Adaptive Position Anticipation in a Support Robot for Overground Gait Training Enhances Transparency

Christophe Everarts[1], Heike Vallery[2,3,4], Marc Bolliger[5] and Renaud Ronsse[1]

[1]Center for research in Mechatronics; Institute of Mechanics, Materials, and Civil Engineering; Université catholique de Louvain; Belgium
[2]Department of BioMechanical Engineering; Delft University of Technology; The Netherlands
[3]Sensory-Motor Systems (SMS) Lab; ETH Zurich; Switzerland
[4]Department of Biomedical Engineering; Khalifa University of Science; UAE
[5]Spinal Cord Injury Center; Balgrist University Hospital; Switzerland

Introduction

Better performance in rehab robots if the patient is left with the capacity to influence the robot trajectory.

➔Rehabilitation robots being developed nowadays rely on force and/or impedance control.

The simplest mode of force control is when the robot has to be transparent (often used as a testbed).

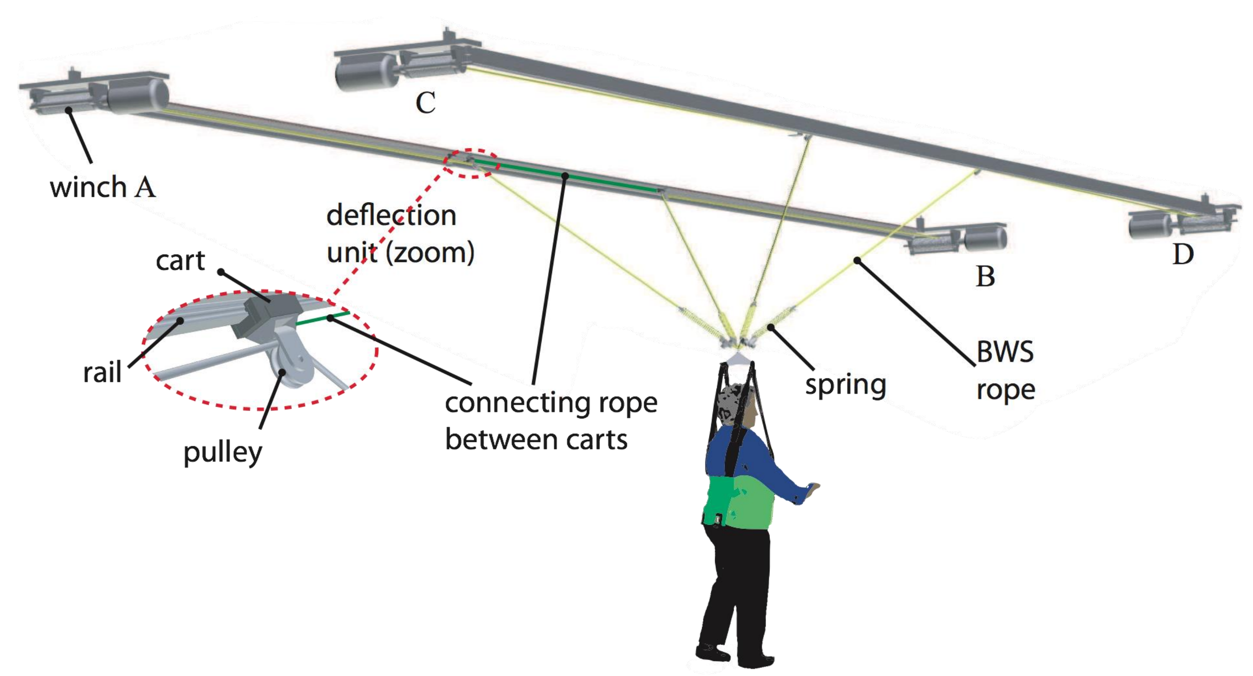
This contribution proposes a method to improve transparency on a support robot for overground training. The method consists in:

- learning the patient's movement by using adaptive oscillators
- Anticipate its future evolution in order to synchronize the robot movement.

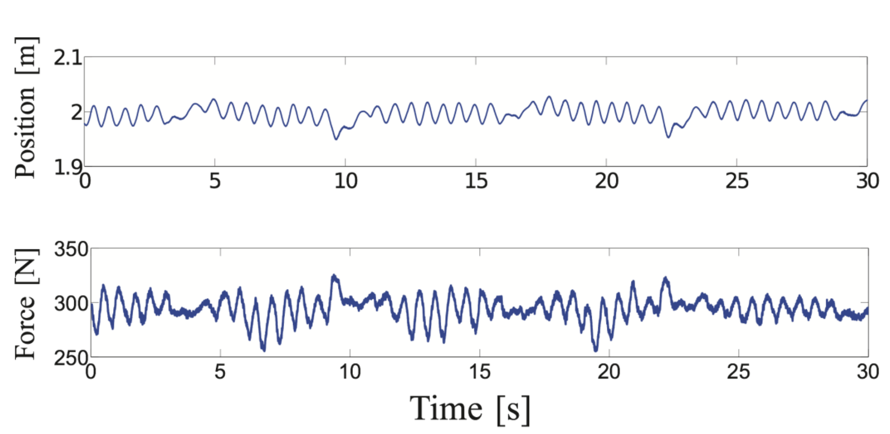
In experiments with human subjects walking in the gait support robot FLOAT, this method can decrease the undesired oscillations of the support force applied to the human user by up to 50%.

FLOAT

The robot used in this study is called FLOAT.



This robot can provide a vectorial (3D) force to support a human during walking. The robot controls force on the node in Cartesian space by means of a proportional-integral force controller.



In the current implementation, force control performance in vertical direction needs to be improved:

- Undesired fluctuating interaction forces with a magnitude up to 40 N acting on the subject.

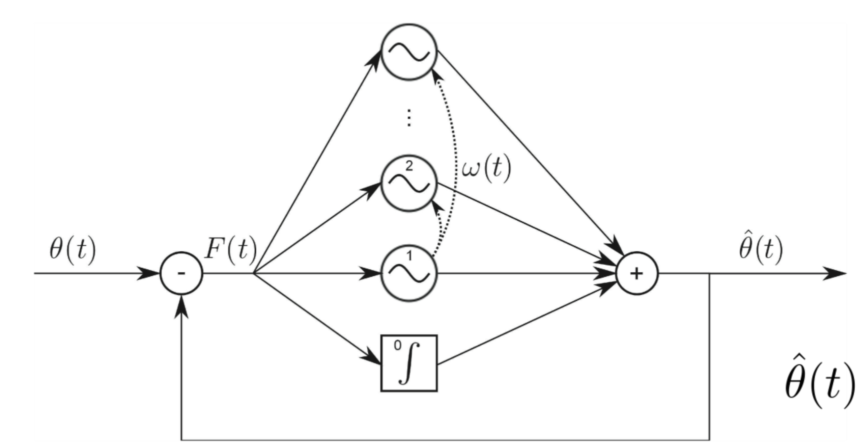
Undesired forces are the result of the robot (hardware + software) impedance in response to human movement. It is almost periodic in Z direction

→ Learning with an adaptive oscillator.

The method proposed here to increase the robot transparency requires to add predictive components to the existing PI force controller:

- *The predictive layer:* predicts the future position of the node with an estimator.
- *The equilibrium layer:* calculates the winch positions required to apply the reference force on the node, considering a static equilibrium for a given position (the predicted one).
- *The position control layer:* is a proportional-gain position controller giving reference forces to reach the winch positions calculated in the second layer.

Adaptive oscillators

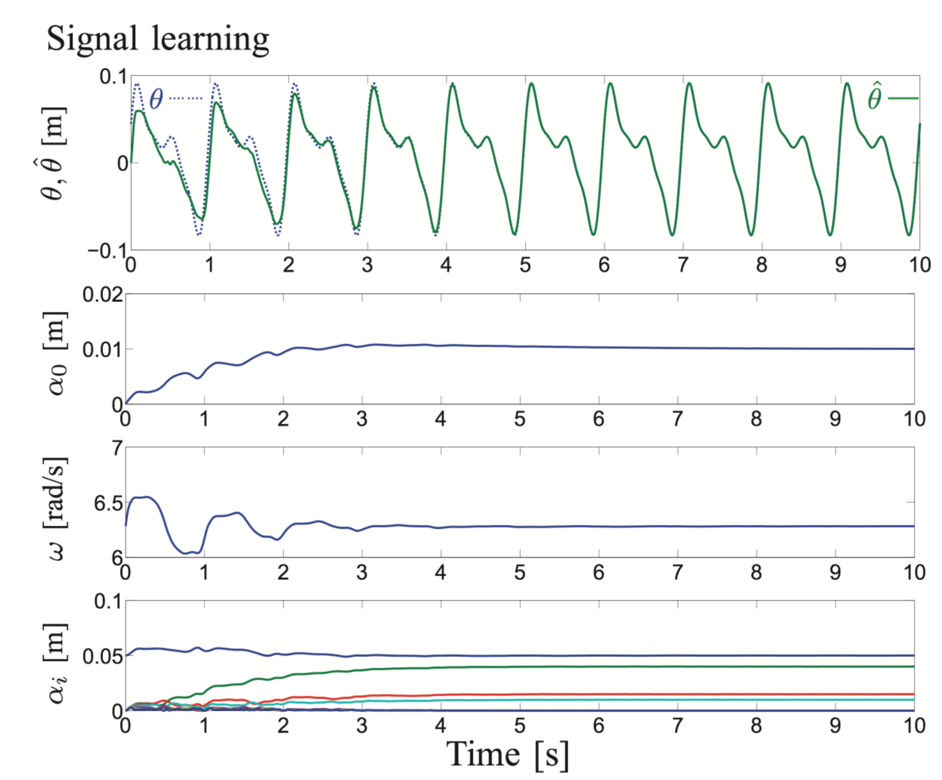


$$\begin{aligned}\dot{\phi}_i(t) &= i\omega(t) + \nu_\phi \frac{F(t)}{\sum_i \alpha_i(t)} \cos\phi_i(t)\\ \dot{\omega}(t) &= \nu_\omega \frac{F(t)}{\sum_i \alpha_i(t)} \cos\phi_1(t)\\ \dot{\alpha}_i(t) &= \eta F(t) \sin\phi_i(t)\end{aligned}$$

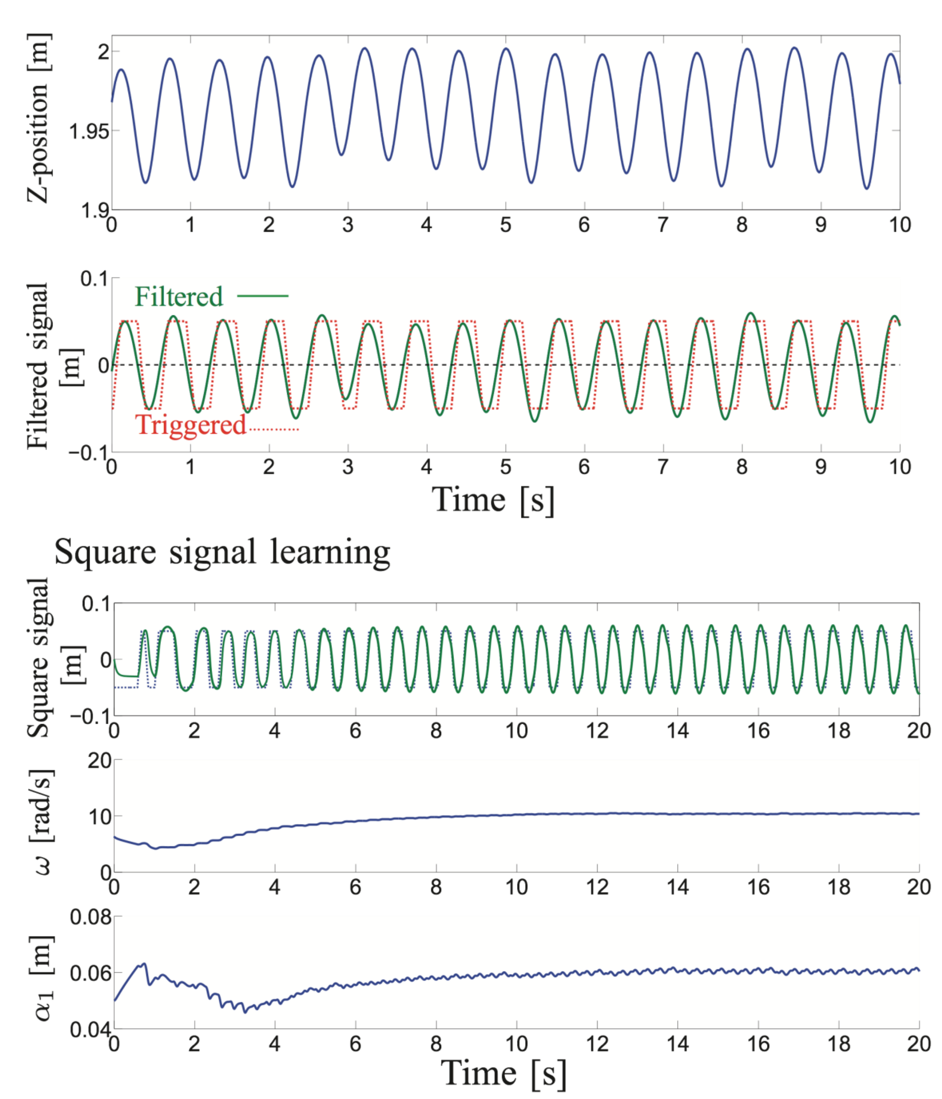
$$\hat{\theta}(t) = \sum_{i=0}^{K} \alpha_i \sin(\phi_i) = \sum_{i=0}^{K} \alpha_i \sin(i\omega t + \varphi_i)$$

An adaptive oscillator is a dynamical system having the capacity to synchronize to a quasi-periodic input by learning its features in state variables. This estimator performs a kind of real-time Fourier decomposition of the input signal, keeping K harmonics.

Learning of a signal containing an offset and four harmonics with different phase lag.



Signal learning



The signal is first cleaned with a series of simple filters, to isolate its first harmonics as much as possible.

Frequency learning :

- Filtered with a second-order bandpass filter to eliminate some high-frequency noise and remove the signal offset.

$$H(s) = \frac{s}{(s+1)^2}$$

- Saturated with a nonlinear block

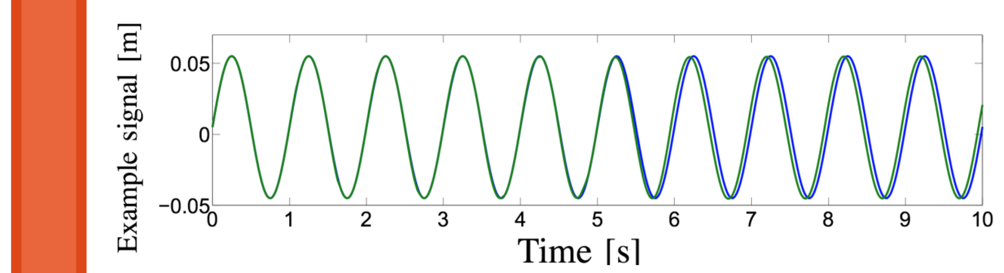
$$\begin{cases} T = 0.05 & \text{if } Z_f > 0 \\ T = -0.05 & \text{else} \end{cases}$$

- Square signal learned with adaptive oscillator

Prediction

When the signal was learned, a prediction was computed, by using oscillator equations but with a time lead δ_l

$$\hat{\theta}_{\delta_l}(t) = \sum_{i=0}^{K} \alpha_i \sin(\phi_i + i\omega\delta_l)$$



Signal linearly blended from predicted to current position within 1 s.

Results

Oscillations in the force signal were evaluated with the root mean square (RMS) around the reference value of the force.

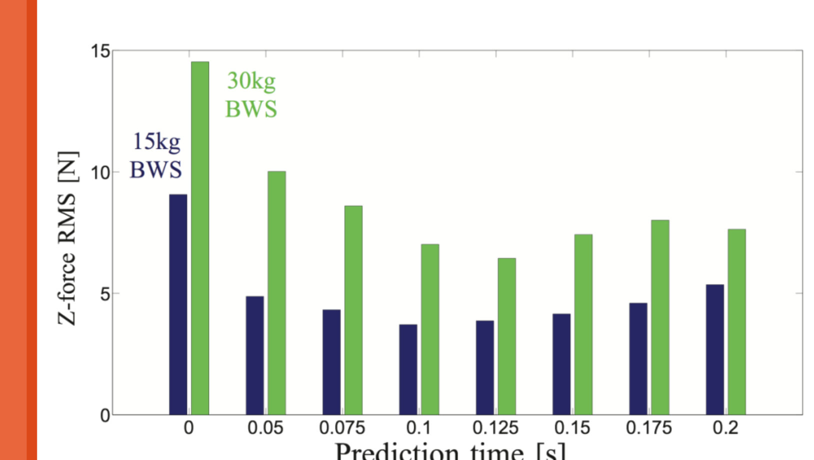
Predicting the vertical component of the position signal decreases the oscillations of the vertical force.

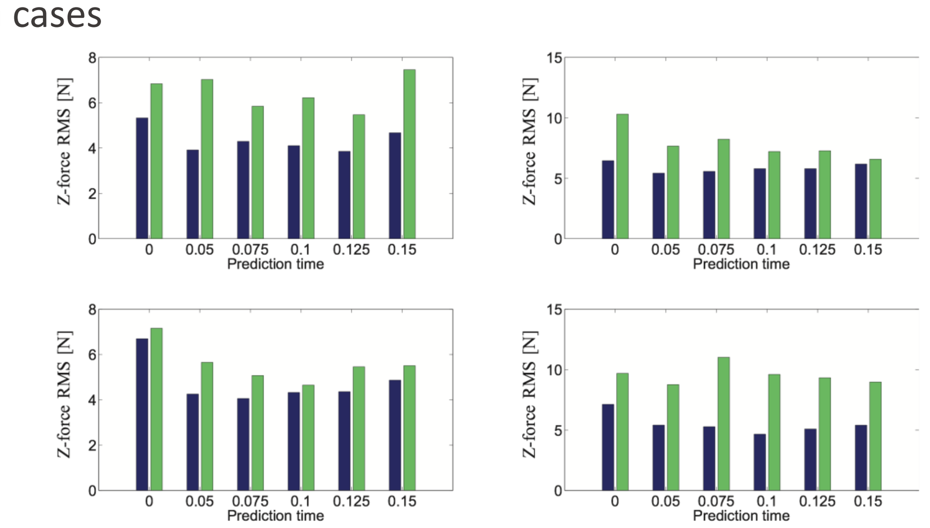
The best value for the prediction time:

- 100ms with 15 kg BWS
- 125ms with 30 kg BWS.

$$RMS = \sqrt{\frac{\sum_{i=1}^{n}(F(i) - F_{ref})^2}{n}}$$

Oscillations decreased by about 50% in both cases





Conclusion

The proposed method decreased the dynamical effects of a rehabilitation robot felt by the user by relying on a trajectory estimator based on an adaptive oscillator.

The principle was to add a block in parallel to the robot controller to predict and anticipate the user's movement. When the movement features were learned by the oscillator, it had the capacity to accurately predict the future signal. This prediction, corresponding to the robot position in the near future, can be used to anticipate the dynamical effects.

Concretely, the method presented here allowed to decrease the force oscillations in the vertical direction by up to 50%.

These encouraging results for the Z direction motivate further extension of the concept also to the two other directions. Interestingly, the learned frequency should be usable for the three directions.