HUMANOIDS 2017 - Workshop “Human-Humanoid collaboration: the next industrial revolution?”

Humanoid Control for Co-Manipulations Tasks with Whole-body Human Dynamics Reconstruction

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I. INTRODUCTION

Physical human robot interaction (pHRI) will become increasingly important as robots move into shared spaces with humans, such as factory floors and homes. A limitation in most existing controllers for pHRI is that the representation of human state is vastly simplified (e.g. as external force or poses of end effectors). The whole-body state of the human is rarely considered, which limits the types of interaction that are possible. Some works consider a human model [1][2][3], but they only simulate kinematics and/or don't run in real-time for control. Our controller performs whole-body human dynamics reconstruction [4][5].

We describe a real-time humanoid controller which allows the robot to keep itself stable, while also assisting the human in achieving their shared goals. Our formulation uses a multi-robot quadratic program controller, which solves for human motion reconstruction and optimal robot controls in a single optimization. Our experiments with a simulated robot demonstrate the ability to generate interaction motions and forces that are similar to what a human collaborator would produce.

II. BACKGROUND

Recently, research on humanoid whole-body control has converged to formulating the floating-base inverse dynamics problem as a quadratic program (QP). QP controllers allow simple specification of desired behavior as quadratic objectives, which we call “tasks”.

We use the multi-robot quadratic program (MRQP) framework introduced in [6], which is an extension of QP controllers that can model interactions among multiple entities. In this paper, we consider three entities (“robots”): humanoid robot, human, and co-manipulated object.

The MRQP formulation combines the dynamics of the individual entities by ensuring that forces between the entities follow Newton's third law (equal and opposite) and that contact points between entities move together. The formulation is equivalent to a single-robot QP controller, with the addition of the constraints for contacts and collision-avoidance between the entities.

This optimization problem can be solved at real-time rates (200Hz) to control multiple “robots”. The tasks can be written for the combined system (e.g. combined center-of-mass) or imply desired behavior through a task on a single robot (e.g. task on the position of the co-manipulated object that drives all the robots in contact with the object).

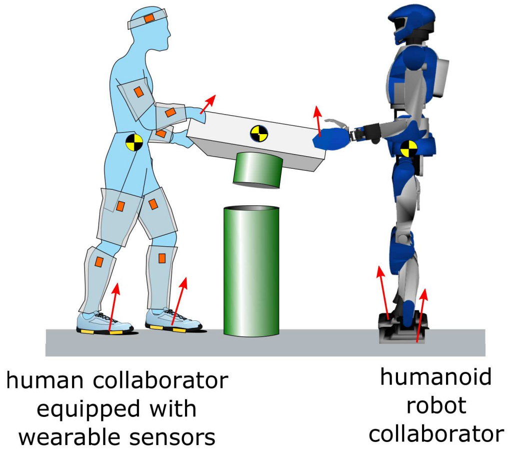

Fig. 1. In collaborative tasks, the humanoid robot must reason about: goals of the task, interaction forces with the human, and its own balance. The human collaborator's motion is tracked with wearable sensors.

III. MULTI-ROBOT QP WITH HUMAN MODEL

We incorporate a full-body dynamics model of the human into the MRQP as a simulated human that tracks the real human's motions. The controller generates the human motion reconstruction, and uses it to reason about the human-robot system's combined dynamics. Motion capture data from an XSens MVN suit [7] is mapped onto our parametrized human model, which is a 22 joint rigid-body-tree. To reconstruct human motion within our MRQP, we set high-weight motion tracking objectives on the human “robot”, which take motion capture data as time-varying setpoints.

For the robot's individual tasks, we set objectives that keep the robot balanced and in a natural posture away from singularities. We then add objectives that define the desired interaction between the robot and human, which define the desired robot motion as an implicit function of the human's motion.

We set a regularization objective on contact forces, to avoid unrealistic behaviors in which the humanoid leans on/pushes the human excessively. For our experiments, we assumed that the human and the robot are performing a symmetric motion in which they face each other and perform mirrored versions of each other's motions. To achieve this,

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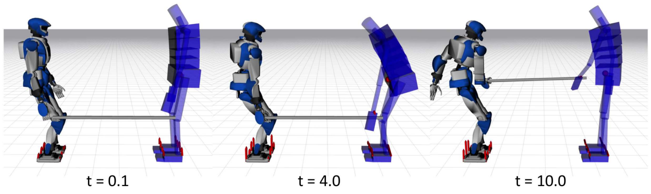

Fig. 2. Steps of co-manipulation task: symmetric manipulation

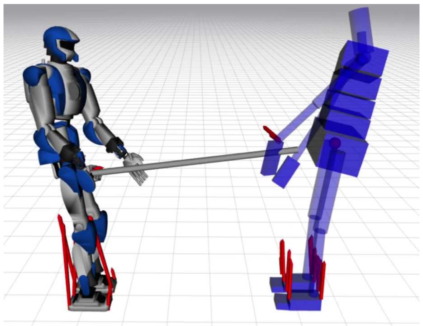

Fig. 3. Robot assisting human with balance. Forces on robot and human shown in red.

we set the desired pose of the robot's end effector to be a mirrored version of the human's end effector pose. Some other interaction tasks that can be used are: collision avoidance between robots, minimization of distance/orientation errors between human and robot end-effectors (e.g. for a handoff), minimization of simulated human joint torque (i.e. induce the robot to carry more load).

IV. EXPERIMENTS

We performed several experiments in simulation with an HRP-4 humanoid robot. These experiments were done using recorded motion of a human during a human-human collaborative task: only one partner was equipped with a motion capture suit, as the second partner is replaced by the robot in our simulations. We expect the MRQP controller to produce realistic robot motions/forces that are similar to what the human partner produced.

The first experiment is a collaborative pick-and-place experiment, in which the human and robot work together to move a pole from one side of their bodies to the other. This task shows a simple application of the mirroring heuristic for generating robot follower motion.

In the second experiment, the human leans their center-of-mass outside of their own support polygon while holding onto a pole together with the robot. In the initial recording of the human-human motion, this required the partner (who the robot replaces) to pull back on the pole, keeping the human in balance. Using our controller, the robot generates a similar motion in order to keep the human- (depicted in Figures 3 and 4). This experiment shows the advantage gained from modeling the whole-body dynamics of the human; methods using simplified models of the human would have a hard time generating this behavior.

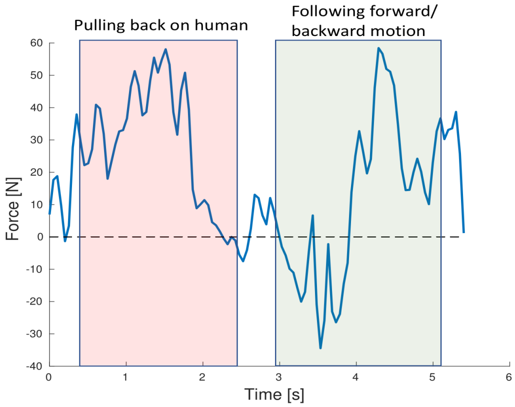

Fig. 4. Interaction forces (forces on the robot) in the forward/backward direction on the robot's right end effector during balance-assistance. Our controller generates realistic interaction forces that keep the collaborative task stable.

V. CONCLUSION AND FUTURE WORK

We make a formulation of humanoid control for pHRI, which uses a multi-robot QP to model the whole-body dynamics of the human. This method is highly flexible and is easily adapted to varying robot morphologies, as well as different motion objectives. Our future work will focus on implementing this controller on a real robot for physical experiments. We will then move on to integrate higher-level planning with predictions of human intent, as well as improved modeling of human dynamics and reactions to external forces.

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