optacon gives the blind user access to a wide range of printed material. Separate lens attachments have heen developed which provide the user with access to computer terminal displays. The currently planned additions of a speech synthesizer and automatic scanner will soon make the device suhstantially easier to use [SCHO81].

2.2.1.2.2 Transient Braille.

One of the major problems with hraille is its sheer volume. A significant improvement for the storage of hraille was the innovation of the transient braille display. This medium works on the same principle as the Optacon's display mechanism. Characters are represented through an array of pins which are elevated in the form of hraille cells to convey meaning to the reader. The display is a mechanical device which inherently adds more expense and higher risk of failure than electronic components. However, the usefulness of the mechanism may outweigh its disadvantages.

The advent of the transient braille display has offered new opportunities to the braille reader from which he was once excluded. Transient displays may be attached to computer terminals to give the blind individual full access to computer capabilities. Braille books may now be stored on cassette tape and played back through the use of special aids which employ the medium. Devices using this mechanism have been developed which make it substantially easier for the blind student to take notes in class. The braille reader was once forced to emboss braille on thick paper, a noisy and cumbersome procedure with no edit capabilities. Devices such as the Versabraille have been created which use the transient braille display in conjunction with a braille keyboard and tape recorder. The Versabraille allows the user to enter information onto tape which can later be edited and stored for future use. The instrument may also be utilized as an interface to the computer terminal, thereby allowing even greater flexibility [DURR84], [HOLL81].

2.2.1.2.3 Speech Synthesis.

Many recently developed devices for the blind employ the technology of speech synthesis. The advantages offered the blind through this facility are obvious. Devices which incorporate speech synthesis are much easier and faster to use than devices relying on tactile stimulation. They also provide a reading facility to persons who for some reason are unable to use braille. Speech synthesizers employed by reading machines give the blind population access to printed material. Computer terminals utilizing the technology provide the blind individual with computer facilities. Exercising this technology for use by the visually impaired population does, however, have major disadvantages. Most aids employing synthesizers enable a person to read, but have no facility to allow him to write [MOYE81]. Also, few search or edit capabilities are available to individuals using speech synthesis as an interface to computers. Two significant problems are the limited vocabularies employed by many speech synthesizers and the fact that the untrained listener can very often simply not understand the output [ROSS81], [ZING81]. These problems have been overcome for more sophisticated synthesizers, but their expense is generally cost prohibitive to the disabled population.

2.2.1.2.4 Braille Trainer.

Three of the five major causes of blindness effectuate a slow deterioration of the eyesight. The other two may either cause sudden blindness or may gradually render their victims sightless. Researchers have developed a device which makes use of this time to help an individual learn braille while he still retains some vision. The Computer Aided Braille Trainer, CABT, was designed to facilitate the learning of braille and to lessen training cost. Because many blind persons must attend special schools or hire private tutors in order to learn braille, the process can be both expensive and time consuming. Research has shown that being able to see a braille cell simplifies the learning process and assists an individual in memorizing its structure. Also, even a person with very limited vision is more likely to be able to recognize an object through sight than through an untrained sense of touch. The CABT comprises special hardware and software which interfaces with a COMMODORE 64 microcomputer to assist the user in learning braille. The keyboard is patterned after a Perkins Brailler, a braille embosser used by many blind individuals. When the user keys in a character, it is displayed in print on the top half of the screen and braille on the bottom half. The CABT is a simple, relatively inexpensive device that could give an individual who is going blind invaluable practice in learning braille [SIBE84].

2.2.2 Hearing Impairment.

Computer technology has provided a variety of systems to aid the hearing impaired individual overcome his handicaps. Devices have been developed which allow deaf people to communicate over telephone lines and to interpret sound through the sense of touch. Instructional systems have been implemented to provide the deaf with instant feedback when learning to speak or finger spell. This section provides an overview of typical aids for the hearing impaired.

2.2.2.1 Telecommunications.

Until 1964, the deaf had no access to a device which had become commonplace to most of society - the telephone. That year, a deaf physicist designed an acoustic coupling device which allowed teletype machines to communicate over telephone lines. This marked the beginning of the Telecommunications For The Deaf, TTY, network. The ensuing years saw a distinct standard being set in telecommunications for the deaf. The similarity of TTY components to those of computer terminals ensured a substantial price reduction when the latter was mass produced, enabling many disabled persons to purchase the device [WALS81]. Telecommunication devices utilizing current technology far surpass the limitations of the TTY; however, the established network is so firmly entrenched in modern day society that there is little hope of changing the standard. Researchers, recognizing this problem, have sought to develop advanced aids which are either compatible with the TTY network or offer such significant improvements over the TTY that they may be considered viable alternatives.

Although the TTY is a very useful device, it has several deficiencies which further isolate deaf individuals from the hearing population. Its baud rate of 45.5 bits per second is very slow by today's standards. Its communications protocol is incompatible with the standard ASCII terminal. The TTY user is unable to store messages for subsequent transmission, and utilization of the device requires a similar aid at the other end of the communication link. Finally, it is a large and bulky device, making it impractical for portable use. These factors combine to make the TTY useful for deaf individuals to communicate with other deaf persons or close friends and family, but otherwise unsuitable. Hearing persons without deaf friends or relatives are unlikely to ever own such a device. However, even given TTY access, a hearing individual, who is accustomed to instant communication via the telephone, is likely to find its utilization very slow and frustrating, leading to disuse. Compounding this, the slow baud rate will necessitate higher charges for telephone line usage [LEVI81].

In an attempt to alleviate some of the problems associated with the TTY network, researchers have designed aids to both complement and replace it. Several devices have been developed which use DTMF (Touch-Tone) signals as a communication medium. Utilization of this medium would require that special hardware be located only at the residence of the deaf individual. Anyone with access to a standard Touch-Tone telephone may communicate with deaf persons using the DTMF signals. Because there are three letters on each Touch-Tone key, various schemes have been developed to encode the signals to ensure against ambiguity. One such method involves the user depressing the key with the desired letter followed by entering either 1, 2, or 3, depending on the position of that letter on the key [JOHN81]. Another scheme requires that the user depress the key with the desired letter one, two, or three times, again depending on the letter's position [SHEN84]. Characters from the

ASCII character set not appearing on the standard telepbone keypad have been predefined to allow for utilization. A keypad overlay, available with most systems, allows for ease of use. Special equipment at the otber end of the transmission link receives the DTMF signal and converts it to either the standard ASCII or TTY format. If the deaf individual is also mute, he would require special assistance in formulating a reply. This could be accomplished either through the use of Morse code, again using DTMF signals, prerecorded replys on tape, or the use of a speecb synthesizer.

Anotber telecommunications aid takes advantage of the widespread popularity of the personal computer in today's society. The "Universal Translating Modem" was designed based on the premise that the personal computer is becoming a standard appliance in most bouseholds. The device allows the deaf to communicate with anyone owning eitber a TTY or a personal computer. Upon receipt of a transmission, the modem will convert between the ASCII and TTY character sets as necessary. This not only allows tbe deaf individuals to communicate with a wider range of people, but also gives them access to a number of data bases currently available tbrough telecommunications [BOZZ81].

2.2.2.2 Programmable Hearing Aids.

Microprocessor technology may well serve to reduce many of the problems currently associated with hearing aids. Hearing aids commonly employ a signal processing device to correct a distinct type of bearing disorder. However, there are many different types of audiological dysfunctions and eacb hearing impaired individual is likely to suffer from more than one of them. According to E. Villchur, "tbe effectiveness of signal processing in current hearing aids is probably greatly compromised by the lack of a systematic metbod of matching tbe processing, botb qualitatively and quantitatively, to the residual hearing of the person being fitted [VILL81]." Unfortunately, hearing aid selection generally involves choosing from the available aids the one that most likely matches the hearing disorder. This crude method of selection could be eliminated by a programmable hearing aid. Ideally, the utilization of such an aid would allow for custom fitting for each individual's unique hearing impairment. Extensive testing must be performed, the proper signal processing pattern must be determined, and the hearing aid must be programmed to suit an individual's particular requirement. All of these functions would be greatly facilitated by the use of a computer. A programmable hearing aid should greatly reduce the need for special hardware requirements for hearing aids and alleviate many of the problems encountered by the hearing impaired individual [VILL81].

2.2.2.3 Tactile Stimulation.

Persons who suffer from sensory deprivation must very often rely on their other senses for compensation. Researchers are attempting to optimize sensory substitution for the deaf through tactile stimulation. Several systems have already been designed which discriminate critical components of speech and present them to the deaf user through vibrators applied to the skin. Various systems utilize different signal processing techniques to analyze speech components; however, all systems work on the basic premise that the deaf individual must learn to recognize meaning from vibratory sensation. The systems generally consist of a microphone to capture sound, a microprocessor to analyze the acoustic signal and vibratory stimulators to propagate that signal. Prototype systems have been tested and have shown good results. Almost all persons tested were able to understand complex sentences using a combination of vibratory sensation and lipreading. Further tests have shown that lipreading skills improve considerably as a result of being utilized in conjunction with tactile stimulation. In fact, many persons tested were better able to lipread even when use of the stimulation was terminated [KANE81], [ROSO84].

2.2.2.4 Teaching Aids.

The computer's inherent tolerance for repetitive tasks deems it an excellent teaching facility for the disabled. A variety of instructional systems have been developed to aid the hearing impaired population in overcoming their handicaps. One such system aids the speech therapist in training a deaf individual to speak intelligibly. A child generally learns to speak through hearing his parents' voices and imitating their sounds. Parental response, along with the sound of the child's own voice, provides feedback necessary for the learning process. The deaf individual is denied this experience. The purpose of the automated speech therapy system is to offer visual feedback for deaf persons learning to monitor their own voices. Typical systems display graphical representations of critical speech components on a computer terminal. First, a graph representing the correct pronunciation of a word is created when either the therapist or a pre-recorded tape provides the correct enunciation. In a typical system, the correct graph is shown continuously on the top half of the screen while graphs representing the student's pronunciation are displayed on the bottom half. The student may practice pronouncing the word and receive instant feedback on his progress [DUFF81]. Special speech therapy systems have also been developed for deaf children to help make learning fun. For instance, in "ball-game" the child must orally direct a pitch controlled basket ball along a predefined path in order to score a point. Another system for smaller children employs a "happy face" which teaches a child to monitor the volume of his voice by covering its ears when the child yells or speaks too loudly [HATO81]. Systems have also been developed to assist the deaf in learning to finger spell. These systems are typically comprised of visual displays representing the deaf alphabet, and they allow the user to practice recognition of words spelled out by an automated hand [KIHN81].

2.2.3 Motor Impairment.

The use of microprocessors has the potential of offering a great deal of independence to persons with motor disabilities. A vast number of systems have already been developed to provide communication and environmental control to those who are otherwise unable to manage tbese functions. Systems are also in development to provide entertainment and personal care facilities. This section presents an overview of these systems and possibilities for the future.

2.2.3.1 Communications.

Man-machine interfaces have been developed to facilitate the use of personal computers by motor impaired individuals. This not only provides a means of written communication, but also if used in conjunction with a speecb synthesizer, allows oral communication for the severely disabled.

The most popular interfacing method in use is a row/column scanning system. This metbod utilizes a two dimensional matrix of words and/or letters. The cursor scans down the rows until a switch is activated by the user, indicating that the current row contains the desired item. The cursor then scans through each item on the row until the user makes a selection. The selected item is placed on a line below the matrix and the scanning is resumed. Upon completion of tbe task, tbe user may select to store, print or vocalize the text.

There are several different theories concerning tbe optimal implementation of matrix scanning. Systems have been developed such that the items which are most frequently used are the most easily accessed. For example, the often used letters "e", "a", and "t" are positioned in the upper left hand corner of the matrix. This method significantly reduces selection time. Software has also been developed to utilize dynamic matrices so that, based upon the previous selection, items are positioned according to the probability that they will be selected next. For instance, the letter "u" has the highest probability of being selected after the letter "q" and is positioned accordingly [JONE81]. Another school of thought holds that elements in the matrices should have a static position. Subscribers to this philosophy believe that selection times are increased with the utilization of dynamic matrices due to the time required for the user to orient himself to the new matrix. A system which uses static matrices allows the user to become familiar with character positions, thereby decreasing selection time [WEIS85].

Other systems have been developed based on the inference that children, who have been unable to communicate for most of their lives, may be unable to form effective sentences. These systems allow frequently used phrases to be stored according to their grammatical use. For example, frequently used responses are stored in an "answer" array, and typical questions are accessed from a "question" array. A special mode will allow the child to form unique sentences by prompting for information based on the rules of sentence syntax. For instance, if the child has selected the phrase "will eat" from the verb array, the system will respond with the prompt "who" and display the noun matrix. A spell mode will allow the child to use words or phrases not found in the established arrays [TILL81].

Row/column scanning systems can be implemented using a variety of switching mechanisms depending upon the capabilities of the user. The minimum requirement is a single switch allowing a person with only one functional muscle group to operate the system. Persons with greater muscular capability may utilize redundant switches in order to reduce fatigue, or may use enhanced scanning systems which take advantage of these capabilities.

Recently, row/column scanning software has been integrated with commercially available software packages. This integration precludes the need to develop special software packages for use by the disabled, thereby greatly enhancing the usefulness of the personal computer [KULI84].

2.2.3.2 Environmental Control Systems.

In order for the motor disabled person to achieve any independence, he must first be able to control his environment. Micro-computers can be used in conjunction with commercially available systems to allow the severely disabled a minimal but very important amount of environmental control.

Typical environmental control systems allow the user to manipulate a number of electrical appliances by means of a microprocessor. A list of controlled devices may be accessed by a disabled individual through the use of a voice recognition unit or scanning software such as that described above. The user selects a particular mechanism and indicates that it be turned on or off. The system may be enhanced to operate drapes, doors, and similar objects if connected to a motor driven device which can be regulated by the controller. Some systems allow the user access to the outside world by means of a standard telephone equipped with an external speaker. The user may dial by selecting the proper sequence of numbers and issuing the dial command.

Many quadriplegics are confined to their beds for the majority of each day. An environmental control system using a voice recognition unit was recently developed to enable a patient to utilize the system from either his bed or his wheelchair. The Voice-Operated AC Controller (VOAC) was built using a Z-8 Zilog CPU and a voice recognition integrated circuit. The system utilizes an LED display on which appliance and command codes are scrolled. There is no display until the user activates the scrolling process by speaking the word "SEARCH." The commands "FASTER" or "SLOWER" may be used to alter scrolling speed. When the proper appliance and code are displayed, the user terminates scrolling with the "STOP" command. Upon receiving the "GO AHEAD" command, the system generates the proper signal and transmits it along the house wiring. The signal is decoded by a commercially available carrier-current-operated switch at each appliance outlet to determine if an action is required. Upon receipt of the proper signal, power is either supplied or terminated to the appliance [HOGA83].

2.2.3.3 Robotic Aids.

Robotic aids have the potential of providing many manipulative functions required to restore the independence of the quadriplegic. Robotics have been used in industry for some time to perform repetitive functions in a controlled environment. Recently, rehabilitative engineers have applied this technology to aid the handicapped. Typical aids are comprised of telemanipulative functions, which are completely controlled by the user, and robotic functions which are controlled by a computer. Telemanipulators offer full flexibility of function but are slow and cumbersome to use because each step of each function must be commanded. Computer control allows repetitive functions such as feeding to be executed quickly and accurately.

Researchers at the Johns Hopkins University Applied Physics Laboratory have developed a robotic arm which when used in conjunction with a structured worktable provides some manipulative capabilities for the quadriplegic. The system provides the user with the facilities necessary for reading, eating, and using a telephone, environmental controller, or personal computer. The robotic arm/worktable and the user's wheelchair can be operated by the same low profile chin controller. An infrared link provides the control path between the wheelchair and the robotic arm, eliminating the need for special assistance in using the system.

The robotic arm is preprogrammed to perform specific functions. The user selects the desired program from the LED display which scans the available preprogrammed tasks. These programs require that the work table be structured in a specific manner; for example, the program "PICK UP BOOK" demands that the book rack and reading stand be in specific locations. Similarly, the patient may operate the telephone, environmental controller, or self-feeding facilities. User specific programs may also be written using a specially adapted forty key calculator keypad which can be connected directly to the micro-controller of the robot arm.

The user may also select to operate the system in manual mode using the arm as a telemanipulator. In this mode, the patient may select one of the six available degrees of freedom from a scanning display by issuing a command through the use of a discrete switch such as a puff sensor. He may then control the selected joint by manipulating the chin controller. Movement of the joint is proportional to displacement of the controller [SCHN81].

Researchers at Stanford University are developing a mobile robotic aid for the handicapped. The aid consists of a commercially available industrial robot arm mounted on a three wheel omni-directional base. The user may elect to employ preprogrammed manipulative tasks or may assume direct control through a voice recognition system. A small camera mounted on the robot's arm provides a video signal which is transmitted to the console, allowing the patient to monitor and control its movements even from another room. The robot is equipped with a bumper sensor to protect it from unexpected objects in its path. If the robot does encounter such an object, it will back up, move to the side and attempt to proceed, in effect, moving around the object.

Voice control of the robotic aid proves to be difficult to implement due to the fact that the English language is task rather than movement oriented. Currently, in the prototype system, researchers use a very small portion of the Kurzweil Voicesystem's 1000-word recognition capability. The present command language is highly technical and would be cumbersome for the average user. A natural command language is planned for the final system, and will require at least two additional years to implement [SLAT86], [LEIF81].

Currently, motors for robotic arms are large, heavy, and subject to mechanical failure. Research is presently underway, however, to replace these motors with lightweight, more compact, and more reliable drive systems. Researchers at Duke University are developing a robotic arm which, because of its few moving parts, is less prone to failure. The arm is comprised of flexible tubing which is corrugated on one side. Computer controlled air blasts cause the corrugated side to inflate, thereby bending the arm in the opposite direction. This design allows the arm to bend at any point. Presently, it only bends in one direction; however, researchers believe that the use of spirally corrugated tubing will increase its flexibility [TYND87]. Another innovation currently being studied by researchers is the shape memory alloy (SMA) effect as an actuator for robotic arms. According to Dr. L. Schetky, SMA is based on the principle that "a part deformed or stretched at one temperature will, upon being heated to a second temperature, completely recover its original shape [SCHE84]." Hitachi has applied this technology to create a compact, lightweight robotic hand. Two spring loaded fingers and a thumb are regulated by pulling their associated drive wires. SMA strips contained in the forearm control the tension on these wires by contracting when electrically heated. Tbe size and weight of the entire robotic arm is reduced by eliminating the need for electric motors [NAKA84].

2.2.3.4 Entertainment.

The need for a severely disabled person to communicate or to control his environment is certainly very great, but probably more important for the disahled child is the need for entertainment. Generally, by the time a child is given the power to communicate tbrougb a computer, be bas already adapted to bis lack of verbal exchange. Also, regardless of his intellectual ability, the non-oral child is commonly spoken to less often and less intelligently than if he were normal. Very often, by the time a child is exposed to the computer, he has lost any incentive to attain the slow communicative ahilities it can provide. The need for pleasurable activities that take advantage of a child's remaining motor abilities is apparent. The child may not only express his individuality through the use of computer games and art, but he may also learn from tbe activities, and eventually accept tbe computer as a potential aid [GOLD81].

E.P. Goldenberg of Tufts University School of Medicine has recognized the need for computer systems which entertain as well as teach a child. Utilizing the knowledge that many motor disahilities are cbaracterized by lack of control ratber than paralysis, Dr. Goldenberg has developed an algorithm which filters the "noise" from an input signal generated hy victims of certain diseases. He has implemented tbis process to enable athetoid children to use a joystick or graphics tahlet to play computer games. The graphics tahlet also lends itself to freehand drawing or writing whicb gives the cbild a much welcomed opportunity to produce recognizahle figures. Computer interaction has served to replace some of the everyday learning experiences denied to the handicapped cbild. For example, one bright fourteen year old demonstrated an unawareness of the behavior of a bouncing ball when playing a computerized version of ping pong for the first time. After a period of time, the child apparently began to understand, when he was able to anticipate the action of the ball [GOLD81].

It is also very important for the severely disabled adult to have recreational outlets. Much research and development has been done on communication and environmental control systems; however, entertainment facilities have been somewhat neglected. Some systems have been developed to allow a user to express himself through musical composition and art; however, much more work needs to be done.

2.2.3.5 Summary.

It is important that many of the facilities available to tbe motor disabled be incorporated into an integrated system. One such system was designed specifically for an eighteen year old man who was left quadriplegic, non-vocal and nearly blind as the result of an automobile accident. The system provides a combination of communication, environmental control, and entertainment facilities. Tbe user may access any of the features through a series of top-down menus which are displayed on the screen as well as being vocalized through a speech synthesizer. The user may control menu selections either by noise activation, a sip and puff switch, or a touch switch that can be controlled by any functional part of the body. The system offers communication by allowing the user to build sentences from stored phrases, words or letters, which he may then store, print or vocalize using a speech synthesizer. Appliances can be managed through the use of an environmental control mode. The system also allows a person to express his individuality by creating music and color graphics. The music is created according to user response to special menus, and may be stored and played back on a music synthesizer. Color graphics are created in conjunction with the music. The time and effort devoted to creating this system had to be considered worthwhile when, after a short training period, the patient was able to form the word "APPRECIATE" [HOLM81].

2.3 Replacement of Function.

The eyes, ears, and other sensory organs transform external stimuli into an electrical signal which can be interpreted by the brain. The brain reacts by transmitting signals to muscles which respond with the appropriate movement. Any interruption of the communication will result in the loss of sensory or motor function. The technology of applied neural control offers the possibility of replacing those functions lost due to physiological impairments [MORT83].

Applied neural control utilizes the fact that nerve fibers and muscles can be electrically stimulated to produce a desired action. Electrical stimulation has enabled functionally blind persons to see light, deaf persons to hear sound, and paraplegics to walk. Practical utilization of the technology is years away; however, continued research offers hope.

Electrical stimulation has been practiced in the medical field for some time. The Roman physician, Scribonius Largus first observed the healing powers of electricity in 46 A. D. when a patient was cured of gout after stepping on a torpedo ray, a fish which produces an electric shock. Later, when scientists first learned to generate and store electricity in 1740, cures were reported for paralysis, kidney stones, epilepsy, and other disorders. Benjamin Franklin is reported to have had good results relieving convulsions with electrical shock [CHIZ85]. An important milestone for the technology was reached in 1927, when it was discovered that electrical stimulation could control the heart rate, leading to tbe development of the cardiac pacemaker [HITC83].

In recent years, more emphasis has been placed on the use of electrical stimulation in medicine. Methods are being developed to treat scoliosis (curvature of tbe spine), incontinent bladders, respiratory dysfunctions and spasticity [MORT83]. Computer chips are being designed to implant in the body to not only reconnect damaged nerves but also to restore their functionality [EDWA87]. Research is also underway to restore sight for the blind, hearing for the deaf, and mobility for the paralyzed.

2.3.1 Visual Prosthesis.

Scientists are attempting to restore sigbt througb visual prosthesis. It has been known for some time that electrical stimulation of the visual cortex of the brain will cause a person to see a spot of light, a 'pbosphene'. Furthermore, it has been sbown tbat a direct mapping exists between the visual cortex and the retina of the eye. Tbis knowledge has been the basis for several experiments in wbich electrodes are implanted or inserted percutaneously onto the visual cortex. The tests have been largely unsuccessful from the patients' point of view, but have produced valuable information for researchers.

The first visual prosthesis was developed and implanted by G.S. Brindley in 1967. The implant consisted of two silicone rubber caps, an extracranial cap enclosed between the scalp and tbe skull and an intracranial cap placed beneatb tbe skull at the visual cortex. Eighty radio receivers attacbed to the extracranial cap were connected to eighty electrodes attached to the intracranial cap via wires extending through a hole in the skull. Control of the electrodes was estahlished by radio signals generated from outside the hody.

There were two major prohlems with this experiment. The design of the prosthesis required that the patient wear a helmet containing radio transmitters mounted directly opposite their respective receivers on the implant. It was very difficult at that time, however, to make radio transmitters both small and powerful enough to fit the required numher onto the helmet. Another prohlem encountered was that the number of radio channels suffered a high failure rate over time. Although the prosthesis was made of the hest materials available at that time, the high voltage and compact size required in such a device made it susceptihle to failure. The prosthesis was removed in 1982, fifteen years after it was implanted. Of six receivers cut out of the extracranial cap, only one remained functional [DONA83].

The second visual prosthesis was created hy P.E.K. Donaldson and E. Sayer and implanted in 1972. The hasic design was similar to the first prosthesis, but technology had yielded smaller and more adequate materials for implantation hy that time. One major difference was the use of "AND" logic in the transmitting and receiving of signals. This time five "row receivers" and fifteen "column receivers" controlled seventy-five electrodes. In this method, two receivers must be activated simultaneously in order to apply voltage through an electrode. The use of "AND" logic, therefore, significantly reduced the number of radio transmitters and receivers required in the prosthesis.

Once again, the prosthesis proved more valuahle to researchers than to the patient. Induced phosphenes appeared large and indistinct to this patient, where the first patient had discerned small, bright shapes. Scientists believe that this was due to the extensive amount of time the patient had been blind. In spite of this obstacle, researchers were able to elicit phosphenes in the form of braille symbols which were recognizable to the patient. He was able to distinguish ninety percent of the symbols when shown them for only a second. Given an unlimited time period, the patient could discern all of the symbols.

This second attempt at visual prosthesis fell to the same fate as the first. The number of induced phosphenes decreased with time, presumably due to corrosion or failure of implant components [DONA83].

Other attempts at visual prosthesis have subsequently been made. Each attempt has taken full advantage of technological advances, but much progress is needed before the process can be of any practical use. Components must be small enough to fit in the available space in the head, yet able to operate at the relatively high voltages required in a visual prosthesis. Logic must be devised to produce the best possible use of these components, and each element of the prosthesis must be encapsulated to protect it from the harsh environment of the body [DONA83].

Although attempts at visual prosthesis have been largely impractical so far, continued research could be very valuable. Among the possibilities for this exciting field, is the theory that it might someday be utilized to show a blind person scenes from his own environment. If the problems with a visual prosthesis are overcome, and advances are made in computer vision technology, it is reasonable to believe that a camera could transmit a picture to a computer which would then filter "noise" from the scene and generate signals to be transmitted to the prosthesis. The scene could then be recreated in the form of phosphenes to be viewed by the patient. As research continues, scientists will increase their knowledge of the biomechanics of vision with an ultimate goal of the restoration of sight.

2.3.2 Cochlear Prosthesis.

Scientists are developing a method to restore some auditory sensation for the deaf through a cochlear prosthesis. In order to comprehend the function of such a device, one must understand how the ear responds to sound waves. Changes in the atmospheric pressure between 20 and 20,000 Hz. enter the external ear causing a corresponding movement of the ear drum. The ear drum along with the three small bones in the middle ear transform sound into mechanical energy. The vibration produces fluid movement in the inner ear, the cochlea, which causes hair cells on the basilar membrane to vibrate, exciting the neurons at the base of each cell. The neurons produce an electrical signal which is passed along the 30,000 fiber auditory nerve to the brain. It is damage to the hair cells of the cochlea which is the major cause of deafness [PARK83].

State of the art medical techniques have made it possible to repair almost any disorder of the external or middle ear; however, this is not true for the inner ear [WHIT81]. A cochlear prosthesis is an artificial device designed to replace the lost function of the inner ear. This device must transform sound into electrical stimulation which can be interpreted by the brain. To accomplish this, the prosthesis must consist of three basic subsystems: 1) an external transmitter/signal processor unit, 2) internal receiver electronics, and 3) an electrode array. The external device is responsible for collecting sound, transforming it into the proper stimulation pattern, and transmitting it to the internal receiver. The receiver, in turn, transfers the signals to the proper electrode(s), which delivers the electrical impulse to the auditory nerve.

Electrode arrays can be configured in several different manners. The first generation of prostheses was implemented using a single channel configuration, one active electrode and one return electrode. This provided the user with sufficient auditory sensation to distinguish environmental sounds such as the telephone ringing, a siren, or a knock on the door. The technique also enhanced a patient's lip-reading ability and allowed him to monitor the volume of his own voice [PARK83]. Subsequent research has proven that multichannel stimulation has increased the patient's speech discrimination capabilities. According to C.W. Parkins, "there is now good evidence that a multichannel information system can produce significantly better speech discrimination than a single-channel information system" [PARK83]. Therefore, in the future, it is more likely that a multichannel system will provide a patient with not only speech discrimination but also speech intelligibility.

There is some debate as to the optimal placement of electrodes in the inner ear. Experiments have been conducted such that electrodes are positioned directly on the auditory nerve. This has the advantage of requiring lower stimulus levels than are needed by electrodes placed in the cochlea. However, the potential damage to the auditory nerve greatly outweighs the benefit of low power [PARK83]. Another school of thought holds that there should be no invasion of the cochlea whatsoever. Subscribers of this theory believe that insertion of electrodes into the cochlea risks further damage to neural structures. Their approach is to place the electrode on the promontory, the round window at the entrance to the cochlea, and optimize its use through single channel signal processing. The minor surgery required of this method allows the patient to obtain a temporary implant, so that he may assess the usefulness of the device without making a long term commitment. This method has only been implemented using a single pair of electrodes; therefore, the major disadvantage lies with the problems inherent with a single channel device [ROSE81]. The final and most widely used approach is the insertion of the electrode(s) directly into the cochlea. New methods of insertion have minimized the threat of neural damage. Selective placement of multiple electrodes along the basilar memhrane enable the stimulation of targeted neurons, taking full advantage of multichannel signal processing [PARK83].

The external processor is probably the most complex of the three components of a prosthesis. It must function to collect sound waves, convert them into the proper electrical signal and transmit that signal to the internal receiver. Some researchers believe that the entire acoustic signal should be transmitted to the brain; however, most believe that the signal should undergo a feature extraction process. State of the art prostheses consists of approximately eight to ten data channels, but the ear has close to thirty thousand. According to R.L. White, "In this restricted-bandwidth system it is imperative that the few channels available be used effectively. The limited bandwidth must he utilized to transmit only the significant features of speech" [WHIT81]. In this case, the external processor must employ a feature extraction algorithm. In some multichannel systems, the external unit is also utilized to separate the signal into frequency bands so that each distinct band can be delivered to the appropriate electrode.

Deaf people are very susceptible in life threatening situations because they can not hear warning signals that the hearing take for granted. They must endure the everyday inconveniences of being unable to hear the door bell or the sound of a baby crying. But worst of all, they must suffer the social isolation of silence, of being unahle to communicate at will. As technology advances, cochlear prostheses should alleviate many of these problems. However, before the prostheses can supply practical treatments for deafness, several obstacles must be overcome. Coding schemes for effectively processing an acoustic signal must be perfected if speech intelligibility is to be attained. The electrodes, conductors and internal receiver will require further miniaturization and specialization if the number of data channels currently used is found to be inadequate. If these tasks can be accomplished, the cochlear prosthesis should alleviate many problems for a large portion of the deaf population.

2.3.3 Functional Neuromuscular Stimulation.

Approximately twenty people are partially paralyzed every day due to an accident involving damage to the spinal cord. Depending on the location of the injury, the patient may be paralyzed from the waist down (paraplegic) or from the neck or shoulders down (quadriplegic). In either case, he loses not only the use of his limbs, but also a great deal of independence, job potential, and in some cases, tragically, even his self-respect. Researchers are developing methods of helping these victims by restoring some of their lost functions through the technology of applied neural control.

Functional neuromuscular stimulation (FNS) is the practice of electrically exciting muscles to restore some use to limbs paralyzed due to nerve damage. Paralysis is generally caused by an injury to the spinal cord, the transmission link from the brain to other parts of the body. In most cases, paralyzed limbs are isolated from any controlling signals from the brain, but are otherwise undamaged. It is the aim of scientists working with FNS, to bypass the spinal cord lesion and deliver appropriate signals to muscles in order to restore their functionality. The task is very difficult due to the complexities of the central nervous system, but significant progress has been made.

Researchers have been studying the possibilities of how electrical stimulation of muscles might aid paraplegics and quadriplegics for over twenty-five years. In 1960, a paraplegic was able to stand for several minutes when his leg muscles were electrically stimulated. Electrodes attached to the skin caused muscle contractions in his legs, which, in turn, straightened his knees. Since then, paraplegics have been able to stand, walk short distances, climb stairs, and even ride bicycles. Quadriplegics have been able to attain enough hand and arm control to be able to feed themselves and brush their teeth. The future of FNS holds a great deal of promise, but many problems must be overcome before the system can be made commercially available [CHIZ85].

One of the most basic difficulties faced by researchers is determining the optimal method of muscle stimulation. For example, surface electrodes attached to the skin are clearly the simplest and most convenient means of stimulation; however, because the electrical impulse must travel through the skin and fatty tissue of the body, little selectivity is achieved and a number of different muscles and nerves are stimulated. Surface electrodes also suffer from slippage during use and many must be replaced daily. Intramuscular electrodes inserted through the skin offer much more selectivity, but their installation, while not requiring surgery, is still very difficult to perform. Another disadvantage is the fact that anything inserted through the skin eventually leads to infection and is rejected by the body. The best alternative for long term use appears to be the implantation of electrodes directly on specific nerves. This, however, does require surgery and is therefore impractical to use during research [CHIZ85].

Another factor constraining FNS research is the extreme complexity of the human motor control system. Each muscle unit consists of thousands of muscle fibers and one motor nerve. In a healthy body, the brain generates a signal which is transmitted through the spinal cord to a motor nerve. The muscle fibers, stimulated by the motor nerve, convert chemical energy in the body into a contractive force causing movement. The brain must coordinate and transmit an enormous number of signals simultaneously in order to create natural movement. FNS researchers have been able to establish rudimentary control of paralyzed limbs, but they are nowhere near simulating the natural movement produced by a healthy body. According to H.J. Chizeck, "We simply don't yet know how to coordinate the transmission of signals to and from a large number of electrodes simultaneously. No more than 50 electrodes are now being used even in the most sophisticated experimental systems. The body's natural system of motor control, in contrast, employs thousands of simultaneous signals to regulate movement. [CHIZ85]"

To date, most FNS systems are controlled by one of two methods. The first technique, most frequently used for paraplegics, is controlled by a binary switch. When the switch is turned on, a computer generates the signals which activate the proper electrodes to cause movement. An individual might walk, climb stairs or ride a bicycle. In any case, the computer must be preprogrammed to generate the proper signals for the desired movement. The method is satisfactory for many of the repetitive motions needed by paraplegics for activities like walking, but offer very little help for quadriplegics. The second controlling technique utilized by FNS systems is much more suitable for quadriplegics. This method involves an individual using a muscle or muscles unaffected by the injury to convey the desired movement. For instance, a quadriplegic might move his right shoulder to indicate that he wishes to extend his right arm. Electrical impulses causing the shoulder movement can be detected and subsequently analyzed by a microprocessor which would then determine the correct stimulus pattern to extend the right arm. This technique is obviously much better suited for the non-repetitive movements needed for arm and hand control required to aid the quadriplegic, but it also offers distinct advantages to the paraplegic. Researchers are currently developing an FNS system for paraplegics which allows the upper body (above the spinal cord lesion) posture to control the patients' movement. Their theory is that the system is much safer than the binary switching method because posture-mapping can determine if the patient's balance is adequate for the execution of a step and thereby prevent potentially hazardous movements [GRAU83]. Another system in development allows a patient to control his gait by simulating the ambulatory motion with two fingers [THOM83].

In spite of the progress in recent years, all FNS systems are experimental and will not be commercially available until many problems are solved. At present, all paraplegics using FNS in laboratories require auxiliary support to maintain balance. Many researchers believe that the development of a practical system, even for use with crutches, or walkers, will not be completed for at least a decade. A system not requiring the use of a support device is at least twenty to thirty years further in the future. According to M.J. Rosen, "few experts have been bold enough to predict that a system with the basic capabilities of moving a leg to catch one's balance can be developed for practical use within their lifetime. [ROSE85]"

When FNS systems are commercially available, quadriplegics are much more likely to benefit from them than paraplegics. Paraplegics are already afforded a great deal of mobility through the use of wheelchairs. FNS systems would need to increase mobility significantly before they would become a legitimate financial alternative. The system would also need to be easy to use and inconspicuous before many paraplegics would use them. For instance, braces are available for use by many paraplegics; however, the added capabilities they provide often do not warrant the physical and mental effort they require. Quadriplegics, however, are much more likely to find the systems invaluable. Adequate control of the arms and hands will afford them some independence and eliminate the need for full time nursing care. This alone could save millions of dollars in health care costs; therefore, insurance companies are likely to provide financial assistance.

2.3.4 Computer Utilization.

The practice of applied neural control would be unrealistic without the use of computers. Computers have played a major role in the investigation of biomechanics to determine the optimal method of employing the technology. They are used during testing of prototype systems to record and analyze results, thereby allowing further improvement of the system. In the case of visual and cochlear prostheses, computers must perform signal processing on data gathered from the environment. Another important function is the determination and generation of the proper stimulus pattern to elicit the desired response. In the future, computers will also be used to analyze feedback data in order to insure proper operation of the system and to protect the body from any injury caused by the system.

2.3.5 Conclusion.

Significant progress must be made before the application of neural control can be perfected. Internal components must be miniaturized and rendered biologically inert so that long term subcutaneous devices are practical. External components must also be miniaturized and packaged inconspicuously to avoid drawing unwanted attention. As knowledge of the biomechanics of the body increases, the effectiveness of these systems will also increase.

CHAPTER 3

WHEELCHAIRS

3.1 Introduction.

This chapter presents a study of wheelchairs, both manual and motorized. A description of the evolution of wheelchairs is included along with a discussion of the problems resulting in the lack of innovation in wheelchair design. This chapter is intended as a background study for the design of an autonomous wheelchair.

3.2 History of The Wheelchair.

The mobile indoor vehicle has a long, poorly documented history. Researchers have been forced to glean information about the earliest such vehicles from the drawings and engravings of relics from the past. Such evidence has included illustrations on an Ionic vase dated approximately 530 B.C., engravings on two Chinese stone coffins from the 6th century A.D., and woodcuts from the Middle Ages. This information indicates that mobile indoor vehicles were in use long before there was any written documentation attesting to that fact.

It was not until the 16th century, that detailed descriptions of the predecessor to the modern day wheelchair were recorded. The most notable vehicle of that time was a mobile chair designed and built for Philip II, the King of Spain. This chair bore an amazing resemblance to wheelchairs built three centuries later. The chair was equipped with four small wheels and featured a reclining back and elevated footrests. The major difference between this chair and the subsequent wheelchair was the absence of any means of self-propulsion.

The first self-propelling wheelchairs were built in the 17tb century. The preliminary chairs of this type were driven by two cranks which turned a single front wheel. The first chairs to be propelled by rotating the two large wheels were built almost a century later. It was not until the Civil War tbat tbe wheelchair came into use in the United States. At that time the wheels were made of wood, and it was not until the bicycle craze of the late 1800's that wire-spoked wheels were adopted for wheelchair use. As with all wars, World War I stimulated the demand for assistive medical devices, and the need for wheelchairs was intensified. The increasing popularity of the automobile prompted the demand for easy handling chairs which were light and foldable. From here, the wbeelcbair evolved into tbe standard wbeelcbair of the present [KAME86].

3.3 Present-Day Wheelchairs.

The wheelchair is not just a means of transportation. Through the use of a wheelchair, persons who would otberwise be confined to bed are provided the freedom to move about the home, office, or even the outdoors. It is a practical aid which may preserve the heart, sustain the body and motivate tbe will. For many sick or disabled persons it can mean the difference between dependence and independence.

There are several different types of wheelcbairs currently available to accommodate the various needs of the disabled community. This section presents a description of each type.

3.3.1 Nonfolding Chairs.

Still in extensive use today is the traditional, bigb-backed, institutional cbair. Its inexpensive, sturdy construction makes it an ideal cboice for use in hospitals and nursing homes. The chair is generally made of wood with caned backs and seats.

Some models féature reclining hacks and elevated footrests. The chair is generally quite large, hut pillows may he used to compensate for the had fit. Modern day, nonfolding chairs are huilt from tuhular steel and are much smaller than the wooden chairs. This type of chair is generally used for transporting patients in hospitals and nursing homes or to provide a patient with a change of scenery during long periods of hedrest.

3.3.2 Rearwheel-Drive Chairs.

The rearwheel-drive chair is the most frequently used wheelchair and is the most appropriate for the majority of wheelchair users. Commonly known as the standard wheelchair, it is well-suited for hoth indoor and outdoor use. The chair is customarily made of steel tuhing with the hack and seat composed of fahric or plastic. A user with adequate strength in his arms and hands can propel himself hy turning the two large wheels positioned at the rear of the chair. Skilled users can tilt the chair hackwards, raising the front wheels enough to climh curbs. Push handles are located at the upper back of the chair for use hy an attendant. A tipping lever positioned at the lower hack of the chair provides easy tilting hy the attendant for navigating curhs. The chair usually weighs at least forty pounds; however, there are more expensive models which are lightweight hut less sturdy.

3.3.3 Sports Chairs.

The advent of a lightweight, sturdy wheelchair used in sports could he one of the most significant advances in wheelchair technology in recent years. Sports chairs have only been availahle on the commercial market for a short time, hut wheelchair athletes have already tested their strength and versatility [BRUB86]. The sports chair features a solid frame constructed with a lightweight, corrosion-free alloy which makes it much more robust than the standard chair. Wheels on the sports chair may be attached at different levels to provide optimal performance hy the athlete [KAME86].

It is currently the policy of many physicians to prescribe a standard wheelchair unless justification is given to acquire a specially-equipped chair such as the sports chair. However, the performance and durability of the sports wheelchair is so commendable that it has been suggested that this policy be reversed. Let the physician prescribe a sports wheelchair unless justification is given to prescribe a standard chair. Unfortunately, the policies of many third-party reimbursers have prohibited the general acceptance of the sports chair. One can only hope that the technology utilized in the creation of the sports chair be adapted in the design of other wheelchairs [BRUB86].

3.3.4 Frontwheel-Drive Chairs.

The frontwheel drive chair is mainly for indoor use. With the two large wheels located at the front of this chair, its major advantage is that it requires less space than the standard chair, therehy making it much easier to maneuver in tight spaces. The location of the wheels does, however, make lateral transfer in and out of the chair impossible. This chair is less likely to tip over backwards than the standard chair making it more suitable for users without legs or legs which have atrophied. Because the user must lean forward slightly to propel himself in this chair, he must have good trunk stahility to avoid falling forward.

Though primarily for indoor use, the chair may he used outdoors if curhs can he avoided. The location of the wheels makes it extremely difficult to negotiate curbs even with the aid of an attendant. The front wheel drive does, however, smoothen the ride over uneven terrain.

3.3.5 Amputee Chairs.

The amputee chair is a wheelchair designed specifically for the user without legs or with atrophic legs. Wheelchair users with either of these conditions may have difficulty with a standard chair due to the instability created by the lack of weight at the front of the chair. For instance, when travelling up a steep incline, the user's weight is positioned predominately at the back of the chair. The absence of weight at the front could easily tip the wheelchair backwards. The wheels of the amputee chair are repositioned to compensate for this unusual weight distribution.

3.3.6 One-Arm-Drive Chairs.

The one-arm-drive chair is a wheelchair designed specifically for users with one arm missing or paralyzed. The chair features two handrims on one side of the chair. The first is the typical handrim attached directly to the adjacent wheel. The second is positioned outside the first, and is connected to the wheel on the other side by an axle. The outer handrim is smaller than the inner one to simplify the use of one handrim at a time. The double handrim may be fitted to various types and sizes of wheelchairs. The major disadvantage to this chair is that self-propulsion can be difficult to learn for those who are slightly disoriented.

The one-arm-drive chair was specifically intended for wheelchair users with the use of only one arm; however, others may benefit from the design. Users with a weak upper arm may tend to avoid using that arm when propelling a standard wheelchair. The use of a one-arm-drive chair, even for a few weeks, would force him to exercise that arm. The chair may also be well-suited for persons who need one arm free for carrying tbings. For instance, a mother migbt prefer this type of chair so that she can bold a baby in her free arm.

3.3.7 Motorized Chairs.

Motorized wbeelchairs are available for use by the severely physically disabled or those who must conserve energy due to an illness. Motorized chairs are usually operated by displacing a control knob or joystick in the desired direction of travel. The chair is recommended for use by individuals who cannot otherwise operate a wheelchair, or for persons with cardiac problems or poor muscular endurance [KAME86]. Until recently, the use of a motorized wheelcbair was not recommended in many cases because it was felt tbat tbe user would benefit from the exercise expended in self-propulsion. However, tbere is now a growing conviction among bealtb care professionals that the wheelchair user should conserve his physical energy for useful tasks other than self-propelment [SEAM81].

Special control mechanisms are now available for persons with very limited muscle function. Among them are voice control through the use of a voice recognition system [MILL85], and chin control indicated by the directional displacement of tbe chin [SEAM79]. Also in use is a sip-and-puff mechanism which requires the user to suck or blow througb a mouthpiece(s) to indicate direction and velocity [KAME86]. A wbeelcbair is in design which allows the user to direct his cbair simply by turning bis head in the desired direction. The position of the head is determined tbrougb the use of ultrasonic sensors mounted on the back of the wbeelchair [JAFF81]. Still in the experimental stage is a myoelectric control mechanism. This device is able to determine a muscle's activity by measuring the electrical impulses stimulating tbat muscle. Tbrougb tbe use of this mechanism, the user could control bis cbair by flexing different muscles to indicate the velocity and the various directions. This type of device could also be utilized in conjunction with a scanning display so that the user could select the desired command simply by flexing a single muscle [ROSS79], [DURI78].

Some of the disadvantages associated with the use of a motorized wheelchair are that spastic movements or movements made during periods of inattention are amplified [KAME86]. This could lead to accidents and serious injury. Also, there are so many attachments for many of the motorized wheelchairs that users are often overwhelmed and embarrassed by all the gadgetry.

3.3.8 Costs.

The purchase cost of wheelchairs varies greatly depending on the type of wheelchair, and the accessories and customization needed. The standard wheelchair is the least expensive on the market and may cost between $400 and $1700. Sports chairs generally cost from $800 for a racing model to $1500 for a general sports model. The most expensive chair, the motorized chair, may cost from $2000 to $5000 [SHEP84], [HOOP86].

3.4 Lack of Innovation.

Numerous factors inherent to the disabled population contribute to an absence of innovation in wheelchair design. Among them are an overall ignorance of the types of wheelchairs available, third-party reimbursement policies for the purchase of said vehicles, and the threat of product liability. An explanation of these factors is presented in this section.

3.4.1 Consumer Market.

In order to understand the elements which retard the innovation of wheelchair design, it is necessary to be cognizant of the consumer market and the manufacturing policies affecting the design. A 1977 survey revealed tbat one out of every two hundred Americans, approximately 1.2 million individuals, is a wheelchair user. Approximately half of these individuals reside in nursing homes, and tbis percentage is growing at a rate of 1.5 percent annually. In 1982, roughly 338,000 wbeelchairs were sold in the United States for a total of 126 million dollars. It has been estimated that 250,000 of the wheelchairs sold annually are general-purpose, manual wheelchairs sold to rental agencies or institutions (e.g. nursing homes, or hospitals).

There are approximately fifty-three manufacturers and importers of wheelchairs in tbe United States. However, Everest & Jennings, Inc., Invacare Corporation and a few otber large organizations dominate the market, constituting an oligopoly. The significance here is that there is limited competition stemming from tbe knowledge that an action by one manufacturer will constitute a retaliatory action by the others.

3.4.2 Third-Party Reimbursers.

The wheelchair market is largely subjected to tbe doctrines of third-party reimbursers. Approximately balf of all wbeelcbairs purchased are at least partially funded by the government. Forty to forty-five percent are funded by private insurers, leaving only five to ten percent paid for in full by tbe user. The large percentage of externally funded purchases directs innovation to the types of devices whicb are eligible for reimbursement. Altbough the doctrines of insurers vary, all will pay for a wheelchair which is "medically necessary." Some agencies, such as the Veterans Administration and Medicaid, consider wbeelchair accessories tbat psychologically benefit the user as medically necessary. However, many insurers will only pay for tbe least cost wheelchair which will meet the pbysical needs of the user.

All insurers seem to employ the pbilosophy of price over performance in the funding of wheelchairs. In many cases, inexpensive wheelchairs will incur higher maintenance and repair costs than better quality, higher priced chairs. Unfortunately, this does not seem to be considered in the payment policies of third-party reimbursers. As a result, manufacturers are unlikely to be able to sell the higher priced models. Tbis is a strong deterrent to the manufacturing of such a chair.

3.4.3 Standards.

The FDA currently bas no official standards for wbeelchairs. Performance standards are presently being developed by a delegation from the Rehabilitative Engineering Society of North America; however, compliance will be strictly voluntary.

The Veterans Administration, VA, does however, have standards for procured wbeelchairs. Because the VA is the largest single purchaser of wbeelcbairs in tbe United States, manufacturers are obliged to conform to established guidelines. Unfortunately, however, until recently VA standards were developed with a particular wheelchair in mind. Actual performance standards were not adopted until 1977 for manual wheelcbairs and 1982 for motorized wheelchairs. Until these standards were set, the VA guidelines essentially catered to the interest of the manufacturers. When standards were written in accordance witb a particular model, it was in the manufacturer's best interest to produce chairs which conformed to the specifications of that model. Tbis obviously curtailed innovation. In addition to this, a recent survey indicated that many manufacturers were unsure of the methodologies utilized by the VA in evaluating new products. This lack of knowledge makes innovation hazardous due to the uncertainty of whetber products will meet VA standards, and if not, whether those standards might be cbanged.

3.4.4 Consumer Unawareness.

The selection of the correct wheelchair to purchase is usually the task of a dealer or therapist. A physician's prescription is ordinarily required for third-party reimbursements, but physicians are generally not apprised to the various wheelchairs and accessories available. If the prescription does not indicate a particular brand, it is ordinarily left to the therapist or dealer to select a model. Most dealers, however, only handle the larger brands of wheelchairs. The decision concerning which brands to carry is usually dependent on quality, previous service, and profit margin. Dealers often buy large quantities of wheelchairs in order to receive substantial discounts and will generally only stock the models for which they were given the best price. Compounding this, they tend to carry wheelchairs with a higher percentage of profit. The lower priced manual wheelchairs carry a forty percent markup, while motorized wheelchairs generally have a thirty percent markup. Since most wheelchairs users are unaware of the various chairs and accessories available to them, they generally rely on the dealer's or therapist's recommendation and rarely order a special wheelchair.

3.4.5 Product Liability.

The threat of a product liability suit is another major obstacle to innovation. According to one manufacturer, product liability suits have succeeded medical malpractice suits as the most opportunistic lawsuits filed today. The imminence of a lawsuit discourages physicians, dealers and therapists from recommending new products. This is especially true for entirely new products and less true for variations of existing products [SHEP84].

CHAPTER 4

DESIGN CRITERIA FOR AN AUTONOMOUS WHEELCHAIR

4.1 Objectives.

This chapter presents the preliminary design criteria for an autonomous wheelchair. This design is expected to incorporate the optimal features of existing technology with certain innovative concepts to resolve problems associated with current motorized wheelchairs and to relieve the user from unnecessary tasks. It is the primary objective of this design to offer the disabled user a safe, reliable means of transportation. Secondary to this, but still of prime consideration, are the issues of aesthetic value, reasonable costs and ease of use. Included are suggested modifications to the basic wheelchair design which should promote the safety and health of the user. Also proposed is the incorporation of a microprocessor-based control unit. The utilization of such a device would alleviate many navigational difficulties and allow simple customization for a user's residual capabilities through software. The criteria presented in this document are intentionally flexible so that the design engineers may incorporate the latest technological advances and modifications to further enhance the design.

It is the hope of this author that the criteria proposed here, along with each step of the design, be subjected to the review of potential users, rehabilitation engineers, and orthopedic surgeons as well as the various technical experts needed to implement the design. There would be no satisfaction in wasting valuable time and resources on research and development to create an aid which is either unwanted or impossible to finance.

4.2 Microprocessor Control Unit.

In order to achieve maximum capability, the proposed wheelchair should be microprocessor controlled. The utilization of a microprocessor control unit would eliminate many of the problems associated with present day motorized wheelchairs. It would also provide a significant number of additional facilities to the wheelchair user. Potential capabilities of this type of control are discussed in this section.

4.2.1 User Customization.

The hardware modifications needed to customize a motorized wheelchair for a user's residual capabilities are major contributors to the inordinate expense of the chair. For instance, a paraplegic generally has the ability to respond much more quickly in a given situation than the quadriplegic. This would indicate that the paraplegic would be capable of driving the wheelchair at greater speeds. For many motorized wheelchairs, this requires a hardware modification, a costly, time-consuming procedure. The wheelchair proposed in this document will utilize the microprocessor to allow the user or therapist to enter such customization variables. Likely parameters would include forward velocity, reverse velocity and maximum accelerations. These variables could easily be modified as the user's capabilities change.

4.2.2 Signal Processing.

Many disabled persons suffer from spasticity or other conditions which cause unintentional or irregular motions. Such a motion involving the input control mechanism could be a source of inappropriate movement by a motorized wheelchair causing sudden acceleration or directional change. Such a movement could easily force the wheelchair to tip over. Through the use of a microprocessor, the user input signal could be processed to filter out erratic or inappropriate signals, resulting in a smoother, safer ride. Digital filtering could be implemented for all users, regardless of their capabilities, to guard against moments of inattention or recklessness. However, the reduced response time may annoy users who are not in need of the capability. Therefore, it is recommended that this feature be included as a customization option.

4.2.3 Closed Loop Control.

Many motorized wheelchairs use only the displacement of the user interface control mechanism (e.g. joystick) to determine velocity. This is referred to as open loop control because no feedback data is collected or processed by the system. Closed loop (self-correcting) velocity control would be of great benefit to the wheelchair user. This would, in effect, be a cruise control facility for the wheelchair. The implementation of this control methodology would relieve the user of having to compensate for the incline when ascending or descending ramps. This could also prevent sudden acceleration or deceleration when driving from one type of surface to another. For instance, a wheelchair using open loop control could experience a sudden acceleration when passing from deep-pile carpet to a hardwood floor. Closed loop control provides a safety advantage, as well as convenience, and should be included in the design specifications for the proposed wheelchair.

4.2.4 Automatic Sensors.

The use of automatic sensing devices has been incorporated in the design of a motorized wheelchair at the Palo Alto Veterans Administration Medical Center. The sensing devices provide safety measures as well as navigational aids which are well worth considering in the design of the proposed wheelchair.

The Veterans Administration "smart" wheelchair bas heen designed to incorporate ultrasonic sensors for safety and convenience purposes. Sensors mounted on the front of the chair detect obstructions in the user's path. If tbe obstacle is within a preprogrammed distance, the chair will slow down and stop to avoid a collision. The technology is responsive enough to sense the sudden opening of a door. An additional feature allows the chair to detect an object (person) moving slowly in front of it and slow down to follow that object.

Additional sensors mounted on each side of tbe cbair allow the user to travel parallel to a wall with no user guidance. The "follow-that-wall" mode will detect and disregard doorways; however, if an opening of more that a few feet is detected, control of the wheelchair will automatically be returned to the user. The disregarding of small apertures allows the user to "follow" a picket fence [JAFF81].

In order to avoid reinventing the wheel, the technology utilized in the creation of the Palo Alto "smart" wheelchair should be investigated. An additional, similar feature which should be considered for tbe proposed wheelchair is tbe "follow-that-person" concept. A mode in which the wheelchair would travel parallel to a moving ohject could be extremely useful in allowing a wheelchair user to keep pace with a walking companion.

4.2.5 Path Memory.

A wheelchair designed at the Atlanta Veterans Administration Medical Center incorporates a path memory feature which allows the wheelchair to back out of confined spaces in which it is too difficult to maneuver. The feature utilizes closed loop control to measure and record distance and direction. If the user should encounter such an impediment, he would simply use the path memory feature to back out of the confined space along the same route upon which he entered [KELL84]

The path memory feature should be incorporated into the design of the proposed wheelchair. It could be of great benefit to the handicapped individual, particularly to the severely disabled person who has little freedom of movement. It is suggested that the path memory feature be extended in the proposed wheelchair to, in effect, memorize routes which are frequently travelled by the user. This capability would relieve the user from unnecessary navigation when travelling familiar routes. A learning mode would be utilized when traversing a path for the first time in order to measure and record distances travelled in various directions. Upon arrival at the destination, the route would be associated with a unique key and stored for future reference. Once a route has been learned, it could be utilized in a playback mode to enable the user to once again travel that route. The chair would be automatically propelled to its destination according to the directions and distances previously recorded. If an unexpected, stationery obstacle was to be encountered, the chair would halt, and control would be returned to the user. If a moving obstacle was detected, the chair would slow down and follow that obstacle until it no longer presented a threat of collision. The playback mode could be used to either assist the user in travelling to a particular destination or retracing his path to the original starting position. A pause feature could be incorporated to allow for necessary moments of interrupted travel, such as the time spent in an elevator.

4.2.6 User Interface.

Severely disabled individuals can be stricken by a wide variety of debilitating conditions. Their residual capabilities vary so greatly that the selection of a single type of user interface to the proposed wheelchair would be unwise. It is recommended, therefore, that the microprocessor control unit be capable of accepting various types of input. The input could then be translated to a standard format for subsequent processing.

It should be noted that the standard wheelchair interfaces (i.e. joystick, sip-and-puff mechanism, etc.) limit the number of functions available to the user. It may be necessary, tberefore, to incorporate the use of a scanning display in order to access the special capabilities of tbe chair. In this case, the user would continue to navigate bis chair through tbe standard interface and utilize a discrete switch to control the scanning display. The utilization of a less restrictive interface mechanism, such as a voice recognition unit, would eliminate the need for the display.

4.2.7 Personal Computer Interface.

An interface to a personal computer should be included in the design of the proposed chair. A physical link would provide the facility to transfer information between the on-board control unit and the personal computer. This would be useful in setting customization variables when the chair is newly purchased or when tbe capabilities of the user cbange. This could also provide extra storage for frequently travelled routes if tbe patb memory feature is utilized. The physical link would be of great benefit; however, many disabled persons would be unable to establisb that link without belp. Therefore, it is recommended that a remote link also be incorporated in the design. An infrared link could easily be establisbed by the user by depressing a discrete switcb mounted on the cbair. Once control is transferred to tbe personal computer, a scanning or menu display could be incorporated to give the user full access to the computer's capabilities. This should include access to an environmental control system.

4.2.8 Miscellaneous.

Many severely disabled individuals are highly susceptible to pressure sores because they are unable to feel discomfort in their lower backs and legs. After being seated in one position for a lengthy period, healthy individuals feel discomfort and shift positions to compensate. Because many disabled persons can not feel this pain, they are unlikely to alter tbeir positions and consequently develop pressure sores. To remedy this situation, the control unit of tbe proposed wbeelcbair could generate a tone at timed intervals to audibly remind the user to shift his weight.

Additional features which should be considered in the chair's design are as follows:

- an emergency alarm system to allow the occupant to call for help in the event of a mechanical failure,
- a failsafe switch to stop the chair and to temporarily shut down all motive properties of the cbair in case of an emergency,
- a battery voltage monitor to alert the user to low battery power, and
- a self-diagnostic system to detect possible failures in the components of tbe cbair and alert the user to those possibilities.

4.3 Hardware.

The hardware utilized in the formation of the proposed wheelchair should incorporate the most reliable, economical and aesthetically pleasing components available at the time of construction. Consideration must be given to the fact that many severely disabled individuals essentially live in tbeir chairs. They are largely dependent upon the reliable service of these chairs and would be greatly inconvenienced if a breakdown should occur. The appearance of tbeir vehicles is also of great importance. Many motorized wheelchairs are aesthetically offensive due to the massive number of attachments mounted on the chair. Many users spend the majority of their day in wheelchairs and could be embarrassed or even psychologically damaged if confined to an unsightly chair.

This section presents suggestions concerning the hardware components and mechanical design of the proposed wheelchair. This author does not presume to be a mechanical expert nor do the criteria presented here cover the full range of hardware specifications required in a wheelchair design. These are merely ideas to be considered based upon the extensive readings of the author.

4.3.1 Basic Design of Chair.

The mechanical design of the proposed wheelchair should incorporate modifications to the design of the standard chair. Except for the sports chair, the design of present day wheelchairs is basically the same as that of wheelchairs built fifty years ago. It is recommended that this design be challenged.

A likely candidate for examination would be the structure of the chair. The basic structure of the wheelchair was not designed for the greater speeds (i.e. five to seven MPH) capable of today's high performance wheelchairs. As a result, chairs are more likely to tip over due to excessive acceleration or deceleration, during high speed turns, or when ascending or descending inclines. Several of these problems may be solved by performance limitations programmed into the software which controls the motive force of the chair (e.g. maximum acceleration). However, preprogrammed performance limitations are unlikely to remedy all these situations. The obvious mechanical solution to the problem would be to lower the center of gravity and extend the wheel base of the chair when travelling at higher speeds. Also to be considered in the design is a shift of the center of gravity when ascending or descending ramps. A forwards sbift of the center of gravity would increase tbe stability against rearward tipover wben ascending ramps. A rearwards shift would stabilize the cbair against forward tipover when descending ramps. Tbese sbifts of tbe center of gravity could be automatically controlled by the on-board microprocessor.

The materials utilized in the construction of the seat and back of the wheelchair should also be given prime consideration. Many present day wheelchairs have slung seats and backs constructed from fabric or plastic. This type of seating can promote pressure sores and postural deformities if used for extended periods of time. Because the proposed wheelchair is intended for severely disabled persons who are largely confined to their chairs, it is not advisable to use tbis type of seating. A solid seat and back would be much more suitable for preserving the bealtb and well-being of tbe user. Tbe factors listed below have been determined to promote good seating quality and should be considered in the design of the proposed wbeelcbair. The wbeelchair seat unit sbould:

- be adapted to the physique of the occupant,
- stabilize the occupant's sitting posture,
- enable tbe occupant to sbift his weight,
- support the occupant's body weight and evenly distribute the pressure,
- maintain a comfortable temperature at tbe seat surface, and
- conduct moisture away from tbe surface of the seat [BRAT83].

4.3.2 Efficiency.

The design of the proposed wheelchair should be streamlined to obtain maximum efficiency in use. This could be largely accomplished through the examination of each component of the chair. Each unit which translates electrical battery power into locomotive energy should be examined for its efficiency, consistent with the objectives of reasonable costs, reliability and strength. Even components which do not directly affect the electrical system should be scrutinized. For example, studies have shown that smaller wheels are more efficient in use than larger ones. Since the wheelchair will be electrically driven, it is unnecessary to utilize the standard twenty-four inch wheels. Self-propulsion is the only purpose for these wheels, and motorized chairs are much too heavy to be propelled by the disabled user.

4.4 Modularity.

Extremely important in the consideration of design specifications should be the concept of modularity. The various features incorporated in this design should be separate and distinct so that the user is able to purchase exactly the options that he desires or that his residual capabilities dictate. This also implies that the microprocessor-based control functions associated with the proposed wheelchair be adaptable to existing motorized wheelchairs and their input interfaces (e.g. sip-and-puff mechanism, joystick, etc.). This would obviate the need for the user to purchase another wheelchair if he already owns one, and it would allow him to continue using the input interface which is best suited for his capabilities or with which he is most comfortable.

4.5 Extensions.

Suggested extensions to the design of the proposed wheelchair are presented in this section. Although these ideas are considered reasonable and beneficial, the stifling deterrents to innovation in wheelchair design dictate that these features not be included in the preliminary design. Before incorporation of these features is seriously contemplated, it should be ensured that a potential market actually exists and is able to finance the options.

The incorporation of a "map" feature could be very beneficial for wheelchairs used in an institutional setting. The map would consist of a physical diagram of the building and would be stored in memory. The wheelchair user would simply indicate his destination and would be driven there automatically. The "map" concept was derived from a recent innovation in the automobile industry. This innovation features a visual monitor, connected to the automobile's dashboard, which displays a map of the city. When the driver indicates his destination, a potential route is displayed on the monitor. The current location of the automobile is determined through the use of a satellite and special sensing devices. Utilizing this equipment, an on-board microprocessor determines the location of the automobile and displays that location on the monitor. The display is refreshed as the automobile proceeds to its destination.

A map feature for the proposed wheelchair could be implemented using the same basic design. A map of the building stored internally would consist of the various distances and directions involved in travelling from one place to another. The current location of the wheelchair could be determined through sensing devices placed intermittently in the halls. For example, radio transmitters broadcasting unique frequencies might be placed in the corridors, allowing the chair to determine its location. From this information, the map could be used in determining the proper route to the destination. Personalized information concerning each wheelchair user could be stored on cassette tape to allow the wheelchair to be used by more than one person. Vital information might include the individual's room location, doctor's office, and gender (to determine which restroom was appropriate).

4.6 Conclusions.

This chapter has presented preliminary design criteria for an autonomous wheelchair. Navigational and safety problems associated with wheelchair usage have been addressed and potential solutions have been offered. The criteria presented in this document have been purposely open-ended to allow for further technology advances which may be incorporated in the final design. It can not be overly stressed that rehabilitation experts as well as the potential users themselves be consulted during each step of the design. Surveys should also be conducted to determine the potential market for the wheelchair and whether sufficient financing can be obtained for its purchase. Finally, it is highly recommended that the design specifications comply with the Veterans Administration's standards for procured wheelchairs and the FDA standards, once they are adopted.

CHAPTER 5

CONCLUSION

5.1 Deficiencies.

In spite of the recent progress in technological aids for the handicapped, there are many problems yet to be solved. Among them are the relatively high cost of equipment which is intended for a society largely unemployed, a general lack of knowledge concerning the availability and dissemination of said products, and the absence of human engineering in the design.

5.1.1 Acquisition.

The acquisition of technical aids by the disabled can be beset with many problems. Although the price of computing facilities has dropped substantially in recent years, the cost of adaptive equipment for the handicapped can still be quite high due to the small consumer market. Many disabled persons are either unemployed or have low paying jobs and can not afford expensive equipment. In many cases, third party reimbursers, such as Medicare or Medicaid, are charged with the responsibility of financially aiding the purchase of such equipment, but this can turn into a nightmare of red tape. Several third party reimbursers will only pay for the least cost aid which is medically necessary and will not accept copayments by the disabled individual [SHEP84]. Often, even finding the correct agency to contact can be difficult. The Office of Technology Assessment has published a case study on health technology. The following paragraph, cited from this study, refers specifically to the obstacles faced by speech impaired individuals in obtaining financial assistance, but could easily apply to most disabled persons.

> Tbere is an old axiom in medicine that when there are many different treatments for the same disorder the likelihood is that none of them works very well. From tbe perspective of the severely pbysically disabled nonvocal person, tbe same principle applies in finding a payment mecbanism for tbe assistive communication device that will meet his needs: The many potential sources for funding disguise the reality tbat reimbursement can be very difficult and sometimes impossible to obtain. Because no single agency in government or the private sector is specifically autborized to assist this population, all tend to say it is not tbeir responsibility and try to sbift that responsibility elsewbere [OTA83].

Also contributing to the expense of computer aids, is the high cost of research and development. Frequently these projects are funded by the government or agencies from tbe private sector. However, many devices which have been separately funded still sell at tbe same approximate cost as similar devices offered by different manufacturers with no cost savings passed on to the consumer [PFRO85].

One of tbe most promising outlooks for the development of aids appears to be tbe practice of technology transfer. As with all types of information, tecbnology can be passed from one type of application to another. In the case of the handicapped, the utilization of existing technology may belp to reduce the cost of research. For instance, a fully implantable, programmable insulin pump for diabetics was recently developed using NASA's tecbnology for the Mars Viking space probe to release culture medium onto that planet's soil [EDMU87].

If tecbnology developed for tbe disabled could also be utilized by tbe general population, the cost of resulting aids could be reduced significantly. For example, a tracking device has been developed which could assist the families of victims of Alzheimer's disease to keep informed of their loved one's whereabouts. The device is worn on tbe wrist, mucb like an ordinary wristwatch, and generates signals wbicb can be detected by special tracking equipment. If an Alzheimer's sufferer sbould wander from home, he could be located through the use of this device. Utilization of tbe aid could relieve tbe minds of many families, but the equipment is much too expensive to be put into limited use. Sadly, it will not be until the general population begins to use this device for keeping track of their pets that the price will be reduced sufficiently to be of use to the disabled.

5.1.2 Human Engineering.

With all the fervor over the benefits of computer aids, it is important to remain realistic about their advantages. Aids can only do just that - aid the user in overcoming bis handicaps. There is not a device in existence today which will completely restore a function lost due to a severe impairment, and there is not likely to be in the near future. Utilization of a speech syntbesizer does not mean that a person can talk and it does not serve anyone's best interest to pretend otherwise [BRAD84].

Most important in tbe design of technological aids is tbe buman engineering factor. So often, in large conferences and conventions, handicapped people are strictly for appearance only. It is so easy to listen to them speak, admire their courage and come away toucbed by their accomplisbments. But very little enligbtment and understanding has taken place [GALL80]. It is too easy for engineers to begin tbe design of an aid witbout fully realizing the actual need of the disabled. For example, no one would design an aid which utilized a warning light for the blind user. However, how many engineers, when designing a portable aid for the blind would stop to realize tbat tbe blind individual essentially has only one band? The implication bere is that the blind person will almost always have one hand occupied by a long cane or a guide dog, so that any aid which must be carried in both hands is virtually useless to him [GLAS80].

Although there has seemingly been great progress made in the development of aids for the handicapped, relatively few disabled persons have profited by it. Consider the following:

- Fewer than 0.3% of the more than 500,000 people with speech impairments use any type of auxiliary aid for communication,
- Fewer than one hundred automatic page readers have been placed in libraries for use by the blind, and
- Fewer than two thousand disabled persons customarily use telecommunications networks for the purpose of message or information exchange [TRIM85].

These figures indicate that a very small percentage of the handicapped population is actually benefiting from computer technology. It is important to understand the causes of this under-utilization in order to resolve the associated problems and enable the handicapped to enjoy the services available to them. Several of the more apparent reasons include problems inherent to the handicapped population such as low income, third party reimbursement and small consumer market. But it is commonly felt that the problems go much deeper than this. Many handicapped individuals seem skeptical of the computer's usefulness in everyday life. If this is the case, then it is evident that the systems available today have not been designed to satisfy the demands of the disabled population. This implies that rehabilitation engineers must place more significance on understanding the needs of the disabled and applying the technology to appropriately solve them [TRIM85]. For as E. L. Glaser has pointed out "Of what benefit is all that power, all that capability, when the one who needs it the most is denied it through a thoughtless or incompetent design? [GLAS80]"

5.2 Summary.

The purpose of this document has been to inform the reader of the great progress which has been made in the area of computer aids for the handicapped. The advent of the microprocessor has reduced the size and expense of computing facilities effectuating a rise in the development of technological aids. Many disabled individuals may witness a reduction of handicap and consequently increased independence due to the availability of technical aids. Devices are currently in development to not only reduce the handicap of disabled persons but also to restore the impaired function using applied neural control.

This document has also presented a study of wheelchairs. A description of the evolution of wheelchairs was included along with a discussion of the problems resulting in the lack of innovation in wheelchair design. The purpose of this study was to establish the background for the design of an autonomous wheelchair.

In spite of the recent progress in advanced technological aids, there is still much work left to be done. By encouraging more disabled persons to directly contribute to the design and development of aids, problems with human engineering will be reduced significantly. The practice of technology transfer must be exploited to the full extent, and aids should be designed to incorporate further advancements in technology. This is essential for continuing the progress in computer aids for the handicapped. For as C. Emerson has reminded us, "... we should remember that the disabled are the only minority group anyone can join [BURN85]."

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APPENDIX

GLOSSARY OF TERMS

ALS Amyotrophic Lateral Sclerosis, A syndrome marked by muscular weakness and atrophy with spasticity due to degeneration of motor neurons of spinal cord, medulla, and cortex. Commonly known as Lou Gehrig's disease.

Alzheimer's disease Presenile dementia, wbicb is similar to senile dementia but occurs in tbe 40 - 60 year age group. The disease has a relentless and irreversible course but may take from a few montbs to four or five years to go to the stage of complete helplessness.

athetoid Affected witb athetosis.

athetosis A condition wherein tbere are slow, irregular, twisting, snakelike muscular movements seen mostly in tbe upper extremities, especially in the bands and fingers.

atrophic Pertaining to or marked by atropby.

atrophied Wasted. Afflicted witb atropby.

atrophy Decrease in size or wasting away of a body part or tissue.

braille A system of writing for the blind that uses characters made up of raised dots.

cachectic Affected by cacbexia.

cachexia General pbysical wasting and malnutrition usually associated with chronic disease.

closed loop An automatic control system for an operation or process in which feedback in a closed patb or group of paths acts to maintain output at a desired level.

cochlea A winding cone-sbaped tube forming a portion of tbe inner ear. It contains the organ of Corti, tbe receptor for bearing.

cortex An outer layer of an organ or part, as of the kidney.

cutaneous Of, pertaining to, or affecting tbe skin.

DTMF signals Dual Tone Multiple Frequency signals - Toucb Tone signals.

dearth An inadequate supply.

disability Any restriction or lack of ability (resulting from an impairment) in performing an activity in the manner or within the range considered normal for a buman being.

electrode A collector or emitter of electric charge or electric-charge carriers, as in a semiconducting device.

fasciculation Muscular twitching involving contiguous groups of muscle fibers.

FNS Functional Neuromuscular Stimulation - The practice of electrically exciting muscles to restore some use to limbs paralyzed due to nerve damage.

gout Metabolic disease marked by acute arthritis and inflammation of the joints. Joints affected may be at any location but gout usually begins in the knee or foot.

handicap A disadvantage for a given individual, resulting from an impairment or disability, that limits or prevents the fulfillment of a role that is normal for that individual.

impairment Any loss or abnormality of psychological, physiological or anatomical structure or function.

infrastructure The underlying foundation or basic framework.

lesion An abnormal change in structure of an organ or part due to injury or disease.

myoelectric Pertaining to electrical properties of the muscles.

neural Of, relating to, or affecting a nerve or the nervous system.

neuromuscular Concerning both nerves and muscles.

orthosis The straightening or correction of a deformity or disability.

open loop A control system for an operation or process in which there is no self-correcting action as there is in a closed loop.

paraplegia Paralysis of lower portion of the body and of both legs.

pedometer An instrument that records the distance a walker covers by responding to his body motion at each step.

percutaneous Passed, done, or effected through or by means of the skin.

phosphene A luminous impression due to excitation of the retina or visual cortex.

pressure sore A sore cause by pressure from a splint or other appliance, or from the body itself when it has remained immobile for extended periods of time.

prosthesis Replacement of a missing part by an artificial substitute.

quadriplegia Paralysis affecting all four limbs.

scoliosis Lateral curvature of the spine. Usually consists of two curves, the original one and a compensatory curve in the opposite direction.

spasticity Hypertension of muscles causing stiff and awkward movements: the result of upper motor neuron lesion.

transcutaneous Passing or entering through the skin (as in an inoculation).

transducer A device that is actuated by power from one system and supplies power usually in another form to a second system.

tactile Of or relating to the sense of touch.

ADVANCED TECHNOLOGICAL AIDS FOR THE HANDICAPPED

by

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AN ABSTRACT OF A MASTER'S REPORT

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There is a significant number of bandicapped individuals in society today, and their number is ever increasing. Included in this number are tbose who suffer from motor disabilities, blindness, deafness, and speech impairment. These disabilities may be caused by congenital defects, accidents, war, degenerative nerve and muscle diseases and numerous other reasons. The computer has long been considered a potential aid for the bandicapped, but it was not until tbe advent of tbe microprocessor that it bas become inexpensive and compact enough to be of any practical value.

This paper establishes the need for advanced technological aids for the handicapped. An overview of the state-of-the-art in these aids is presented, making a distinction between aids which reduce the handicap and those whicb replace tbe impaired function using tecbnological methods. The paper also presents a study of wheelchairs, both manual and automated, and concludes with tbe design criteria for an autonomous wheelchair. It is proposed in this design to utilize available technologies which represent low cost, reliable solutions in order to provide the most sophistication and capability at the minimum cost.