Exploring a Unique Design Tool for Close Proximity Human-Robot Collaboration

YI ZHAO*, LIAN LOKE*, DAGMAR REINHARDT*, School of Architecture, Design and Planning, The University of Sydney*

With the increasing interest in how designers can participate in the creation of robots and human-robot collaboration (HRC) tasks, a lack of adequate design tools has been identified through analysis of current mainstream engineering and designerly design methodology. Following the research-for-design approach, we have created a preliminary HRC design tool based on the leader-follower model of interaction for close proximity collaboration. The tool will be tested and further developed through workshops with students/designers and through research-through-design studies. Preliminary prototypes for co-drawing applications have been created using augmented reality and two different cobots, with the goal of generating new knowledge and theory for the HRC community. We encourage attendees to participate in our research on design tools to enhance the influence of design in the HRC research field.

CCS Concepts: • **Human-centered computing → Interactive systems and tools**; **Systems and tools for interaction design**; • **Computer systems organization → Robotics**.

Additional Key Words and Phrases: Design tool; Human-robot Collaboration; Human-robot Interaction; Human-computer Interaction

1 INTRODUCTION

The improvement and popularization of Industry 4.0 are fundamentally changing the interactive relationship between the human and the robot [10]. The old world (Industry 3.0) has a clear boundary isolating the communication between human(s) and robot(s) [18]. In this hierarchical operation system, industrial robots are unconditionally controlled by unidirectional instructions from the human. However, with the application of the Cyber-Physical System (CPS) - an iconic technology of Industry 4.0, the robotics in the factory are endowed with the intelligence attribute enabling cross-hierarchy communication between each infrastructure. Therefore, in the new (Industry 4.0) world, the robot is given the same status as the human operator, working as the team mates [18]. This transformation of the relationship has also spawned a new concept - human-robot collaboration (HRC). It depicts a close proximity working scenario between the human and robot allowing them to complete the same task simultaneously. In this process, the execution advantages of robots such as fast, heavy-duty payload and precise are strongly integrated with the flexibility and adaptability of the human operator, which is not only the chief contribution of the concept of the HRC, but also becomes the development direction of the human and the robot in the future. In the context of the collaboration form, many typical HRC application cases have emerged, such as assembling the front axle drive with KUKA iiwa collaborative robot (Cobot) at BMW [8] and adjusting the headlight with Cobot at Ford [9]. Thanks to the forward-looking HRC concept and assistance of CPS, this collaborative model also shines in other spheres such as the cooking robot for peeling the fruit [3], the medical robotic arm for COVID-19 testing [7] and drawing robot for co-drawing with human [12]. Although this emerging collaborative pattern offers a platform enabling robots to be present and ubiquitous in everyday life, the manufacturing and programming of robots at this phase requires the expertise of designers in the construction of new robotic morphologies and interactions with humans. Thus, in this workshop, we will express our opinion on design contribution to the HRC community and share a new HRC design tool. Our research aims to create a unique design tool offering for designers (especially for interaction design practitioners) without the robotic

Author's address: Yi Zhao*, Lian Loke*, Dagmar Reinhardt*, {yi.zhao1,lian.loke,dagmar.reinhardt}@sydney.edu.au, School of Architecture, Design and Planning, The University of Sydney* 148 City Rd, Darlington, NSW, Australia*.

development experience of the HRC project, allowing them to explore the problem, challenge, context and scenario in the HRC field. Thus, in this project, we look at solving one main research question: "What dimensions of human-robot interactions should be supported in design tools to assist designers to explore and specify human-robot interactions for collaborative activities?" We use a research-for-design (RfD) approach [4] to construct a conceptual design tool and follow the research-through-design (RtD) [26] methodology to iterate the framework of the tool and contribute the intermediate-level knowledge in HRC/HRI community. In the interaction stage, we take collaborative drawing (Co-drawing) as a design case study. This collaborative behaviour includes a scenario of a human and a robotic arm drawing on the same canvas, whereby the robot and human gestures interact to complete a drawing duet.

2 REVIEW OF EXISTING DESIGN APPROACHES FOR HRC

2.1 Engineering Design Methodology for HRC

Currently, the engineering development process is one of the primary means of designing HRC applications. It is result-oriented and has four steps: (1) Exploring the design questions and problems; (2) Constructing the artefact/interaction; (3) Testing; (4) Analysing; (5) Repeating the step (1) - (4) until satisfied[2]. Indeed, this logically rigorous approach can assist the engineer in completing the new robotics and interactive behaviour, quickly contributing new knowledge such as releasing a unique sensor and motion algorithm in the HRC community. However, simulation, which is the core implementation method during the loop, brings unavoidable limitations to the final solution designed by this method. With current technology and computing level, it is not always possible to include any environmental parameters or simulate the physical world with sufficient details especially for the open-ended scenario. Thus, a usual approach for the engineer is to parameterise key variables that are highly related to aims and requirements of the task and greatly simplify, obscuring or even ignoring secondary parameters that are hard to quantify such as the complicated social context. This leads to the fact that when engineers develop HRC projects, they are almost certain that solutions can work. Engineers tend to produce "satisficing" solutions just meeting all the needs rather than producing the best outcomes taking into account the appropriate responses between the human and the robot [2].

2.2 Designerly Design Methodology for HRC

The technical exploration and pursuit of the results drive the engineering design approach to be heavily used, guiding the development of HRC to date. Potential user needs and the actual social and cultural behaviour and reality cannot be fully considered in this process. To bridge this gap, many interaction design practitioners advocate for focusing on the impact of users who will operate the robot and analysing their feedback from the interactive context throughout the design procedure. Lupetti et al. [14] propose a concept of designerly design approach for HRC development. Corresponding to the structure of engineering design methodology, they add a reflection as an entrance at the early stage for developers to quickly explore and iterate on user needs, interactive objects, interactive behaviours and usage scenarios. The approach of reflection is basically inherited from the design process in human-computer interaction field, through a series of sketching and prototyping to build the artefact. This design artefact can not only be regarded as the outcome to visually display the concept of HRC application but according to the concept of RtD ([27], [5], [20]), the process of creating the artefact can also explore and generate the intermediate-level knowledge for the design and HRC community. Hoggenmueller et al. [6] utilise this design-centred approach to create the "Woodie" robot finding the emotional connection between the pedestrians and the creative digital placemaking and Alves-Oliveira et al. [1] use a paper-robot prototype to inspire creativity of children and rely on this study process to make a "YOLO" robot.

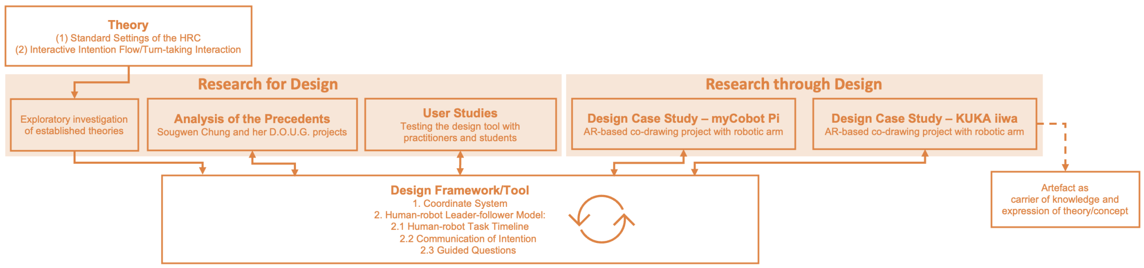

Fig. 1. the Research Design and Methodology

These examples by using reflections and iterations to output knowledge for the HRC domain allow the designerly design methodology to receive more attention in recent years [15]. The user-centred design and participatory design have also been integrated into the designerly design methodology. Projects of [11], [13] and [16] use the reflective process to specifically focus on the improvement of user experience. Although the designerly design methodology can guide interdisciplinary researchers to cooperate with engineers enhancing user experience and adaptability in multiple scenarios for the HRC application, due to borrowing many concepts and theories from the HCI field, the non-native feature leads to some unique interactive issues such as close-proximity human-robot interaction, identification of intention flow and safety problems that cannot be unfolded meticulously and specially [24].

3 EXPLORING A UNIQUE HRC DESIGN TOOL

We believe that in the near future, with the improvement of Industry 4.0 and the catalysis of CPS, interacting with the smart robot will be closer to interacting with the actual human and smart robots will also enter various domains having more intersections with our everyday life. Thus, compared to the human-centred design logic from HCI, we pursue a design tool that can inspire designers to explore the characteristics of robotic behaviour and interaction, such as morphological settings, safety protection, intention transmission, etc, enabling robots to communicate and work with humans as partners in the HRC project.

According to the Figure 1,the research design and methodology starts with a conceptual perspective of the HRC design - exploration and specification of (1) Standard Settings of the HRC and (2) Interactive Intention Flow. Thus, following the RfD, the preliminary HRC design framework is constructed by researching on existing and established design principles from HCI and User Experience (UX) fields. As shown in Figure 2, it contains a 3D coordination system representing a reference model at the preparatory stage for collaborative design. Referencing works from Malik and Arne [17] and Wang et al. [22], the X,Y and Z axes cover three factors - the *team composition* [23] [21], *interaction level* [25] and *safety standard* [19] - that have decisive impacts on human engagement with the robotic interactions. We believe that by flexibly adjusting a coordinate point in this three-dimensional space, even designers without robotic development experience can also quickly understand the meaning of the basic robotic information and setting by various combinations. After a coordinate point is placed, the design tool needs to support the designer to focus on intention communication between the human and the robot. We believe that robots should act as human companions in the HRC task rather than exploited tools in the old world (Industry 3.0 and before). Similar to human-to-human communication, the transmission of intent and turn-taking play signification roles in the collaboration. Thus, the human-robot leader-follower model is developed and carried by the coordinate point. Namely, in addition to its role in the coordinate system, the point itself can be treated as a parameter from the fourth axis reflecting the relationship between the human and robot during the collaboration.

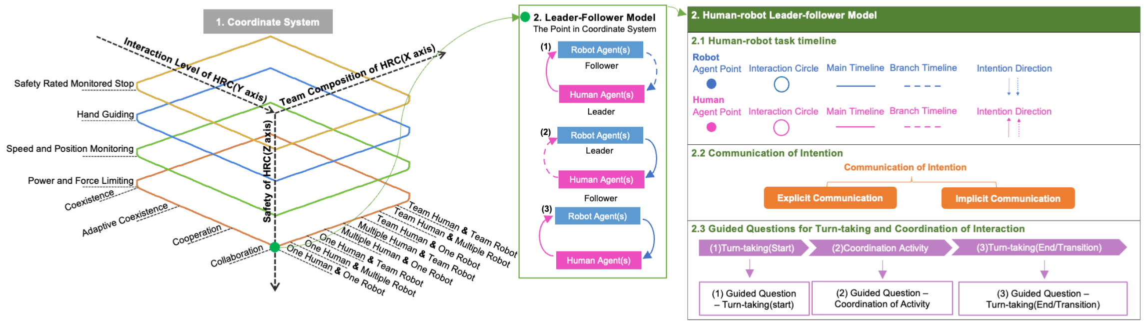

Fig. 2. the Preliminary HRC Design Tool

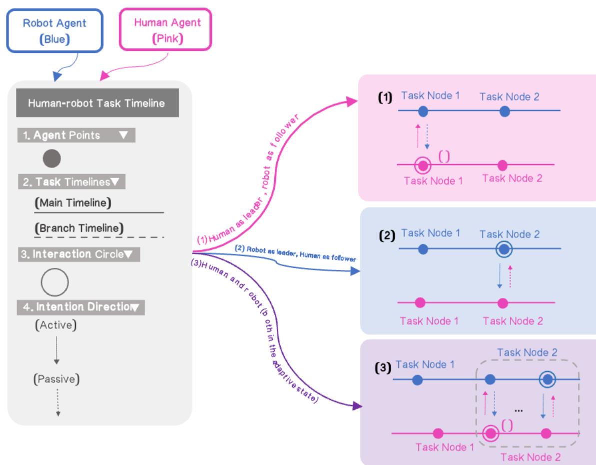

Fig. 3. the Human-robot task timeline

According to the different leader-follower roles of interaction, the intention transmission is divided into three models, distinguished by the direction of the arrow - (1) human as the leader and robot as the follower (the arrow starts from the human pointing to the robot), (2) robot as the leader and human as the follower (the arrow starts from the robot pointing to the human) and (3) the human and the robot are both in the adaptive state (the arrow can start from the human or from the robot). Along this rule, the human-robot task timeline is developed (Figure 3), through a series of figurative icons (agent points, interaction circles, the main timeline, branch timelines, and interaction directions) to visualise the interactive intention. After completing the setup of a collaboration task drawn by the specific icon combination, the guided questions can assist designers to plan the behaviour details of each interaction point from the perspective of turn-taking. Guided questions have three aspects covering Turn-taking (Start), Coordination Activity (processing) and Turn-taking (End/Transition) and used with the Communication of Intention diagram, designers can choose the appropriate form of communicative method for the interaction initiator (leader) according to the context.

In order to further test and iterate this tool, we follow the features of RfD and RtD to develop a series of processes. In the RfD section, we use this tool to deconstruct a precedent co-drawing project named D.O.U.G. created by artist Sougwen Chung[1], aiming to analyse its implicit interactive logic. In parallel, we designed a workshop to study how the students and designers initially generate design concepts for HRC, and then how our proposed design tool can help

[1]https://sougwen.com/

them explore and specify the HRC tasks. In the RtD section, we prepare to design AR-based co-drawing projects with KUKA iiwa (new generation collaborative industry robot) and myCobot Pi (small desktop robotic arm). The Microsoft HoloLens is the main device for accessing the AR world. Through the development of two robots with different sizes and usage scenarios, we not only find the influence of different robotic morphologies on interaction behaviours between the human and robot but also the co-drawing application as the artefact carries the knowledge and expression of theory/concept, contributing to the HRC community.

4 FUTURE WORK AND ANTICIPATED CHALLENGES

We have completed the investigation and analysis of the existing interaction design theories and have constructed the initial version of the HRC design tool (Figure 2), utilising characteristics of the human-robot leader-follower model to express the point of concretisation of the interactive intention between the human and robot. Upon here, we have preliminary answers to the research question raised in the introduction and through analysis of a precedent (Sougwen Chung's project) have evaluated the usage flow of the design tool. Therefore, iterating and reflecting upon the HRC design tools through the evaluative means generated by RfD and RtD are the focus of future work. As the user study workshop (general group - students and designers) has obtained ethical approval from The University of Sydney, the first workshop for students/designers will be held soon. With the continuous update of the HRC design tool content, two AR-based co-drawing projects with KUKA iiwa and myCobot Pi will be implemented in parallel. The preliminary prototypes have been developed, guided by the preliminary HRC design tool. Next, through two platforms of Unity and Robot Operation System (ROS), we will build the communication between the AR glasses (HoloLens) and the robotic arm, fulfilling the first co-drawing activity this year. The co-drawing action is spontaneous and improvised. On the one hand, these unpredictable drawing behaviours and drawing outcomes resemble the collaboration of two human painters pursuing aesthetic exploration. On the other hand, this close-proximity interaction can be extended to a broad range of activities outside the domain of aesthetics. We plan to share more details about possible development routes of HRC design tool and its potential contribution to the HRC community in this HRC workshop. Currently, one main challenge is that at the current level of technology, there is a considerable distance for robots to truly possess the level of human intelligence and have similar flexible and adaptive capabilities as humans. Although our design tool is rooted in human-to-human communication, the content of the design tool has to dynamically add and adjust instructive guideline and recommendations according to the different types and sizes of robots and emerging technologies. Thus, in this workshop, we warmly invite attendees to participate in the discussion of the new design tool for HRC, facilitating the acceptance and application in the HRC community.

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