Human-Robot Collaborative Dance

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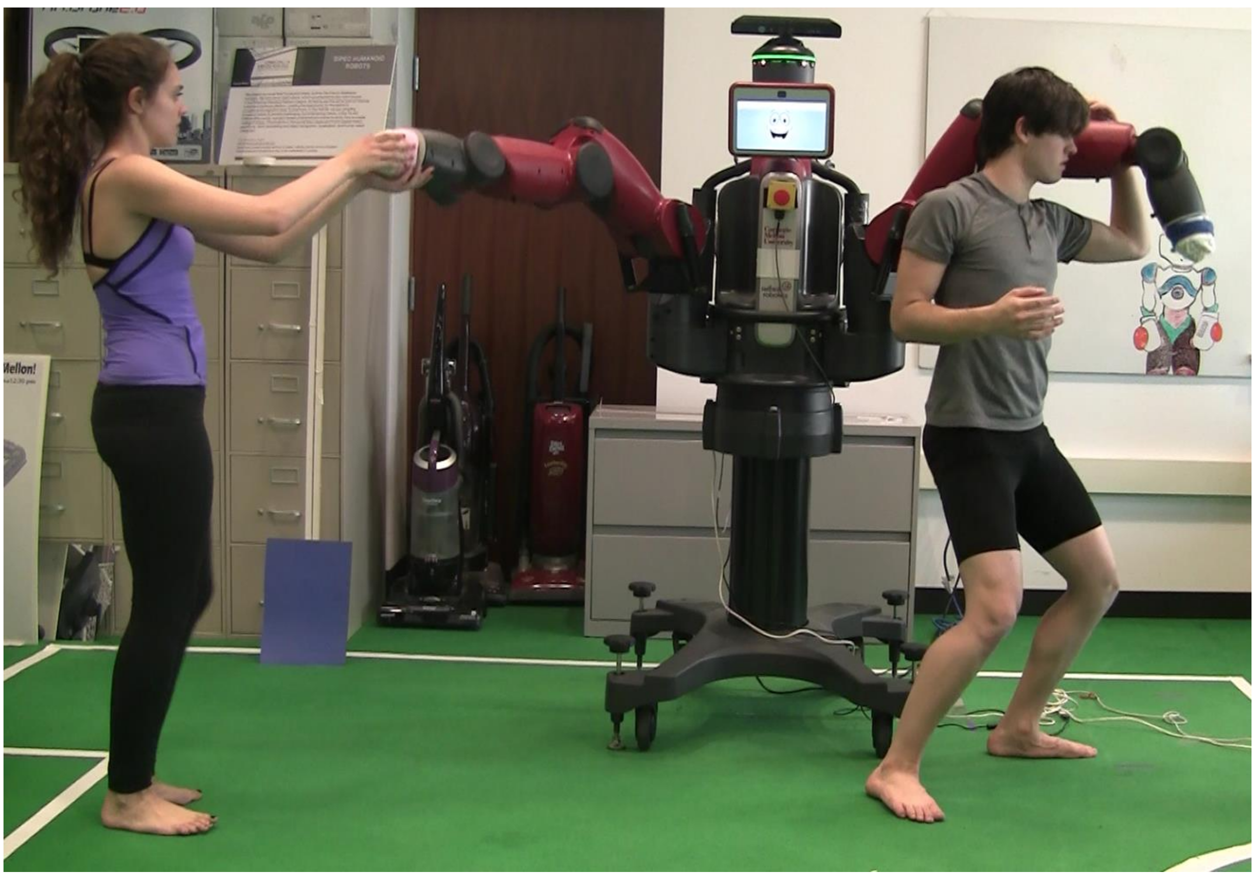
16-662: Robot autonomy
Final project report



Motivation

Artistic applications of robotics, although having been largely overlooked, have mainly focused so far on non-collaborative tasks involving expressiveness/creativeness of robot behavior with limited interactivity. Examples include robot painting [1], robot theater [2], or robot dance [3]. In this project, we will explore the idea of a human-robot collaborative artistic task, in which a dancer and a robot interact with each other to create an improvisational dance piece. The two dimensions we will explore are safety and motion expressiveness. We enable dancers to physically interact with a robot in an improvisational dance piece involving two modalities: motion and physical contact. The second component was inspired by a dance form called contact improvisation[1].

Problem Statement

"How can a robot interact with a dancer through motion and physical contact in a way that is both safe and creatively valuable?"

System Architecture

The following figure shows the system architecture:

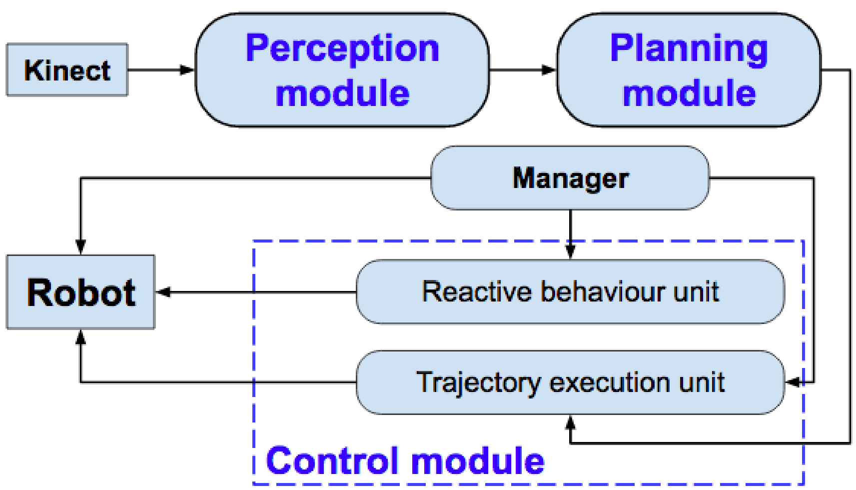


Figure 1 - System Architecture Diagram

The project has three major subsystems, namely, the Perception Module, Planning Module and the Control Module. The perception system receives depth images from the Kinect 3D sensor

[1] Thanks to Isabel Valverde and Ana Moura for the inspiration.

and processes them to produce a filtered point cloud. The planning module uses the point cloud to plan in the environment while ensuring that the trajectories it plans are both expressive and safe from the dancer's point of view. The trajectories generated by the planning module are executed by the control module. This module communicates directly with the robot to ensure the joints move in the desired trajectories. The Manager module monitors the trajectories and ensures safety behavior of the planning algorithm using the reactive behavior unit.

Control Subsystem

The control subsystem has two sub-units as shown in Figure 1 above. The trajectory execution unit uses torque control using a proportional derivative (PD) control to execute the trajectories. The following equation gives the torque command for each joint using the PD controller.

$$\tau = k_p * (\theta_d - \theta) + k_d * (\dot{\theta}_d - \dot{\theta})$$

$where,$

$\tau \rightarrow torque\ applied\ to\ joint$

$k_p \rightarrow Stiffness\ Factor$

$k_d \rightarrow Damping\ Factor$

$\theta_d \rightarrow desired\ joint\ position$

$\theta \rightarrow current\ joint\ position$

$\dot{\theta}_d \rightarrow desired\ joint\ velocity$

$\dot{\theta} \rightarrow current\ joint\ velocity$

The torque command ensures compliant behavior while they are clamped to a saturation value to ensure safety in the presence of the dancer. The following graph shows the torque saturation to make the interaction process safe.

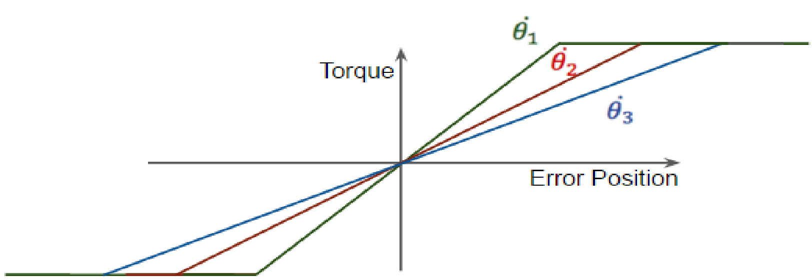


Figure 2 - Torque and Error Relation

The reactive sub-unit is also responsible for safety checking. Whenever the robot might collide with the dancer, the manager unit switches the control to a reactive behavior. In this control mode the normal of the vector point away from the dancer is computed and then the link that was expected to collide with the dancer is moved away in this direction. The control is run in a velocity PD control mode to move the link in the required direction. The following equation explains the joint velocity calculations:

$$\dot{\theta} = (J(\theta)^T J(\theta))^{-1} J(\theta)^T \dot{x}\, \hat{n}$$

$where,$

$\dot{\theta} \rightarrow joint\ velocities$

$J(\theta) \rightarrow\ updated\ jacobian\ based\ on\ joint\ positions$

$\dot{x} \rightarrow default\ end\ effector\ velocities\ for\ reactive\ behavior$

$\hat{n} \rightarrow normal\ pointing\ away\ from\ the\ centroid\ of\ the\ point\ cloud$
$\quad and\ the\ collision\ link$

Perception Subsystem

The perception subsystem uses the Kinect RGBD map to produce a point cloud using OpenKinect, Freenect, and Point Cloud libraries. The Kinect produces a point cloud of voxels using the depth sensor. This point cloud is filtered to remove the background and also down sampled to only represent the dancer and Baxter using as few cloud points as required to ensure fast processing of the system and that the dancer is well represented, using a distance filter and a requirement that the object in view is a certain size. Then the point cloud is filtered to ensure that the robot does not perceive itself while collision checking and for marker detection, using a proper coordinate transformation (TF) that moves the camera into the robot's frame, and padding that guides how far from the robot it should ignore points. From the filtered point cloud a marker is created at the centroid of the point could to represent the dancer's location. The head of the robot is moved to point at the marker location. This helps the dancers see that the robot is aware of where they are and also adds a further human interaction element to the process.

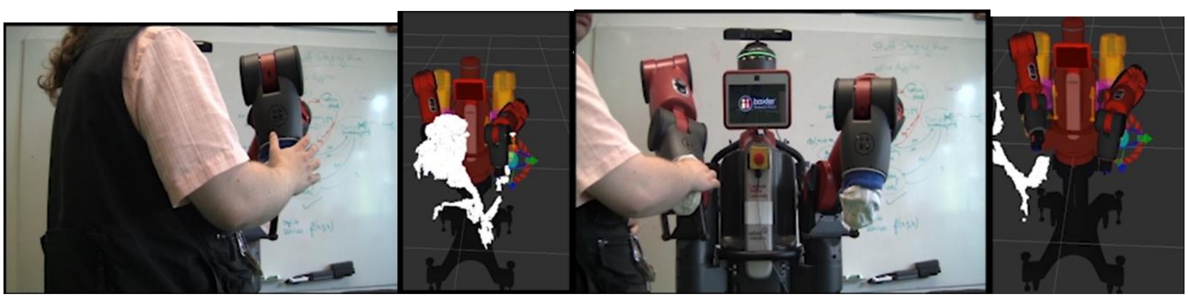


Figure 3 - Downsampled Voxels and Self Filtered Voxels

Figure 4 - Centroid Marker and Robot Facing Human

Planning Subsystem

The planning subsystem is responsible for trajectory generation based on the perception data. Here we incorporated two approaches. The first approach is to use the MoveIt planning library to plan around the dancer to create a turn taking performance between the two. However, this method failed to create expressive trajectories and did not enable a fluid interaction between the robot and the dancer. For this reason, we opted for a database of kinesthetically recorded trajectories. In this approach we have a database of motion primitives which the robot may select from while dancing. The selection of the trajectories is based on quadrant and the location of the dancer in the quadrant. The following figure highlights the quadrants.

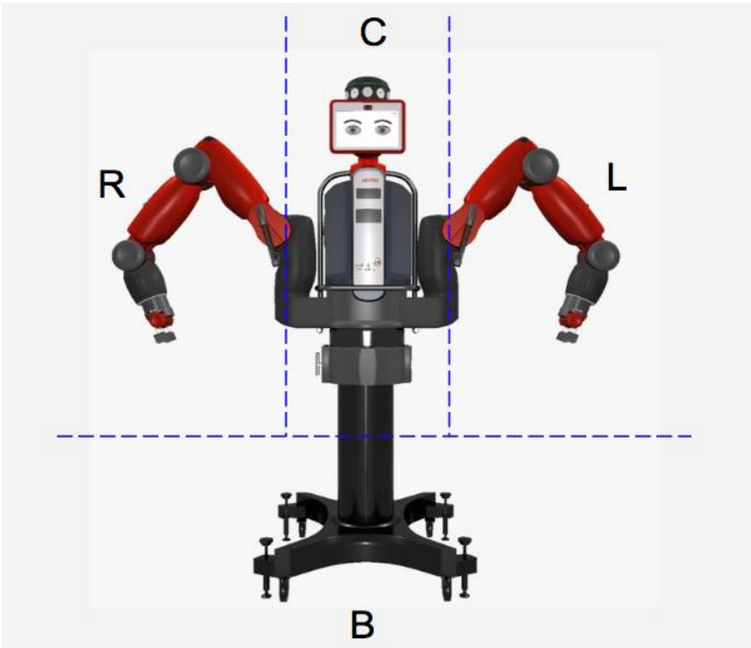


Figure 5 - Dance Quadrants

The robot will execute only trajectories in the quadrant where the human is not present. Once a trajectory is executed the robot nods its head and turn its head LED ring to a red color to signal to the dancer that it is switching to a different trajectory. Here the dancer may look at the head position to ensure that the robot knows where the appropriate location of the dancer is. This method has also been extended to account for labels which are based on the music. A few labels are slow, fast, playful etc. with the identification of the quadrant for each motion primitive.

Evaluation

We conducted an user study in which we recruited 2 dancers from the School of Drama (1 male and 1 female) and 1 observer acting as a spectator. We had 2 experimental conditions:

C1 (Baseline): Compliant joints torque control (no trajectory following)
C2: Our approach

Each dancer interacted with the robot in the two conditions (i.e., a within-subject study design) and were asked to fill the same questionnaire after each condition. The questionnaire used was the “Anthropomorphism, Animacy, Likeability, Perceived Intelligence, and Perceived Safety of Robots” survey by Bartneck et al. [4]. In order to eliminate any habituation effects, the order of the conditions was counterbalanced. The observer rated the performance using the same questionnaire.

Our results are summarized below where the numbers reported are all on 5-point Likert scale (no statistical results are reported due to the small amount of participants).

- Subject 1 reported increased: perceived safety (+1.33), animacy (+1.17), likeability (+1), perceived intelligence (+0.8), and anthropomorphism (+0.6) when using our system (C2) compared to the baseline (C1) (average increase 0.98).
- Subject 2 reported negative results on all five dimensions except for likeability and perceived intelligence where no change in rating was reported (average -0.45). However, the average in scores changes for both dancers remains positive. We attribute the negative result of participant 2 to the fact that the order of the conditions wasn’t controlled as for participant 1 which may have introduced noise in the data. Indeed, participant 2 first interacted with the robot and participant 1 all together before trying condition C2; C1 was performed at the very end of the session when the participant seemed to become much more comfortable with the robot (hence the habituation effect might have been more pronounced than for participant 1).
- The observer showed an increase in rating between C1 and C2 on three of the dimensions (anthropomorphism, animacy, perceived intelligence) and a slight decrease on two dimensions (likeability, perceived safety). The overall score was positive (+0.23)
- The perceived safety, regardless of the condition order, increased with number of trials with the robot for both dancers (average increase for the 2 dancers +0.78).

Conclusion

In this project, we have proposed and implemented a system which enables a dancer and a robot to interact through motion and physical contact to perform an improvisational dance piece. Our system is composed of a control module executing trajectories and providing several safety mechanisms to protect from hard collisions with the dancer, a perception module which detects the location of the dancer in the workspace of the robot, and a planning module which select appropriate sequences of motion primitives to execute from a database of kinesthetically recorded trajectories designed to be both safe and expressive. We evaluated our system from a dancer’s perspective and an observer’s perspective and showed that compared to a baseline where the robot was only reactive to physical contact, our approach was generally preferred along five different perception dimensions.
The final output can be seen at https://www.youtube.com/watch?v=AXcVSwuUL28.

References:

[1] Tresset P., and Oliver D. ”Artistically skilled embodied agents.” (2014)

[2] Zeglin, G., et al. ”HERB’s Sure Thing: A rapid drama system for rehearsing and performing live robot theater.” Advanced Robotics and its Social Impacts (ARSO), 2014 IEEE Workshop on. IEEE, 2014.

[3] Shinozaki K., Akitsugu I., and Ryohei N. ”Concept and construction of a robot dance system.” International Workshop and Conference on Photonics and Nanotechnology 2007.

[4] Bartneck, C., Kulić, D., Croft, E., & Zoghbi, S. (2009). Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots. *International journal of social robotics*, *1*(1), 71-81.