THE INFLUENCE OF HIP JOINT STIFFNESS ON CRUTCH SUPPORTED PARAPLEGIC STANDING - A MODELLING STUDY

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Abstract – In this study, the use of hip joint stiffness to control crutch supported paraplegic stance was investigated. A model was made and simulations were performed. Currently experiments are performed to validate the modelling results.

MODEL

A 2 dimensional 2 link segment model was made of crutch supported paraplegic standing (fig. 1) [1]. The crutches were modelled as a massless link, putting a position constraint on the shoulder. This resulted in a system with only one degree of freedom. Important parameters are the crutch length d_3 , the crutch to foot distance R_1 , segment angles ϕ_1 and ϕ_2 and hip joint angle ϕ_{hip} . Inputs are external torques applied around ankle and hip, T_1 and T_2 respectively. It was investigated what hip stiffness was required to stabilize posture in statical and dynamical situations for various system parameters.

Fig. 1: model of crutch supported standing

METHODS

In the statical analyses, equilibrium postures for different values of R_1 , d_3 and hip stiffness K_S were determined [1].

In the dynamical analyses, also damping was used. Damping gain K_D was chosen such that a relative damping of 0.7 was to be expected based on a small signal analysis. Balance was perturbed by applying a pulse shaped external torque $T_{2,ext}$ to the hip joint. The following analyses were performed:

- Determination of maximum hip torque disturbance to be applied before instability occurred
- Studying stabilization after perturbations for various values of R_1 , d_3 and K_S and K_D .

RESULTS

From the statical analysis it could be seen that for stiffness over 80 [Nm/rad], stable postures were found. Increasing R_1 led to increased arm forces exerted on the crutches.

Figure 2 gives dynamic responses of the hip joint angle ϕ_{hip} for various disturbance torques, in both directions. In this simulation, $K_S = 100$ [Nm/rad] and $K_D = 20$ [Nms/rad].

Fig. 2: ϕ_{hip} as a function of time for various values of hip flexion torques (a) and hip extension torques (b)

Figure 3 gives the maximum disturbances that could be applied to the system before instability occurred, for disturbance in flexion and extension direction. The dotted line represents the disturbance boundaries for the situation plotted in figure 2.

Fig. 3: disturbance boundaries in flexion and extension direction

CONCLUSIONS AND FUTURE WORK

From the dynamical analysis it could be concluded that using higher stiffnesses, stability is better controlled against disturbances. Also, more disturbance in extension direction can be applied than in flexion direction. Modelling results suggest that applying increased hip joint stiffness stable crutch supported paraplegic standing can be achieved. However, for functional applications, too high hip stiffness decreases freedom of movement.

Experiments are currently being performed in which the hip joint stiffness has been realized by placing a spring with a particular spring constant over the subject's hip joint. During perturbation trials, the feasibility of using hip stiffness to control stance is studied, and results are compared with modelling predictions.

REFERENCES

- [1] Van der Spek, J.H., van der Maas, M.C., Veltink, P.H., "Control of crutch supported standing in paraplegics – a model based study", *Proceedings of the international Biomechatronics Workshop* (1999), pp. 162 - 167

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