System Identification and Control of a Gait Trainer

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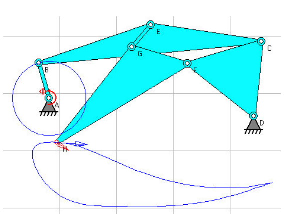
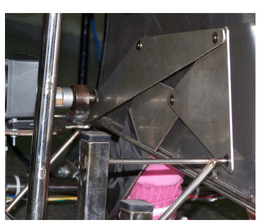
INTRODUCTION

This paper investigates the design and control of a gait trainer. In clinics, treadmills and gait trainers are frequently used to train proper gait trajectories for patients with cerebral palsy (CP). For example, Schindle [1] utilized partial body weight support for patients and observed performance improvement on their gait and motor ability. However, therapists are required to accompany the patients when using gait trainers. Therefore, in this paper we applied automatic control to a designed gait trainer in hope of relieving the working load of therapists. From a system point of view, the trainer is a nonlinear system. Therefore, delicate control algorithms should be applied to provide smooth system responses. The study was carried out in three phases. Firstly, a motor driven gait trainer was realized by a six-bar linkage such that the desired gait pattern can be described by time trajectories of the motor position. Secondly, system identification techniques were adopted to find linear transfer functions of the system at various operating points. Finally a time-varying controller was designed to provide smooth system responses. From both the simulation and experimental results, the gait trainer followed the desired pattern even when the load was changed.

METHODS

Using a mechanism simulation package, called *Roberts Animator*, a motor-driven six-bar linkage mechanism was designed (see Figure 1) to provide desired gait trajectories. Therefore, the gait paths can be described by the time trajectories of the motor position. The mechanical realization of the design is illustrated in Figure 2. With a fixed PD controller, the rotational responses of the motor are shown in Figure 3, in which the output responses did not follow the reference very well by tuning controller parameters. Besides, the tracking errors can be large if the load changed (i.e. used by different patients).





Fiigure 1. A six-bar linkage. Figure 2. Mechanical construction.

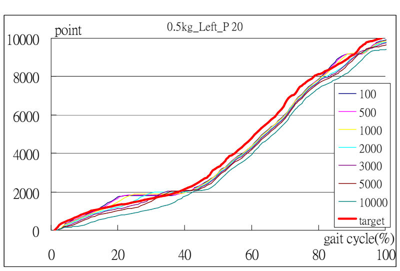


Figure 3. The responses of the motor.

It was noted that the gait trainer is a nonlinear system. Therefore, we built the model on Matlab/SimMechanicas™ and linearised it at four operation points, with the following transfer functions:

$$G_0(s)=\frac{1}{(s+0.3582)(s-0.3582)},\quad G_{90}(s)=\frac{1}{(s+0.1937i)(s-0.1937i)},$$
$$G_{180}(s)=\frac{1}{(s+0.1679)(s-0.1679)},\quad G_{270}(s)=\frac{1}{(s+0.2647)(s-0.2647)},$$

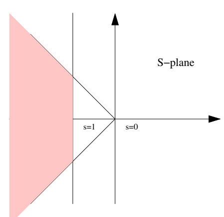
in which G_θ is the linear model of the system when the rotational degree of the motor is θ. We then designed corresponding PID controllers for the models. A PID controller can be represented as follows:

$$C(s)=K_p+\frac{K_I}{s}+K_D s=\frac{k(s+z_1)(s+z_2)}{s}.$$

Our design goal was to tune the controller parameters such that the closed-loop poles located in the shadowed area on the *s*-plane, as shown in Figure 5. Four controllers were designed as follows:

$$C_0(\mathrm{s})=\frac{s^2+8s+20}{s},\qquad C_{90}(\mathrm{s})=\frac{s^2+18s+101.25}{s},$$
$$C_{180}(\mathrm{s})=\frac{2s^2+8s+10}{s},\qquad C_{270}(\mathrm{s})=\frac{s^2+6s+20.25}{s},$$

where $C_\theta(s)$ is the corresponding controller for $G_\theta(s)$.



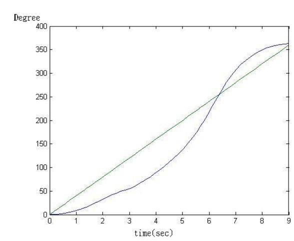


Figure 4. Closed-loop poles. Figure 5. The time responses.

RESULTS AND DISCUSSION

To implement the controllers, we then divided the control into four regions. That is, controller C_0 was applied when $\theta\in[-45^\circ,\ 45^\circ]$ and, similarly, C_0, C_0, and C_0 were applied when $\theta\in[45^\circ,\ 135^\circ]$, $\theta\in[135^\circ,\ 225^\circ]$, and $\theta\in[225^\circ,\ 315^\circ]$, respectively. Note that an extra pole was added to *C(s)*'s to make them proper. The time responses of the motor angle are shown in Figure 5.

CONCLUSION

In this paper, a nonlinear gait trainer was designed and modeled at four operating points. Then a time-varying PID controller was implemented to provide satisfied performance for the system. From the results, it was shown that the proposed controller deemed effective.

REFERENCES

1. Schindl MR wt al. Arch Phys Med Rehabil 2000;81(3):301-6.
2. Norman, KE et al. Arch Phys Med Rehabil **76**(8): 772-8.