2nd International Workshop on Designerly HRI Knowledge. Reflecting on HRI practices through Annotated Portfolios of Robotic Artefacts.
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A User Interface for Multi-Robot Furniture

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Over the last decade, researchers have discovered the value of robot furniture systems as they offer an economical platform to study HRI social interactions [1,2,5,6,9-12]. We present on our work to create an effective UI for commanding a multi-chair-robot system to reflect on design ideas. We chronicle the impact of various studies, pilots, and design exercises on our implementation of and attitude towards multi-robot furniture. Primary design insights include the creation of dual physical and digital interfaces, and the importance of leveraging automation with complimentary commands at diverse levels of abstraction. We aim to inspire UIs for future social semi-autonomous multi-robot systems.

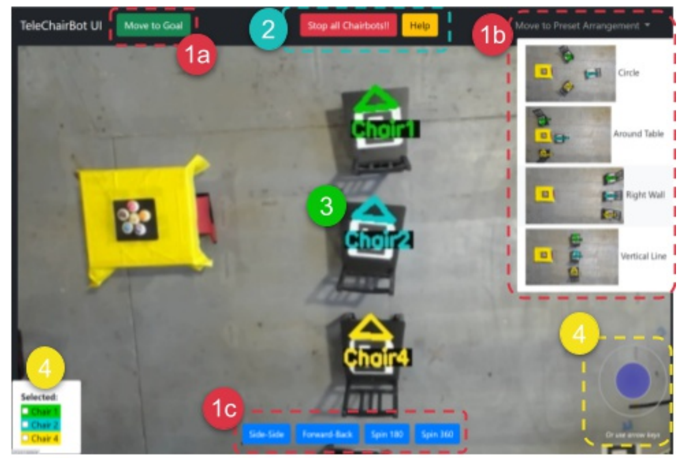
INTRODUCTION

Instead of being told to "find a seat" wouldn't it be better for a seat to find you? To prepare for a future in which humans and robots coexist harmoniously, it is vital to enable early prototype aspirational scenarios before they are technologically feasible. One method common in HRI is to use a human Wizard of Oz (WoZ) operator to economically achieve the high levels of perceived autonomy needed for pioneering HRI research [9]. Unfortunately, as the number of robots increases, the workload required to WoZ them quickly reaches a breaking point; one reason few studies in HRI include groups of robots [8].

The initial goal of this project was to improve the operator interface for our multi-chair-robot platform (ChairBots) to enable multi-human, multi-robot studies (Fig 1). In developing this system, aspects of effective interface design for the general application of multi-robot furniture were realized such as the usefulness of dual physical and digital interfaces, task specific abstractions, and expressive gestures.

PRIOR FURNITURE ROBOTS

Prior implementations of robot furniture span art exhibits, functional prototypes, and HRI studies. Art exhibits utilize the familiar morphology of furniture along with anthropomorphic motion of robots to challenge cultural norms or express ideas, such as a self-destroying and repairing chair [4]. In the commercial sector, Nissan marketed its self-parking cars using a self-parking chair prototype [7]. In HRI, early work by Sirkin and Ju [9] established roboticized furniture as an experimental design tool for HRI studies. In recent years, a Cambrian explosion of robotic furniture has evolved in these sectors, including our multi-robot system: ChairBots.



1. Abstract controls enable a user to move robots autonomously: Goal Setting (a), Arrangement Templates (b) and Gestures (c)
2. Prominent "big red" stop button enables quick recovery from precarious situations and help button toggles definitions
3. Overlays on a live video feed shows relevant info: chair id, and orientation
4. Joystick or keyboard controls enables direct motion control of selected robot(s) when autonomy fails

Figure 1. The current ChairBot user interface with major affordances and visualizations highlighted and explained.

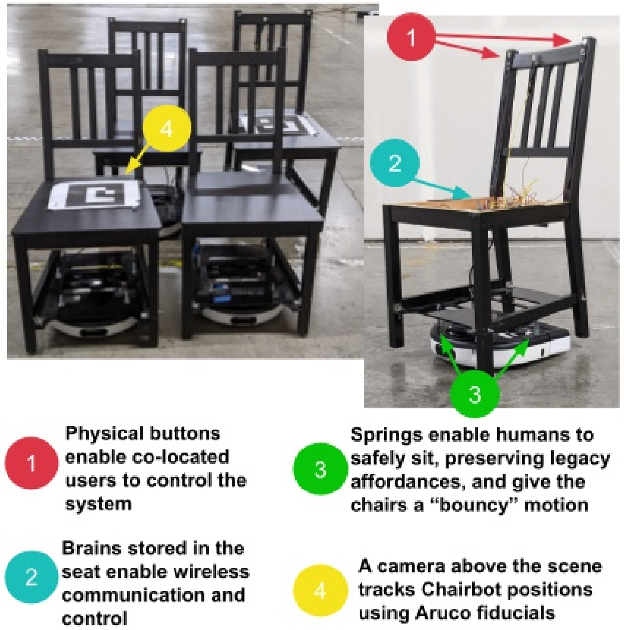


Figure 2. Description of the ChairBot robot with major features highlighted and explained.

DESIGN REFLECTIONS

We reflect on multi-robot furniture insights gleaned through our effort to build an effective WoZ UI. Two ideas stand out as especially relevant: the utility of a **dual UI embodiment** (digital and physical), and the importance of **complimentary command abstractions**. In our initial needfinding study [5], we found that the ratio of robots to humans varies by orders-of-magnitude depending on the situation. For example, an event organizer (i.e., a wrangler) setting up for a keystone talk at a conference may wish to wrangle tens-to-hundreds of ChairBots into neat rows (1:10s). The wrangler being analogous to a WoZ operator. Talk attendees (i.e., sitters) interact with those same robotic chairs in an intimate 1:1 experience requiring precise adjustments such as moving to sit closer to colleagues or to get a better view. Effectively controlling robots across in each case reveals specific UI challenges which we approached with a dual UI embodiment, and complementary commands at diverse levels of abstraction.

Robot furniture benefits from **both physical and screen-based digital interfaces**, as they enable remote and co-located control. Multi-robot furniture must be usable by users in proximity (sitters) and those rearranging them from afar (wranglers). Early on, we realized that sitters wishing to move ChairBots may resort to legacy affordances (e.g., pickup and move) rather than set up a digital interface (e.g., download an app). At the same time, we found the digital interface better suited for highly abstract command affordances involving multiple robots as physical UIs are constrained by the cost, and time needed to augment the hardware for all robots in a fleet. The downside to dual embodiment is that designers and developers must now create two interfaces and solve emergent edge cases (e.g., race conditions as two users send commands).

We found including multiple, complimentary command abstractions in our digital UI key to making multi-robot furniture usably wrangle-able. Efficiently wrangling multiple robots at once is an unsolved question in HRI that is often approached by leveraging autonomy to abstract control thereby decreasing operator workload. Following this framework, we programmed ChairBot(s) to move to a goal position and orientation autonomously [5]. For command abstractions, we determined the following four desired traits: low operator workload, efficient movements, full customizability, and simplicity (few "clicks" to use). Of which, only ~2.5 were achievable in a single level of abstraction (Fig 5). To study this tetralemma, three UI variants with complementary abstractions were tested [11]. All were found to be similarly usable suggesting the effectiveness of UIs with complimentary command abstractions is robust to different implementations.

THE SAGA OF THE CHAIRBOT UI

We chronicle ChairBots history of studies, deployments, and exercises over the years to highlight how our UI evolved and the source of our design insights.

THE CHAIRBOT (SINGULAR) - 2017

The ChairBot was a system originally designed as an inexpensive platform for conducting HRI studies (Fig 2). It consists of a wooden chair mounted on a mobile robot base with springs to allow a human to sit (a vital legacy affordance given the morphology). The initial interface consisted of an optional website with a live video feed, and a PS3 controller sending low-abstraction motion commands to the ChairBot: forward, backward, or turn (Fig 3a). This platform was used to study low-DOF motion to cue social responses [6], recruit participants [2], and entertain [12]. A single chair has limited sociability, so we scaled our system to more robots.

THE MULTI-CHAIRBOT SYSTEM - 2019

A multi-robot ChairBot system offered increased opportunities for HRI studies and was initially used with few changes to the interface. Buttons were added to the webpage that mirrored the PS3 controller and the network was upgraded to allow for multiple operators to each control one ChairBot at a time. This version of the ChairBot platform was leveraged to enable an experiment where ChairBots ran a cafe as greeters, waiters, servers, and (naturally) chairs [1]. It was also dressed and deployed on several Halloweens to entertain, harass, and offer candy (Fig 6). The limitation of this interface was the 1:1 ratio of human operators to ChairBots requiring significant logistics to conduct a study.

In parallel, the usability of a new physical interface was explored (Fig 3f). Quickly, we found capacitive buttons unreliable. More interestingly, users expected robot chairs would be controllable remotely in addition to the physical button interface creating the concept of a dual physical and digital interface. Additionally, users desired the capability for autonomous motion to a goal position. From interview responses, we constructed five command abstractions based on this capability: saving and recalling arrangement templates, traveling long distances efficiently by maintaining a relative formation, and snapping-to a

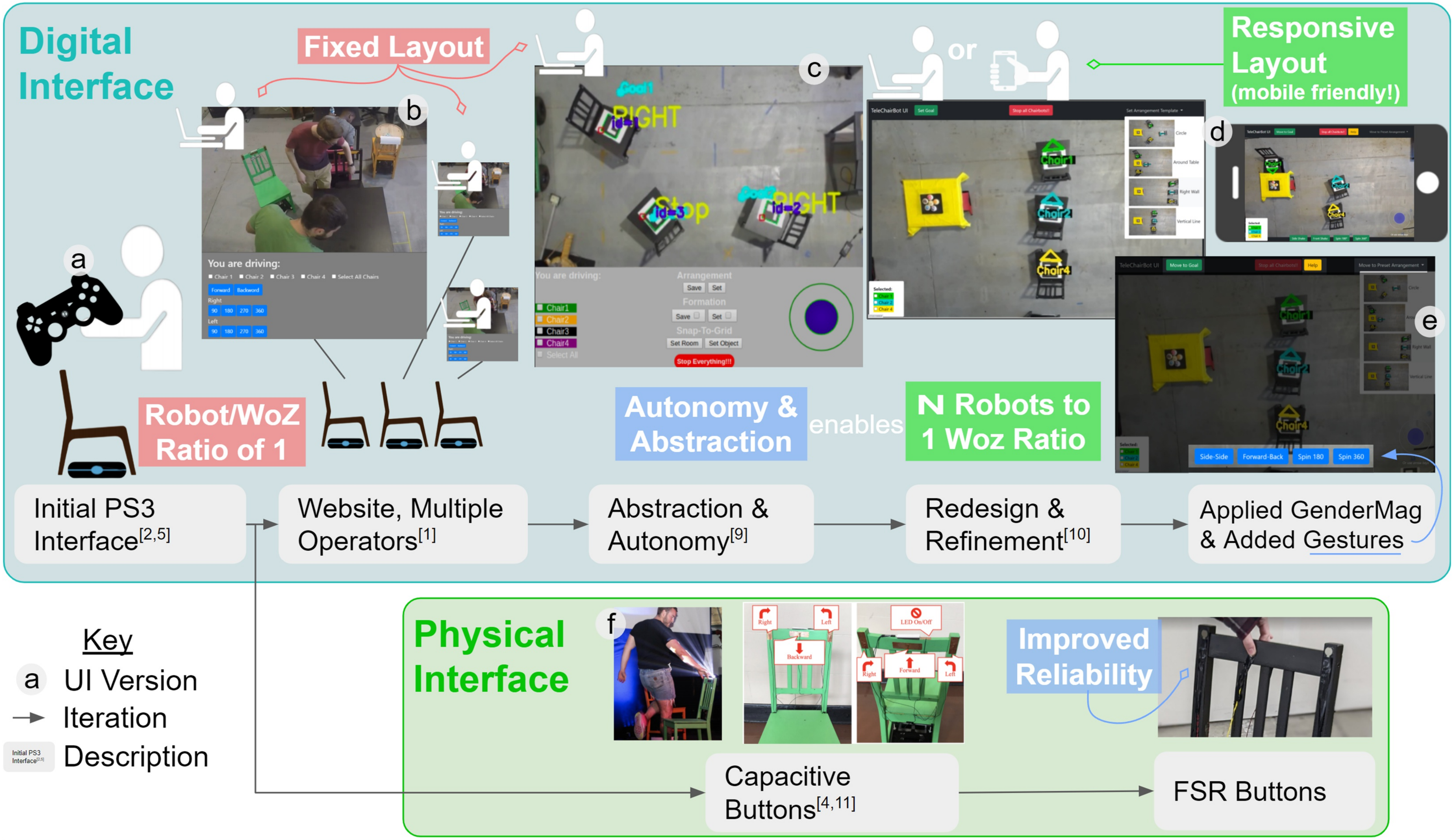


Figure 3. A diagram showing the history of interfaces for a multi-robot furniture system built for WoZ HRI studies. Evolution of the physical and digital interfaces are shown in parallel with the digital interface receiving more attention because of Covid restrictions.

relative orientation. Situationally, this could be relative to other ChairBots or "intelligently" relative to the environment. This study motivated an effective digital multi-robot user interface and seeds for command abstractions.

TELE-CHAIRBOTS - 2020

We found the usability of a multi-robot UI robust to exactly which command abstractions were implemented. Abstractions discovered in a usability study [5] were added to the video streaming website used in prior work [2,6]. Additionally, directional buttons were replaced with an SVG/Javascript joystick (Fig 3b).

Early pilots found the website was too ugly (to the point of being unusable), and most abstractions were not useful for our implementation of 3-4 ChairBots in a single room. The website was improved by reworking the layout, importing a CSS library, and filtering command abstraction to those shown in Fig 3d, 4, and 5. Resultant abstractions included recalling (but not saving) formation templates, setting a goal location with orientation, and manual joystick control. Additionally, updated camera overlays improved the saliency of ChairBot ID, orientation, and goal which, we believe, only scratches the surface of the potential for augmented reality in this application.

A study was then run to determine which combination of command abstractions would be most effective for tele-operating the ChairBots to arrange furniture based on open-ended prompts [11]. The results surprisingly determined that all tried combinations were useful. This suggests that UIs for wrangling multi-robot furniture should include a diverse range of command abstractions with specific exclusions having little impact.

APPLYING GENDERMAG - 2021

Running GenderMag [3] exercises helped us to identify and address several inclusivity "bugs" and correct biases in the UI. Keyboard controls were added in parallel to the virtual joystick (which assumed familiarity with video games), button text was edited to be self-explanatory rather than the names given by researchers (e.g., "Set Goal" changed to "Move to Goal"), and a help button toggling helpful definitions was added (Fig 3d). As far as we know, this was the first time that GenderMag was applied to a robot UI which we found it to be well-suited for.

PILOTING GROUP ICEBRAKER GAMES - 2022

A study on affective factors for intermixed groups of robots and humans playing icebreaker games was piloted using Google Slides. Remotely and simultaneously, participants moved images of themselves on the same slide using keyboard command (arrow keys to move, alt+arrow keys to turn). Games were run with a WoZ operator controlling multiple images of chairs using similar controls as the Tele-ChairBots interface. From this pilot, **gestures**--pre-recorded time-based animations (similar to [6])--were added to the user interface to increase ease of use and encourage expressiveness (Fig 3e). The full in-person study was postponed due to covid concerns.

CONCLUSION

We present several years of iterations of a multi-robot furniture UI reflecting on two major designerly insights, various implementation decisions, and findings about this unique application. First, a dual UI embodiment with physical and digital interfaces enabled seemingly antithetical user stories. Second, multiple diverse and complimentary command abstractions allowed for effective multi-robot arrangement which was robust to implementation. We implemented dedicated buttons for expressive gestures, invented task-specific command abstractions, and path visualization via augmented reality overlays. We hope that this collection of ideas may inspire future UIs for furniture-like, low-DOF multi-robot HRI systems.

The intersectional nature of multi-robot furniture makes it interesting to study. Furniture has both utility and artistic value leading to different requirements for than robots addressing either purpose alone. This legacy intersectionality, along with the potential for sociability makes robot furniture an exciting application to explore.

We look forward to the day when the phrase "find a seat" is replaced with "a seat will find you shortly".

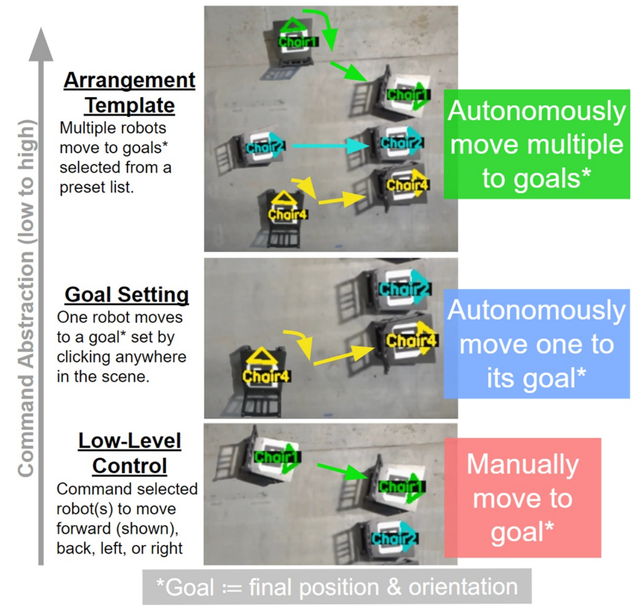


Figure 4. Diagram showing three levels of command abstraction designed to facilitate in nonsocial arrangement of multi-robot furniture tested in [10]. Robot paths and starting and ending positions for a single user command (e.g., button press) are shown.

	Low Workload	Efficient Movement	Fully Customizable	Simple to Learn
Arrangement Template	●	●		◖
Goal Setting	◖	◖	●	◖
Low-Level Control			●	●

Figure 5. Which command abstractions achieve ●, approach ◖ , or lack desired traits.

Figure 5. Collage exhibiting the ChairBot system during studies (left & top right), testing (center-left), performances (center-right), and Halloween deployments (right).

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