Human Coordination Dynamics with Heterogeneous Robots in a Team

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***Abstract*—Robots with different behaviors will be a part of human-robot teams in the future and will impact the overall interaction patterns of teams. In this paper, we investigate how the presence of robots affect the coordination of human-robot teams when a single robot or multiple robots with the same or different behavior are the part of that team. We compare two different event anticipation methods for robots, and then extend those findings to assess its effects on the group coordination. Our results indicate that humans are significantly more synchronous as a group when they danced alone than with the robots. We also find that an addition of a robot with a different anticipation algorithm to a single robot team significantly reduces the group synchrony. This work will prove useful for the robotics community to build more fluent human-robot interactions in the future.**

I. Introduction

Robots are now becoming our partners in many activities, from dexterous factory jobs to assisted living. While working alongside humans, a robot might encounter people performing various social actions, such as engaging in group activities, or performing synchronous movements in exercise [1]. Thus, robots need the ability to interpret, anticipate, and adapt to human actions to synthesize fluent interaction with humans accordingly.

Recent work in robotics has focused on developing methods to predict human activity, as well as modeling human-robot synchronous group coordination to make interaction more fluent [2], [7]. For example, Hoffman et al. [2] proposed an adaptive action selection mechanism for a robot to make anticipatory decisions based on the confidence of their validity and relative risks, and the results suggested an improvement in joint task efficiency compared to a purely reactive model. Additionally, Lorenz et al. [7] found that humans synchronized their movements with the movements of the robots during a goal-directed, but unintentional, coordination task.

While this work will improve the ability of robots to have fluent interactions, most of these methods are best suited for dyadic interaction. This work inspired us to explore methods for robots that will work robustly in groups with the understanding of the internal dynamics. To address this, we designed a group *Synchronization Index based Anticipation (SIA)* method taking high-level group behavior into account during an intentional synchronous joint action (SJA) task [4].

Moreover, the presence of robots will affect the coordination of the human-robot teams. The coordination dynamics may also change based on the number of robots and their behavior. These factors motivated us to explore several research questions. The first question concerns the introduction of robots into a human-human teamwork scenario - what are the effects on humans' synchronization to one another and the whole group if we add one or two robots to the group? The next two questions ask, how do different anticipation algorithms on robots affect human behavior, and might algorithms more sensitive to human group dynamics affect motion differently?

II. Methodology and Setup

As our experimental testbed, we used a synchronous group dance performed by a human-robot team. A group of human performers along with a group of mobile robots (i.e., Turtlebot robots) performed a dance to a song. Each phase includes four iterations of the following steps in order: move forward and backward twice, clap, and a 90-degree counter-clockwise turn. To acquire the movement data of the humans during the dance sessions, we used four Microsoft Kinect version 2 sensors. To maintain a time reference for all the machines, we implemented a client-server architecture for communication between the clients and the server [4], [6].

From the 3-D skeleton joint positions of the human performers captured by the Kinect sensors, the clients detected five high-level events during the dance performance. After detecting the events, each client sent the processed data to the server. Then, the server ran one of the anticipation methods to predict future actions of the humans. Based on these predictions, the server generated necessary commands for the robots, using the Robot Operating System (ROS) platform, to perform appropriate actions in a timely fashion [4], [6].

III. Experiment 1

To model anticipation, we build on our prior work, which introduced a non-linear, event based method for detecting synchrony in a group [5]. Here, we employed a *Synchronization Index based Anticipation (SIA)* algorithm to inform robots' movements. *SIA* takes the group's internal dynamics into account, and operates under the premise that if the robot follows the movements of the most synchronous person during the last iteration of the dance, it is more likely to move synchronously during the next iteration [4].

To establish a reasonable comparative anticipation method for *SIA*, we created an *Event Cluster based Anticipation (ECA)* method for predicting the timing of future events [4]. The *ECA* method relied on the assumption that the movement events of one iteration are more or less similar to the events that happened in the previous iteration.

978-1-4673-8370-7/16/$31.00 © 2016 IEEE

Each group had a learning and practice session, and then participated in three dance sessions. During the first dance session, only the humans participated in the dance movements, while a robot joined the humans in the dance during the last two sessions. We used the anticipation methods in alternating sessions. We recruited a total of 9 groups (27 participants, 3 persons per group) for this study [4].

A. Results and Discussion

To compare the performance and accuracy of the two anticipation methods, we first measured the group synchronization index (*GSI*) for each session by using the method proposed in [5], [3], including the robot. The results suggested that for 22 out of 36 total individual dance iterations, the *SIA* method yielded a higher *GSI* than the *ECA* method.

As another measure of accuracy, we measured the timing appropriateness (*TA*) of each event. *TA* was calculated by taking the absolute time difference between the times when the robot performed an action, and the ideal timing of that action. The ideal timing was calculated by taking the average timing of that action performed by the humans [4]. We conducted a Wicoxon Signed Rank Test, and found that the *TA* values for the *ECA* method were significantly larger than for the *SIA* method, $z = -4.399, p < 0.05, r = -0.18$.

The results suggest that the human-robot team was more synchronous when the *SIA* method was used opposed to when the *ECA* method was used. Moreover, the robot was able to perform the actions significantly closer to the appropriate timing of an event when *SIA* method was used. This supports the idea that a prediction method with the knowledge of the internal group dynamics is well-suited to provide more synchronous movement coordination during an SJA scenario [4].

IV. Experiment 2

To explore the effect on the synchronization of the group by adding multiple robots with homogenous or heterogeneous behaviors, we performed another set of experiments. We also used *SIA* and *ECA* as the anticipation methods [4].

There were four experimental conditions, where 1) only three humans performed a synchronous dance in a group, 2) one robot joined a group of humans to perform a synchronous dance, 3) two robots joined the group of humans, where the same movement anticipation and generation method was used for the both robots, and 4) two robots joined the humans, however, different movement anticipation and generation methods were used for the robots (See Fig 1).

During all the experimental conditions, the humans could either directly see or overhear the sound of the robot's movements. We analyzed a total of six groups for this study, with three people per group (18 participants in total).

A. Results and Discussion

To explore the effect of introducing multiple robots in a human-robot team during an SJA task, we first measured the group synchronization index (*GSI*) by using the method proposed in [5], [3], both with including and excluding the robots. One-way repeated-measures

Fig. 1: Three participants danced together across three conditions, A) humans alone, B) humans with one robot, and C) humans with two robots.

ANOVA with the Bonferroni correction indicated that the *GSI* values of the whole group, including the robots, across the experimental conditions were significantly different, $F(5, 115) = 22.59,\ p < 0.05,\ \omega^2 = 0.21$.

Our results suggest that the humans were similarly coordinated across all the experimental conditions, regardless of the addition of robot(s) to the group during an SJA task. Additionally, an addition of a robot with a different anticipation algorithm to a single robot team significantly reduces the overall group synchrony. However, the group synchrony did not vary significantly among the conditions when one robot vs two robots of similar behavior were performed with humans.

V. Discussion

Building on this foundation, we plan to develop and incorporate methods to improve the high-level activity detection of the humans by using the on-board multimodal sensors of the robot. To overcome the challenges regarding robot's motion and noisy depth data, we plan to use an activity recognition approach similar to Ryoo et al. [8] using a robot-ego-centric view. We are also planning to incorporate other human cognitive models from the literature to robots which can model the tempo changing behavior by combining adaptation and anticipation during an activity.

Our current research will directly support other researchers exploring *fluency* during human-robot interactions. Moreover, this research is directly applicable in fields beyond HRI, such as social signal processing. Our hope is that this research will help machines to be more socially aware, as well as be more acceptable to people [4].

References

[1] J. Fasola and M. Mataric. A Socially Assistive Robot Exercise Coach for the Elderly. *J. Human-Robot Interact.*, 2013.

[2] G. Hoffman and C. Breazeal. Cost-Based Anticipatory Action Selection for HumanRobot Fluency. *IEEE Trans. Robot.*, 2007.

[3] T. Iqbal, M. J. Gonzales, and L. D. Riek. Joint action perception to enable fluent human-robot teamwork. In *IEEE RO-MAN*, 2015.

[4] T. Iqbal, S. Rack, and L. D. Riek. Movement Coordination in Human-Robot Teams: A Dynamical Systems Approach. *Under review*, 2016.

[5] T. Iqbal and L. D. Riek. A Method for Automatic Detection of Psychomotor Entrainment. *IEEE T on Affective Computing*, 2015.

[6] T. Iqbal and L. D. Riek. Detecting and Synthesizing Synchronous Joint Action in Human-Robot Teams. In *ACM International Conference on Multimodal Interaction, Doctoral Consortium*, 2015.

[7] T. Lorenz, a. Mortl, B. Vlaskamp, a. Schubo, and S. Hirche. Synchronization in a goal-directed task: human movement coordination with each other and robotic partners. In *IEEE RO-MAN*, 2011.

[8] M. Ryoo, T. J. Fuchs, L. Xia, J. Aggarwal, and L. Matthies. Robot-centric activity prediction from first-person videos: What will they do to me? In *ACM/IEEE HRI*, 2015.