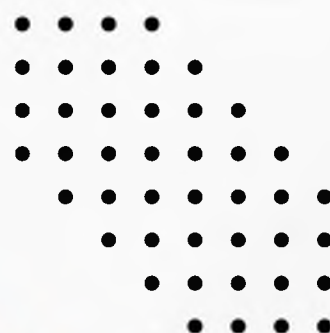


CITSM 2023 Proceeding

ISBN

979-8-3503-0596-8



2023 11th International Conference on Cyber and IT Service Management (CITSM)

**Makassar, Indonesia
(Hybrid Conference)**

November 10-11, 2023

ISBN: 979-8-3503-0596-8

2023 11th International Conference on Cyber and IT Service Management (CITSM)

Makassar, Indonesia (Hybrid)

Phone: +6281384175979

Email: contact.citsm@uinjkt.ac.id

Website: <https://citsm.id>

November 10-11, 2023

ISBN: 979-8-3503-0596-8

2023 11th International Conference on Cyber and IT Service Management (CITSM)

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ISBN: 979-8-3503-0596-8

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Curran Associates, Inc.

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Control Improvements of an Electromyography-Based Lower Limb Gait Trainer

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Abstract— This paper presents an investigation of a control improvement for an electromyography (EMG)-based gait trainer. Gait impairments can severely affect an individual's mobility and quality of life. EMG-based gait trainers offer a promising solution by utilizing bioelectrical signals to facilitate natural and efficient walking patterns. However, challenges remain in refining control strategies to ensure accurate and intuitive assistance. This paper aims to improve the precision, adaptability, and user experience of EMG-based gait trainers. The proposed control enhancements are validated through experiments to demonstrate significant strides toward more effective gait rehabilitation systems.

Keywords—control improvement, electromyography, EMG-based gait trainer, Fuzzy, gait rehabilitation, PID

I. INTRODUCTION

Gait impairments can result from various factors, including neurological disorders, musculoskeletal conditions, and traumatic injuries[1]. These impairments often lead to limited mobility and reduced independence for affected individuals[2]. EMG-based gait trainers have gained attention as an innovative solution to address these challenges[3]. By utilizing bioelectrical signals generated during muscle contractions, these devices aim to restore natural walking patterns[4][5]. However, achieving optimal control mechanisms remains a key challenge.

Previous research has explored different control strategies for EMG-based gait trainers. A well-known commercial gait trainer robot in the market is Lokomat [6]. Several robots for rehabilitation are controlled using a Fuzzy Logic Controller[7][8][9]. Fuzzy systems have been used in numerous research investigations for rehabilitation. Segmenting the gait cycle is a suggestion made by Vasileious et al.[10] for lower limb rehabilitation systems. To address lower limb neuromuscular problems, this segmentation will be used to extract rules for the creation of rehabilitation Fuzzy Logic Control Systems (FLCS)[11][12]. For a hand rehabilitation robot, Abbasimoshai et al. created an adaptable self-organizing fuzzy sliding mode controller[13]. An upper limb rehabilitation robot's control system that manages force, impedance, and other variables was also created[14]-[17].

Ho and Chen.[18] developed a physiotherapy device with a motorized CPM/CAM mechanism, which was controlled using a sliding-mode fuzzy neural network control loop. In this study, a neural network architecture

was employed to accurately classify gait stages based on input data consisting of force measurements. They use fuzzy membership functions and rules to express the rehabilitation expert knowledge in the system so that it can be used in practical applications[19]. Since the 1980s, research on human motion tracking for rehabilitation has been ongoing. The rise in the number of patients with strokes and other motor function impairments has served as its driving force[20].

Several control algorithms have been created that automatically adjust the reference trajectory of various reference-based controllers and the impedance magnitude of an impedance controller to the intended motion of the individual patient[21][22][23]. Despite advancements, there is a need to refine these approaches to enhance the accuracy and adaptability of the gait trainer

II. METHODS

In this research, a lower limb gait trainer hardware was developed. The gait trainer consists of an exoskeleton composed of two manipulators and two degrees of freedom. Each manipulator functions to move the patient's leg movements being trained. Trajectory tracking accuracy is the key to successful therapy. The trajectory has been determined by a medical expert or therapist intended for the patient. Changes in the patient's load will result in changes in the system response of the manipulator control.

A. Mechanical Design

Figure 1 depicts the mechanical configuration of the gait trainer manipulator. It is a two-link planar manipulator robot for each leg. Therefore, the overall system consists of two manipulators. Fig. 2 shows the manipulator rendered 3D design. It shows the motor and the gearbox position in the manipulator. Fig. 3 shows the overall system of the gait trainer. It consists of two independent two-axis planar manipulators.

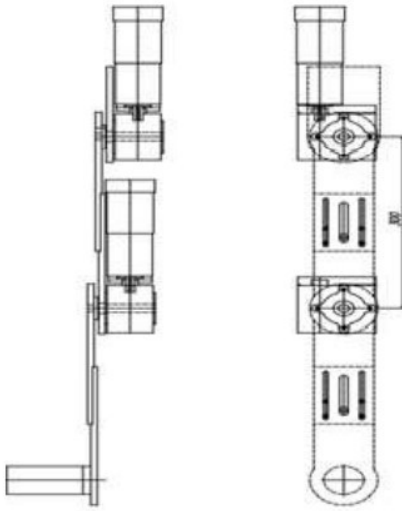


Fig. 1. Mechanical design of the gait trainer manipulator

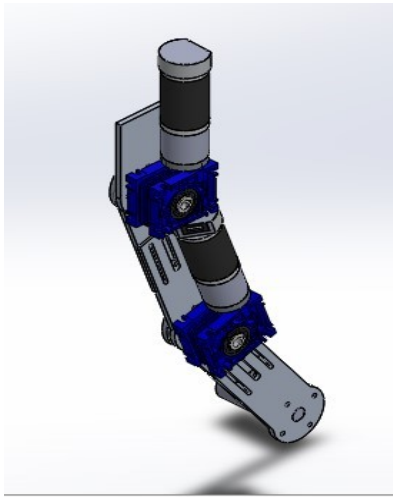


Fig. 2. Manipulator rendered 3D design.



Fig. 3. Gait trainer system

B. Electronic Design

The gait trainer system is controlled using an EMG signal. The EMG amplifier or interface used in this research is based on the AD8226 instrumentation amplifier. The potential difference between two different electrodes is recorded using the EMG device.

Fig. 4 depicts the EMG sensor, which is based on the AD8266.

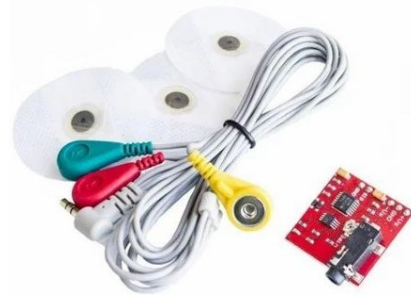


Fig. 4. AD8266-based EMG sensor

Fig. 5 illustrates the positioning of the electromyography (EMG) electrodes on the thigh. In order to measure the potential difference generated by the muscle, it is necessary to assign electrode 1 for the ground, electrode 2 for the negative, and electrode 3 for the positive. The EMG signal triggered the system to move the robot manipulator.



Fig. 5. Placement of eletromyography electrodes

Fig. 6 shows the electronic block diagram of the gait trainer. It consists of 4 Arduino UNOs as the low-level controller for the geared dc motor, and one Arduino Mega for the high-level controller that gives the trajectory reference command for the Arduino UNO.

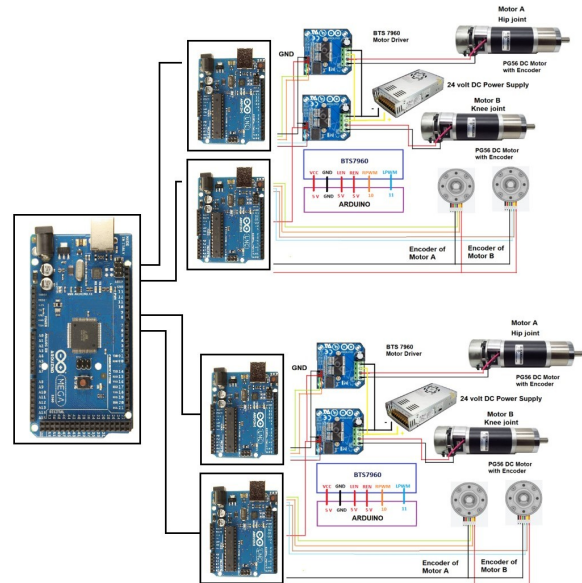


Fig. 6. Electronic wiring diagram of the gait trainer.

C. Control Design

The control algorithm being tested was the PID controller and Fuzzy Logic Controller. Proportional, integral, and derivative parameters are all combined into a single set of control inputs by a PID controller. The transfer function of PID can be demonstrated as follows:

$$u(t) = K_c e(t) + \frac{K_c}{\tau_i} \int_0^t e(t) dt + K_c \tau_D \frac{de(t)}{dt} \quad (1)$$

Fig.7 shows the block diagram of the PID controller, with

$u(t)$: PID controller signal

K_c : controller gain

$e(t)$: error signal

τ_i : integral time

τ_D : derivative time

K_P : Proportional constant

K_I : Proportional constant

K_D : Proportional constant

M : system plant

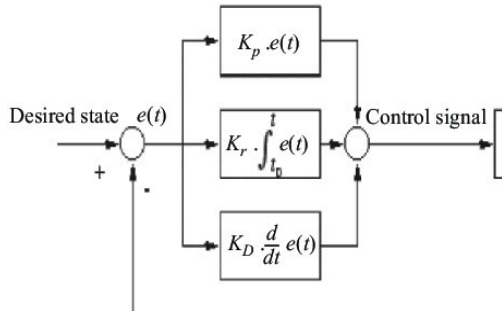


Fig. 7. PID block diagram

The foundation of fuzzy logic control is fuzzy set theory[24]. In accordance with the principles of fuzzy set theory, every element possesses a degree of membership that quantifies its extent of inclusion within a specific set. Fuzzy sets are comparable to classical sets but lack significantly sharper boundaries. When intermediate precision is needed, and there is little need for significant mathematical analysis in the plant, fuzzy logic controllers (FLC) are more frequently utilized. Fig. 8 shows the FLC block diagram.

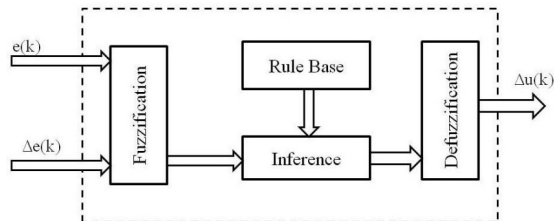


Fig. 8. FCL block diagram

Fig. 9 shows the membership function of the error and the d_error of the dc motor closed-loop control, respectively. Fig. 10 shows the membership function of the output position of the system. The FLC uses a

trapezoidal membership function. Fig. 11 shows the rule surface of the FLC.

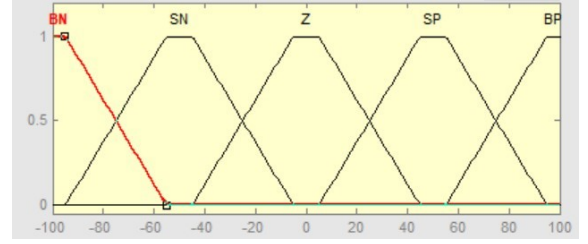


Fig. 9. The function of input membership.

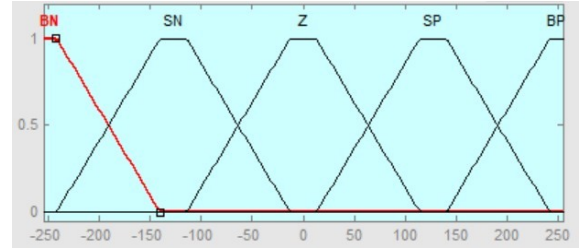


Fig. 10. The function of output membership

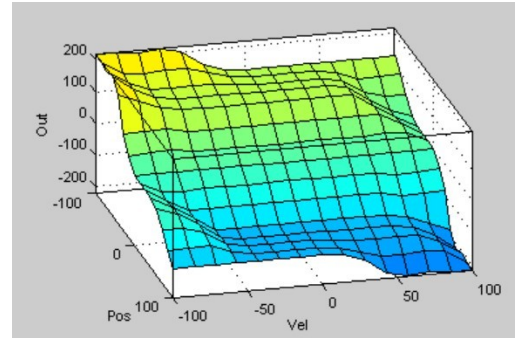


Fig. 11. Surface of the Fuzzy Rules

III. RESULT AND DISCUSSIONS

Using the PID controller, the system can be moved to the desired reference position. It is just that when there is a change in load, the PID controller produces a slight oscillation but occurs over time. Fig. 12 shows that at a setpoint of 90 degrees with 100% load, the PID controller can control the system so that it can stop well at the 90-degree position. However, when the load is reduced to 75% at the same setpoint, the PID controller is also able to go to the desired position, but the system cannot stop stably at the setpoint. Small oscillations occur all the time, as shown in Fig. 13.

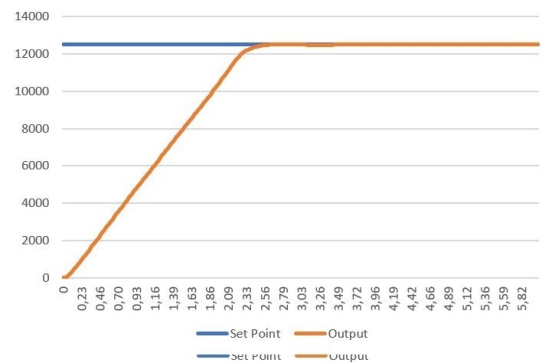


Fig. 12. System response using PID controller with 100% load

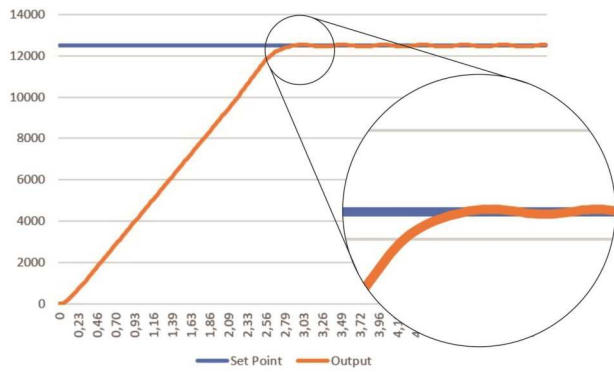


Fig. 13. System response using PID controller with 75% load

This is different when using fuzzy controllers. Even though the resulting system response has a larger rise time, the final position can be achieved properly. Even when there is a change in load, it does not give an oscillatory effect as experienced by the system when controlled using a PID controller. Fig. 14 shows the system with a Fuzzy controller response when the setpoint is 90 degrees with 100% load.

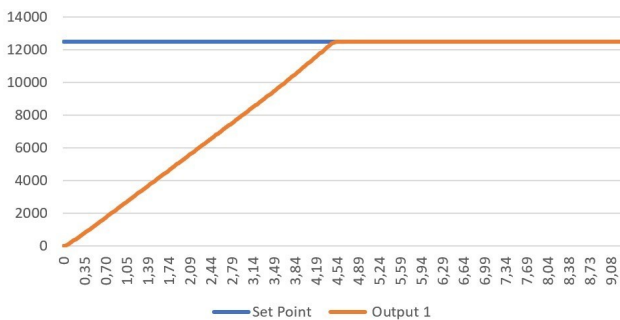


Fig. 14. System response using FCL controller with 100% load

Fig. 15 shows the system with a Fuzzy controller response when the setpoint is 90 degrees with 75% load.

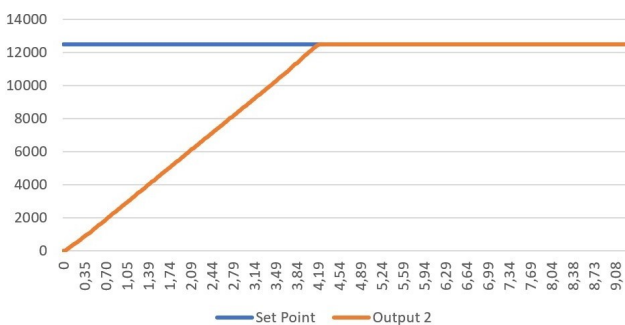


Fig. 15. System response using FCL controller with 75% load.

Fig. 16 shows the output of the EMG signal. Using Arduino analog input, the signal quantized from 0 to 1023. When the muscle is in a relaxed condition, the output reading of the signal is around 180. When there is a contraction from the muscle, the EMG signal rises to around 240. The activating threshold can be chosen in between those values.

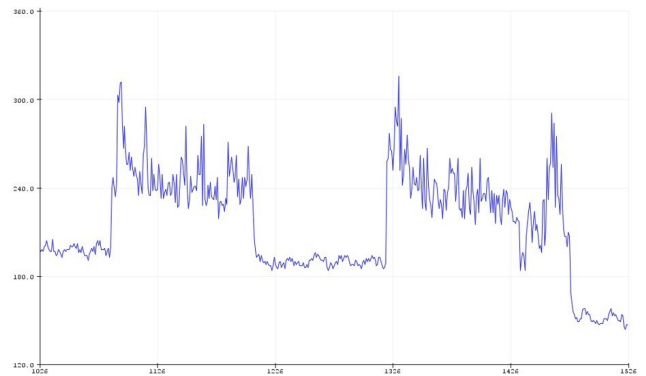


Fig. 16. EMG signal plot from the Arduino analog reading

IV. CONCLUSION

The gait trainer system has been successfully built. In the tests carried out, the system has succeeded in operating well. The gait trainer manipulator can move toward the specified setpoint. It's just that the PID controller's response experiences oscillations when there is a change in load. However, the response of the Fuzzy controller can operate properly even though there are changes in the load on the system.

ACKNOWLEDGMENT

The authors would like to express their gratitude to the Sanata Dharma University, Indonesia and Rajamangala University of Technology Thanyaburi (RMUTT), Thailand, for providing research facilities

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