PERFORMANCE EVALUATION OF ANKLE FOOT ORTHOSES BASED ON BIOSIGNAL FEEDBACK AND ANKLE POSITION

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ABSTRACT

Ankle Foot Orthoses (AFO) is a supportive device attached onto the lower part of the leg to support patient's walking gait. It has been developed for several years using many kinds of actuators that can be controlled electronically. There are two control systems for AFO, namely active and passive control. Although there are a lot of developments on active control schemes, only a few developments on passive control. Currently, we are developing a PICAFO (Passive Control Ankle Foot Orthoses) using Magnetorheological (MR) brake as the actuator, in which the stiffness of MR is proportionate to the applied current amperes. Fuzzy logic controller (FLC) has been chosen to control the PICAFO. The human gait is identified as Electromyography (EMG) biosignal and ankle position as the feedback to the FLC inputs. The FLC determines the amount of the current supplied to the MR brake based on the condition of inputs.

In this paper, the performance of the PICAFO is evaluated and discussed. First, we have tested and observed the output surface of FLC using LabVIEW before we applied it to the PICAFO. An experiment has been conducted on several healthy subjects to observe the effect of PICAFO on human gaits. In the experiment, a subject walks on the treadmill with the speed of 0.5 m/s for 120 seconds. A series of data is collected in the second minute as the first minute is just used for adaptation purpose. The EMG signal (mV), ankle position (θ), and voltage (V) are observed in the experiment. It is revealed through the experiment that the controller can fulfill its purposes, in which we gain a high current when the EMG signal is low and vice versa. Moreover, the ankle position stays in positive value when the EMG signal is low to indicate that the PICAFO is successful in preventing foot drop.

1. INTRODUCTION

AFO is a supportive device attached to lower part of the leg which is usually used in post stroke rehabilitation e.g., gait training or walking. It covers the foot until the calf to give a movement limitation at the ankle at which to prevent foot drop. In the development of AFO, electronic actuators had taken their part for control system to improve the whole system.

There are two types of AFO's control systems: active control and passive control. The differences between active control and passive control can be seen from the actuator. An active control system usually uses actuator for movement like a DC motor and pneumatic valve. On the other hand, actuators that restrict the movement such as dampers and brakes are used in passive control system. As reported in (Jimenez & Verlinden, 2012), there are a lot of developments in active control system, but very few for passive control system.

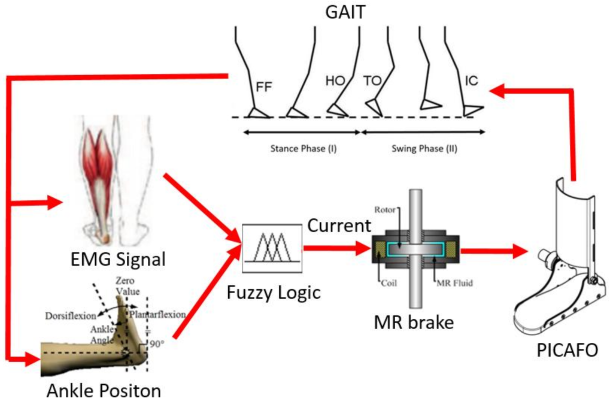


Fig. 1 Overview of Study

In this research, we have developed a PICAFO using MR brake as the passive element. Passive control is chosen because it is enough to prevent foot drop. In comparison to active control, it has advantages in terms of: weight, cost, miniaturization, and simplicity (Kikuchi, et al, 2010). Figure 1 shows the overview of this study.

Gait is classified based on the EMG signal and ankle position which will be processed by the FLC to produce a sufficient Ampere for the MR brake. Thus, it will generate torque which affects the gait and the cycle is repeated.

In this paper, the performance of the PICAFO is evaluated and discussed. We briefly discuss about the PICAFO controller development in Section 2. The PICAFO experiment apparatus, setup, and procedures are discussed in Section 3. Section 4 discusses the result of the experiment and the analysis. Lastly, a concluding remark is presented in Section 5.

2. FUZZY-BASED CONTROL DESIGN

Initially, the fuzzy controller for the PICAFO has been developed using trapezoid membership functions. However, the membership function is changed to the Gaussian-typed because it has smoother function than the trapezoid (Bernadette, 1996). The proposed controller has two inputs: EMG biosignal and ankle position; and only one output, which is the voltage. The membership functions for each input and output are presented in Figure 2.

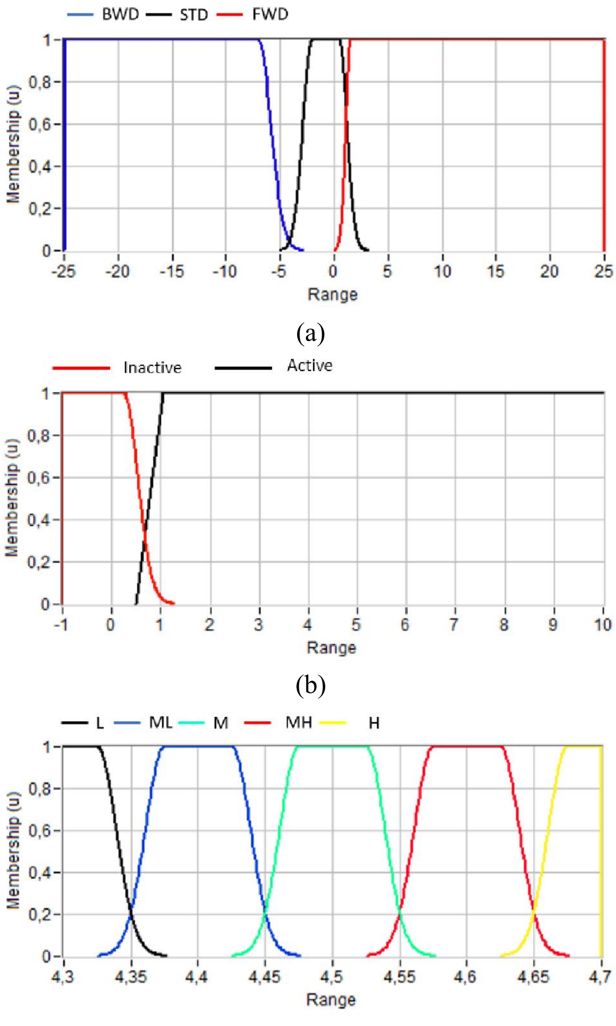


Fig. 2 FLC membership function: (a) Ankle Position; (b) EMG signal; (c) Voltage

The voltage is used to drive current for the MR brake by means of MOSFET circuit. A 4.3 V is corresponding to low current 0.33 A, while 4.7 V is corresponding to high current 3.06 A. The output membership functions are defined as low (**L**), moderate low (**ML**), moderate (**M**), moderate high (**MH**), and high (**H**). The EMG signal has two membership functions i.e., Active and Inactive while the Ankle Position has three membership functions for instances backward (**BWD**), stand (**STD**), and forward (**FWD**).

The heuristic rules for the controller are defined based on the purpose as follows:

- Gradually increasing current during stance phase from backward to forward ankle position.
- High current during swing phase on forward ankle position.

Stance phase (I) is a condition where the foot touches the ground and the swing phase (II) is a condition where the foot does not touch the ground. Thus the total of the rules is six and presented in Table 1.

Table 1. FLC rules

		Ankle Position		
		Backward	Stand	Forward
EMG Signal	Inactive	L	ML	H
	Active	L	M	MH

3. EXPERIMENT

The purpose of the experiment is to observe the effect of PICAFO on human gaits while walking. Observation parameters are the EMG biosignal, ankle position, and voltage output. A short video of the walking subject was also recorded for investigation so that the parameters can reflect to the real condition of the subject. The overview of the experiment setup is shown in Figure 3.

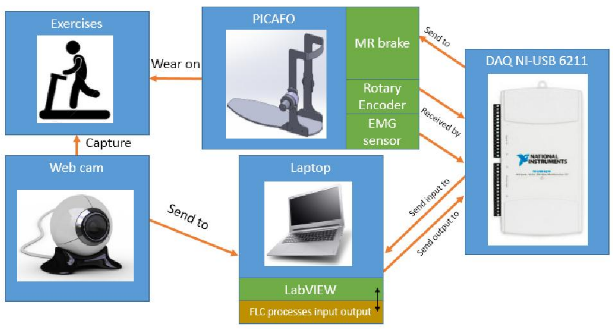


Fig. 3 Experimental setup

3.1 Experimental Apparatus and Set Up

The EMG signal is recorded using a muscle sensor and the electrodes are appropriately patched to the gastrocnemius muscle as this muscle can give a significant reading during walking activity as well as easy to locate (Vieira, 2013). Ankle position is measured using a rotary encoder which is located on the ankle joint.

It is in the same axis as the MR brake shaft. Figure 4 shows the sensor placement on the subject.

All sensors are connected to a circuit terminal before connecting to the National Instrument USB-type 6211 data acquisition (DAQ). The DAQ is connected to the laptop where the controller is designed and the inputs are observed. The MR brake acting as the actuator of PICAFO is controlled by means of MOSFET circuit. It is also located at the circuit terminal. An external power supply is used to power up the sensors for adequate current for the MR brake. In order to operate the MR brake, the current should be more than 0.1 A (Gudmundsson, et al., 2010).

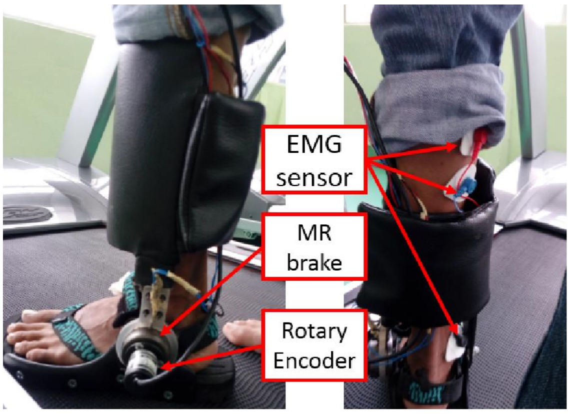


Fig. 4 The Orthoses with EMG Sensor placement

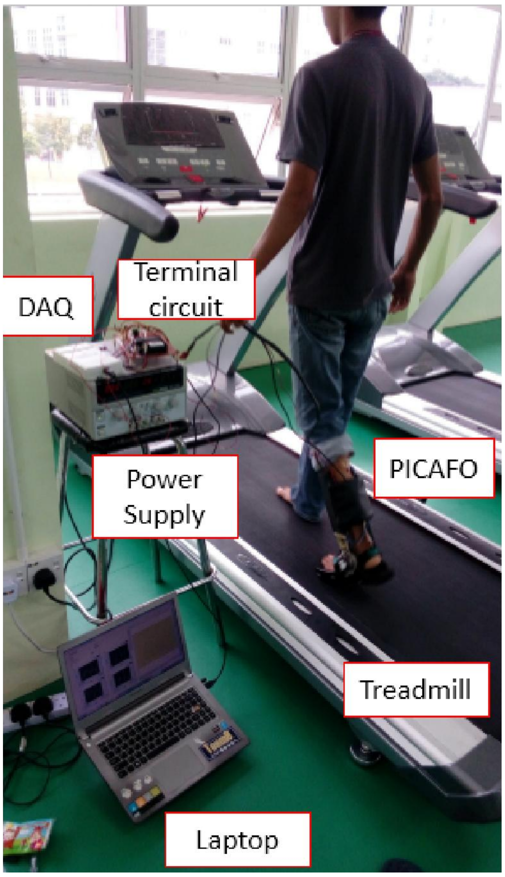


Fig. 5 Hardware setup and arrangement

A camera that is used for recording in this study was a personal smartphone connected wirelessly to the laptop by using Droid Cam software. By recording the video, the measured signal can be validated with the real situation. Figure 5 shows the hardware arrangement for experiment.

3.2 Experimental Procedure

The experiment was done by instructing the subject to walk on treadmill. The speed of the treadmill is constant, so the subject's walking speed can be determined to be 0.5 m/s. The duration for each walking experiment is about two minutes, with the data recorded after one minute (Mahon, 2013). During the experiment, not only the activity of the inputs and output is recorded but also the observation in real time using LabVIEW software. The front panel of the LabVIEW consists of all signal, voltage output, ankle position, EMG signal, and recorded video.

4. RESULT AND DISCUSSION

4.1 Fuzzy Logic Simulation

A surface fuzzy viewer is used to simulate the behavior of the FLC. By using the viewer, we can observe all the possible output of the FLC. Figure 6 shows the surface fuzzy of PICAFO FLC.

It can be seen that when the ankle position is in the forward region, the voltage is high as indicated by blue color and even higher when the muscle is inactive. For ankle position with 5 degrees and the EMG signal is 0 V, the voltage output is 4.67763 V.

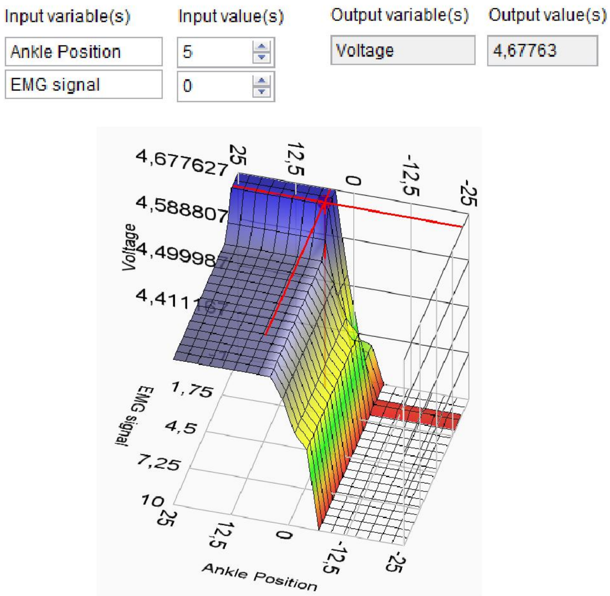
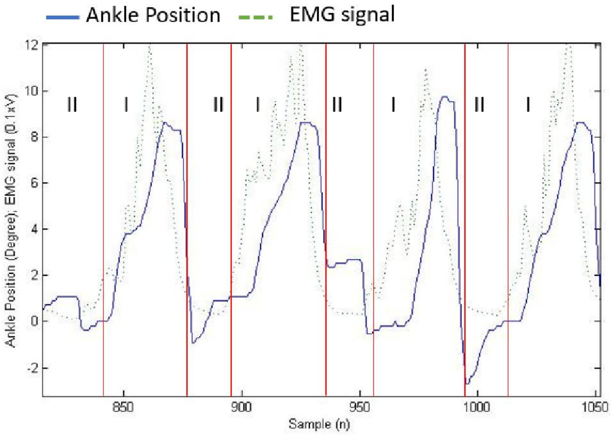


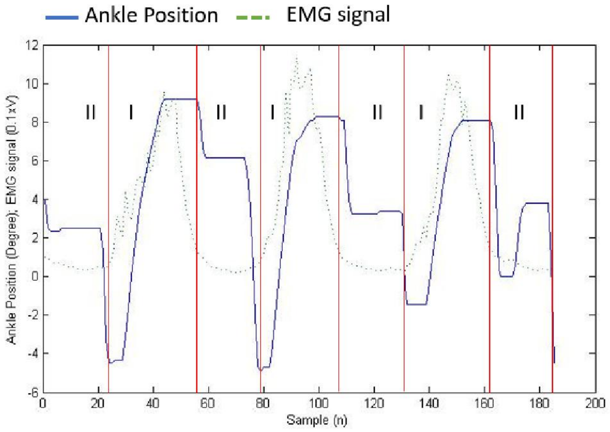
Fig. 6 Surface fuzzy viewer of FLC

4.2 Experiment Result

The PICAFO control system is expected to control the ankle position indicated by the forward ankle position during swing phase which means the foot drop problem is successfully prevented. Thus the ankle position before and after the PICAFO control system is applied are shown in Figure 7.



(a)



(b)

Fig. 7 (a) ankle position without PICAFO support; (b) ankle position with PICAFO support

The stance phase and swing phase are indicated by I and II respectively. Before the controller is activated, the ankle position is decreasing drastically during swing phase but after the controller is activated, the ankle position is decreasing a bit before it stays at some forward degree during swing phase.

However, during the stance phase, the ankle position is increasing quite suddenly when the controller is not activated. Right after the controller is activated the ankle position is gradually increasing. The ankle position after the controller is activated is smoother than the controller is activated beforehand.

CONCLUSION

In this paper, an experiment setup for PICAFO's performance is presented. In the experiment, the subject walks on the treadmill in two minutes. The ankle position, EMG signal, and voltage are the recorded data collected after one minute of the experiment run. Throughout the experiment, it is found that by applying PICAFO control system when walking, a foot drop problem can be prevented during swing phase. During stance phase, the ankle position is smoother than before. However, the experiment in this paper was done on subject who is in healthy form. An experiment on unhealthy subjects is proposed for the future work so the PICAFO can be proven to be useful for patient in rehabilitation.

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