A nonlinear model for identifying human-exoskeleton coupling parameters in lower extremities

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Abstract. In this paper, a nonlinear human-exoskeleton coupling dynamics model is proposed for identifying the human-exoskeleton coupling parameters. The accuracy of the new model is verified by the coupling forces predicted by the human-exoskeleton coupling parameters. We recruited 10 adult male and 10 adult female volunteers (Age: 25 ± 4, Height: 168 ± 14mm, Weight: 73.85 ± 28.30 kg) to participate in the experiment. In contrast to the linear parameter identification method, the result of experiment has verified that the nonlinear model is more widely applicable in different human-machine coupling situations.

Introduction

In the study of the existing exoskeleton systems, many researches assume that the lower limb exoskeletons can perfectly track human gait[1]. This presumption ignores the human-exoskeleton coupling effect that can affect the comfort of the wearer. The human-exoskeleton coupling effect is very critical for the comfort of wearing exoskeletons. Thus in our previous study, a new human-exoskeleton coupling model is proposed in literature[2] to study the human-exoskeleton coupling effect. This exoskeleton model abandons the user-defined virtual coefficients and replaces them with the damping and stiffness of physical lower limbs as control parameters. Our study[2] has demonstrated the reliability of the linear model. However, further studies reveal that the asymmetry of the coupling force is ignored, and the accuracy of the linear model will decrease significantly in the scenarios of slack coupling in the linear model. To address these issues, we refine the model through adding nonlinear factors into the model.

Results and discussion

Out of the experiments, two typical sets of coupling force predicted by human-exoskeleton coupling model are displayed in Fig. 1. It is seen that both the linear and nonlinear model yield good predictions of the coupling force in Fig. 1(b). However, in Fig. 1(a) which the coupling between human and exoskeleton is very slack the differences in predicted coupling force between the two models emerge. The linear model has poor accuracy, but the nonlinear model is still very reliable in this case. In practical applications, it is a common phenomenon that individual differences in wearers could lead to a different coupling situation. Our further research has found that the human-machine coupling parameters vary in different human-machine coupling situations. Changes in human-machine coupling parameters will result in the changes in human-machine interaction force which is critical for users' feelings. This is why we modified the linear model of human-exoskeleton coupling proposed in our previous study[2].

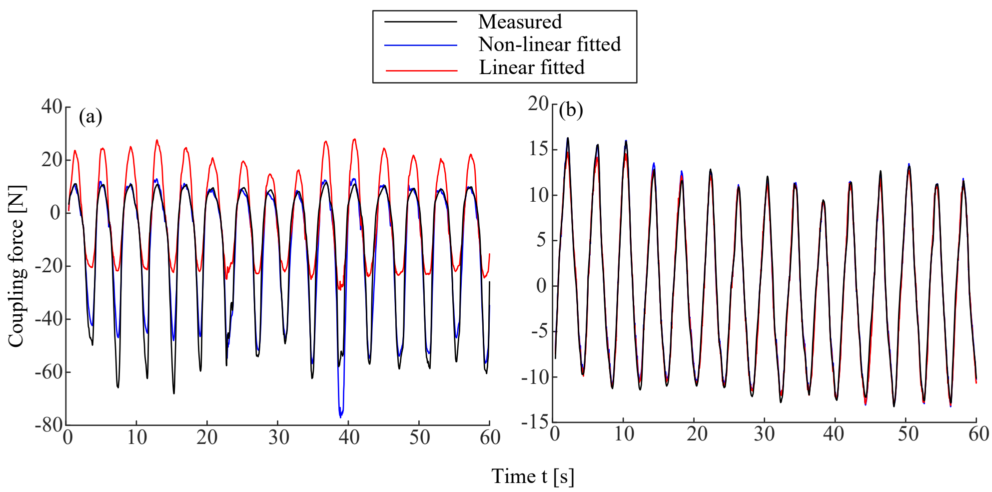

Figure 1: Measured coupling force (black line) and fitted coupling force separately predicted by linear (red line) and nonlinear model (blue line) with different coupling situations: (a) coupling is slack and (b) coupling is tight.

References

[1] S. Glowinski, T. Krzyzynski, A. Bryndal, and I. Maciejewski (2020) A kinematic model of a humanoid lower limb exoskeleton with hydraulic actuators. *Sensors* **20**:6616.

[2] Y. Yan, Z. Chen, C. Huang, L. Chen, and Q. Guo (2022) Human-exoskeleton coupling dynamics in the swing of lower limb. *Applied Mathematical Modelling* **104**:439-454.