Correction of drop foot using a fuzzy logic controlled miniature stimulator

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Abstract

Purpose: To design, implement and evaluate a miniature stimulator which would incorporate closed loop control of ankle dorsiflexion for the swing phase of gait. The system was to be of such physical dimensions and complexity to enable its use by patients on a daily basis.

Methods: A miniature stimulator was built which had a fuzzy logic controller in the embedded processor. The derived closed loop control system used a simple resistive goniometer to monitor ankle flexion angle and a force sensitive resistor to detect heel-ground contact. The microcontroller continuously read these two sensors and adjusted the intensity of the stimulation according to the embedded control law. The system was initially tested in the laboratory on three subjects and was compared to an open loop system. It was subsequently given to two subjects to use outside the laboratory and the performance was evaluated and compared to an open loop system over the course of a day.

Results: The fuzzy logic controlled stimulator performed better than the open loop controlled stimulator showing an increase in number of steps for which ground clearance was achieved, a reduction in step to step variability and improvements in the quality of foot ground contact.

Conclusion: The closed loop control system was used by patients outside the laboratory in their own environment. This system had consistently better performance than an open loop system both in and outside the laboratory.

Keywords: Functional electrical stimulation (FES), drop foot, closed-loop control.

1. Introduction

Drop-foot stimulation has been the most successful and most widely used application of FES over the last four decades. Surface and implantable systems have been developed some featuring ambitious control algorithms which have been tested in the laboratory and for small trial groups[1]. However the most widely used drop foot systems to date use open-loop architecture [2] and these systems require active user participation for the adjustment of stimulation parameters both during initial set-up and daily usage. Many people with drop foot also have impaired hand function and also may have cognitive problems thus making set-up and adjustment of the stimulator difficult. Furthermore most of these systems are bulky and may be considered cosmetically unacceptable.

The aim of this study was to develop a miniature stimulator which could perform closed-loop control of the ankle. The stimulator was to be of such physical dimensions and complexity that would be practical to set-up by the patient and be used on an everyday basis outside the laboratory.

2. Methods

The closed loop drop-foot stimulator featured two layers of control, an outer layer that performed the event sequencing and organised the stimulator as a finite state machine and an inner, lower level of control that performed cloed loop adjustment of the stimulation parameters when activated by the outer layer. Both layers were implemented using the same microprocessor. A simple resistive goniometer was used to monitor ankle flexion angle and a force sensitive resistor to detect heel-ground contact. Intensity of the stimulation was adjusted according to the embedded control law. The system was compared to an open-loop system and was subsequently given to two subjects to use outside the laboratory. Performance was evaluated and compared to an open-loop system.

3. Results

Over the course of the laboratory experiments the open loop control scheme could not deliver enough stimulation to cope with the increased moment around the ankle joint towards the end of flexion (fig 1). The closed-loop system detected this drift from the set angle and increased the stimulation intensity, progressively increasing the ankle angle towards the target angle.

Over 250 steps taken by each tested individual the fuzzy logic controlled stimulator performed better than

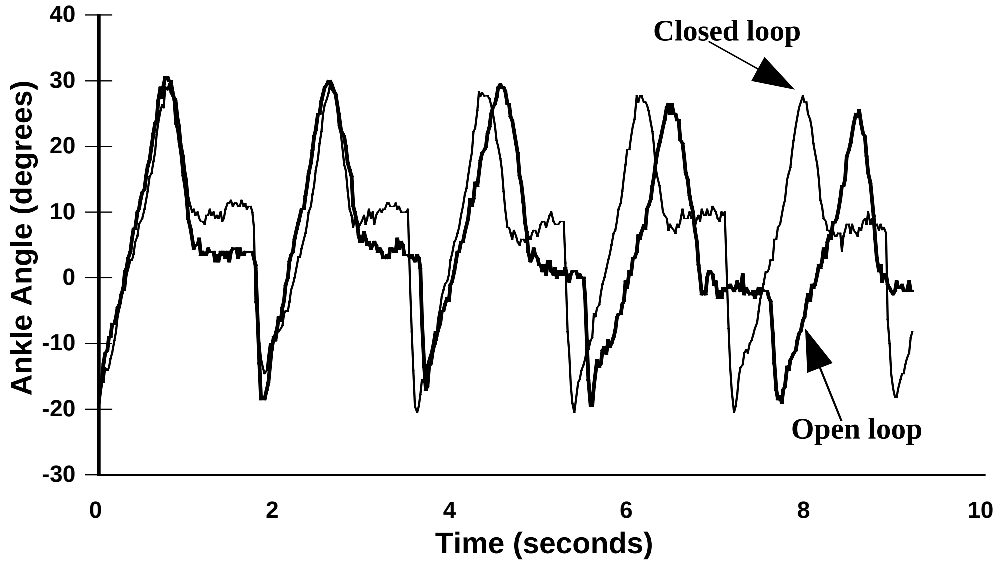

Figure 1 Ankle flexion angle profile recorded in a typical laboratory experiment. Open loop stimulator results are shown as the thick trace and closed loop (fuzzy-logic) results are shown by the thin trace.

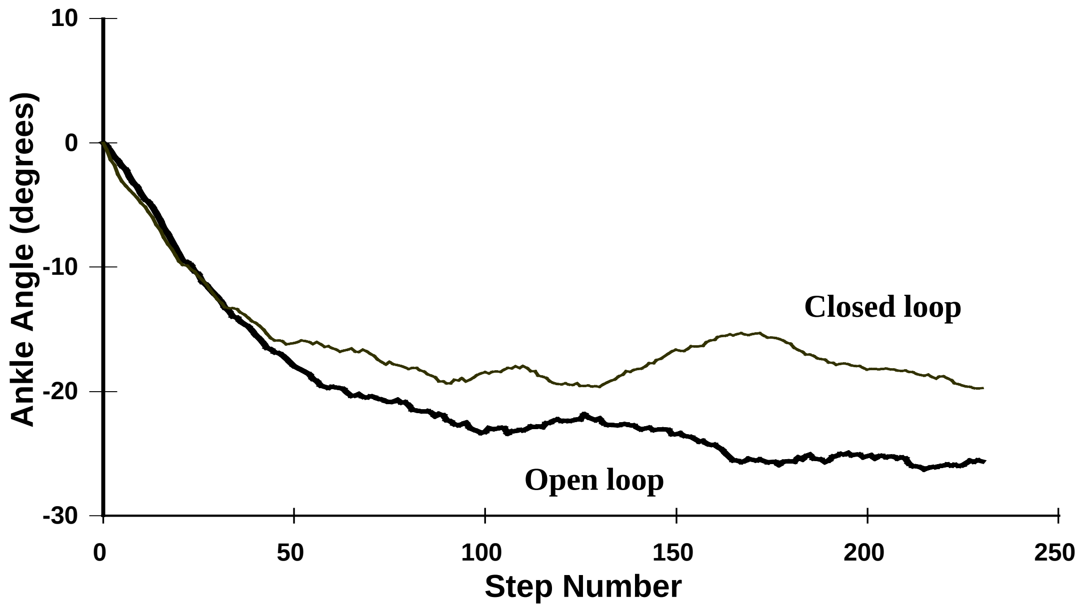

Figure 2 Absolute drift of the mean flexion angle over two laboratory sessions from the initial averaged value. Open loop stimulator results are shown as the thick trace and closed loop (fuzzy-logic) results are shown by the thin trace

the open loop controlled stimulator showing an increase in number of steps for which ground clearance was achieved (fig 2). There was also a reduction in step to step variability and improvements in the quality of foot ground contact, as determined insole foot switch pattern [3].

4. Discussion and Conclusion

The closed-loop control system was used by patients outside the laboratory in their own environment. This system had consistently better performance than an open-loop system both in and outside the laboratory. The miniature drop-foot stimulator achieved improved functional performance and was cosmetically better than traditional bulky open-loop systems. The main disadvantage of this closed-loop system was that it required additional hardware which reduced the overall system reliability.

References

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