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

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

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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

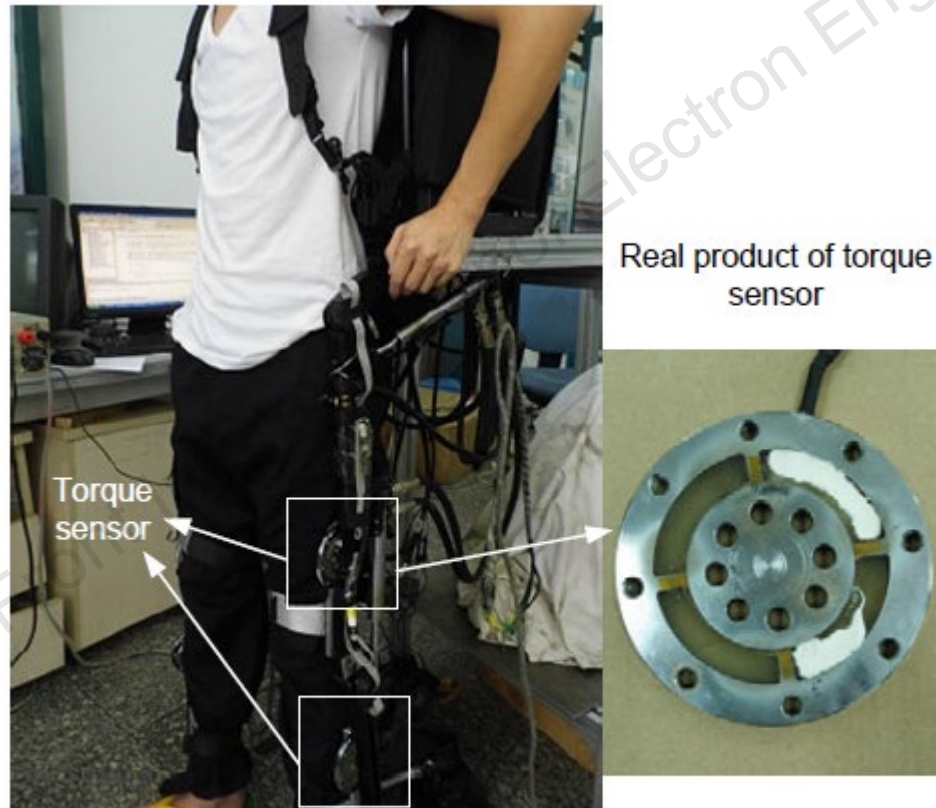


Fig. 3 Diagram of torque sensor placements on the lower limb

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

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1  for  $i=1, 2, \dots, 2000$  do
2     $F_{L,A}(i)=F_{L,1}(i)+F_{L,2}(i)+F_{L,3}(i)$ 
3     $F_{R,A}(i)=F_{R,1}(i)+F_{R,2}(i)+F_{R,3}(i)$ 
4  end for
5  Obtain the sum of the GRF values at the initial state
    $F_{L,A}(0)=F_{L,A}/2000, F_{R,A}(0)=F_{R,A}/2000$ 
6  Initialize weight parameters  $\alpha_L, \beta_L, \alpha_R,$  and  $\beta_R$  to satisfy
    $\alpha_L < 1 < \beta_L$  and  $\alpha_R < 1 < \beta_R$ 
7  Collect GRF values  $F_{L,A}(k)=F_{L,1}(k)+F_{L,2}(k)+F_{L,3}(k)$ 
   and  $F_{R,A}(k)=F_{R,1}(k)+F_{R,2}(k)+F_{R,3}(k)$ 
8  if  $\alpha_L F_{L,A}(0) \leq F_{L,A}(k) \leq \beta_L F_{L,A}(0)$  or  $F_{L,A}(k) > \beta_L F_{L,A}(0)$ 
   and  $\alpha_R F_{R,A}(0) \leq F_{R,A}(k) \leq \beta_R F_{R,A}(0)$  or
    $F_{R,A}(k) > \beta_R F_{R,A}(0)$ 
9    Output  $P=1$  (double stance)
10 else
11   if  $F_{L,A}(k) > \beta_L F_{L,A}(0)$  or  $\alpha_L F_{L,A}(0) \leq F_{L,A}(k) \leq \beta_L F_{L,A}(0)$ 
   and  $F_{R,A}(k) < \alpha_R F_{R,A}(0)$ 
12     Output  $P=2$  (left stance and right swing)
13   else
14     if  $F_{L,A}(k) < \alpha_L F_{L,A}(0)$  and  $F_{R,A}(k) > \beta_R F_{R,A}(0)$  or
    $\alpha_R F_{R,A}(0) \leq F_{R,A}(k) \leq \beta_R F_{R,A}(0)$ 
15       Output  $P=3$  (left swing and right stance)
16     end if
17   end if
18 end if
```

3. The control architecture

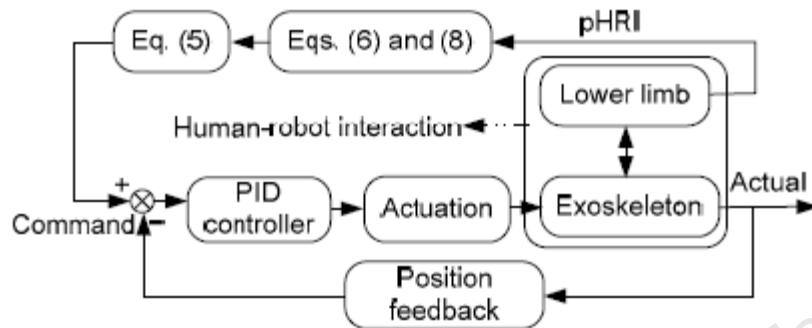


Fig. 5 Control diagram for the exoskeleton

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

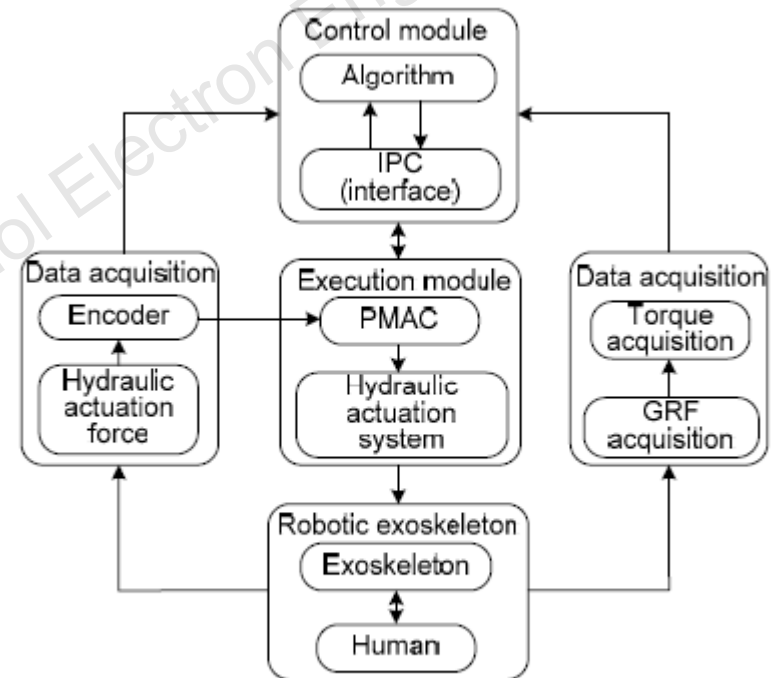


Fig. 6 Modularized structure of the control software

Experiment results

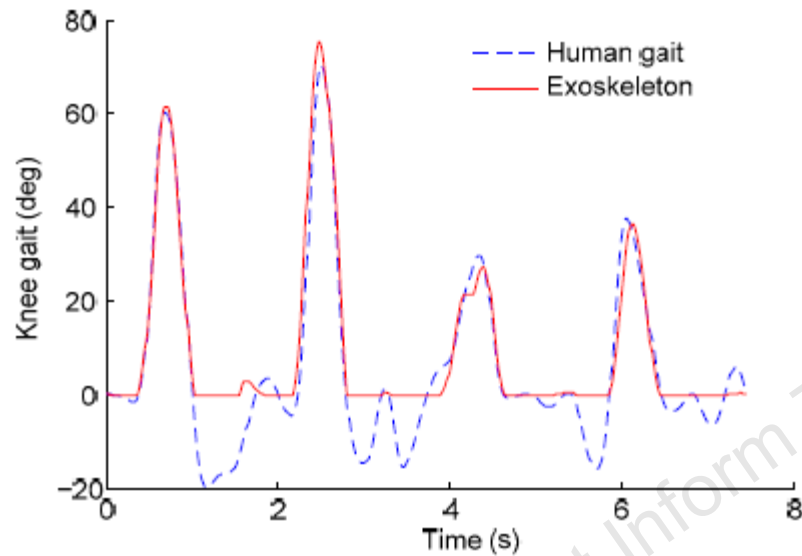


Fig. 10 Human gait trajectory in tracking the knee joint

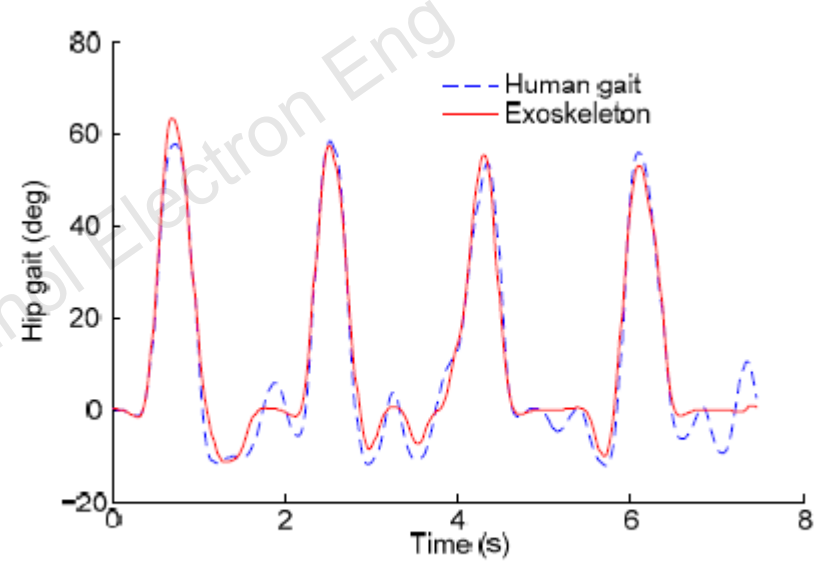


Fig. 11 Human gait trajectory in tracking the hip joint

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.