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A VOICE CONTROLLED MICROCOMPUTER SYSTEM FOR MULTICHANNEL FUNCTIONAL ELECTRICAL STIMULATION OF HAND

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Abstract:

Appropriate functional electrical stimulation of systems with many degrees of freedom, like the hand, requires multichannel stimulation techniques. The long-time on-line control of multivariable system by quadriplegics, however, causes stress in a high degree. Thus the purpose of programmed multichannel stimulation is the limitation of the task of concious control to the installation phase of the so-called "programmed movements". After that installation phase, only the initiation of the preprogrammed movements has to be done by the disabled.
By means of the described system eight-channel programmed movements may be created, each of them consisting of a series of up to 16 subsequent phases. The stimulation parameters which may be varied are the pulse-amplitude, the pulse-width and the pulse-frequency. For command input two modes of operation are provided: keyboard input and speech command input. Voice recognition is done by a speaker-dependent, descrete-word speech recognizer with an eighty words vocabulary. The stimulation pulses are generated by a programmable stimulator. The system consists of an eight-bit microcomputer and two self-contained subsystems for voice recognition and stimulation-pulse generation which are connected by serial RS-232-C lines.
The purpose of the system is the evaluation of the programmed multichannel stimulation technique and of the voice command input for disabled. Therefore it is used by quadriplegic patients in a rehabilitation clinic.

1. Introduction

Even simple hand movemets require for the appropriate control of muscles a complicated spatial and temporal pattern of nerve

pulses. In the case of paralysed persons who are using functional electrical stimulation to regain more mobility, these nerve pulses have to be replaced by a suitable sequence of stimulation currents.

The task of conscious on-line control of many stimulus parameters, however, requires attention in a high degree. The stress coused by this control task may result in the rejection of the stimulation device by the patient.

One approach to ease the mode of operation may be achieved by programmed multichannel stimulation. This reduces the user's control activity to the initiation phase of the movement. Thus the patient is burdened with the task of direct control of all stimulus parameters only during the installation of the socalled "movement program"

2. Programmed stimulation

The temporal sequence of stimulation patterns which caused the desired motion (the movement program) is stored in a computer memory. In order to execute this movement the stored stimulation pattern will be sent sequentially to the paralysed muscles. Supposing constant stimulation characteristics, open loop control of muscles will result in the desired motion. The use of such a simple feed-forward control requires an approximately constant characteristic of contraction, otherwise the motions will vary too much.

2.1 The movement program

Generally spoken the movement program is a series of stimulus parameeters. The stimulus parameters which can be split into at maximum 16 phases from start to end. Each phase of the motion corresponds to a certain stimulation pattern consisting of a set of up to 24 parameter values. Figure 1 illustrates the components of the movement programm. For the sake of clearness, only one of three stimulation parameters is shown in figure 1.

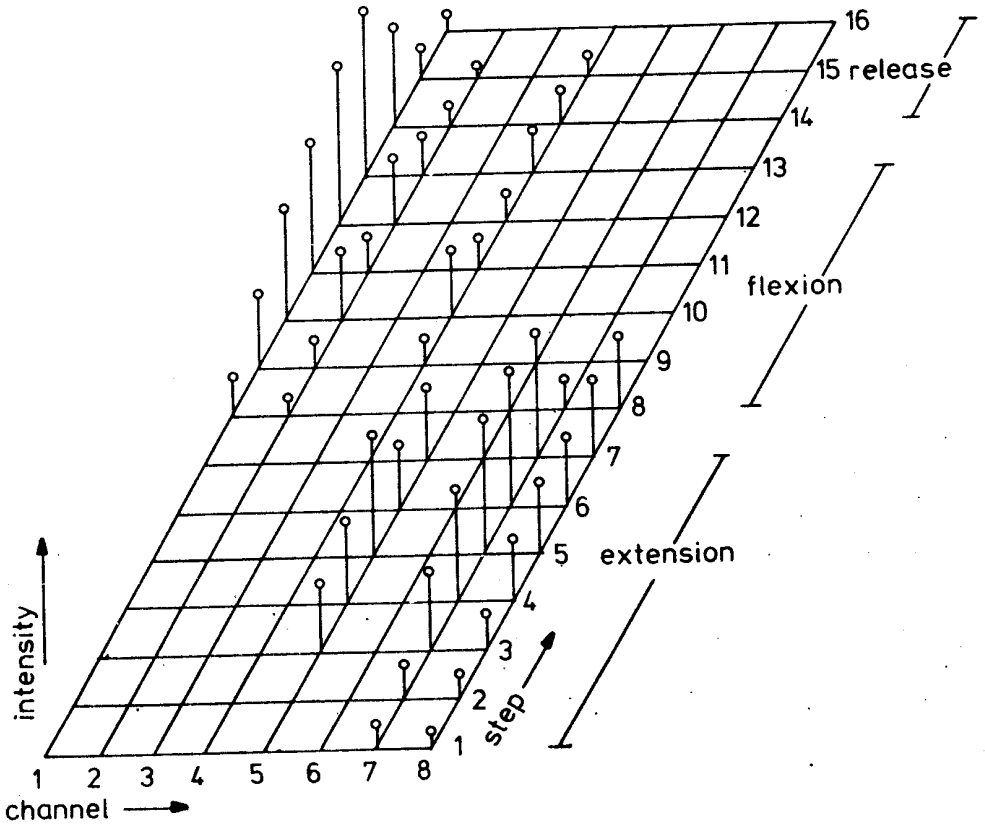


Figure 1: The "movement program"

2.2 Creation and modification of movement programs

Most of the input commands are provided for the creation and modification of movement programs. The creation and modification procedure is illustrated by a simple example which refers to figure 1:

Supposed the disabled wants to open his hand, grasp an object, and then release it. For the opening of the hand the

extensor muscles of the forearm have to be stimulated. This will be achieved by,let's say,channel 7 and 8. For the grip the excitation of the flexor muscles has to dominate, for example by using channel 1 and 2. Two further channels for thumb adduction and opposition may be provided e.g. channel 4 and 5. Now the complete movement has to be devided into 16 steps, for example like this:

- step 1 to step 7: opening of the hand
- step 8 to step 13: closing of the hand
- step 14 to step 16: release.

In order to create the movement program the disabled now adjusts at each particular step the necessary degree of contraction. Therefore he sets the stimulus parameters of all channels until the position of the hand is in accordance with the desired pattern. By switching to the next step the preceeding values are stored in the computer memory. The former stimulation currents, however, are still sent to the muscles in order to start the next adjustment procedure at the previous stimulation levels. So the disabled continues until the last step is reached and the entire movement is programmed.
Modification of particular steps can easily be done by switching to the step which has to be changed, and by readjusting its stimulus parameters. The old values will be replaced by the new ones by switching to the next step or by leaving the creation mode.

2.3 Execution of movement programs

Execution of preprogrammed motions is easily achieved by giving a start command. This command is either a simple number (the number of the movement) or an arbitrary name which can be related to the motion, for example like "grip", "release", "open" and "close".

After the start the stored stimulation patterns are output step by step. At any time during stimulation the run of the program can be stopped by giving the "stop" command. Now the stimulation values are kept at the momentary level. Thus the disabled has enough time to move his hand to the object he wants to grasp. By using a continuation command the movement program will step forward again. By means of the "backward" command the program can

be run in reverse direction.
The speed of the preprogrammed motion can be changed from "default" to "slow" or "fast" at any time.
The change over to the next step of the pattern is smoothed by filling up the difference to the next parameter values with three interpolation steps. Thus uncomfortable sensations possibly caused by sudden transitions to higher or lower currents may be avoided.

3. Voice command input

For quadriplegic patients the control of a rather sophisticated multichannel stimulation system poses a severe problem; the few motoric functions which are left have to be used for other tasks in the daily routine. Under this point of view the major advantages of voice command input for disabled persons are obvious:

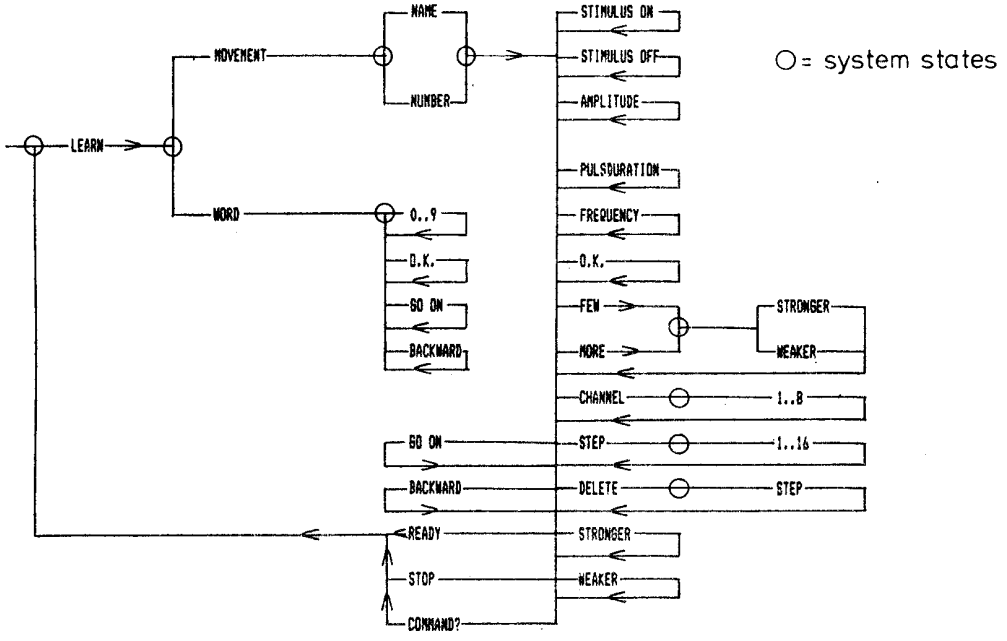
- few motoric activity of upper limbs is needed
- the high information transmission capability of the audio-vocal channel can be used
- natural syntax faciliates operation for persons without technical education
- physical separation of man and machine is permitted

3.1 The command syntax

Both keyboard input and voice command input are provided. Keyboard command syntax and voice command syntax are equal. Each keaboard command corresponds to a single command word. The sequential character of spoken language leads to a sequential command input. The realization of the syntax is based on a state description of the system. At each time the system is in one of several well-defined states. The transitions to other system states are permitted only under certain conditions. These conditions represent the syntactical rules. Consistency with syntax is chekec by a table lookup. A table containing information about the permitted commands, the transistions to other state, and the subroutines which have to be executed is related to each state. On receipt of a command the system checkes the table. If the command is present, certain actions depending on the table contents will be executed, otehrwise "syntax error" is indicated.

The major advantage of this state description and of the use of tables for definition of the syntax is the possibility of subsequent modifications. By changing or adding some positions in the syntax tables modification and expansion of the command syntax can easily be done. Even the addition of new system states can be chieved by creating a further table.
The realized stimulation system consists of 23 different states. 57 voice commands or keyboard commands respectively are available. The phonetic articulations which are assigned to the 57 voice commands are completely arbitrary. For more transparency of command language, however, it is recommended to chose words which point to the effect of the command. Most of the commands deal with creation, modification and execution of movement programs. A second partition deals with the training of the voice recognition vocabulary. The remaining commands are used for storage of data, test and security functions.

In order to get acquainted to the command syntax the operation is organized interactive; the system points to commands which are available in the actual state on an alpha- numerical display. Syntax errors are indicated by an audible signal("bleep"). In the very beginning the disabled has the possibility to use graphical representations of the system states and the permitted commands as it is illustrated in figure 2.



4. The system configuration

For the present the ralized system is composed of four major components as showed in figure 3. The central unit is an eight-bit microcomputer. Voice command input is performed by a self-contained automatic speech recognition system. Supplementary to voice input the user communicates with the system by means of an alpha-numerical pocket terminal. Generation of stimulus pulses in accordance to the chosen parameter values is achieved by a programmable eight-channel stimulator. All components are connected by serial RS-232-C interfaces.

4.1 The speech recognition system

For voice data entry an Auricle-1 speech recognition system from Threshold Technology Inc. is provided. It is a singleboard microcomputer that accepts speech input from a head-set microphone and outputs digital characters that identify spoken words. Auricle-1 is a discrete word recognizer with a vocabulary of 80 words. It must be "trained" by each user; i.e. each user must say each word three times before Auricle-1 is ready to recognize the user's verbal commands. Constant background noise and proper microphone placement provided, an accuracy of 99% can be reached at best. In practical use the word recognition reliability can be worse because of noise, hoarseness of reduced vital capacity of the disabled. An accuracy of about 90% seems to be still tolerable.

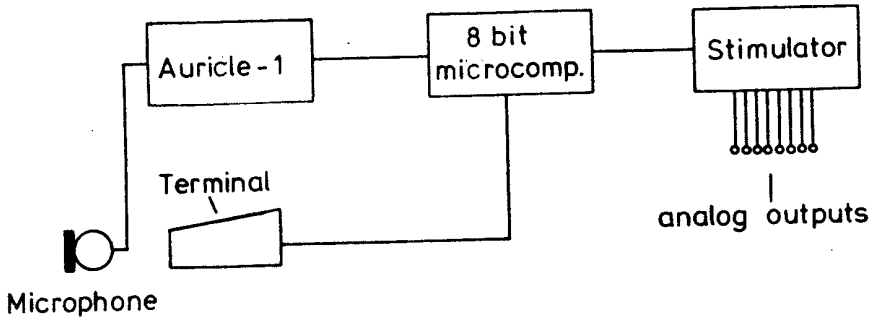


Figure 2: Syntax of the command 'learn'

4.2 The stimulator

Processing of stimulus pulse data is done by a Z80 single-board microcomputer system. The following parameters of each stimulation channel can be programmed individually:

- the amplitude in 256 steps
- the pulse width in the range from 20 µs to 2.5 ms with an increment of 10 µs
- the interval between the pulses from 10 ms to 100 ms in steps of 1 ms

The shape of the stimulation pulse of each channel is digitally stored in a programmable read-only memory (PROM). It may be changed by using another PROM circuit. After digital-to-analog conversion the voltage stimulus pulses are output to voltage-controlled current sources that are connected to the muscles by surface electrodes.

5. Security functions

Beside the usual electrical safeguards some additional security features are provided.

At the very beginning of operation the user has to enter his identification code: i.e. he has access only to programs of his own. After that the upper limits of all parameters have to be adjusted, so that painful sensations are avoided in any case. Recently speech recognition techniques have reached a high level of reliability. Neverhteless, for the purpose of more security of operation, both keyboard operation and voice command input are provided. During the voice input, the touching of any key of the keyboard immediately interrupts stimulation and switches back from voice input to keyboard input. Speech recognition is speaker-dependent, i.e. only that person who "trained" the vocabulary is able to enter spoken commands. In order to avoid unintentional effects due to recognition errors, important commands are monitored on the terminal and have to be verified by the user.

6. Discussion

The purpose of the described four-component system is the evaluation of programmed multichannel stimulation technique and of voice command input for disabled. Therefore the system will be

used by upper limb paralysed persons under the supervision of technical and medical staff in a rehabilitation clinic. The present system is not designed for daily use at the disabled´s home. Therefore it whould have to be more compact, e.g. for installation at a wheelchair. To this end sigle-board speech recognition systems which now are available /3/ may be incorporated.

If the disabled doesn´t accept the head-set microphone it may be replaced by an more unconspicious one for example a throat microphone.

In order to adapt speech input to natural language a more flexible command syntax based on artificial intelligence principles may be developed.

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