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# Non-Dyadic Human-Robot Interaction: Concepts and Interaction Techniques

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***Abstract*—With the increase in robot complexity and the diversity of domains in which we encounter robots, there is an increased need for research focusing on more varied aspects of human-robot interaction. While most research has focused on the dyadic interaction (one-to-one) between one human and one robot, we are currently observing a paradigm shift towards increased attention to HRI in non-dyadic systems. However, we still have limited knowledge of which interaction techniques work well for non-dyadic HRI combining human participants with multiple digital artefacts, including robots. We investigate what characterises non-dyadic HRI in various contexts, including the home and industry, and how the addition of robots affects how we interact in groups. This paper presents our research questions, preliminary results, and plans for future studies, thereby contributing to a better understanding of the concepts and interaction techniques in non-dyadic interaction in human-robot groups in various contexts.**

***Index Terms*—Non-dyadic HRI, interaction techniques in groups with robots, human-human interaction**

## I. Introduction

The increasing emphasis on ecologies of technologies communicating and interacting with each other (e.g., speakers, watches, lights, personal assistants, robotic vacuum cleaners) changes how we interact with technology. This shift in focus from dyadic systems, as in one technological artefact with one human, towards digital ecologies [13] brings new challenges and new ways of understanding technology and interaction. While most current research still focuses on dyadic HRI [15], we currently observe a paradigm shift towards non-dyadic interaction in a variety of contexts (e.g., domestic or industrial) in the field of human-robot interaction [11]. Non-dyadic human-robot interaction is more than the mere upscaling of dyadic interactions between one human and one robot [9]. Multiple humans interacting with robots add a new layer of complexity, namely human-human interaction [9]. How is the interaction affected by the presence of other humans, non-robotic technologies, and robots? How do humans interact with each other to accomplish a given robot-supported task? What type of interaction techniques are utilised in these non-dyadic settings? How does non-dyadic HRI affect the spatial and temporal dimensions of the interactions? These are just some of the questions that are relevant to answer in order to understand the current development of robots in non-dyadic settings fully.

### A. Research Questions

In order to achieve a better understanding of what interaction in non-dyadic settings mean and how it affects the human-robot and the human-human interaction in these settings, our work is guided by the following three research questions.

1) Which concepts characterise research on non-dyadic human-robot interaction?
2) What impact do robots have on interaction in mixed human-robot groups?
3) How do robots influence human-human interaction in non-dyadic interaction?

## II. Background

Different aspects of non-dyadic interaction with robots have been investigated, including: reduction of loneliness [8], impact of robotic co-workers in industry [14], interaction with robots in hospitals [10], [12], collaboration in groups [6], [9], [19], human perception of groups of robots [5], [7], robot mediated intimacy [20], human reaction to robot abuse [2], [3], or literature reviews investigating non-dyadic HRI [15], [17]. Yet, an increasing number of research has called for a greater need to investigate HRI going beyond the dyadic interaction between one human and one robot (e.g., [5], [8], [20]).

Three recent examples of studies investigating different aspects of non-dyadic HRI are [5], [8], [12]. Fraune et al. [5] investigate how the presence, or absence, of entitativity (feeling of belonging to the same group) changes human perception towards triads of robots. Their study manipulates robot entitativity using four distinct factors (robot appearance, motion, decisions, and proximity). Based on this study, Fraune et al. argue for a better understanding of investigation using robot groups, as this knowledge is crucial for robots to reach their full potential when working in human groups. In order to combat loneliness in young adults, Jeong et al. [8] conducted a study in the domestic context, in which multiple households were connected through the robot Fribo. The robot would, anonymously, notify each household in the group about activities identified through audio performed by the other households. Even though these participating households were still alone, the interaction through the robots was sufficient to start a change in human-human relations and increase the feeling of closeness to others. Lastly, we want to highlight a

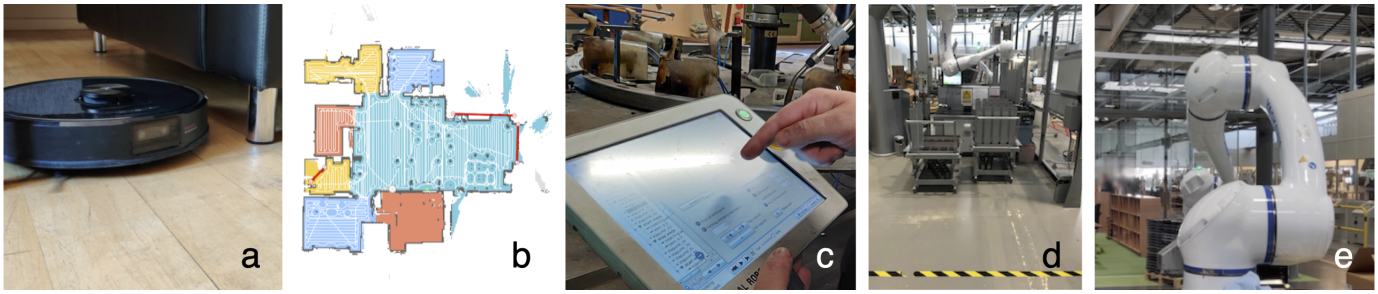


Fig. 1. Various photographs/screenshots taken during home visits (a, b) and visits in companies using collaborative robots (c, d, e).

recent study by Pelikan et al. [12] considering the importance of spatiality when introducing robots in the hospital context. Based on two years of extensive data collection in operation rooms, both robot-supported and non-robotic, Pelikan et al. identify changes in human-human dynamics depending on the robot's presence. For instance, the addition of the robot distributes team members spatially, thereby leading to an increase in the cognitive distance, making it harder to achieve a coherent situational awareness across team members.

## III. Research Approach and Results to Date

In order to approach an answer to *RQ1*, we investigated current non-dyadic research conducted in the HRI community. This was done through a comprehensive literature review on all HRI publications from 2006-2020, including both years, forming an initial corpus of 587 full papers. To structure our research approach, we used the 4C framework for interaction in groups [18]. Modifying the framework, as presented in our previous work [15], allowed us to classify current efforts of investigating non-dyadic HRI. Further, this analysis helped us to identify tendencies, as well as shortcomings of current research. Key findings include; i) a heavy focus on *simultaneous* over *sequential* interaction in non-dyadic HRI; ii) an uneven configuration of groups (human-to-robot) investigated, as 52% of all non-dyadic HRI research was focusing on systems involving multiple digital technologies, including robots, but only one human participant; and iii) we present empirical evidence to an ongoing 'paradigm shift' [11] towards an increased emphasis on non-dyadic interaction—even though HRI still has a strong focus on dyadic interaction studies (only 27.9% non-dyadic).

To investigate *RQ2* and *RQ3*, we conducted several qualitative studies in the wild, specifically in the domestic [16] (see Figure 1a & b) and industrial (see Figure 1c, d, and e) contexts (two industrial studies are ongoing projects). Using in-situ interviews, contextual technology tours [1], observations, and audio/video recordings during an in-the-wild study (*N = 24*), we were able to present three primary insights on robot interaction in the home. Firstly, the introduction of robots fragments previous coherent tasks, only some of which are automated. Secondly, interacting with domestic robots is rarely a dyadic interaction. The use of these is a group effort, both while collocated and remotely, which requires behaviour and environmental change from all household members. Lastly, digital technologies and humans acting as proxies are vital for breakdown intervention and recovery.

The two most recent studies (still ongoing), investigate the industrial context and how the introduction of robots shapes not only the interaction with the robots itself but the interaction and social dynamics between team members of a manufacturing cell. Methods used include company visits (including observations, demonstrations, and informal conversations), semi-structured interviews, webinar participation, as well as discourse analysis of over 100 case studies presented by cobot manufacturers. Findings include the impact of spatial re-arrangement, necessitated by the robots, and its, primarily positive, impact on human-human interaction. These findings were in some regard contradictory to findings presented in the hospital context [12]. Furthermore, we identified a similar task fragmentation as in the domestic context, which in the industry led to changes in human job identity from, e.g., 'welder', to 'robot supporter'.

## IV. Remaining Work

As part of this PhD project, we plan one additional study. The final study will be conducted in collaboration with researchers from Cornell University and MIT, and focus on investigating *RQ2* and *RQ3*. The current study design, which is still in development, is based on a video analysis of triads of human workers completing two assembly tasks. Through this video analysis, we hope to learn how groups of humans entrain [4] to each other, thereby obtaining new insights into how this can be transferred to robots to improve collaboration in non-dyadic human-robot teams. A follow-up study for this is planned, though not part of this PhD, which centres around the mapping of the identified strategies of entrainment to a Franka Emika robot to entrain as a member of a mixed group of humans and robots.

## V. Conclusion

In this paper, we have given a brief overview of recent work related to non-dyadic HRI and why we believe this investigation is essential. Furthermore, we present our previous research [15], [16] as well as how these are related to the three research questions as presented in Section I-A. Lastly, we presented some initial plans on the remaining studies part of this PhD project.

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