Yi LONG, Zhi-jiang DU, Wei-dong WANG, Long HE, Xi-wang MAO, Wei DONG, 2018. Physical human-robot interaction estimation based control scheme for a hydraulically actuated exoskeleton designed for power amplification. *Frontiers of Information Technology & Electronic Engineering*, 19(9):1076-1085.
https://doi.org/10.1631/FITEE.1601667

Physical human-robot interaction estimation based control scheme for a hydraulically actuated exoskeleton designed for power amplification

Key words: Exoskeletonl; Physical human-robot interaction; Torque sensor; Human gait; Kalman smoother

Corresponding author: Wei Dong
E-mail: dongwei@hit.edu.cn
ORCID: http://orcid.org/0000-0001-6576-5555

Motivations

Human-exoskeleton interaction signals can be measured by biomedical or mechanical sensors. The measured signals can be used to estimate the human gait trajectories.

In this study, torque sensors mounted on the exoskeleton links are proposed for directly obtaining physical human-robot interaction (pHRI) torque information. A Kalman smoother is adopted for eliminating noise and smoothing the signal data.

1. Using the torque sensor to measure physical human robot interaction force

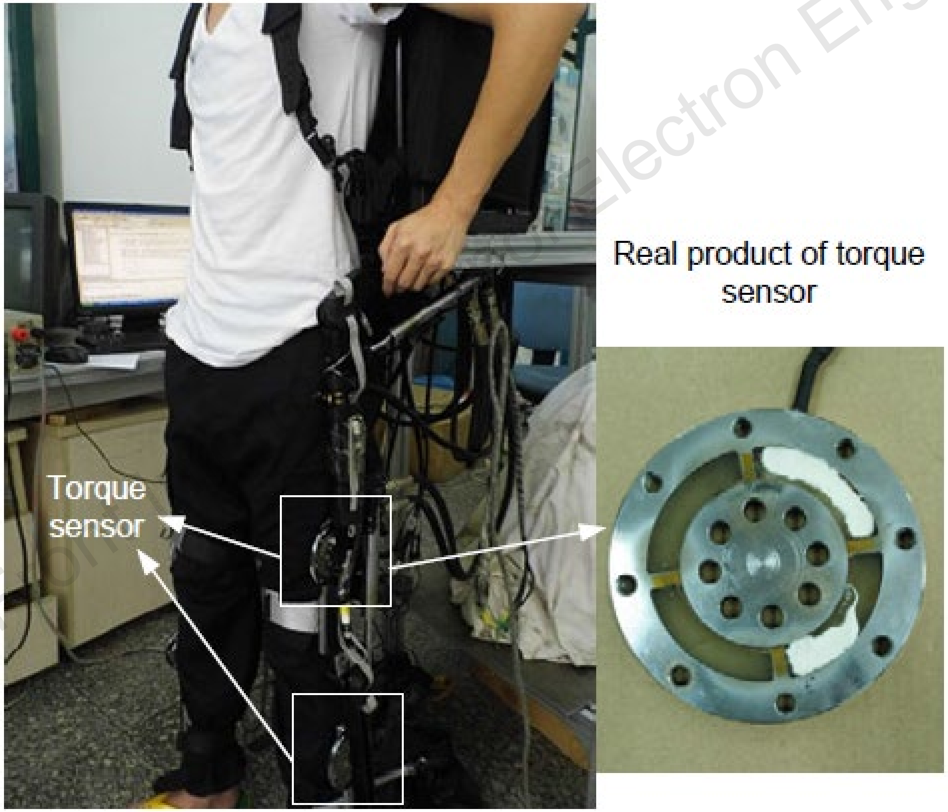
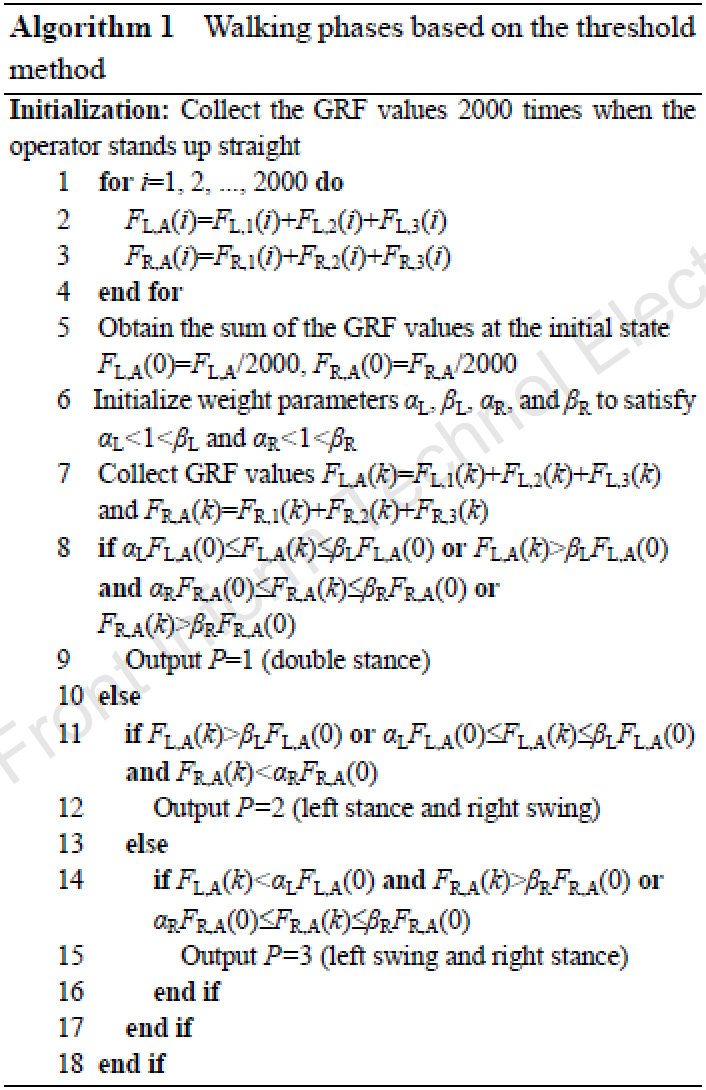


Fig. 3 Diagram of torque sensor placements on the lower limb

2. Mapping between pHRI and human gait



Algorithm 1 Walking phases based on the threshold method

Initialization: Collect the GRF values 2000 times when the operator stands up straight

```
for $i$=1, 2, ..., 2000 do
    $F_{\mathrm{L,A}}(i)=F_{\mathrm{L,1}}(i)+F_{\mathrm{L,2}}(i)+F_{\mathrm{L,3}}(i)$
    $F_{\mathrm{R,A}}(i)=F_{\mathrm{R,1}}(i)+F_{\mathrm{R,2}}(i)+F_{\mathrm{R,3}}(i)$
end for
Obtain the sum of the GRF values at the initial state
    $F_{\mathrm{L,A}}(0)=F_{\mathrm{L,A}}/2000$, $F_{\mathrm{R,A}}(0)=F_{\mathrm{R,A}}/2000$
Initialize weight parameters $\alpha_{\mathrm{L}}$, $\beta_{\mathrm{L}}$, $\alpha_{\mathrm{R}}$, and $\beta_{\mathrm{R}}$ to satisfy
    $\alpha_{\mathrm{L}}<1<\beta_{\mathrm{L}}$ and $\alpha_{\mathrm{R}}<1<\beta_{\mathrm{R}}$
Collect GRF values $F_{\mathrm{L,A}}(k)=F_{\mathrm{L,1}}(k)+F_{\mathrm{L,2}}(k)+F_{\mathrm{L,3}}(k)$
    and $F_{\mathrm{R,A}}(k)=F_{\mathrm{R,1}}(k)+F_{\mathrm{R,2}}(k)+F_{\mathrm{R,3}}(k)$
if $\alpha_{\mathrm{L}}F_{\mathrm{L,A}}(0)\le F_{\mathrm{L,A}}(k)\le\beta_{\mathrm{L}}F_{\mathrm{L,A}}(0)$ or $F_{\mathrm{L,A}}(k)>\beta_{\mathrm{L}}F_{\mathrm{L,A}}(0)$
    and $\alpha_{\mathrm{R}}F_{\mathrm{R,A}}(0)\le F_{\mathrm{R,A}}(k)\le\beta_{\mathrm{R}}F_{\mathrm{R,A}}(0)$ or
    $F_{\mathrm{R,A}}(k)>\beta_{\mathrm{R}}F_{\mathrm{R,A}}(0)$
    Output $P$=1 (double stance)
else
    if $F_{\mathrm{L,A}}(k)>\beta_{\mathrm{L}}F_{\mathrm{L,A}}(0)$ or $\alpha_{\mathrm{L}}F_{\mathrm{L,A}}(0)\le F_{\mathrm{L,A}}(k)\le\beta_{\mathrm{L}}F_{\mathrm{L,A}}(0)$
        and $F_{\mathrm{R,A}}(k)<\alpha_{\mathrm{R}}F_{\mathrm{R,A}}(0)$
        Output $P$=2 (left stance and right swing)
    else
        if $F_{\mathrm{L,A}}(k)<\alpha_{\mathrm{L}}F_{\mathrm{L,A}}(0)$ and $F_{\mathrm{R,A}}(k)>\beta_{\mathrm{R}}F_{\mathrm{R,A}}(0)$ or
            $\alpha_{\mathrm{R}}F_{\mathrm{R,A}}(0)\le F_{\mathrm{R,A}}(k)\le\beta_{\mathrm{R}}F_{\mathrm{R,A}}(0)$
            Output $P$=3 (left swing and right stance)
        end if
    end if
end if
```

3. The control architecture

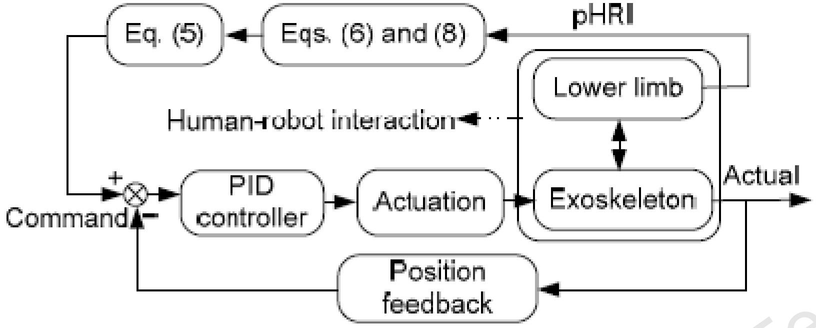


Fig. 5 Control diagram for the exoskeleton

The outside loop obtains the joint trajectory from the torque signal; the inner loop is to control the exoskeleton to follow the joint trajectory

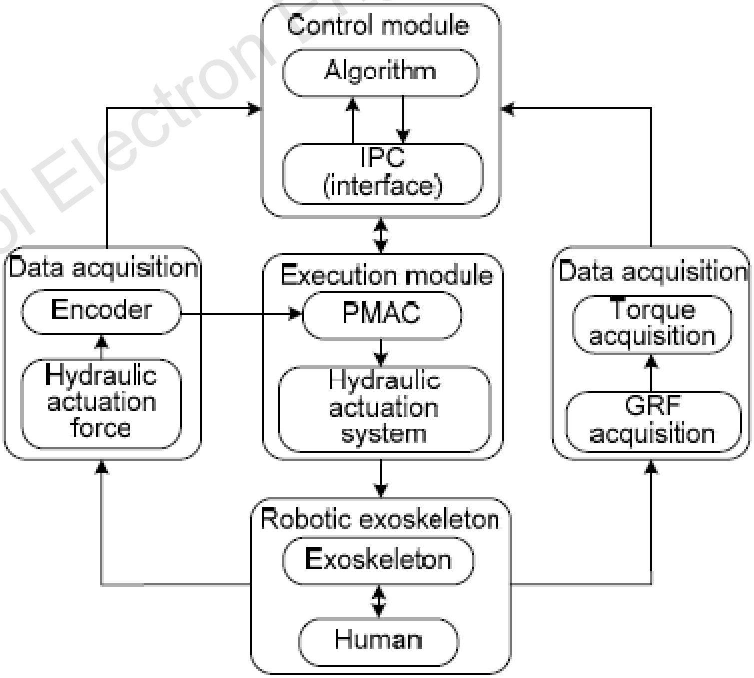


Fig. 6 Modularized structure of the control software

Experiment results

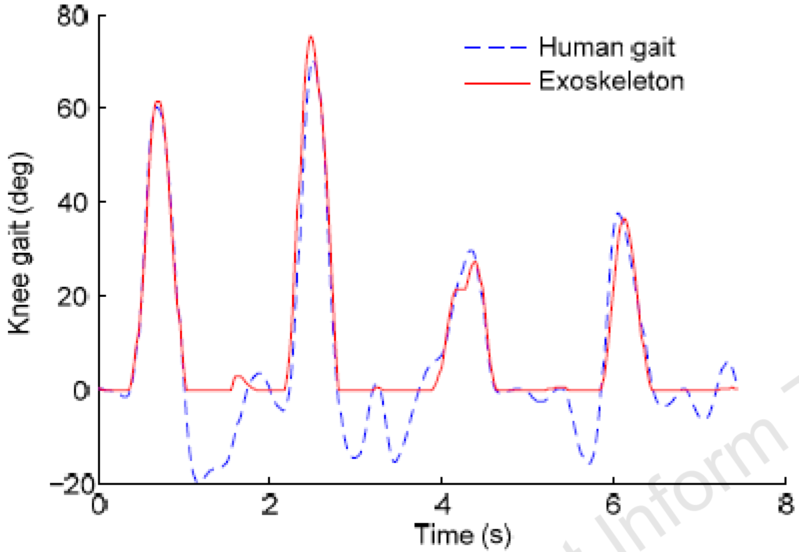


Fig. 10 Human gait trajectory in tracking the knee joint

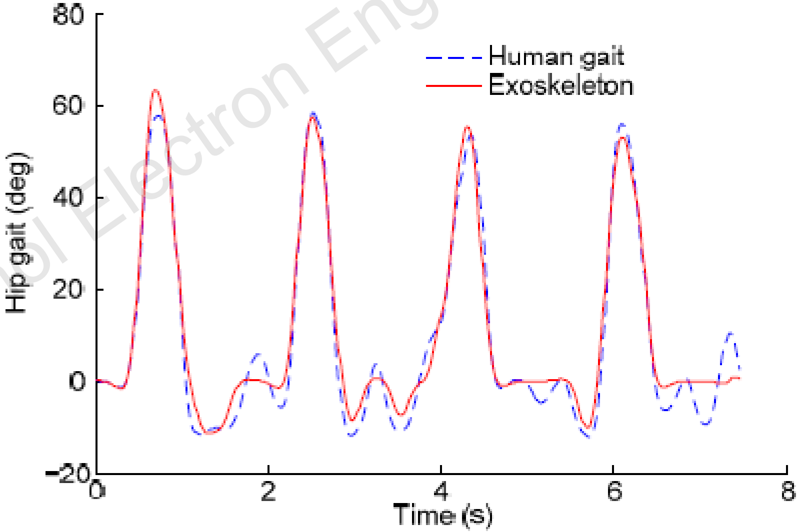


Fig. 11 Human gait trajectory in tracking the hip joint

Conclusions

1. A one-dimensional torque sensor has been used to measure the HRI between the wearer and the exoskeleton in the sagittal plane. A mapping for HRI to the human gait has been defined according to a real application.

2. A simple identification algorithm for the walking phase has been proposed to construct the state machine for the control scheme. This study provides an alternative method for developing a lower extremity exoskeleton for power amplification.