Multi-Party Social Human Robot Interaction: A Survey

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***Abstract*—This report reviews Multi-Party Social Human-Robot Interaction: interaction between multiple humans and a robotic system involving some social element. We begin by defining this field and placing it within the broader context of human-robot interaction. We then describe the different modes of analysis we use to generate our insight into the structure and trends within the field. Within the modes of analysis this survey covers the key insight or observation of each of the forty works making up the field for the last decade. Finally, some key limitations and guidelines for future work are outlined.**

***Index Terms*—Human-Robot Interaction, Social Robotics, Multi-Party Interaction**

I. Introduction

The field of Human-Robot Interaction (HRI) consists of "Understanding, designing, and evaluating robotic systems for use by or with humans." [1]. Alternatively, it can be described as "The study of humans, robots, and the way they influence each other." This is different from Human-Computer Interaction (HCI) and Human-Machine Interaction (HMI) in that it involves systems (i.e. robots) which have complex, dynamic control systems, which exhibit autonomy and cognition, and operate in changing, real-world environments." [2]. HRI is unique in that it combines the traditional challenges of robotics and artificial intelligence with the challenges posed by the complex, non-Newtonian dynamics of human interaction.

Although there are many challenging elements to HRI, one of the most challenging elements is the social interaction. Specifically, Socially Interactive Robotics (SIR) focus on the social, emotive, and cognitive aspects of the interaction [3]. This is distinct from teleoperation, in which humans act through a robot, rather than with a robot. It also includes Socially Assistive Robotics (SAR), though it is not limited to social interaction at the exclusion of physical interaction, as SAR is [4]. Although SIR can include swarm robotics, in which robots interact with each other, this paper focuses on the intersection of HRI and SIR, which excludes the swarm applications.

Within the intersection of the fields of HRI and SIR there is a further distinction between individual interaction and multi-party interaction. Here, we define individual interaction to include interaction between one human individual and a robotic system and we define multi-party interaction to include the interaction of a robotic system with multiple people. We call the intersection of HRI, SIR, and multi-party interaction, *Multi-Party Social Human-Robot Interaction* (MP-S-HRI) 1. Although HRI and SIR have been around for decades, there has only recently been any progress or interest in exploring MP-S-HRI. This is a sign of the growing maturity of HRI and SIR, enabled by technical advances in hardware and software over the last decade. On the hardware side, there are now standardized, feature rich platforms available for researchers to use (e.g. the Nao, Furhat, among others) that greatly lower the barrier to entry. Also, the development of cheap depth sensing equipment and faster and more powerful computers has enabled processing environmental input in ways that are drastically more advanced than a decade ago. On the software side, the development of open source vision and dialogue software has dramatically increased the interaction potential of robotic systems. Additionally, the explosion of deep learning algorithms and the hardware to support them has enabled researchers to learn more robust features and control algorithms from the data they collect.

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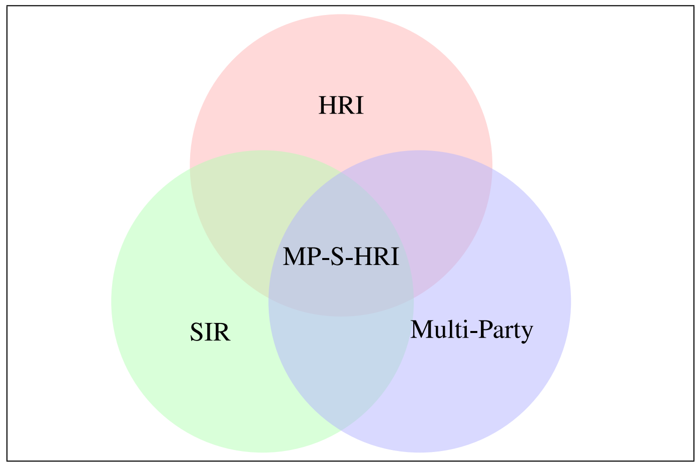

Fig. 1: Diagram of the work covered by the Multi-Party Social Human-Robot Interaction

The rapid growth in MP-S-HRI, as seen in Figure 2, has been driven by a recognition of the possibility of and the need for extending HRI and SIR to include multi-party interaction. For robotic systems to work in the wild (i.e. the real world)

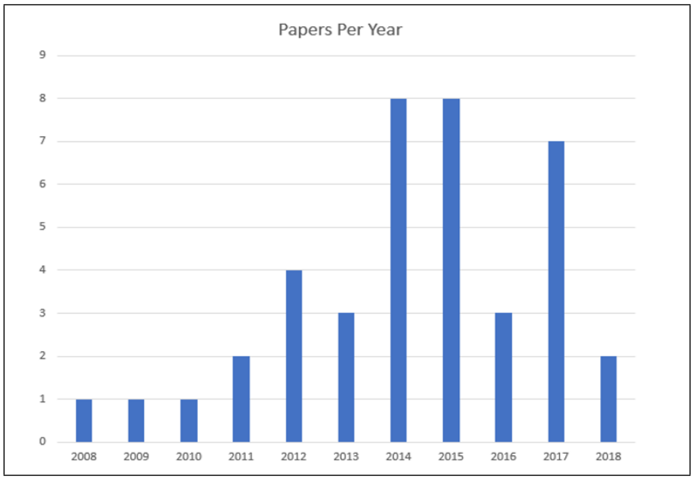

Fig. 2: Papers in MP-S-HRI each year from 2008 to 2018

they will commonly need to be able to handle situations in which they must interact with multiple people. Interacting with multiple will also increase the robots utility by allowing it to extend its influence in the real world.

In this paper, we present a survey of multi-party social human robot interaction. In this survey we articulate the state of the art in a rigorous, coherent, and organized manner. We include the key accomplishments, insights, and limitations of seminal works. We provide a recommended path for future work. The paper is organized as follows: Section 2 describes how the systematic literature review was conducted and how the papers were found, organized and analyzed. Section 3 provides an overview of the papers surveyed within the context of the key themes. Finally Section 4 presents the key limitations, recommendations, and conclusions which can be drawn from this body of work.

II. Methodology

A. Review Protocol

In order to analyze the research on MP-S-HRI we conducted a systematic review of the published, peer reviewed works on multi-party social human-robot interaction in the last decade. We searched through the published works of the top robotics technology conferences for papers that met our survey criteria. We utilized Google Scholars Advanced search feature to find papers published between 2008 and 2018 matching the following search query: "multi-party" AND "human-robot interaction" AND "social". This returned 738 results, which were then screened to only include papers that:

1) Included an actuated, embodied robot
2) Included two or more humans
3) Included some form of social interaction
4) Were full papers published in a peer reviewed robotics and technology conference

B. Modes of Analysis

To provide a meaningful analysis of the selected literature we reviewed each paper along three major modes of analysis and four minor modes of analysis. The major modes of analysis focus on what is being done and why it is being done. They and include: Research Motivation—what real world purpose or ends is this research being conducted for? Interaction Setting—what is the actual form of the interaction between the humans and the robot? Engineering Motivation—what technical challenge is being solved by this work? The minor modes of analysis focus on the details of the research. They include: Robot Relationship—how do the robot and human relate to one another? Control—what type of algorithm is being used? Study Design—what type of study has been conducted? Physical Setup—what are the perceptual and affect capabilities of the robot? Although not all papers had or specified each mode of analysis, we extrapolated from what was available when possible and included the exclusion of the mode when it was not. Additionally, for each paper we also noted key observations, results, conclusions, and limitations.

1) Research Motivation: The primary, and most important mode of analysis is the Research Motivation. The research motivation explains what useful purpose the MP-S-HRI interaction could serve in real life. Although the possibilities for research motivation are innumerable, we found that they could be grouped into the following five categories, detailed below. Although these categories are not mutually exclusive, we found that most papers focused on just one category. For the first two categories, teaching and mediation, we found that the papers motivations could be further subdivided, whereas service, problem solving, and entertainment were not developed enough to warrant further grouping.

The first category is teaching, which can take the form of dispensing information, tutoring, or guiding. In tutoring, the focus is on helping a group understand a given topic in a meaningful way. We find this is distinct from dispensing information, where the goal is not the learning of a topic but providing information that is needed for a certain situation, often in answer to a question. Guiding, which often takes place in museums, malls, or similar environments is a combination of tutoring about relevant topics to the location and dispensing information to audience questions.

The second category that motivates MP-S-HRI research is mediation. In mediation the goal is for the robot to understand and control the dynamics between people in a group. We found that mediation can be loosely divided between moderating flow and mediating relationships. Moderating flow places the robot in charge of a group of people and seeks to control the flow or sequence of events in an interaction, particularly as it relates to the activity or topic at hand. Mediating relationships on the other hand, seeks to understand and improve the interaction dynamics between group members, and is often agnostic to the topic or activity at hand.

The third category that motivates MP-S-HRI research is service. Although service in robotics is often physical in nature, the research in MP-S-HRI focuses on understanding the needs of the individuals being served and the communication portion of the service interaction.

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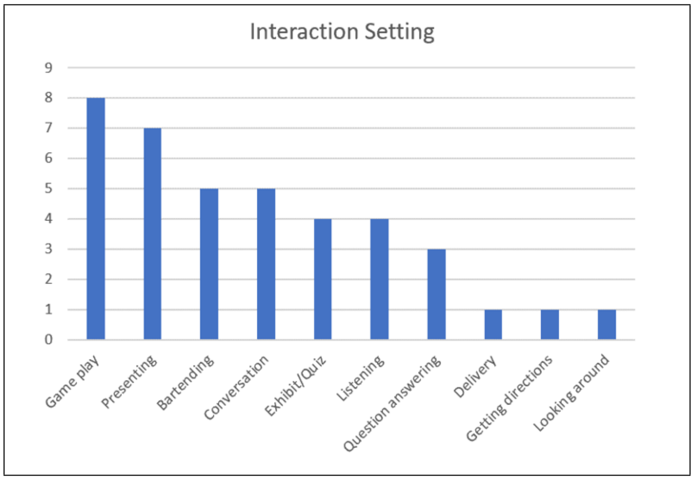

Fig. 3: Papers per interaction setting category.

problem solving. In problem solving we find robots that are seeking help from humans in order to solve a problem. In this context the robot brings a problem to a group of people and asks for their help in order to solve it.
The fifth category that motivates MP-S-HRI research is entertainment. Entertainment can take many forms and includes most research that is not focused on the practical goals of teaching, mediation, service, and problem solving.

2) Interaction Setting: In our analysis of the interaction setting, we explore what setting the researchers chose to conduct their MP-S-HRI in. We find that the literature can be clustered into ten different settings, each with a different interaction characteristic. We define the interaction characteristics in terms of the medium and direction of communication (e.g. who is or is not speaking). In no particular order, the settings include:

- Conversation—both the participants and the robot speak to each other
- Exhibit/Quiz—the robot speaks, and participants answer questions
- Question Answering—the participants speak, and the robot answers questions
- Presenting—the robot speaks, and the participants listen
- Listening—the participants speak, and the robot listens
- Looking—neither group speaks, both communicate non-verbally
- Game play—either group can speak, but interaction also occurs through the game
- Bartending—participants make simple requests and the stationary robot responds with a signal or a drink
- Delivery—participants make simple requests and the mobile robot responds with a signal or an item
- Getting Directions—the mobile robot makes simple requests, and the participants answer questions

The interaction setting is important precisely because each setting has unique requirements upon the robot, and presents deferent levels of difficulty due to the complexity of the allowed interaction. The number of papers per setting can be

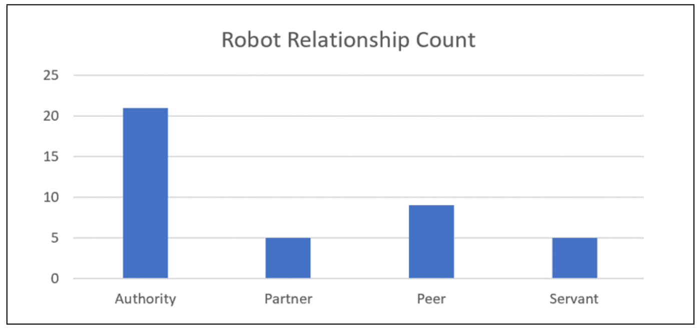

Fig. 4: Papers per relationship category

seen in Figure 3

3) Engineering Motivation: Independent from the Research Motivation and the Interaction Setting, most studies also address a specific technical challenge. After analyzing the selected literature, four key themes emerged as engineering challenges addressed in the MP-S-HRI literature: Control Algorithms, Perception Processing, Design, and Modelling Dynamics. In Control Algorithms, an algorithm for controlling the robot action during the interaction was developed and tested. The type of algorithm used for control is independent of the setting and research motivation, but the details of its implementation were not. The second challenge addressed by some papers was Perception Processing. Perception Processing is the method by which a robotic system makes sense of the raw inputs (i.e. video and audio) and interprets them into something useful (i.e. expression and words). Genuine MP-S-HRI demands a high level of perception processing, and many papers focused on developing novel and robust methods of synthesizing sensor data to make sense of the environment. The third theme to emerge, Design, was the challenge of learning human preferences for robot action and appearance during an interaction. This often-overlooked aspect of engineering is crucial for successful human-robot interaction. The final engineering challenge, Modeling Dynamics, refers to the difficulty of modeling the hidden states of humans that relate to interacting with each other and with a robot in order to have a successful sequence of interactions in a given setting. These themes were not mutually exclusive, and many papers focused on more than one at a time.

4) Study Details: **Robot Relationship:** In every human robot interaction there is an interaction dynamic related to the power balance between the parties. In a Peer relationship the robot is at the same level as the participants, though it does not necessarily share the same goals as the participants. In a Partner relationship the robot is also at the same level as the participants, but it is on the same side as the participants. In an Authority type relationship, the robot is positioned to have more power than the participants, as it will give directions and or commands to the participants that they are expected to follow. In a Servant type relationship, the robot is subservient to the participants, and although it may make suggestions, it will take the orders and directions of the participants. The papers per relationship category can be seen in Figure 4.

Control: In this section we examine the level of complexity of control algorithm the robot used. This can vary from having no control algorithm in Wizard of Oz (WoZ), to minimal control algorithms in Open Loop and Reactive control models, to complex controllers such Model, Goal, and Utility Based controllers. For WoZ control, the robot would not be able to accomplish its assigned task if not for the input of a human who is not part of the interaction task. This form of control is the simplest computationally but can function in complex scenarios at the cost of actual autonomy. For an Open Loop controller, the robot action is dependent solely on the time since the last action, with no use of the robots sensors. For a Reactive controller the robot can respond to stimuli in the environment but only with actions determined by a fixed set of rules. For a Model based controller, the robot can use its sensors to update an internal model of the state of the world and then act according to a set of rules. For a Goal based controller the system also updates an internal state of the representation of the world, but then it will act based on the predicted effect of its actions relative to the goal. A Utility based controller is the same as a Model based controller, but the system can have more than one goal.

Study Design: To characterize the studies that were run in the MP-S-HRI literature we examine several variables related to the study design. For each study we record the Size the total number of participants, the Group Size the number of humans in each trial, the Duration the total number of minutes each participant spent with the robot, the Control whether the study was single case or controlled, and finally Intervention whether the study involved analyzing open source data or running a new intervention.

Physical Setup: In examining the physical setup of the robotics system for each paper, four key areas were recorded, including the Input Modalities, the Processed Features, the Robot, and the Affordances of the robot. For the Input Modalities the input types were divided into video, audio, depth, position, and touch. For the Processed Features, the way the robot processed the Input Modality to generate meaningful percepts was recorded (e.g. video was processed for gaze, facial expressions, and pose). The type of robot was also recorded, and the affordances of that robot. For example, the Nao robot can use speech and pose, but does not have facial expressions or gaze.

III. Analysis

The analysis here is organized by Research Motivation. Each of the four main categories will be examined to see what work has been contributed and what results and observations were presented.

A. Teaching

As was described above, the teaching motivation for MP-S-HRI involves the robot doing some form of activity in order to provide information or knowledge to the humans it is interacting with. In the multi-party context that typically breaks down into either the dispensing of facts in answer to questions, performing some sort of exhibit guiding, or tutoring. In examining the literature here we see that all but one [5] (Partner) take the form of an Authority relationship. This is likely due to the power dynamic in which the robot has information that the person does not, and so people will natural tend to listen to and follow the robot.

One form of Teaching is through Dispensing Information, in which the robot will either answer specific types of questions or simply share facts. In the four papers on Dispensing Information we find one of the seminal works on MP-S-HRI [6], in which they use gaze behavior to shape the roles that each participant takes in the interaction. In this paper the authors develop a model of interaction dynamics using only gaze behavior. In [7] and [5] the authors focus on the engineering challenge of perceptual processing, contributing an improved speech recognition algorithm [5] and an algorithm for predicting user disengagement [7]. In a similar work by the same authors, [8] explore how to robustly control a robot that gives directions, and make the key observation that in the real world users are often distracted and may regularly seem to break engagement with the robot even when they dont mean to.

The most popular teaching form of research motivation was Exhibit Guiding. In these works, the robot is either simply Presenting (teaching the audience about something) or Exhibit/Quizzing in which the robot shares information but will also ask questions to improve learning. In the Presenting case, the engineering motivation focusses on the Modeling Dynamics problem, whereas in the Exhibit/Quiz case the engineering motivation is both Modeling Dynamics and Perception Processing. Some of the key results here include that asking questions will increase retention [9], people will interact more amongst themselves with a robot than with a human [10], that when a robot giving tours points towards the group it is talking to it will increase engagement but also confusion [11], and surprisingly that using the behavior of the robot is the most effective predictor of party engagement, rather than observing the people themselves [12]. One key observation was that when determining who the addressee is in an exchange, just knowing the gaze is not sufficient [13].

One of the promising avenues of Teaching in HRI, Tutoring, has received relatively little attention in MP-S-HRI. In Tutoring the robot is engaged in a longer session in which it tries to teach the students about a specific topic. In the three examples of MP-S-HRI tutoring, the engineering focus was different for each. The latest focused on Modeling Dynamics, specifically conflict dynamics and how to constructively resolve them [14]. In [15] the focus was on Perception Processing, but they came to the surprising conclusion that robot re-engagement strategies lowered learning and recall, possibly due to the fact that children dont have the ability to recover from interruption as well as adults. Finally, [16] focused on the design preferences of Japanese families on who the robot should adapt to (children or adults) when tutoring about itself and its capabilities.

In the MP-S-HRI Teaching literature we see mostly controlled

(10) vs single case (2) interventions (10). There is only one sophisticated controller [7], the rest are Open Loop, Reactive, and WoZ. The studies used the Nao most often (5 times), the Robovie 3 times, and the Keepon twice.

B. Mediation

The second most popular research motivation was Mediation. In mediation the robot attempts to influence the dynamic between members of the group. This can be done through Mediating Relationships, where the robot attempts to directly change the relationship between two individuals or through Moderating Flow, in which the robot tries to influence the relationship in a way specific to the context of the interaction. In the MP-S-HRI literature we found Mediating Relationship was more popular, with six papers, whereas Moderating Flow only had four. For Mediation, Conversation and Game Play were the most popular Interaction Settings, with only two papers, [17] and [18] also exploring the Listening setting.

In the papers that focused specifically on Mediating Relationships, the most popular Engineering Motivation was Design, often paired with the study of a control algorithm or modeling dynamics. In line with the focus on design, [19] and [20] found that users like receiving feedback from a robot, particularly if it involves gestures and [17] found that reacting to the conversation leads to more perception of human character traits in the robot and [21] found that different robot head behaviors can be used to obligate different group members to respond. Two of the most interesting observations made were that interaction behavior should be very specific to the person and context [18], and that robot attempts to repair conflict can actually backfire by increasing the groups awareness of the conflict and acting against the tendency of the group to suppress it [22].

In contrast to Mediating Relationships, the work done on Moderating Flow focused on the engineering challenge of Modelling Dynamics. This work was done in a Game Play setting with a robot that was either an Authority, Peer, or Partner. In [23] the authors explore controlling turn taking, and find that the robot can robustly control who speaks next by smiling or using filled pauses while looking away to grab the floor and using mutual gaze to yield a turn. In 2017, Short et al. produced two works on moderating games. The first, [24] characterized intergenerational dynamics when playing with a robot and found that families would be willing to bring robots into their homes. The second, [25] found that when moderating, the more a robot spoke the higher the group cohesion but the lower the performance. Additionally [26] found that it was possible to predict imbalance and how reduce it in a post-hoc study of the data they collected in hundreds of game interactions in a museum.

Overall it is heartening to see the higher quality of the Mediation work. There was only one WoZ study and one non-intervention study.

C. Service

There were nearly as many papers on Service (9) as there were on Mediation. The papers on Service focused on opportunities for a robot to be of some use to a person or group. The most popular setting by far was Bartending, with five works devoted to Perception Processing and Modelling Dynamics for a robot bartender. Additionally, there were three mobile robots, one for delivery, on for presenting while guiding, and another where the interaction setting was not specified.

In the Bartending context, three of the five papers focused on Perception Processing for detecting engagement or interaction with the bartender. In [27], the authors found that sometimes simple manual rules are better for classifying engagement than learned models. In [28], they found that head pose can be used to correctly identify the difference between requesting attention, ordering, and closing the interaction 78% of the time. In [29], they explored how some perceptual models jump back and forth too quickly leading to poor reactions from the robot. In [30], they found that the robot could detect the desire for a drink but that it would fail under multi-party conditions. The only bartending paper that did not focus on perception was [31], in which the authors explore using gaze cues to effectively indicate what person should receive an object from the robot.

In the non-bartending service context, the focus was on Modelling Dynamics. In their paper on robot delivery, [32] found that the robot could deal with multiple requests by acknowledging the second requester while it dealt with the first. In [33], the authors develop a model for engaging eye contact by 1- attracting attention, 2- establishing contact, and then 3- displaying awareness. One key observation made in [34] was that group detection by spatial organization is more robust than head pose, because it can ignore when people are momentarily distracted. Another key observation, this time made in [35] is that robotic systems can attract more attention when sharing information by looking backwards, as people will tend to stop and observe the robot when they can see its face.

D. Entertaining

The work on entertaining represents a fascinating diversity of Settings, Engineering Motivations, and Robot Relationships. This is in part because the situations and methods we may use to entertain ourselves also have potentially infinitely diverse. In this survey however, this section also includes the projects that did not have a clear or meaningful research purpose, even if it was not explicitly stated as entertaining.

One of the most popular (85 citations) and most interesting works in the Entertainment theme, [36] brings up the notion of interpretive flexibility as key for the success of robots in diverse contexts. Their work shows the importance of robots that can adapt to different users needs. In 2008, [37] test two models of audition, combining vision and speech and find that people prefer the model that is not as easily distracted. In [38] the authors examine how changing group size affects the performance of a disengagement model, observing that models do best on the same group size they were trained on. In [39] the authors implement a robot with a sidekick for interaction with children, and find that it increases attention to spoken elements of the interaction. In a similar but slightly different vein [40] examine groups with both virtual and robotic agents and how well the system can track the participants. In an interesting ethical study on bias, [41] compares in vs out of group bias with that of human vs non human bias, showing that people prefer teammates over humans. Finally, in study modelling conversation dynamics, [42] develop an algorithm that can correctly identify a robots response obligation 86% of the time.

E. Problem Solving

Joint Problem Solving is the smallest group of papers, with only two MP-S-HRI papers addressing this issue. Nonetheless, it is important because it is only through joint human robot teams that we will be able to solve the hardest problems. In the first work in this area a robot attempts to get assistance from a group human in navigating [43]. The work focuses on learning perceptual cues from the environment to know when it is appropriate to interrupt and ask for help. The second work again has a robot seeking help from a group, in this case to brainstorm ideas for to prevent itself from being dumped on the scrap heap [44]. This work focuses on how body gaze and orientation are perceived by the group of humans. Unfortunately, both works are controlled via WoZ, but they are impressively large (n=169, 69, respectively) and well controlled studies.

IV. Conclusion

A. Limitations

Although the field of MP-S-HRI has recently rapid growth in popularity, there is still a vast amount of room for growth. Much of the literature currently focuses on the related elements modelling dynamics and perception processing. Unfortunately, this has been at the expense of using and developing proper control algorithms for these interactions. Without this third leg, the MP-S-HRI will never be robust enough to work in the real world. Additionally, work on both Perception Processing and Modelling Dynamics suffers from the rigidity of over constraints. The models developed and conclusions drawn are often claimed to be robust but only trained and tested in very narrowly controlled circumstances. Additionally, much work stops at simple pilot studies, with $n \leq +30000000050$ making up 40% of all work.

B. Recommendations

Throughout the last several decades there has been a growing trend towards standardization of robotics hardware and software. MP-S-HRI could greatly benefit by leveraging the growing standardization to develop setups and methods that are repeatable and extendable. Currently, one of the greatest barriers to running any HRI study is the long development time, this issue is compounded for MP-S-HRI, but could be aided by researchers open sourcing code and methods. Additionally, as is the case in much of HRI, MP-S-HRI could benefit from larger studies with longer interaction times.

C. Conclusion

As research continues to develop in HRI there will always be room to extend it to cover MP-S-HRI scenarios. This process is not simple however, it requires careful consideration of how to incorporate the more complex dynamics of multi-party. Despite these difficulties, MP-S-HRI remains a very valuable field of study both as a testing ground for the robustness of HRI and as special case with its own merits.

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