Facial Feature Interfaced Cybernetic Experiments

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Abstract

Our submission presents a number of our projects and experiments. Projects and subjects covered relate to: facial feature control and experiments; human and robotic interface; mechanical and electronic design perimeters; safety attributes; risks and benefits. The final summary is from the human perspective, expressing the urgent need for the accessibility of adaptive technologies.

1. Facial Feature Control Basic Concept

Each person regardless of the severity of paralysis or amputation has certain reactionary points, such as eyebrow and nostril movement, which can be used as substitute output data points. They also have applicable sensory points that can be acted upon and regarded as inputs. Through adaptation, the reactionary points can be given a code that can, with practice, control many functions, modes, or provide accurate sensory feedback. Robotics can thereby return voluntary actions and supply the equivalent of artificial involuntary actions.

In our experiments, the basic function is therefore to operate as a basic assistant "brain" (artificial autonomic system) and robotic implementation. This strategy relates well to facial feature control and can afford people who are paralyzed the opportunity of regaining an additional degree of independence.

In each of our early robotic wheelchair experiments the functional modes were hardwired logic consisting of digital logic and simple diode matrixes (Figure 1). For simplicity the feature control input and output attributes were divided into easy to remember methodologies. The control aspect of this is to associate the right and left side of the body with different types of actions. This has been done by relating the patient's features on the left side of the body with regressive movements, such as down, counter clockwise and reverse. In turn the right side is associated with up, clockwise and forward actions. Additional feature control outputs such as nostril movement relate to enabling selection choices such as picking the degrees of freedom for a robot arm and quick access to subroutines. Subroutines can be for additional arms, wheels, remote controls or any other type of mechanical or electronic device that has I/O attributes.

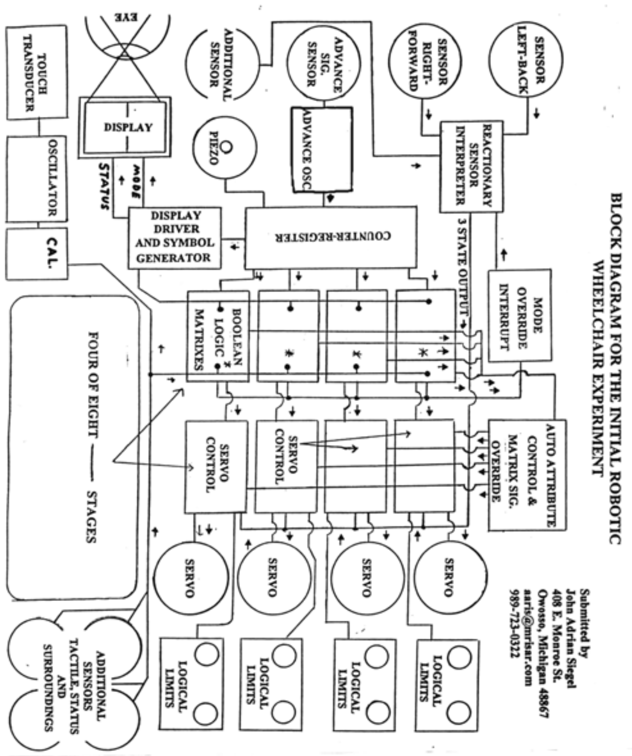

Figure 1: *Block diagram; basic facial feature wheelchair*

2. Applications

A successful development of a cybernetic - robotic device is gauged by it's ability to relate to the surroundings and user. It is also dependent on its endurance and adaptability to certain tasks. Such devices need to directly coexist with a human being as if they are a natural extension of their mind and body. Research has already proven that the psychological and physical relationship between our senses and the world, relates to our learning process and concept of identity. From this vantage, being deprived of sensory input, output and the ability to interact with a persons surroundings, can be damaging to the mental state and to the brains active functional efficiency. Fortunately experiments have also proven that the human brain is extremely adaptable to alternative sensory interface and has a number of self-correcting attributes that aid recovery. Often therapy involves a level of mind reprogramming that is directly related to the stimulation of the effected areas. A rehabilitation robotics-cybernetic technology that is mechanically linked to move limbs, can extend into these areas by providing the patient the opportunity to perform their own therapy, at their own pace, without waiting for assistance.

Rehabilitation robotics-cybernetics affords the ability to combine elements of adaptability through electronics, with a mechanical means of relating to the real world. Mechanical designs involve critical decisions as they provide necessary support for the robot and the expected loads. In some cases they also provide additional support for the patient's inanimate weight, subject to the factors of joint pliability, muscle elasticity and tremors, if present.

2.1 Safety

Degrees of freedom must heed to human parameters as close as possible. Safety limits should be associated with these factors by providing mechanical limitation, when possible, along with logical programmed limiting factors. Logical limit parameters are extremely important for movements that relate to adjoining degrees of freedom (Figure 2). As illustrated, the mobility of the degrees of freedom for a specific joint can be adversely affected by other degrees of freedom in a specific limb. Unlike most mechanical devices, the human body exhibits a number of these interacted movement deficiencies. The illustration shows the approximate difference between clockwise and counterclockwise pivot capability of an arm at the shoulder, subject to the elbow being bent at a ninety degree angle. The other section of the illustration shows the same shoulder pivot as measured with the arm stretched out straight on the horizontal plane. Measurements for this estimation were taken from an individual's arm as the theoretical model. The drastic difference in the specific pivot range of the shoulder joint, illustrates wide variances. In the case of this example, a limit that is not adaptable and is only set for the straight arm limits, would over travel the patient's arm in a bent position, causing injury. Accordingly, measurements of each related joint should be done with the understanding that an individual's measurements can vary. We can sometimes engineer things that surpass nature's dexterity if not it's agility. The difference between nature's design principles and man's, will close rapidly in many ways in the near future as advancements are made in such technologies as electro active polymers [2].

2.2 Mechanical verses Psychological Impact

The human element creates additional design considerations. The psychological factor suggests human appearance. From a mechanical vantage point, we often tend to extend our leverage and other force parameters beyond human dimensional constraints to compensate for mechanical stresses, which can result in a bulky appearance. In the case of exoskeleton designs, this challenge presents itself when designers are faced with triangulated force parameters that must work in spite of the fragile human form they support at various levels of limb extension.

Great care must be employed to prevent chaffing and binding as well. Perspiration buildup and insulation properties of an exoskeleton design can also cause other dermatology stresses on the tissues. If enough motion and air travel is provided by the movement of an exoskeleton device, moister buildup and continuous pressure on any area will be alleviated, reducing the instances of dermatological stress. Exoskeleton devices must be strong and light weight. The designs must be governed by the understanding of the center of each pivot point and be matched to the robotic implementation. Incorrect designs will foreshorten or elongate, relative to the limb they move, and produce slop, or worse, restrictive pressure. Joints often have the center pivot point of their movement off to one side, or at a dissimilar slant to the next corresponding degree of freedom. We have considered the use of arm or leg socks to provide a slick barrier against friction in an exoskeleton design. With care, exoskeleton devices have the potential of operating with relative safety.

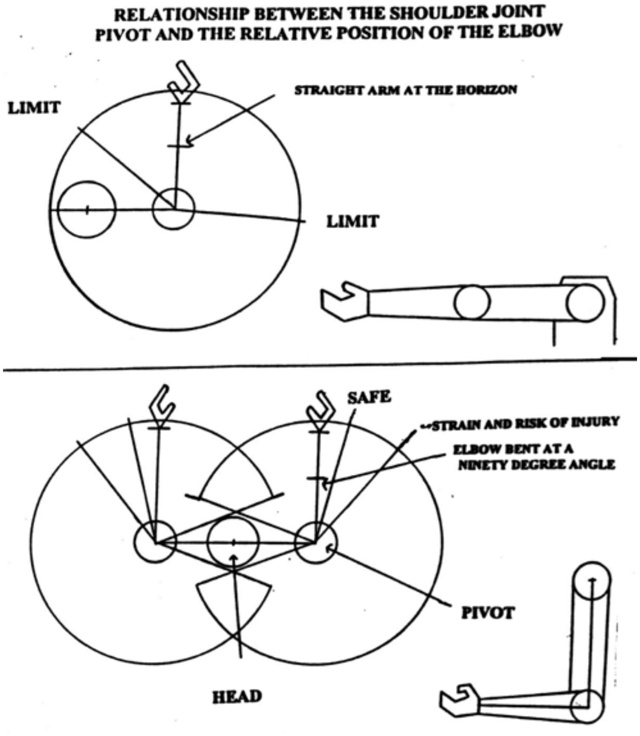

Figure 2: *Shoulder horizontal movement relative to elbow.*

Many decisions must also be made regarding the sensors and movements. How much of a human being's reactions can be successfully automated without interfering with natural free choices or behavior? The design of a full support device for quadriplegics involves intensive consideration of this factor. Ultimately a successful design balances the physiological, philosophical and psychological aspects.

3. Experiments and Designs

My first robotic wheelchair prototype is block diagrammed (Figure 1). The diagram shows only four of the servo and matrix stages. The original device (Figure 3) incorporated two dual state logic circuits for each facial feature sensor connected to a three state control system that directly controlled the servos with simple transistors and relays. The counter-register operated off a third facial feature sensor that selectively enabled and disabled each servo control option. The limits and touch sensors operated independently at each point of reference and were directly mounted to their perspective degrees of freedom. The counter-register simultaneously controlled a mode select display with visual indicators and an audible end of mode choice signal. Each selected degree of freedom or special function is offered as a choice, and if selected awaits the prompting of the patient to execute a specific action. The design was created to allow the system to be extremely cost effective and to be adaptable. The basis for the preliminary experiment is the sketch (Figure 4). One of the important key design features of the device, in spite of its simplicity, is that it formed a collective computer. The properties of each attribute are independently operable, subject to the enable and disable signal to each. Certain attributes also operate automatically without human interaction.

The first cybernetic wheel chair was created on an extremely low material budget of $275.00 US. Developing a project on a low budget have at times led to innovative and cost effective ideas. Although we have designed a more advanced version of the first robotic/cybernetic wheelchair prototype, the primitive experiment was informative and faster to build. During it's testing, I limited my mobility to simulate paralysis. The test inspired me to quickly find the flaws, and to design a vastly improved device. The preliminary experiment used it's three facial movement sensors to utilizes fourteen functions, that controlled a five degrees of freedom robot arm and a mobile wheelchair base, while relating it's status through the visual indicator console. This design was easy to control and allowed some basic multitasking. It maneuvers around a room in any direction, can pick up and move objects on tables, and allows the user to print or draw on a vertical surface with primitive strokes.

The design of the next prototype was an exoskeleton version, based on the same concept, but featuring a number of additional attributes. This design is still being refined. The exoskeleton design redefines the overall concept by reconfiguring the unit to appear to fit like the wearing of armor without the drive components being directly visible. As illustrated in (Figure 5), this design reduces the bulky look associated with such concepts by housing the main servomechanisms under the seat. Each degree of freedom has both mechanical and electronic limits whenever possible with a backup device to insure that hazardous over travel in any given degree of freedom does not occur. The sensor system is self calibrating and is designed to avoid being overly conspicuous. A number of types of sensors have been designed in our workshops regarding facial feature recognition. Some are simple linear devices and others are opto electric devices. The commonality between them is that they track the movements of facial features that are easy to monitor by measuring the specific movements of the features. Movement over a predetermined measurement limit, is considered a logic state signal. What the signal is determined as, is predefined by the units specific setup. In general, features in a relaxed state are considered as an *off*, or *logic zero* signal, and features that are in a tense state are considered a *logic one*, or an *on* signal. The measurement technique can be as simple as a roller or opto electric device, or as advanced as a device that optically reads the position by tracking the texture of the skin.

Figure 3: *Our first feature controlled robotic wheelchair.*

The design also experimented with pulsed signal artificial touch. Pulsed signal pressure can yield a sense of touch. Although the pulsed signal is little more than a buzzing sensation on the skin, it is still better than no sense of touch at all. Our experimental pulsed signal transducer consists of a basic 555 timer IC as an oscillator that is connected to a small switching transistor that powers an electromagnetic coil and movable steel vibration plate measuring approx. 3/8" square. Ideally the electromagnetic coil (transducer) would be replaced with a more eloquent technology such as piezo electric devices consisting of electroactive polymers [1]. A number of interesting experiments regarding such materials have been done. Pulsed signals are easily identified, because they generate a perceivable phase pattern, which readily converts into electrical variances in the nerve pathways. Peltier junctions can also be added to this concept to allow a sense of hot and cold.

In each design, another challenge in configuration is the inability of a patient to easily convey enough motion request data to the artificial system at an adequate speed for fluid movement and quick action to occur. To accommodate this problem, modes of operation are designed to take care of known factors of movement relating to the surrounding environment. Another accommodating factor is to place the interface sensors on areas of a patient that are capable of fairly rapid, repetitive movement, such as the eyebrow, jaw and nose, or other areas, depending on what is available. Fluidity of movement is a consideration as well. If even two of the patient's pivoting motions are still intact they can be utilized for fine movement in dexterous actions such as writing. It is entirely possible to create simple robotic devices that through interface afford the opportunity of doing such things as skilled drawing and writing by using the patient's neck muscles or other areas that have fine movements. I have incorporated this option into some of our current experiments. My first experimental chair deliberately did not take advantage of the fine motion option as it was designed to present the feasibility of a link to the most severely paralyzed, by using the eyebrow and jaw movement. Almost any configuration is possible providing it is based on the specific patient's ability. In cases were tremors are present, the specific variance created by them can be measured and filtered out of the action desired. This can be done through basic electronic design or through the utilization of advanced design principles.

One version of our project is STRAC, (Symbiotic Terrain Robotic Assist Chair). So far STRAC has cost only $831.00 US in materials to build and formed the basis for the development of an exoskeleton device with an all terrain base (Figure 7). Budget has been a major consideration in all of our experiments. It's servos are basic DC pm field gear motors and it's electronics are digitally based logic comprised of basic CMOS, TTL and Linear components. Limit controls and custom made Mosfet servo controllers act as part of it's "collective computer" which is hardwired through the device. All the custom mechanical, structural and electronic boards and assemblies were made in our workshop. As shown in (Figure 6) a variety of interface designs and feature control output points were considered. Most of them can be made discreet through skin colored plastic or covered by a hat.

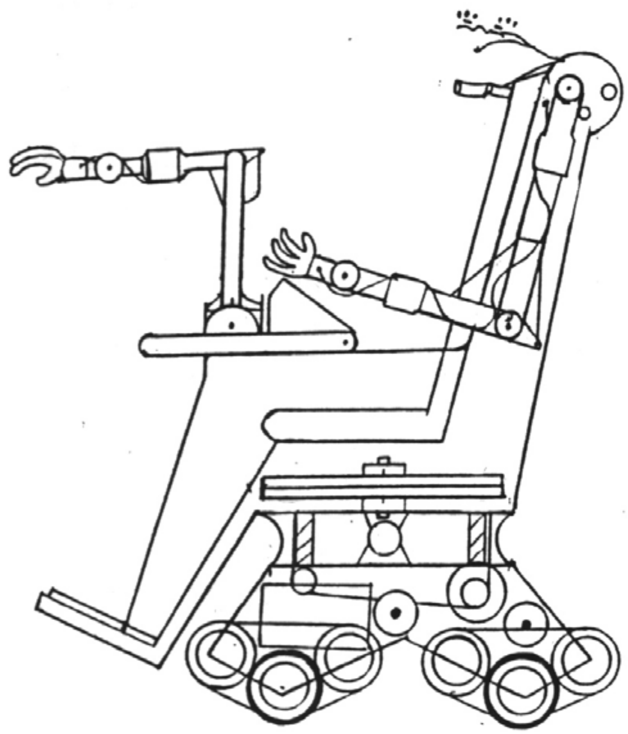

Figure 4: *Preliminary sketch, feature control wheelchair.*

So far our facial feature sensors have been largely mechanical devices, the most basic of which was a simple caliper with a limit switch mounted to it to measure jaw muscle flexing and flap like devices that were hooked onto limits for eyebrow movements. The next progression was to design a rocking type of switch that measured nostril movement and a roller type device that measures skin movement at the eyebrows. Optical designs have also been experimented with as well, but to a much lesser degree. The main factor with each has been to design the device so that it discounts slight movements and only responds to intentional movements. Since a device that reads off of a person's face is in effect on a moving formation the only answer was to make each device so that it recalibrates it's self every time the patient relaxes the specific facial muscle, otherwise misalignments would render it useless within a number of tries due to the shifting that would occur. Such an occurrence plagued the first experiment regardless of the promising results. Further improvements helped debug such effects. The navigation portion of STRAC incorporates an electronic compass, sodar detectors, tilt sensors and adaptable logic to direct the device around objects and control the inclination of it's front and back wheels, which are independently pivoted, relative to the center of balance for the device. The actual prototype is shown in (Figure 7). The artificial hands act as extensions and pivot further than real hands. They feature force feedback touch sensors that impede the signal as pulses to a sensitive area of skin. STRAC uses a miniature readout and lens to focus the image of the selected command directly onto the retina. This enables the display to remain in focus while the patient simultaneously views their surroundings. Another development for STRAC is the use of a virtual link to the chair for remote location use. STRAC has sixteen servos that move it's arms and independently power it's triangular wheels. Each front facing triangular wheel is equivalent to a fifty five inch diameter wheel in spite of taking up only eight inches of height. Naturally the design is only as effective as the quality of the treads. Modifications are currently being made to make all the individual wheels in the triangular design track the surface more effectively. Another hybrid design is being created that combines the design of a basic wheel with the climbing capability of the tread design. The servos that operate the wheels in the STRAC design work in unison, changing their speed in accordance to the inclination of a turn. The goal of the final work on STRAC is to perfect the design and reduce it's weight by approximately half, while increasing it's mobility.

4. Bringing Our Experiments To Market

During the course of experimenting with adaptive technology a great amount of time, effort and other general resources can be used. While this is an expectable part of the creative and critical thinking process, this often can lead to a long timeline between first tests and marketing. For our project the solution to this has been realized in the form of a new, smaller scale series of devices that do simple tasks without theoretical risk. Pictured in (Figure 8) a simple activity center is shown. This center uses eyebrow and nostril movement to move small objects. Other activity centers will draw and print with a similar use of technology. Our current plan is to market a series of these devices as a safe low cost introduction to the technology while we continue to work on the more substantial projects.

5. Technological Responsibility

Relating to the needs of the disabled requires balancing our humanity with our interest in technology. At the age of five our daughter suffered a stroke and was paralyzed on the left side of her body. Although by extreme will power and determination she regained 98% of her mobility, we initially experienced the challenges and grief that such catastrophic changes in mobility and health create, not just for the patient, but for their entire family. Such experiences sometimes led us to reach beyond our own limitations in the process of discovery. The future of the disabled can be more productive and fulfilling providing people with technical expertise apply themselves in this area with creative determination. Many organizations share this ideal and are representatives of the technology. For more information we suggest consulting the proceedings of "ICORR" who hosts regular international conferences [2] and "CWUAAT" incorporated with the Cambridge Workshop on Assistive Technologies [3] (both of which have published some of our research). ICORR and CWUAAT focus on technologies such as robotics and computer technology that are currently being developed for the disabled.

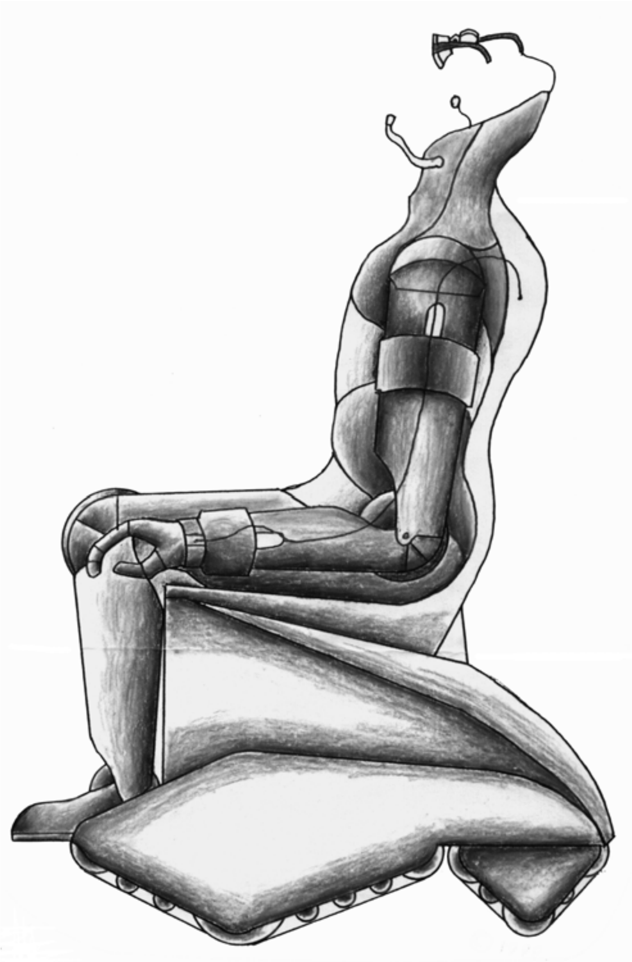

Figure 5: *Concept drawing STRAC robotic wheelchair.*

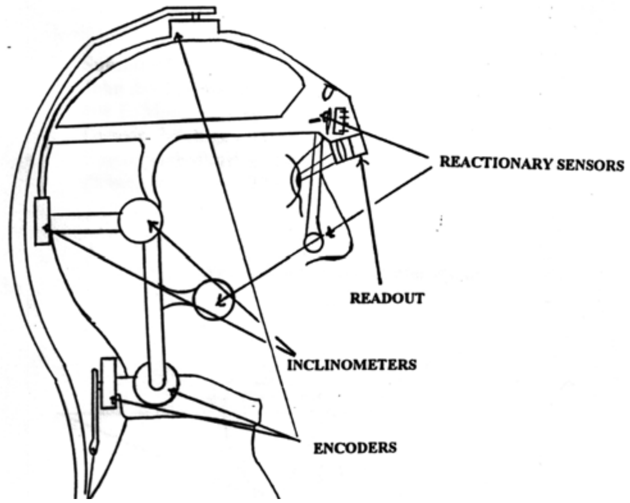

Figure 6: *Feature & gesture control design. Feedback provided by a readout and lens above the left eye.*


Figure 7: *Adult sized STRAC prototype with our daughter Autumn, (who inspired the project)t seated in it.*

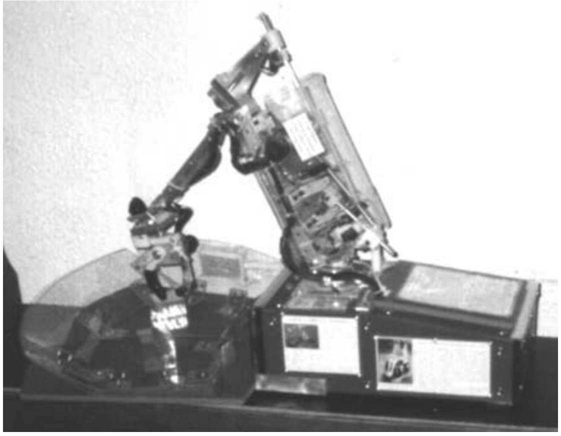
Figure 8: *Facial feature controlled robot arm activity center moves simple objects in response to eyebrow and nostril movement.*

5. References

[1] NASA Jet Propulsion Laboratory, Pasadena, California = "Electroactive Polymer Grippers" http://ndeaa.jpl.nasa.gov/

[2] International Conference On Rehabilitation Robotics = http://rehabrobotics.org/icorr1999/attendees/ ICORR presents conferences and proceeding pertaining to a wide variety of adaptive technologies.

[3] Cambridge Workshop on Universal Access and Assistive Technology; http://rehab-www.eng.cam.ac.uk/cwuaat/ CWUAAT, incorporates the Cambridge Workshop on Assistive Technologies in a conference and proceeding that relates current adaptive technology experiments and devices.