Role Distribution in Synchronous Human-Robot Joint Action

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Abstract— **Robots are becoming a part of our daily lives, and humans and robots are beginning to work together as teams to achieve common goals. In a human-robot interaction (HRI) scenario, it is important to assign roles to both the human and the robot, as these role assignments may affect the fluidity and the effectiveness of the interaction. In this paper, we discuss different role distribution models to assign roles among humans and robots in the context of synchronous joint action. We employed the leader-follower model in a human-robot collaborative task using a method from our previous work to detect synchronous actions of team members. Our results support our choice of the leader-follower model, and suggest that our method is capable of measuring synchronous joint action in an HRI scenario. These results are encouraging for future work aimed at the development of adept human-robot teamwork.**

I. Introduction

Robots are now becoming a part of our daily lives. Robots assist humans in many fields, from the manufacturing and assembly processes, to assistive technologies to help people with disabilities [4], [27]. However, in order to fit into human-social environments (HSEs), robots need to understand the activities happening around them [19]. To be a part of human life, social robots need to understand how humans interact among themselves. This knowledge will enable robots to act accordingly.

Joint action is a very important and challenging field of research in human-human interaction [12]. Sebanz et al. [22] defined joint action as a form of social interaction, where two or more participants coordinate their actions in both space and time, and make changes in their environment. Understanding human-human joint action in a collaborative scenario is helpful for the design of effective human-robot interaction (HRI). Incorporating human behaviors into robots will also help to design more fluent HRI [8], [9], [20].

Many fields including psychology, cognitive science, and dance focus on measuring synchronous joint action in various human-human interaction scenarios [2], [13], [15], [18], [26]. Understanding synchronous joint action in a group is very important, as synchrony is a key indicator of group cohesiveness and the affective behavior of a group [18], [25].

In the context of a HRI scenario, understanding synchronous activity or synchronous joint action is also important, as it may improve the overall engagement of a robot in its environment [5]. Understanding human activity will also help a robot act appropriately [8].

In the case of a human-human team, participants are sometimes explicitly assigned to different roles to accomplish a common goal [17]. However, in some human-human teams, there exist no prior role assignments. In such situations, roles are developed over time based on the goal [14]. Each participant usually does their own assigned work, and/or monitors the activity of others. In the case of an unexpected situation, or change in the goal, participants adjust their actions and inform others accordingly. They may change their assigned roles according to different situations, as well as coordinate with others as a team member. This cooperation and coordination helps the team to achieve a common goal.

Similarly when humans and robots are working as a team, we can assign each of the team members a role. The assigned role may affect the fluidity and the effectiveness of the interaction [23]. Each of these assigned roles defines how humans and robots cooperate with each other. The highest level of cooperation can be achieved by taking into account their reasoning, sensing, and acting capabilities when assigning a role. Moreover, different role assignments can lead to different control strategies in HRI [17]. For these reasons, determining a proper role distribution model based on the goal of a task is important.

In this paper, we discuss role distribution of humans and robots in a synchronous joint action scenario. We first describe different aspects of assigning roles in a group of humans and robots, then describe our position for selecting a specific distribution for human-robot collaborative tasks. We motivate this selection through its application in a research study aimed at understanding synchronous joint action in one such human-robot collaborative task. Our results support this position, and suggest our model is capable of detecting synchronous joint action using our distribution of choice.

In Section II, we describe different role distributions between humans and robots in the context of human-robot interaction. In Section III, we describe our argument for a leader-follower role distribution model in the context of synchronous joint action in HRI. We also describe an experimental study and results to support our position. Section IV discusses the implication of this role distribution in HRI.

II. Background of role distribution in the context of HRI

Similar to human-human teamwork, it is important to employ the team coordination concept in human-robot interaction scenarios [3], which allows the robot and the human to work as a team to achieve a common goal. There might be different types of assignments that can be accomplished through a human-robot team based on the goal of that task. The role assignment may involve a collaborative task, cooperative task, or a competitive task [11], [12]. Both humans

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and robots work as equal partners towards a common goal in a collaborative task. In a cooperative task, the workload is not equally distributed among human and robot participants. In a competitive task, human and robot act as opponents.

In the case of human-robot interaction scenarios, Scholtz defined five types of roles for a human participant [21]. These roles are supervisor, operator, mechanic, peer, or bystander.

A supervisor has the authority to monitor and control the whole interaction process. He or she can change the goal or the intention of the entire interaction at any time. In an operator role, a human can change the control mechanism or the behavioral model of the robot if the behavior of the robot is not acceptable. A person in a mechanic role deals with adjusting the physical component of the robot to ensure the desired behavior.

In a peer role, a person can give commands to robots by keeping the focus on the larger goal of that interaction. Lastly, a person in bystander role does not interact with the robot directly; rather a robot needs to take the actions of a bystander into account when performing some task in its environment. For example, a robot needs to be aware of a moving person in its environment, although they might not interact or work towards the same goal.

In a cooperative human-robot interaction scenario, Ong et al. [16], [17] described the possible role distributions between human and robots to achieve cooperation in a telerobotics system. The major role distributions are master-slave, supervisor-subordinate, partner-partner, and teacher-learner. To describe high-level interactions between humans and robots, this framework is useful, although it might not be suitable for detailed analysis [12].

In a master-slave model proposed by Ong et al. [16], [17], the human always controls the activities of the robot. The robot only can perform the tasks assigned to it, but the human makes the decision to accomplish the goal.

In the case of the supervisor-subordinate role distribution model, the human acts as a supervisor. The responsibility of the supervisor includes dividing a process into smaller tasks and assigning them to the subordinates. The robots act as subordinates in this model, and have freedom to plan and execute to finish the assigned subtask. If something goes wrong, it is the responsibility of the supervisor to step in and find a solution to that problem.

The human and the robot are viewed as partners in the partner-partner role distribution. Here both humans and robots are assigned with some specific tasks, and can help each other to make necessary decisions and actions in the case of a problem. In this scenario, a human and a robot have the same level of authority.

In a teacher-learner role distribution, the human acts as the teacher and teaches the robot. It is assumed that the learner has the ability to understand and learn from the human. A special case of the teacher-learner model is the 'learning from demonstration' (LfD) model. In LfD, a learner observes the actions of the teacher, and tries to replicate the actions with or without taking any direct guidance from the teacher [1].

Another commonly used role distribution is the leader-follower model. In this model, only the follower adjusts its actions based on the actions of the leader [11]. Typically, the human acts as the leader and the robot acts as the follower. For example, Stuckler [24] employed a leader-follower based role distribution in their work. In the cooperative task described in this work, the human and the robot worked together to lift and lower a table. The leader (the human) showed his/her intention of lifting or lowering a table to the follower (the robot). After interpreting the intention of the leader, the follower took appropriate actions to help the leader lift or lower the table together. We show some commonly used role distribution models in HRI in Figure 1.

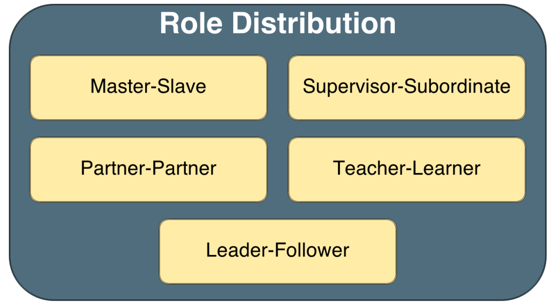

Fig. 1. Some role distribution models used in HRI.

III. Role distribution in a synchronous joint action scenario

A leader-follower role distribution model is widely used in small human-robot teams, in robot-robot teams, and in dyadic synchronous activity scenarios [6], [7]. In these team interactions, usually the robot acts as the follower. The follower may follow the activities or the actions of the leader, who can be a human, or another robot.

Depending on the task in a cooperative scenario, the leader may take actions to adjust its behavior towards the goal, if needed. The follower observes the leader and at the same time works to accomplish the goal. When the leader changes its behavior, the follower may also need to adjust its behavior accordingly. The follower then modifies its actions, and continues working cooperatively.

There are cases when the leader-follower model provides some benefits over the master-slave model. In the case of the master-slave model, the master needs to make decisions about his/her actions as well as the actions of the slave. This computation creates more communication overhead as well as generates more tasks to be performed by the master. The partner-partner or supervisor-subordinate models are similar to the leader-follower model for a small group activity, where only the actions of the followers need to be modeled.

In the case of a leader-follower scenario, the follower robot requires two abilities. First, the robot needs to perceive the actions performed by the leader. Second, depending on the goal of the task, the robot needs to take appropriate actions based on the actions of the leader.

If the group activity is a synchronous joint action, then the follower robot also needs to understand the notion of

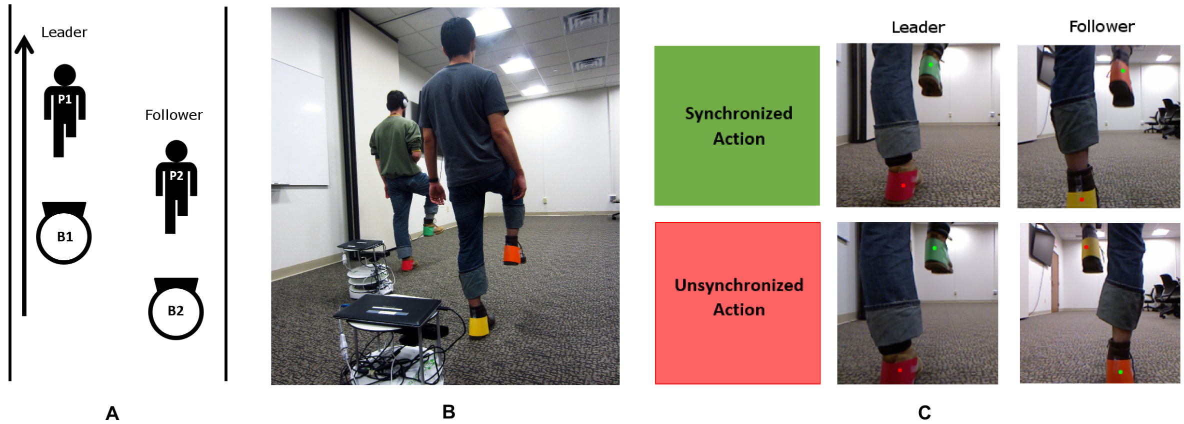

Fig. 2. A) The layout of the experiment. Here we show two cases of leader-follower role distribution. In the first case, one human is following the other human. In the second case, the robots are following each human. B) One experimental session, where a human participant (the leader) followed by another human (the follower) while marching. Two follower robots also followed the humans. C) A synchronous and an asynchronous joint action scenario.

synchrony itself. After perceiving the actions of the leader, the follower robot will take necessary actions to make itself synchronous with the actions or movements of the leader. The leader does not need to care about the actions of the follower, as the follower will always synchronize its actions with the leader. It is the responsibility of the follower to take appropriate actions to make the group synchronous.

To perceive the activity of the leader in a synchronous group activity, the follower needs to understand the actions taken by the leader. If the follower is a robot, different modalities can be used to perceive the leaders actions as well as its environment. These modalities may include a video camera, audio capturing device, depth camera etc. In the case of multiple modalities, there must be some method to fuse the data streams together.

From these data streams, the follower needs to detect the actions of the leaders as well as the environment they are in. After detecting the actions of the leader, the high level activities can be detected. The follower may then try to perform synchronous activities to keep the group or the dyadic interaction synchronous.

In our previous work [10], we proposed an event-based model to automatically measure group synchrony. Our proposed model can automatically measure group synchrony, while taking multiple types of discrete, task-level events or actions into consideration. According to our model, we need to detect the actions of each team member first. The overall group synchrony is then measured from the detected actions.

We employed our model to measure group synchrony in a human-robot synchronous joint action scenario. We validated this model through an experimental setup, where two robots monitored the movements and actions of two humans while they were marching, either synchronously or asynchronously.

The goal of the study was two-fold. The first goal was to detect different types of joint action of the human from a robot. The second goal of the study was to automatically measure the level of group synchrony from the joint action while both the humans and the robots are in motion.

We used a leader-follower role distribution in a team of humans and robots. Two cases of role distribution were used together in this study.

In the first case of role distribution, a human marcher acted as the leader and the second human marcher acted as the follower while they were performing a joint action together. The first marcher always marched at a consistent pace. The second marcher was on the right side of and approximately two feet behind the first marcher and followed the steps of the leader. The follower adjusted his/her steps either synchronously or asynchronously as directed.

In the second case of role distribution, the robots were the followers. Two Turtlebot robots followed the steps of the humans, one for each person. Here the role of the follower was to follow and monitor the activities of the leader.

Figure 2-A shows the layout of the experiment. We show an experimental session in Figure 2-B, where two humans are marching (one is the leader and another one is the follower) with two robots following the humans.

From each robot's video data, two different actions of the human leader and the follower were detected while they were marching. One of the actions was detected when the leader raised his/her leg and it reached its maxima. The other one was detected when the leg left the ground. We present a synchronous and an asynchronous joint action scenario in Figure 2-C. After detecting the actions, the overall group synchrony was measured using our model.

We recorded a total of four experimental scenarios. Each scenario lasted approximately 35 seconds. During the first scenario, the follower was instructed to march synchronously with the leader. In the second scenario, the follower marched asynchronously. For the third scenario, the follower began marching synchronously, became asynchronous after 12 seconds on instruction, and became synchronous again after 24 seconds. The fourth scenario was the same as the third scenario, except in reverse order.

We expected to see a high value of the synchronization index during the first scenario. In contrast, we expected a very low value for the second scenario. For the third scenario, we expected to see a high value for the synchronization

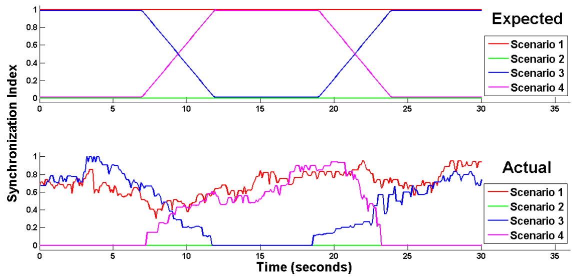

Fig. 3. The expected and actual synchronization indices over time of our experimental scenarios.

index during the beginning of their match, a low value in the middle, and a high value when they began marching synchronously again. We expected a similar result for the fourth scenario, however, in the opposite order of the third scenario. From Figure 3, one can see that the measured synchronization indices reasonably matched the expected synchronization indices for all experimental scenarios.

Our results suggested that mobile robots can successfully identify synchronous joint action through our model. Our results also suggested that our model is robust in detecting the asynchronous conditions as well.

Therefore, by applying our model to the robots, it is possible for follower robots to perceive the actions of the humans in their environment. Thus, the robots have achieved the first requirement needed to be a follower.

The second requirement that the follower robot will need is to perform appropriate actions depending on what it perceives and the goal of that task. If the goal of the task is to keep the group activity synchronous, then the robot's behavior can be modeled to perform synchronous joint action following the leader. Similarly, based on other goals, other behaviors are possible to model.

IV. Discussion

To make a human-robot team work more fluid, it is vital to assign different roles among humans and robots, especially when the robots are situated in human-social environments. The outcome of these types of human-robot interaction also depend on the role distribution among humans and robots. The fluidity and the effectiveness of the interaction depends on appropriate role assignment.

In this paper, we discussed the role distribution between humans and robots in a scenario involving synchronous joint action. We described different aspects of selecting the leader-follower role distribution in this context. Our results to-date suggest that our proposed model is capable of understanding synchronous joint action in the context of HRI.

Future work will include modeling the activity of the robots based on the perceived behavior of the human-robot team. This will help us to design and implement more efficient, intelligent, and fluid human-robot interaction. It will also be interesting to see how other role distributions will work when applied to a different setup in the same context.

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