THE CURRENT STATUS OF AND FUTURE CONSIDERATIONS FOR ENVIRONMENTAL CONTROL SYSTEMS

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INTRODUCTION

This paper deals with the new environmental control systems for high level (C-3, C-4, C-5) quadriplegics. These systems are dynamic because the field is new and one can only begin to envision their potential. Through simple and easy-to-use actuators, the spinal-cord-injured patient can dramatically acquire an effective level of independence.

Included in this paper is a generalized description of an environmental control system; specific systems are later studied within the framework of a generalized system. The last section includes suggestions for further development and improvement of capable environmental control systems.

ELEMENTS OF AN ENVIRONMENTAL CONTROL SYSTEM

An environmental control system is an electronic system which accepts a voluntary action within the patient's realm of activities as input and converts it into the operation of some device. Figure 1 breaks down an environmental control system into its component parts.

The transduction element is the crucial element of the system that converts the patient's response into an alteration of the condition of an electric circuit, resulting in the generation of an electric signal. Examples of transduction elements are: minimal force-actuating touch switches (microswitches) for hand or tongue control; air switches for breath control; sound sensors sensitive to a narrow range of frequencies for voice control, such as whistling at a certain pitch; light sensors for eye control (a light source and a sensor can be positioned on a pair of glasses so that the source points its beam and the sensor picks up reflected light from the corner of the eye. When the pupil moves to the specific corner of the eye, the reflected light is greatly reduced, thus generating an alteration in the state of an electric circuit); and a myoelectric sensor utilizing the electrical potential generated by the stimulation of a muscle along an intact nerve.

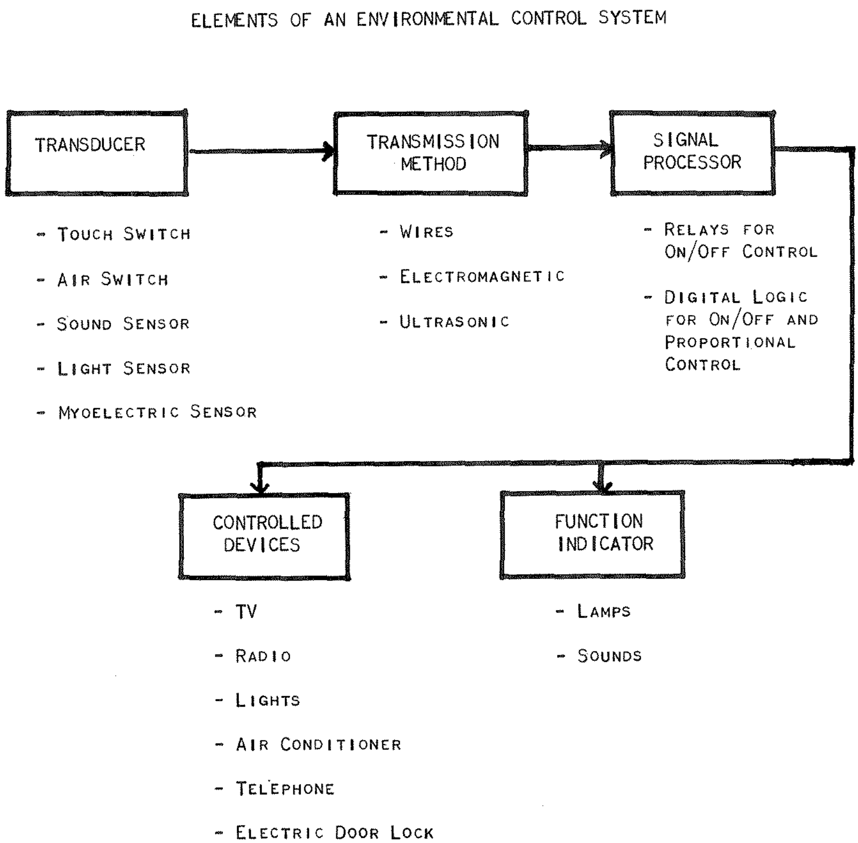


FIGURE 1

The next element of the total system is the transmission mechanism which sends the signal generated by the transducer to the signal controller. Most systems employ direct electrical connections as the simplest and cheapest technique. Other modes of transmission can be wireless, either through electromagnetic or ultrasonic energy. These latter methods increase an evironmental control system's potential.

The brain of an environmental control system, the signal processor, processes the signal from the transducer and places the system in a new desired state by operating a device or appliance. Depending on the capability of the system, the processor may range in complexity from a few relays to a sophisticated digital logic system. A simple processor can effect on/off control of a device, while a high-level unit can initiate proportional control as well. Examples of proportional control are the channel and volume controls on a TV or radio, and the height control on a bed.

The output elements are the devices controlled by the signal processor. Examples of these devices include: alarms or nurse calls, televisions, radios, electric door locks, special telephones, lights, air conditioning units, or any other electrical device.

Finally, an environmental control system needs a feedback element. The system must inform the user what state the system is in. The user must be aware of the result of his next encounter with the system. The most common indicator element is a set of lamps. Another form of feedback is an audio mechanism that generates a sound at a unique frequency for each function that the system performs.

EXISTING ENVIRONMENTAL CONTROL SYSTEMS

Now that a general description of environmental control systems has been given, a discussion follows of some of the current systems in use.

Figure 2 shows the Prentke-Romich Paratrol. The signal processor energizes or deenergizes four standard receptacles. The transducer can be either two types of touch switches or an air switch. By activating the transducer and maintaining it in the activated state, the processor sequentially cycles control capability to each of the four outlets. A bulb illuminates above each receptacle when the processor sequences to that receptacle. Releasing the transducer causes the processor to stop cycling and to change the state of the receptacle whose monitor bulb was

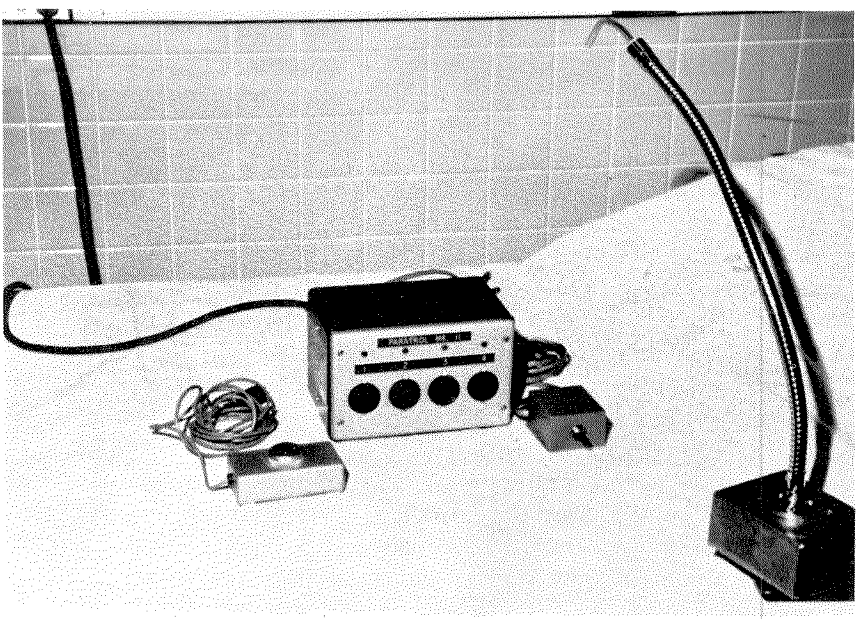


FIGURE 2

illuminated last. The state of a receptacle is maintained during the cycling stage and is not altered until the user releases the transducer at that receptacle. The cycling rate can be easily adjusted with a front panel knob to meet the needs of the user.

Some positive features of this system include the multiplicity of transducers available that enable the system to be used by various types of patients. The cycling speed can be adapted to the patient; in this way, the system need never be too fast or too slow for the patient. The system is small, light, simple to setup, easy to use, and easy to adjust; however, it has limited capability. Its cost is $180.

Figure 3 shows the Prentke-Romich automatic dialing telephone. This is not an environmental control system in the sense discussed, but the telephone has some features worth mentioning. The unit can either stand alone or be easily controlled by an environmental control system. Once the device is energized by hitting the left side of the rocker switch, the user can dial the phone by holding down the right side of the switch. The digits cycle from 1 to 0 at an adjustable rate. The user releases the switch when the desired digit is displayed on the screen. One version of this telephone has the advantage that in the event of a power failure, rechargeable batteries power the unit. Thus, the user can feel safe that his communication medium will remain operational for emergency use.

FIGURE 3

The next device, a typewriter controlled by a light source (Fig. 4), is also an assistive device rather than an environmental control system. The firm that makes this device also makes an environmental control system. Both units use the same name PILOT. The transducer is an example of a light-actuated device. The user wears the light source and shines it on the desired letter, behind which a photocell generates the necessary signal. The processor then types the letter. Once the unit is on, the user can control the speed at which letters are typed. There are three delay settings—maximum delay, minimum delay, and no delay—which determine the reaction speed of the processor to the new input. Thus, the user can learn the system at a slow typing speed and build up his speed with practice. The main disadvantage is that the transducer has poor cosmesis.

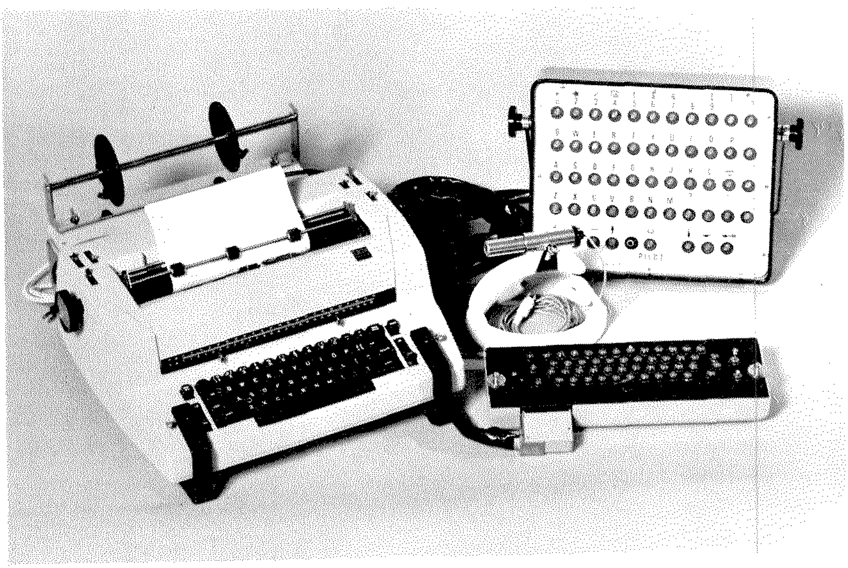


FIGURE 4

The SONOTROL system (Fig. 5) uses a controlled-sensitivity air switch as the transduction element. The processor can control 10 channels. The system starts selecting channels at an adjustable cycling rate when the processor perceives its first puff. A second puff stops the sequencing at a specific channel. If the sequencing stops at channels 1-5, power is supplied to an appliance. If channels 6-10 are chosen, the state of the appliance changes from either off-to-on or on-to-off. Each of channels 1-5 can be on only if the processor is controlling that channel. If channel 2 is activated and a puff causes the processor to start cycling, channel 2 will deactivate.

This system has been evaluated by patients at the Castle Point VA Hospital, and the response was not positive. The two types of logic can be confusing, thus limiting the value of channels 1-5. However, there is one feature of this system which has great potential. Figure 5 does not indicate this, but the processor activates devices by transmitting an ultrasonic signal to a receiver which is at the appliance site and is not connected to the processor. This supports the idea that the processor can be modularized to increase the capability of the system when desired. In addition, since the signal processor need not be a single package, the amount of hardware directly surrounding the user can be reduced. This system costs approximately $1,000.

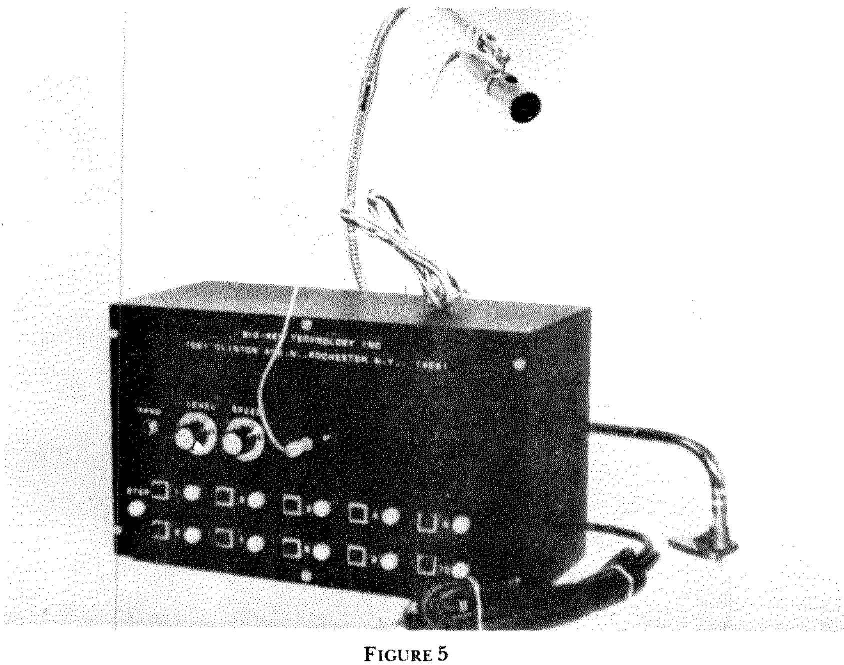


FIGURE 5

The POSSUM system (Fig. 6) is the oldest environmental control system. The transducer can be either an air switch or a microswitch. Continuous activation of the transducer causes the processor to cycle at a fixed rate through 12 channels. Deactivation of the transducer causes the cycling to stop and the state of the selected channel to change. An appliance is thus either energized or deenergized.

FIGURE 6

The final three systems employ processors which have proportional control features; the state of an energized device can be altered other than by just deenergizing the unit.

The first system is the Hayes Sight Switch Environmental Control System (Fig. 7). This is a 10-channel system. The transducer is not shown, but it is the special pair of glasses described earlier. This system requires two light source-sensor elements on the glasses. Movement to the upper left corner by the left eye causes the system to cycle to a sequential channel and to remain on that channel. Another movement cycles the system to the next channel. The right eye initiates the operation controlled by the selected channel. On/off control can be effected, or the system can control the volume and channel on a remote control TV, the height of an electric bed, and any other device that can be adapted to the system.

This system is definitely more powerful than the previous systems, but the method of transduction seems to be somewhat fatiguing. To raise an electric bed or change the TV volume, the right eye must remain in the corner until the desired state is reached. This can be uncomfortable for the user. Furthermore, the user must be careful where he looks so as not to unintentionally activate the system.

Hayes has an idea that should be evaluated, which involves a portable five-channel system built into an attaché case. A mobile system obviously need not restrict a patient to control of appliances in one room only; a user could take his control system to his job. Currently, Hayes is having some engineering problems with these systems.

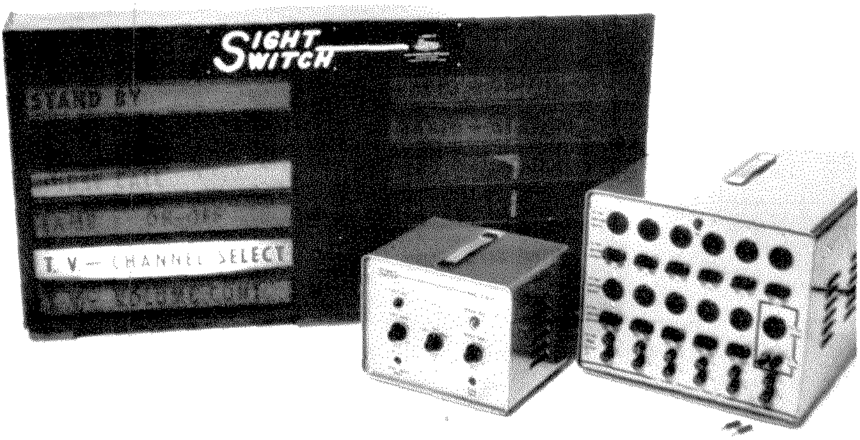


FIGURE 7

The VAPC Hospital System (Fig. 8 and 9) is a 12-channel system which uses a tube connected to two air switches as the transduction element. Sipping results in sequencing through the channels, while blowing alters the state of an appliance. A loaded VAPC system can control the volume and channels on a special radio, the channels on a remote-control TV, the height and the position of the head on a Simmons electric bed, a nurse call request, a special audio-visual emergency alarm. It also can supply power to four other devices. This system also includes up-down indicators for the radio channel and volume.

Unlike some of the other systems, the user does not have to maintain activation of the transducer to operate a proportional function. The user puffs to start a change and puffs when the desired final state has been reached. Each proportional function has three cyclic operational modes: down, off, and up. If, for example, the user wants to increase the radio volume, he puffs on his tube. The radio volume indicator may show a decrease in volume. A second puff would cease operation, and a third puff would result in increasing the volume.

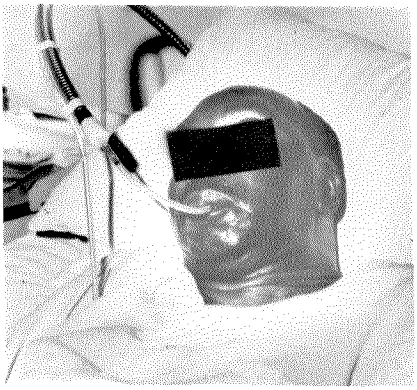


FIGURE 8

The VAPC system is a high-performance system. A communication device, a telephone, could be added to the system easily. One good feature is the box of push button switches which enables people other than the user to operate the system. The system is well-engineered, but the main components are electronic relays which cause unpleasant noise when they switch states. Another problem is that the user must remember to shut off the motors that operate the bed and the radio. If, for example, the bed is lowered to its lowest position, the user may forget the motor is still running and blow a bed circuit breaker. Limit switches on these functions would be a worthwhile addition. The cost in limited production is about $800.

The Bioengineering Research Service has gone a step further and designed a 20-channel system for home use (Fig. 10). With 20 channels, this system can perform more functions than any existing system. The major difference is that the processor has only two 115/volt outlets, 11 outlets (the majority) are low voltage outlets, and the balance are switching jacks for low voltages. However, these low voltage outlets can be used to energize and deenergize appliances. The key to the system is a module which plugs into the outlet formerly used by an appliance. The appliance plugs into the module which is controlled by a low voltage outlet. The object is that one does not need to run powerline cords all over a room; instead, low voltage wires can be used. Hence, the system design provides a great deal of safety from potential electrical hazards such as cracked insulation on a high voltage cable. The advantage of this design is its modularity. To meet the specific needs of each user, special external modules can be designed. However, the main body of the processor requires no alteration. Thus, the main body of the processor and a few types of common modules can be mass-produced at the lowest possible cost. Customers would then have the option of buying either a relatively

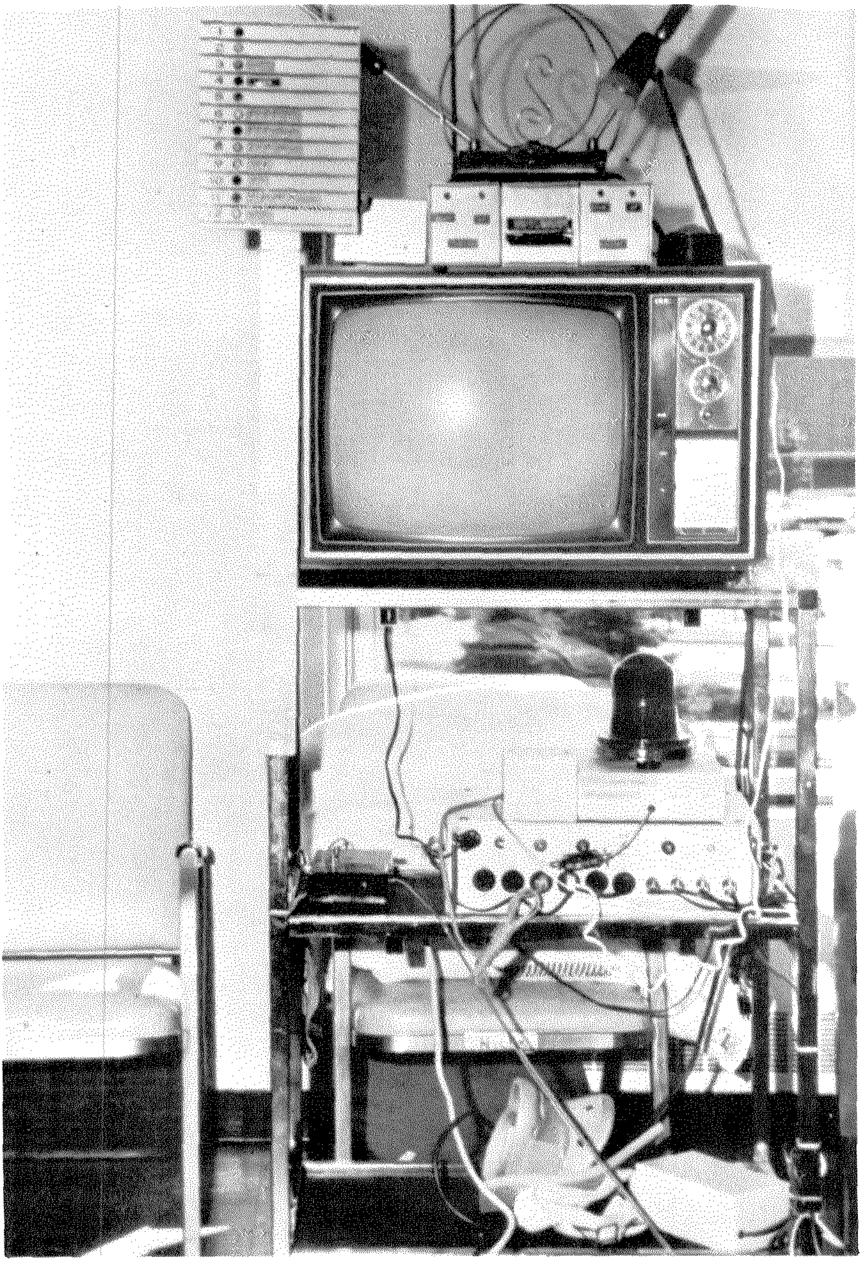


FIGURE 9

inexpensive standard system (the cost in limited production is about $1100) or a more expensive customized system.

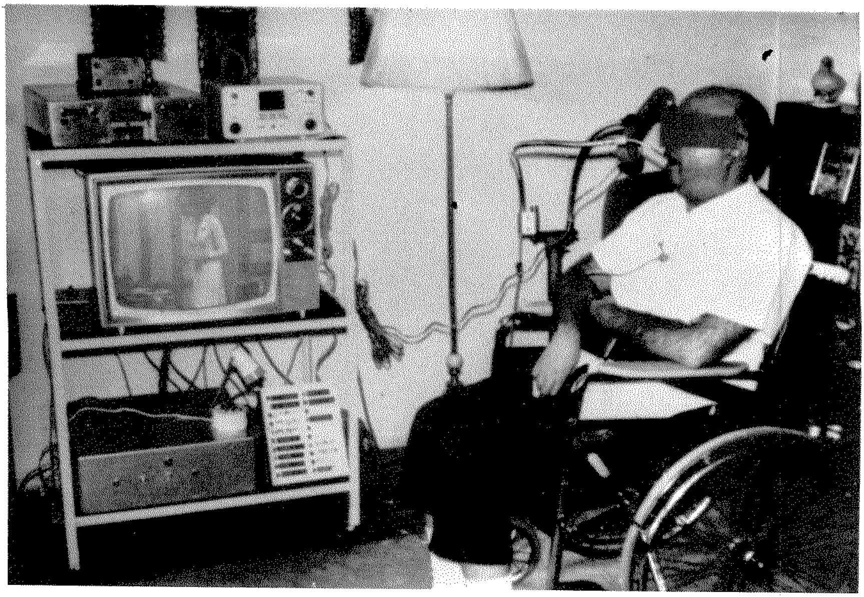


FIGURE 10

The third version of the VAPC environmental control system is the wireless system (Fig. 11). The air switch generates a signal which is transmitted to the main body of the processor via a transmitter. In this case, the transmitter is a garage door controller. The transducer and the transmitter are not tied to either the processor or any power source. The utility of this idea is that the patient can be anywhere in the room and be able to control his system, as long as he has his transmitter. As a result the user is given a greater degree of freedom. So far only a laboratory model has been built.

The final system is the Northwestern University Comfort and Communication System (Fig. 12). It is a well-designed, solid state control system capable of performing eight functions. The system employs air switches for pneumatic control. The user sips and puffs on a straw which in addition to being simpler and cheaper to use than plastic tubing, can be utilized because of the unique arrangement of the system. The monitor and the decoding portion of the processor are enclosed in the module above the patient. The module is attached to an adjustable arm which is mounted with a C-clamp.

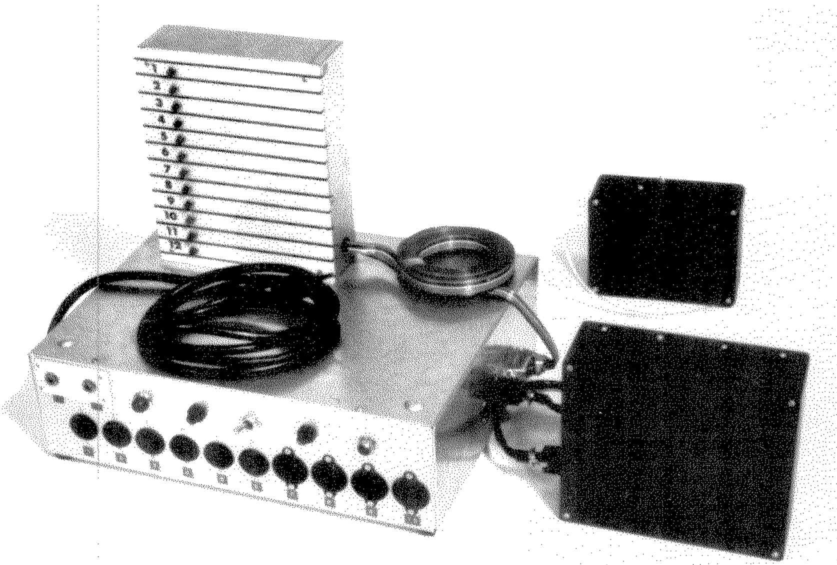
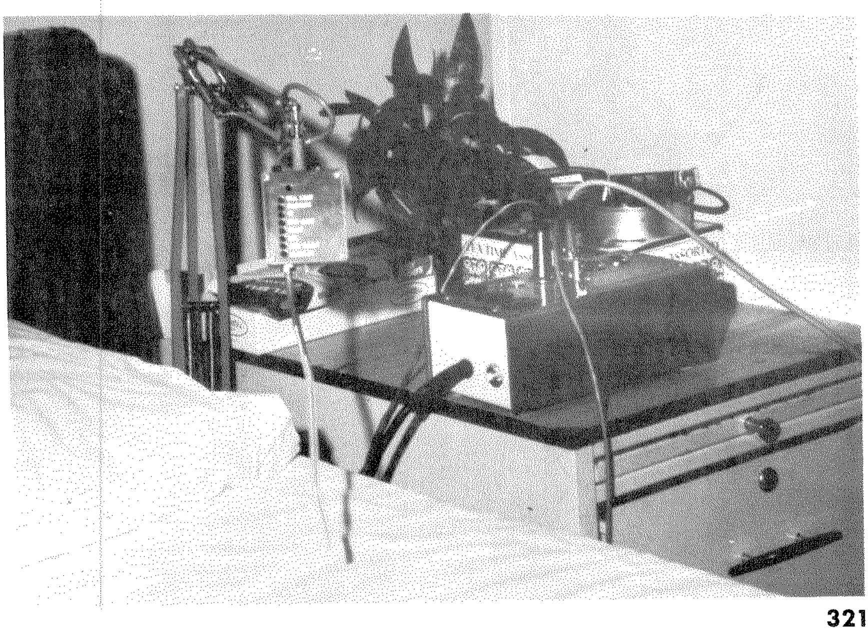


FIGURE 11



The system is operated with a control coding opposite to the VAPC system: puffing changes control functions and sipping operates devices. Three 115-volt outlets energize and deenergize appliances. The system performs five more functions: operation of a speaker phone, changing TV channels, operation of a nurse call system, height control of an electric bed, and operation of an electric page turner.

The major advantage of this system is its small size and low weight. It operates more quietly than the VAPC system's noisy relays. The miniature monitor near the user has merit. The monitor has an additional light which indicates whether the current function is "on" or "off." There are parallel pushbutton switches for use by an aide. Some of the disadvantages of this system are: the user can only dial the operator, suction must be maintained to raise or lower the bed, and the page turner function has not operated properly due to the poor quality of existing page turners. The estimated cost for this system is $700.

CONCLUSION

The systems that have been discussed are indicative of the current state of the art. Now it is necessary to decide whether the premises on which these systems were built generate systems that most optimally meet the needs of the quadriplegic. The answer is probably not. However, no one can really say for sure, because the performance of these systems is difficult to evaluate. The development from no control to the ability to operate a few devices is more than enough reason for a patient to proclaim the system a success. The problem is that the patient, the major source of information, is uneducated with respect to environmental control systems. Before he can provide useful information, he must experience a number of systems which include the unique features of some of the systems that have been discussed. Hence, a study that utilizes more experienced patients will have to be made to determine the optimal design parameters for an environmental control system.

The study should consist of exposing each person in a group of psychologically sound, intelligent volunteers to at least three or four different systems for a reasonable period of time, about 3 to 5 weeks. The user must evaluate each system immediately after completing his testing period with it. This evaluation should include a questionnaire specially designed to extract from the user the advantages and disadvantages of each system, and any additional functions that he feels environmental control systems might perform. After each subject has sampled all systems, he should compare the systems as a group. Finally,the subjects should be brought together to share their thoughts and to generate new suggestions and criticisms. The best results could be obtained if the study were conducted with subjects using the systems in their homes, but the logistics make the idea unfeasible.

To reiterate, the purpose of such a study would be not to find the most useful existing system but to determine what the most useful future system should entail. At Cleveland, we plan to attempt a small pilot study patterned after these thoughts. The VA spinal-cord-injury centers provide enough subjects and support personnel to generate statistically significant data; the VA Prosthetics Center might coordinate such a project. Educating a group of people by the process of experience and then acquiring their thoughts is the most direct method for determining the design parameters for the next generation of environmental control systems.

Although we do not yet have the feedback we would like from the users of these systems, the following are some suggestions that I would like to pose for consideration:

1. *Multiplicity of Transducer Inputs*

All environmental control systems should be capable of accepting a multiplicity of transducer types to meet the needs of as large a population as possible. Parallel pushbutton control to enable an aide or a member of the user's family to operate the system should be a standard convenience feature for all systems.

2. *Ease of Setup and Adjustment*

The system should be designed so that a nontechnical person can set it up and adjust it without the system incurring damage due to incorrect assembly. The more complicated the system is for the family to construct and operate, the less willing they will be to promote the use of the system. (Currently, this does not present a problem, because the setup process is a one-time experience and only a few of the systems have any adjustments at all.)

3. *An Operational Mode to Combat an Internal or External failure*

These systems should be designed with the capability of being operational in the event of an internal or external failure. All systems should have some type of battery-operated failure mode which controls a communication device, a telephone, or an alarm. For example, the Prentke-Romich telephone will operate with battery power in the event of a power failure. Thus, the user need never lose his power of communication and so he gains a greater degree of confidence in his system.

4. *Modular and Expandable*

The systems should be modular and expandable. The building-block approach lends itself to cheaper, more flexible systems. The needs of each user vary, and larger systems with greater capability are not necessarily the answer. We cannot yet say exactly how many channels an average system should contain.

5. *Minimal Size and Weight*

Minimal size and weight is desirable. The Northwestern system appears to be a good design goal.

6. *Electrical Safety*

The need for a safe design is obvious. Both Sonotrol and the VAPC system reduce the number of high voltage power cords that must run to the processor. The units should meet all national safety standards for electronic devices.

7. *Reasonable Cost*

Cost is always a determining factor. A reasonable upper boundary for the cost of an environmental control system is $1000. Prentke-Romich's $180 system offers limited capability, but the price makes it accessible to a majority of the population.

8. *Mobility*

The last design criterion, mobility, seems to be the most important parameter. Currently, most systems limit the user to one location. For example, a standard VA Prosthetics Center system configuration has gooseneck tubing which supports the tube mounted on the user's bed. Whenever the user is out of bed, he is just as dependent upon an aide or family member as before; in order to maintain his level of independence, the user must stay in bed. The system thus induces tendencies which defeat its purpose. However, with the addition of a small transducer-transmitter module to the system, the user can control his system no matter where he is in the room. Futhermore, if the receiver-processors were small, modular 10-channel function controllers, the user could take his portable transducer to any room with a processor and control devices. If the whole system were portable, the user could take his transducer and a processor to his job where the devices he uses are specially adapted to his system. Another benefit of total mobility is a processor module which enables the environmental control system to operate an electric wheelchair. Mobility is the key to augmenting the therapeutic value of environmental control systems.

The ideal system based on these criteria would have a transducer-transmitter module capable of utilizing a number of transducer types. The module would be small and battery-operated. The processor would be comprised of small, portable building-block modules which control 10 functions. The blocks could stand alone or be interconnected to provide increased capability. The ouputs of the processor would be low voltage signals operating external modules which control the appliance or device. This system would be more ideal if the processor blocks transmitted the signals to the device-control modules.

If the VA Prosthetics Center were to use the transmitter-receiver approach on their home system, and if they converted the hybrid to a solid-state, modular, portable system, they would have a near-ideal system. This system is not beyond their capabilities, and its potential applications would be limitless.

In conclusion, environmental control systems can have a greater potential for rehabilitation than demonstrated by current systems. We must set and meet higher goals of rehabilitation for these systems.