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A Fuzzy approach for increasing the efficiency of FES Rowing exercises in paraplegia.

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Abstract - *A transformed mobile custom rowing workout machine was used for this study of the functional electrical stimulator (FES) aided exercise for patients with paraplegia. For smooth movement and an efficient workout, there must be a balance between the artificially achieved movements of the paralyzed legs and the movements of upper body movements controlled at will by the volunteers. To achieve this result of precision and efficiency in coordination, a multi-tier hierarchy employed by an automatic controller was developed and used for this study. And an advanced finite-state controller was adopted to recognize the most recent position of the subject in the rowing state, assisting the fuzzy logic controller to administrate the precise controlled electrically produced movement to the paralyzed muscles of the paralyzed lower half of the body to mimic the natural movements. The data for the study was collected by experiments conducted with the help of a couple of paraplegic volunteers, the result indicated that the use of fuzzy logic control over the currently used manual procedure of constant stimulation increased the efficiency of the workouts and reduced the risk of cardiovascular disease due to inadequate exercise.*

***Key Words*: Paraplegia, Paraplegia workout, Spinal cord injury. Fuzzy logic controller.**

1. INTRODUCTION

The leading cause of demise among patients with lower-body paralysis from injury in the spinal cord or patients with the lower body paralyzed in other words paraplegic is cardiovascular disease. This is because there is a very limited variety of workouts for paraplegic patients such as wheelchair movement and arm exercises to name a few, these restrictions of movements affect the cardiovascular health of patients negatively. To avoid this the patient must include a workout consisting of both upper body exercise and artificially mimicked movements of paralyzed limbs with the help of FES. Such form of hybrid workouts not only helps to increase fitness but also has shown to decrease in blockage of veins in the leg muscles and uptake of oxygen when compared to the currently accepted workout for paraplegics.

For this study, we have taken a mobile indoor workout machine used by the rowers to exercise and have modified it to fit the specification required for the experiment. This hybrid workout is a combination of upper body exercise and artificially achieved lower body movements complementing each other. For the required efficiency of workouts and smooth movements of the paralyzed lower body, the whole body should be in sync. For this balance between upper and lower body movement, multiple manually tuned electric stimulators were tested on the paralyzed muscles. Originally the stimulator was a controller adopted by the subject manually in which they must constantly focus and press the switch to change the supervision of optimal electrical current to the paralyzed part of the body.

This method was not only monotonous and uncomfortable, but it was difficult for the patient with severe spinal injuries as it requires the subject to continuously press the switch to administer the stimulation. To get rid of the repeated motion of pressing the switch and making the process more automated we used fuzzy logic controller and an automatic electrical stimulator was used. An advanced finite-state controller took the neural readings as the input to recognize the position of the subject in the rowing workout cycle and this data is then sent to a primitive constant stimulation controller to give stimulation to the paralyzed legs. But the unusual amount of stimulation in the paralyzed body parts led to early burnout and exhaustion which in turn restricted the amount of time that can be used for exercise. To overcome this problem, we used a closed-loop control structure instead of the constant stimulation controller, this included tactics akin to an on/off shifting bend with PID control. This approach proved efficient in decreasing exhaustion due to overstimulation. This approach was extensively researched and reviewed based on the FLC. FLC has a more docile and nonaligned composition with various parameters. For efficiency during rowing workouts, these parameters can be customized for precise control response. The FLC approach differentiates itself from the original manual controller and constant stimulation stimulator established on the principle akin as the extent including electrical current, the subject's comfort during a workout, smooth and efficient overall movements, etc.

2. WORKING:

2.1. ROWING WORKOUT MACHINE WITH ELECTRICAL STIMULATOR.

An indoor workout machine named Concept II was tuned up to the specification needed for the study. Add on like more comfortable rig for the comfort of subjects, fine-tuned braking system, and for the safety of subjects a safety catch device in case of emergencies, etc. were consolidated in the machine [4]. To recognize the current position of the subject and the paddle during the workout additional hardware was added to the machine, to take the take input and optical encoders were added with rollers of the seat and the chain pulley at the handle. These were precisely tuned by adjusting the data received during the start and end positions. The data were taken into consideration to recalibrate the encoders in stat position and were sent to the electrical stimulator controllers [5].

2.2. ELECTRICAL STIMULATOR CONTROLLER.

To recognize the present stand within the paddle cycle as stated in [5] the advanced FSC uses the neural evaluation, with the stand conversion principle. Within each stand, the advanced controller transmits a stand devoted primitive controller to convey the exact current to the muscles. To administer the electrical current error-free and precisely multiple low-level controllers were used. These controllers were used for distinct states of the rowing workout namely the push, pull and resting states. In the pull position, the legs are extended and oppose the pulling action of the hands, here the controller administers the electrical current in the quadriceps muscle. While in the push and resting positions, fuzzy logic controls were put in action to restrict overstimulation to the muscles. To understand the working of the fuzzy logic controller, refer to the 1st figure. Here both velocities of the seat and its position during the workout were taken as input in the fuzzy logic controller, and the stimulation through controllers at both the knee joint and leg muscles were output for the process. Due to the direct affiliation between the knee movement and seat position during the workout, to move one you must alter the other. When designing the process, the shape and number of the membership functions were taken into consideration and the results and the rules maintain the process in fig.1. For precise results, the principle was manually calibrated with the help of the data from the controllers.

The most well know hybrid workout for the paraplegic combines upper body movement with the electrically stimulated movement on the bicycle. But the results of the electrically stimulated rowing workout showed more efficient use of time and muscle movements.

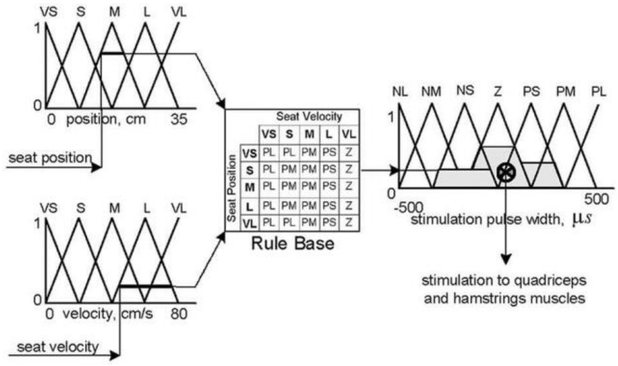

Figure 1. Structure of fuzzy logic controller for the pull position of the rowing.

The fuzzy logic controller for the resting position has a related layout. [1]

In the above figure the letters Z, P, N, V, S, M, L represents Zero, Positive, Negative, Very, Small, Medium, Large respectively.

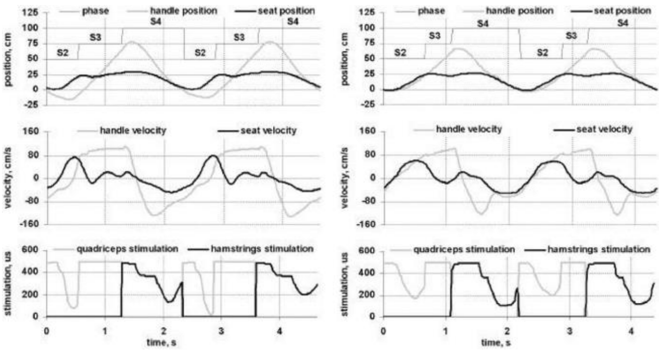

Figure 2. Prototype of trajectories and electric stimulation for 2 complete sets of electrically stimulated rowing workouts by paraplegic volunteers using a fuzzy logic controller. Volunteers PV1 - Left, PV2 - Right.

A functional electrical current rowing workout requires a sensitive balance between both the upper body movement and stimulator lower body movements. The electrically stimulated controller achieves such balance with the subjects still in full control of the rowing workout. The volunteers were more relaxed, and the workout was more efficient with the FLC in play. Fewer efforts were required from the subjects due to the electrical stimulator (FES) it also delayed the exhaustion and burnout from the workout, due to this the subjects were able to perform the workout longer. To avoid current the fuzzy logic controllers' parameter was individually hand-tuned. More competence can be realized by automating the adjustment of the bounds [10][11]. In the hybrid functional electrical current workout if the subject is affected there is no noticeable inequality between the fuzzy logic controller with the constant level stimulation controller. But the fuzzy controller is more user-friendly and easy to control. However, automated controllers require precise assessment sensors and adjustments. For this study, we implemented medium-level optical encoders. This arrangement was more practical than attaching the encoders before each test. Since the rowing workout machine was a general use machine it must be calibrated for each subject before each test. But this is made with a single-user model so this will not be a problem for the end-user. This study was based on the test done with the help of only a couple of volunteers, though the results were encouraging and successful a more detailed study with a wider range of volunteers with a more severe spinal injury is required.

TABLE 1 List of the features of electrically stimulated rowing workout by Volunteers for various controllers.

	PV1-MC	PV1-CSC	PV1-FLC	PV2-MC	PV2-CSC	PV2-FLC
Rowing speed, cycle/min	26.3±1.3	24.1±0.9	25.0±0.7	26.2±0.9	28.1±1.5	27.2±0.7
Seat range of motion, cm	25.5±4.0	26.1±0.9	28.7±1.0	30.7±0.7	25.8±1.2	27.9±0.9
Handle range of motion, cm	96.9±6.4	91.0±2.6	93.1±3.1	75.0±2.4	68.7±2.5	70.5±1.7
Max seat drive velocity, cm/s	62.7±13.5	53.0±5.6	74.3±6.3	75.0±5.3	57.6±5.9	58.6±2.9
Max seat recovery velocity, cm/s	51.4±8.4	46.8±2.9	44.5±3.4	55.0±3.8	47.8±3.1	51.0±1.9
Max handle pull velocity, cm/s	105.3±5.1	99.7±4.2	109.3±2.1	100.8±2.3	99.1±2.3	99.9±2.0
Max handle release velocity, cm/s	140.6±11.9	140.3±9.2	137.2±12.3	161.4±9.0	137.3±14.2	132.1±8.4
Seat motion jerkiness index, m/s^3	31.4±4.4	24.1±6.0	19.7±3.0	36.5±4.0	33.0±3.5	17.0±1.2
Handle motion jerkiness index, m/s^3	47.7±5.4	41.3±3.8	25.2±2.8	65.6±6.6	58.9±7.9	35.9±2.6
Total quadriceps stimulation/cycle, μC	3659±227	3335±159	2719±130	2831±326	2706±276	2227±119
Total hamstrings stimulation/cycle, μC	1114±451	2698±102	1875±169	992±424	2475±215	1755±158

These values are taken from a manual controller, CSC, FLC. These were computed for each complete set of workouts.

3. CONCLUSIONS

The FLC was efficiently used in comparison with the preceding physical controller. In above figure 2, we can see two standard full sets of workouts, which constantly recognize the pose of the seat concerning the paddle. Census of the couple-minute constant paddle with FLC are compared to constant level current controller [5] and hand-operated controller [4] in Table 1. The total current spent by the fuzzy logic controller was relative to that of the physical controller but was less than the CSC to a great extent. Moreover, as designated by the movement instability table, the paddle with the fuzzy logic control was more fluid than the one with the CSC or primitive controller.

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AUTHORS PROFILE

Haziquddin Ansari is a Computer Technology student at Yeshwantrao College of Engineering, Nagpur, India. He is currently learning Fuzzy logic and neural network and their applications. This is his first academic paper on increasing the smoothness of electrically stimulated rowing workout in paraplegia with the help of the fuzzy logic controller.

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Ketan Deopujari is currently working as a Senior Application Developer at IBM Corporation. He graduated from the University of Maryland, with a master's degree in information management. He has 8 years of experience in the industry and has expensively worked on design, development and deployment of data warehouse and web applications.