Cooperative Human-Robot Manipulation Tasks

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***Abstract*— Object manipulation tasks by humanoid robots often do not only involve the hands and upper limbs but require flexible control of whole body movements. Examples are cooperative transportation tasks where a human and a robot carry an object together. Here, the robot has to reactively adapt its walking motion in order to compensate for the pushing and pulling forces exerted by the human via the carried object. Our approach to this problem draws on a learned walking model that is able to predict the robot's center of mass based on proprioceptive sensors and walking speed. Deviations between predicted and measured center of mass can then be used to adapt the robot's walking style to the movements of the human cooperation partner.**

I. Introduction

Cooperative human robot manipulation tasks are a promising application area for robotic assistants. Stückler et al. [1] present a cooperative transportation task where the specialized robot named Cosero follows the human using arm compliance. In doing so the robot recognizes the desired walking direction through visual observation of the object being transported.

A similar setting has been investigated by Yokoyama et al. [2]. The authors use a HRP-2P humanoid robot equipped with a biped locomotion controller and an aural human interface to carry a large panel together with a human. Forces measured with sensors on the wrists are utilized to derive the walking direction. The main drawback of both approaches is that they require special aural and visual input devices or force sensors which are not present on many robot platforms.

In this paper, we propose a method for cooperative manipulation tasks by a human and a humanoid without the need of special input devices. In direct physical human-robot interactions the human touches the robot or moves its extremities as investigated by Ikemoto et al. [3]. In our approach the human applies forces to the robot via the carried object as shown in Figure 1. The human leads the robot who has to react to the exerted forces by increasing and decreasing the walking speed. The pushing and pulling human forces on the transported object can be approximated by their effects on the center of mass (CoM) of the robot. To calculate the relative deviation between expected and measured CoM, we generate a model of the robot's walking behavior.

II. Generation of a Walking Model

The humanoid robot Nao [6] is pre-loaded with a software development kit containing a predefined walking behavior.

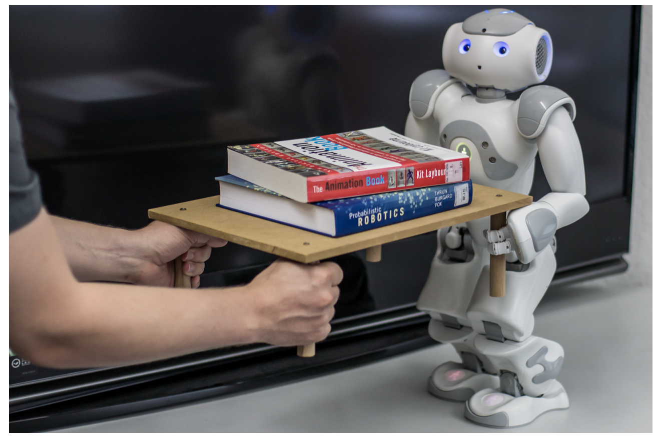

Fig. 1. Walking directions are derived from applied forces to the robot for a transportation task.

This behavior can be executed with varying walk speeds by changing the step length. Positive values lead to forward motions whereby negative values result in backward walks. In order to respond to user input forces in a transportation task the step length of the existing walking behavior needs to be adapted to fit the new force constraints.

Firstly, we calculate a reference model containing the CoM during various walks. A single frame in this model consists of joint angle values for both legs, the CoM of the robot and the step length of the current walk. The latter must be included, because the joint angle values and the CoM are affected by the step length as illustrated in Figure 2.

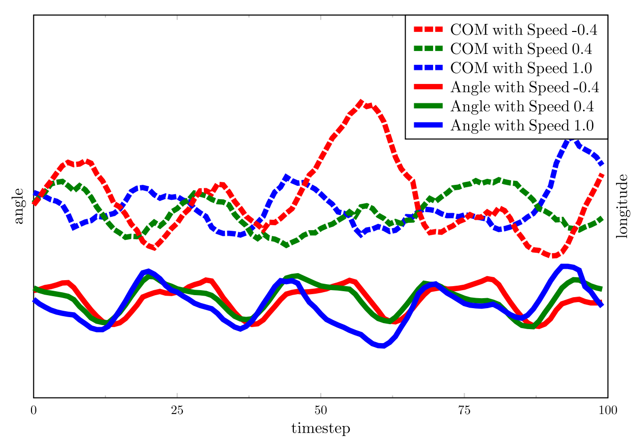

Fig. 2. The longitude of the CoM and the average from left and right hip pitch joint depends on the walk speed.

Since joint angle values are redundant for the left and right leg during the walking behavior, we can half the amount of

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angle values recorded for our database. The resulting data is used to calculate a reference CoM for the current walk speed and posture of the robot. In an ongoing interaction with a user this reference value will differ from the measured value, because of the forces exerted by the human. In order to calculate the reference value from the recorded data basis the Loess algorithm is employed.

Loess is a modeling method for locally weighted polynomial regressions, which was originally proposed by Cleveland [4] and further developed by Cleveland and Devlin [5]. At each frame in the model a low-degree polynomial is fitted to a subset of the data, using points in the neighborhood of the estimated point. The polynomial is fitted using weighted least squares, giving more weight to points near the point whose response is being estimated and less weight to points further away.

The traditional weight function used for Loess has a tri-cube weighting characteristic which has the following appearance:

$$w(x) = \begin{cases} (1 - |x|^3)^3, & \text{for } |x| < 1 \\ 0, & \text{for } |x| \geq 1 \end{cases} \quad (1)$$

III. Cooperative Human-Robot Interaction

At run time we measure the current angles, the walking speed and the current CoM value of the robot. The measured CoM is compared with the predicted reference CoM of the regression model. The percentage divergence between both is the main criterion to specify the new walking speed in a linear way.

E.g., in our transportation task, whenever the human pushes the carried object towards the robot, the measured longitudinal CoM will be less than the reference CoM. This will cause the robot to slow down a forward movement or to accelerate a backward movement.

IV. Model Generation in Simulation

Simulations might be useful to speed up the process of generating the walking model. Figure 3 shows the mean error for walking with several step lengths using different recorded raw data from the real robot as well as the Webots [7] and NaoSim [6] simulation environments. We observe that a model generated from simulated data cannot be used for the real robot, because of insufficient physical accuracy. However, the average error can be used as a quality criterion of simulation environments. Furthermore, with higher step lengths the mean error continues to rise because of considerably increased body-swinging of the robot.

V. Conclusion

In this paper, we proposed a framework for cooperative object manipulation by a human and a humanoid robot. By using a linear regression model, we can clearly identify the effects of human forces to the CoM of the robot. A video with experiments can be accessed on the internet[1].

[1] `http://youtu.be/jti313dojvI`

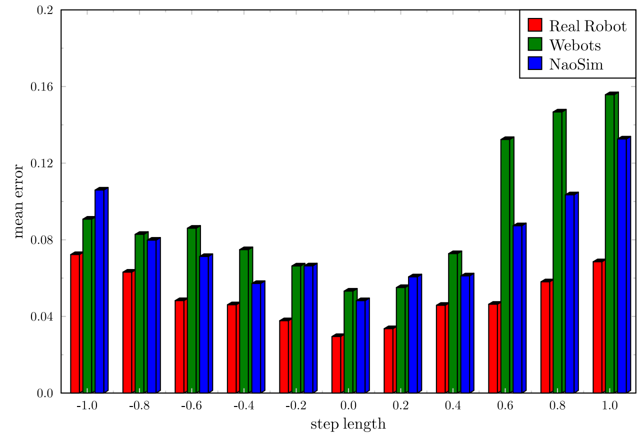

Fig. 3. The mean errors measured on the real robot using different calculated models while walking with different step lengths.

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