Torque prediction for active exoskeleton control using ProMPs

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***Index Terms*—movement prediction; ProMPs; active exoskeleton; Digital human simulation.**

I. Introduction

Occupational activities often expose individuals to significant biomechanical strains that may increase the risks of musculoskeletal disorders (MSDs)[1]. Active exoskeletons are a promising solution to reduce such risks when workers have to manipulate heavy loads.

One problem with active upper-limb exoskeletons is to adapt their assistance to the human motion to provide the correct amount of physical assistance when needed. Any delay in the assistance may be detrimental to the performance. Here, we focused on predicting human motion intention for the control of an upper limb exoskeleton. Intention prediction is usually a problem of predicting future trajectories from observations. It can be done with time series analysis and machine learning techniques. The benefit of using prediction, for an actuated exoskeleton, is to compensate actuation delay of the motor.

Probabilistic Movement Primitives (ProMPs) are skills learning techniques able to reproduce complex motions and encode human movement variability. It can be used to predict human intention from early observations. One of the big advantages is that they require little data for the training compared to other methods, mostly deep learning methods (between 10 and 30 demonstrations regarding the movement complexity). This is more compatible with human-robot situations, because getting human subject data is "expensive" and time-consuming.

II. Methods

The objective is to predict the required torque to assist a human during a particular motion. The assistive torque can compensate the exoskeleton, the payload and the human arm. We can compensate all torques or only some of them regarding the control strategy. In this paper, we focused only on the compensation of the human and payload torques.

ProMPs are used in order to address the problem of predicting user intention to determine the future trajectory, from which the torque is computed. The proposed method is summarized in Fig. 1. In an offline step, we build a database of all the ProMPs associated to the movements to assist using a whole-body inertial motion capture (Xsens system) visible in Fig. 1. In the online phase, the learned ProMPs are used to predict the intended trajectory; then we use the Inverse Dynamic (ID) to get an estimation of the human torque. The training of the ProMPs and trajectory prediction is detailed in [2] [3] [4].

To compute required torque from trajectory prediction, we use RobotDART. RobotDART is a C++11 robot simulator wrapping the DART physics engine. To replay Xsens data in RobotDART, a Digital Human Model with 66 dofs (DHM66). DHM66 is a copy of the Xsens avatar. It has the same degrees of freedom that allow a direct usage of Xsens's data without post-processing. The estimation of corresponding torques of the dynamics of the human carrying a known payload are computed using ID (1):

$$\tau_{H+p} = M(q)\ddot{q} + B(q,\dot{q}) + G(q) + J_{RH}^{\top} W_{RH} + J_{LH}^{\top} W_{LH} \quad (1)$$

With τ_{H+p} human and payload torque, q joint angle, $\dot{q}$ joint velocity, $\ddot{q}$ joint acceleration, $M(q)$ inertial matrix $B(q,\dot{q})$ Coriolis effects, $G(q)$ gravity effects, $J_X^{\top}$ Jacobian transposed hand, W_X payload applied to the hand, LH Left Hand, RH Right Hand.

First, we compute the torques corresponding to the dynamics of the human and the external load. To do so, the value of the inertial matrix, Coriolis effect and gravity effect are computed by the physics engine and RobotDart. For the value of position, velocity and acceleration there are given by the recorded data from Xsens. In our case, the targeted exoskeleton only assist the shoulder elevation and the elbow flexion. Therefore, only the torque generated by the human model for shoulders and elbows are computed.

III. Experiment

Kinematic data were collected on 5 participants wearing an Xsens suit in order to train the prediction algorithms. This experiment was validated by INRIA's ethical committee (COERLE). 4 different gestures were performed corresponding to different load carrying situations. The 5 participants performed 10 repetitions of each movement.

Data for each movement are segmented into 3 parts. To generate ProMPs, segmentation of the kinematic data is a necessary step. This reduces the variability between trials. More complex movement requires more RBF to encode movement, and increase the computational cost for both training and prediction. For all movements, the same method was used.

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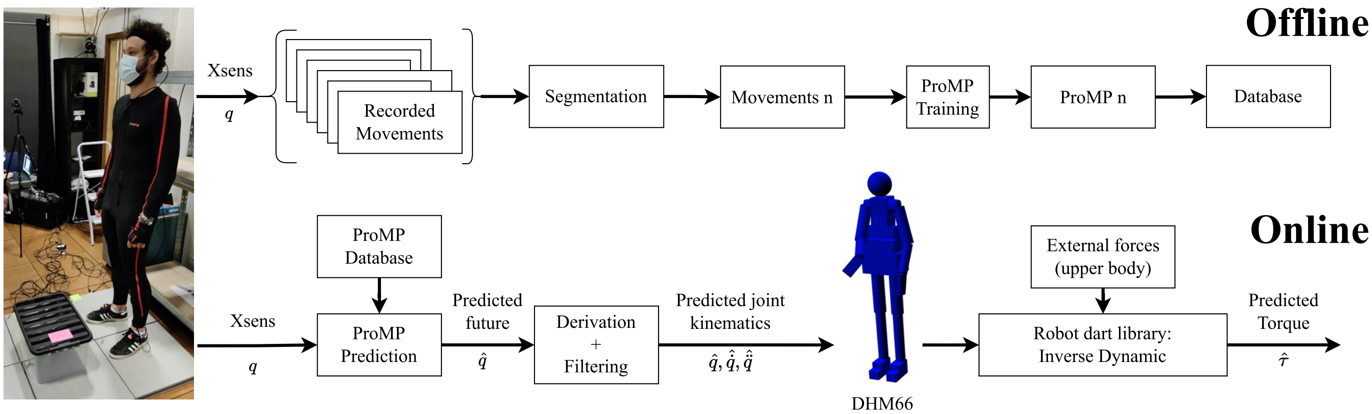

Fig. 1: Global view of the proposed method

Shoulders and elbows joints torques values are computed for each participant, taking into account the weight of the box (3kg). Regarding the distribution of the weight of the box, the hypothesis is a weight uniformly distributed between the right hand and the left hand when the subject lifts the box. Considering a weak influence on the joint torques of the upper limbs, the forces exerted on the lower limbs are not taken into account.

From the segmented kinematic data and the calculated joint torques, the ProMPs could be generated as described in the method.

IV. Results

In Fig. 2 an example of continuous prediction is visible. In such case, only the 1% next values of the prediction are considered before making a new prediction and again took the few next steps after the current observation.

A first result from the proposed pipeline in Fig. 1 is visible in Fig. 3. In blue there is the predicted torque from a predicted trajectory knowing initial 30% observation of the ground truth (in pink).

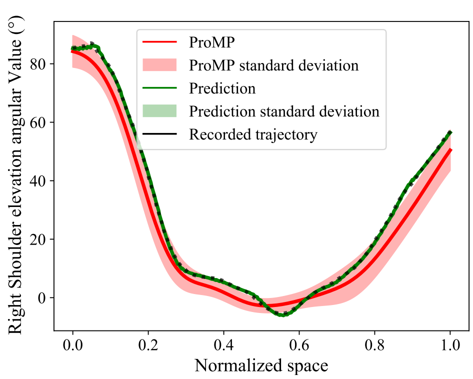

Fig. 2: Example of continuous prediction of human shoulder position from observation every 1% of shoulder trajectory

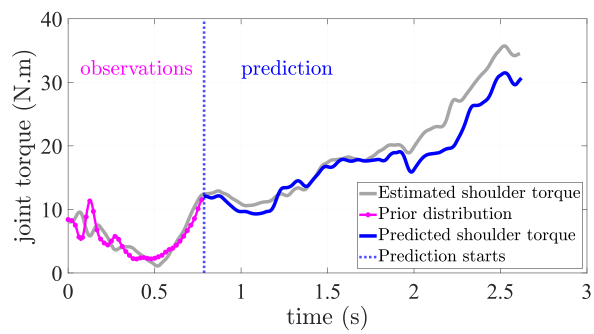

Fig. 3: Example of a human predicted joint torque vs estimated joint torque of right shoulder (flexion/extension) when carrying a load.

Conclusion

ProMPs can be used to predict human intention with few data for the training. At this stage, the prediction algorithm has been mainly tested in simulation, by replaying collected kinematic data. The next step is to test in real time in the simulation. Then, the objective is to inject the prediction torque or joint trajectory in the exoskeleton controller, similarly to what has been done in [4].

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