

# Feasibility of the Cycle-to-Cycle Control Method in Controlling Swing Phase of FES-induced Hemiplegic Gait

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## Description:

Functional electrical stimulation (FES) has been utilized to restore gait in the patient with impairment of the central nervous system caused by the spinal cord injury or the stroke. Restoration of the paralyzed gait using FES needs a sophisticated control strategy. Although the trajectory-based closed-loop control has been developed, it has not been used yet in the clinical FES gait because of difficulties to result in accurate tracking performance. The cycle-to-cycle control delivers the electrical stimulation in the form of the open-loop control in a cycle of gait. The cycle-to-cycle regulations of the stimulation burst durations to achieve certain target joint angles seem to be easy to generate a successful gait. Considering other method of the closed-loop FES gait control, the cycle-to-cycle control method is a candidate.

In previous researches, the cycle-to-cycle control was not studied in a concrete framework of the closed-loop control. Its feasibility to control multi-joint movements has still not been explored clearly. Objective of this study was to test feasibility of the cycle-to-cycle control in controlling multi-joint movements of swing phase of FES gait.

In order to realize the cycle-to-cycle control, a concrete framework of the cycle-to-cycle control was developed through gait analysis and studies of the joint movements during gait and functions of the lower limb muscles. In order to compensate the non-linearity of the musculo-skeletal system responses, the cycle-to-cycle control was implemented using fuzzy controller. In this research, the electrically stimulated musculo-skeletal model and the motion equation for swing phase of gait was designed to evaluate the controller implementing the cycle-to-cycle control method. The motion equation was derived from the geometric diagram of the skeletal system model using the Lagrangian method.

The controlled joint angles were evaluated by comparing to the measured trajectories of the normal gait. The controlled joint angle trajectories were qualitatively acceptable and the controlled gait pattern shown in Figure 1 was not significantly different from the normal gait pattern. This result showed that the fuzzy controller would be effective in realizing the cycle-to-cycle control for multi-joint movements of FES gait.

In order to test design concept of the stimulation schedule for multi-joint control, five knowledge-based stimulation schedules and one EMG-based stimulation schedule were developed

and tested. Gait pattern of each stimulation schedule generated by computer simulation is shown in Figure 2. The stimulation schedule D is preferable to other stimulation schedules. The stimulation schedule A may also be accepted in clinical use. Although the gait patterns of the stimulation schedules C and E shown in Figure 2 were not so far from the normal gait pattern, these stimulation schedules should not be used in clinical application because the values of the minimum foot clearance were very small. The result showed that combination of the information of timing pattern of muscle activation and the knowledge about joint movements and muscle function would be necessary in design of the stimulation schedule for FES gait. The co-activation of the iliopsoas, the hamstrings and the vastus muscles at the beginning of swing phase and that of the tibialis anterior and the soleus at the end of swing phase were found to be effective in swing phase control.

The results of this research showed the cycle-to-cycle control to be feasible in controlling swing phase of FES-induced gait. The fuzzy controller was shown to be effective to implement the cycle-to-cycle control method. The cycle-to-cycle control realized in the fuzzy controller was expected to be tested clinically.

### Application:

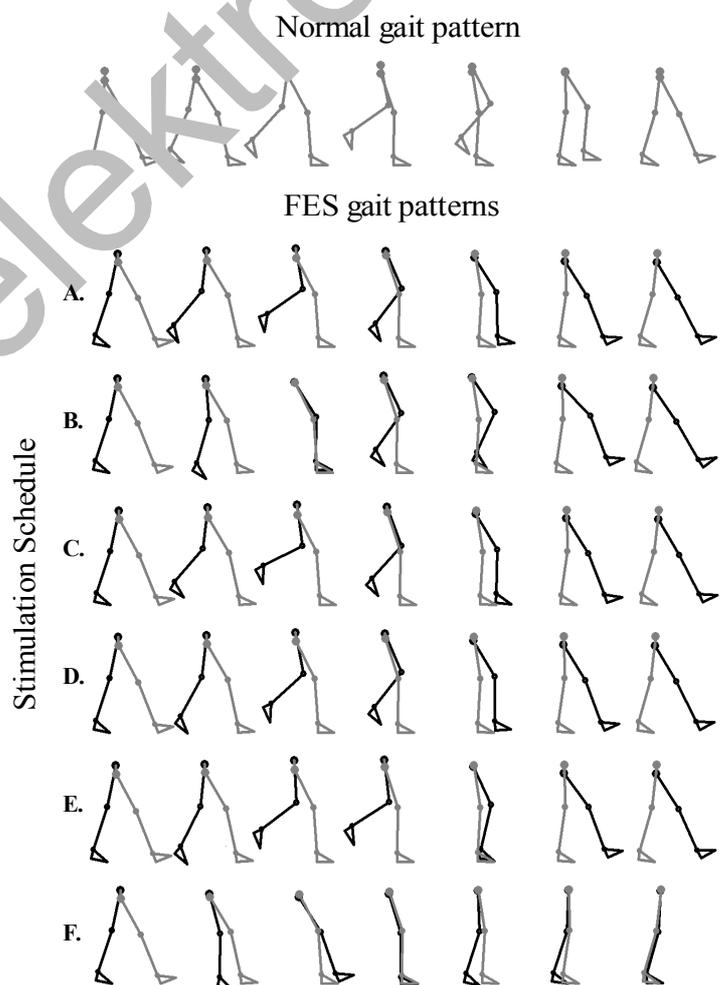
The cycle-to-cycle control method gait investigated in this research is applicable in restoration of functional movements of paralyzed subject after stroke or spinal cord injury using the functional electrical stimulation.

### Technological Predominance:

The cycle-to-cycle control is easy to implement in real application. Additionally, by using the fuzzy controller this method can compensate the non-linearity and time-variant of the responses of the electrically stimulated musculo-skeletal system and has fast response.



**Figure 1.** Stick picture of the controlled gait pattern (black) and the normal gait pattern (gray).



**Figure 2.** Gait pattern of each stimulation schedule. The black leg in the simulated FES gait is the controlled paralyzed swing leg, and the gray leg is the normal stance leg.