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A Human Walking Simulator with Reflexive Responses to Perturbation and Its Evaluation

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Abstract

Most walking assist systems reported are not ready for using in real-world environment; where there are frequent perturbations .Our ultimate goal is to realize artificial reflexes to real-world walking support systems. This goal needs both qualitative and quantitative understanding of human reflexive mechanism. In this study we built a human walking simulator consisting of a Central Pattern Generator (CPG) module, and a reflexive mechanism. As the reflexive mechanism, we used reflexive muscle responses together with a CPG-phase-modulation. Results showed that, the reflexive mechanism could improve the perturbation-resistance for the simulated walker. Also we suggest a quantitative evaluation of reflexive responses by using the rotational energy of lower limbs.

1. Introduction

Recently, walking assist systems, such as robotics system and Functional Electrical Stimulation (FES) for hemiplegic's walking, have been widely studied, for purpose of improving Activity of Daily Living (ADL) for paralyzed people. However, most of the systems couldn't deal with the perturbation resulted from uneven terrain, slips, slopes and obstacles. Our ultimate goal is to realize artificial reflexes to real-world walking support systems for those paralyzed people, whose reflexive system was also impaired to a certain degree. This goal needs both qualitative and quantitative understanding of human reflexive mechanism during walking. In our previous work [1], we built a walking simulator consisting of a Central Pattern Generator (CPG) module that could generate a bipedal locomotion conformable to human normal walking.

In this paper, we report our research effort to construct a rapid responding pathway by using muscle activity profiles of reflexive muscle responses acquired from a human gait experiment, together with a CPG-phase-modulation mechanism, that is the neuro-mechanism of the simulation model. Also we suggested a quantitative evaluation of reflexive responses by using the rotational energy of lower limbs.

2. Simulation Model

The CPG was constructed as coupled neural oscillators, each of which is expressed by a set of simultaneous differential equations. Neurons innervating lower limb muscles were mutually coupled and their oscillations were entrained to each other and the skeletal system controlled by the nervous system presented coordinated motion (Fig.1). By the *feedback* from the skeletal model, the interaction between internal neuro-musculo-skeletal system and external world could be expressed in the model.

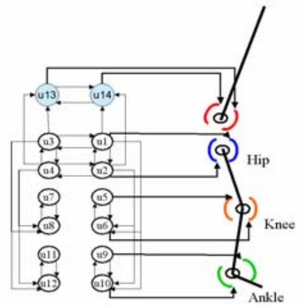


Fig. 1 The neuron-neuron and neuron-link connections

Fig.2 shows the composition of the simulation model. In order to realize the reflexive mechanism to the simulator, the following 3 points, that is, 3 aspects of the reflexive function should be determined: 1) Spatial aspect (the muscles that should be activated). 2) Temporal aspect (the onset time and the interval of muscle activation): They are decided by the result of the measurement experiment or optimal search in computer simulation experiment. 3) Relation with CPG output: the CPG output was cutoff by reflexive activation. The CPG stops oscillation, so that after the reflexive activation, the phase would be the same as that before the reflexive activation (called CPG-phase-modulation).

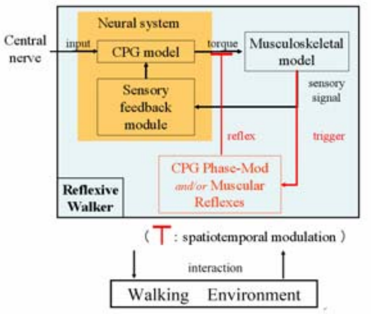


Fig. 2 The composition of the simulation model

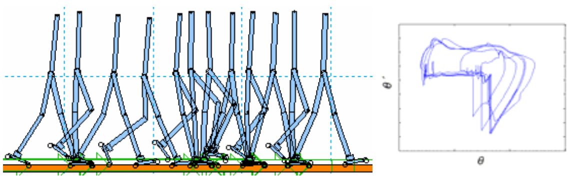
3. Result

Table 1 shows the results of perturbed walking. The "reset time" means the time that CPG-phase-modulation carried out after the perturbation occurs. The balance-recovery is improved by the reflexive mechanism. It is observed that different effective reset times occur for different slip's duration.

Fig. 3(a) shows the walker's perturbation resistant process. At first, to prevent from falling backwards the walker uses the rear leg to support its weight. This is observed in human gait experiment. Fig. 3(b) shows the phase portrait of the walker's thigh. As shown in the figure, after the perturbation occurred, the trajectory deviated slightly from that of normal walking but returned to normal quickly.

Table. 1 Balance recovery when reset-time changes
(O: recover / ×: fall)

slip duration(s) \ reset time(s)	0.1	0.12	0.14	0.16	0.18	0.2	0.22	0.24	0.26	0.28	0.3	0.32	0.34	0.36	0.38	0.4	0.42	0.44	0.46	0.48	0.5	0.52	0.54	0.56	0.58
0.1	O	O	O	O	O	O	O	O	×	×	×	×	×	×	×	×	×	×	×	×	×	O	O	×	O
0.125	O	O	O	O	O	O	O	O	O	O	×	×	×	×	×	×	×	×	×	×	O	×	×	O	×
0.15	×	×	×	×	×	O	O	O	O	O	O	O	O	O	×	O	×	×	×	×	×	O	×	×	×
0.175	×	×	×	×	×	×	×	×	×	×	O	O	O	O	O	O	O	O	O	×	×	×	×	O	×
0.2	×	×	O	×	×	×	×	×	×	×	×	×	×	×	×	×	O	O	O	O	O	O	×	×	×
0.225	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	O	O	O	O	O	O	O
0.25	O	O	×	×	O	O	O	O	O	O	×	O	×	O	×	×	×	×	×	×	×	×	×	×	×
0.275	O	O	O	O	O	O	O	O	O	O	×	O	O	O	O	O	O	×	×	O	O	×	×	×	×
0.3	O	×	×	O	O	×	×	O	O	O	O	O	×	×	×	×	×	×	×	×	×	×	×	O	O
0.325	×	×	×	O	O	O	×	O	×	O	×	O	×	×	×	×	×	×	×	×	×	×	×	×	×



(a) Stick graph of the walker (b) the phase portrait of thigh
Fig. 3 Walker can recover when 0.3s slip-perturbation occurs

In Table 1, a qualitative evaluation of balance-recovery was employed. However, the o/× evaluation could not reflect the difference between the same "fall" or "recovered" cases. In order to realize the quantitative evaluation, we used a difference of rotational energy in swing phase between perturbed and normal walking (called Energy Difference, ED, see Eq.1). After slip, it is observed that at the end of the swing phase the rotational energy is less (especially in the shin) than that in normal walking. (Fig. 4)

$$ED_i = \frac{1}{2} I\omega_{perturbed}{}^2 - \frac{1}{2} I\omega_{normal}{}^2,\ i = \begin{cases} 1: thigh \\ 2: shin \end{cases} \qquad (1)$$

Fig. 5 shows a total ED of two walking cycles after slip with different reset time in case of 0.15s slip. The possibility to fall is high if this value is small. Thus this result suggests that reset time of 0.4s is effective for this case.

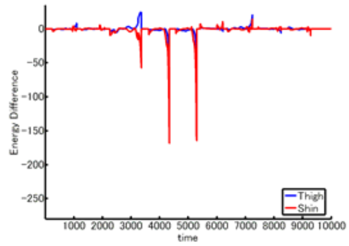


Fig. 4 A difference of rotational energy between perturbed and normal walk (ED) (0.15s slip, reset-time 0.2s case)

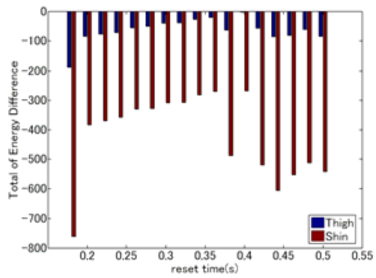


Fig.5 Total of Energy Difference within two walking cycle

4. Conclusion

In this study, we built a simulated walker, and through computer simulation, we showed that 1) On the occurrence of a slip-perturbation, together with the CPG-phase-modulation, the rapid muscular response could improve a perturbation-resistance and maintain balance for the simulated walker; 2) Quantitative evaluation of reflexive mechanism is possible by using the rotational energy of lower limbs. The data obtained in this paper may be of further use in realizing the artificial reflexes to help the paralyzed people.

Acknowledgements

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References

[1] W.Yu(2006): An Artificial Reflex Improved the Perturbation-Resistance of a Human Walking Simulator. World Congress of Biomedical Engineering (Seoul).