An Exploratory Study on Joystick-Based Directing Interfaces for a Collocated Robot

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ABSTRACT

We performed an exploratory study on new joystick-based directing interfaces for a collocated robot. We present a new framing for joystick control, based on either a *human-centric*, *robot-centric*, or *human-robot-centric* control mapping, and further explore the user experience impacts of having a physical cable between the user and the robot. We performed a formal qualitative study and discovered that the existence of the cable can influence user perception of animacy and safety.

Author Keywords

Human-Robot Interaction, Human-Computer Interaction, Robot Control, Joystick, Affective Interaction

ACM Classification Keywords

H.5.2 [**Information systems**]: Information Interfaces and Presentation – *User Interfaces.*

General Terms

Design, Human Factors.

INTRODUCTION

As robotic technology continues to advance we expect to increasingly see robots in assistive roles collocated with the general public. A challenge with such robots is to provide would-be users with safe, non-intimidating yet effective control mechanisms. One likely everyday task is to have the robot carry objects for people, for example, carry groceries for those with mobility problems or carry specialized equipment at a workplace such as a hospital. Interfaces for such robots should enable people to easily and effectively direct the robot as to where they want it to go, and must be robust and safe, particularly when scaled to busy, noisy, and unpredictable real-world environments.

In prior work we presented a dog-leash interface for directing a robot [7]: a user holds a physical cable (a *leash*) attached to the robot while walking to bring it with them. The cable, mounted on a spring-loaded spool, retracts and extends automatically to enable natural walking. The robot monitors the length and the angle of the cable in real time, and moves automatically to follow the person [7]. One major shortcoming of this prior work was that users could not give explicit robot direction commands. For example, if there was an obstacle between the person and the robot, the person would themselves have to move around deliberately to direct the robot to *follow* around the obstacle (Figure 1). In this paper we explore methods for enabling a person to more-explicitly give direction commands to a robot.

We present several new robot-direction interface methods, and the results from an exploratory study where, given our casual-user target audience, we aimed to develop a better understanding of how people use these interfaces for collocated robot direction. We take a mixed methods approach, and focus more on exploring user experience than quantitatively comparing the interfaces. Our study results highlight the importance of the physical human-robot link (the cable) on user perception of animacy and safety. The contributions of this paper are: **a)** the design and exploration of novel input-output mappings for collocated robot direction and **b)** a detailed qualitative account of users' interaction experience with robot-direction interfaces. Both of these contribute to our goal of designing interfaces for robots as assistive tools.

RELATED WORK

One project which explored user experience of collocated robot direction interfaces compared how "natural" users felt different robot following methods were (exact path versus shortest route) [3]. Our prior dog-leash project compared general impressions and sense of safety based on whether the robot followed in front or behind [7]. The general knowledge of how people interact with collocated robot-leading devices is still very limited, a research problem

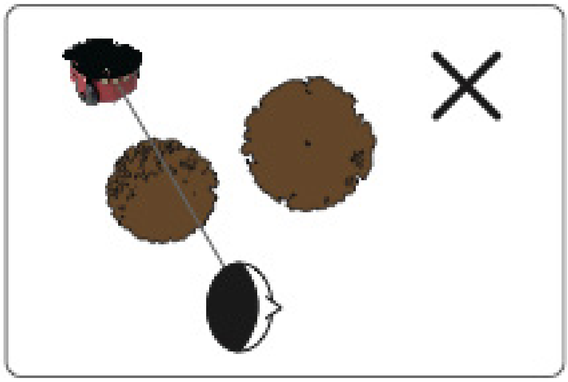

Figure 1. Robot-direction problem. The person wants to direct the robot to go past the stones to the X without having to leave their current location.

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which we target in this paper.

Other collocated robot direction interfaces include a robot which adapts its walking speed to appropriately match people [6], robots take direction via coarse gesture commands [2], or an easy-to-use and precise sketching interface for collocated robot direction [4].

In all of the examples above, either the interfaces do not allow for fine-tuned direction [2,3,6,7], or are not well suited to our target task of direction for taking a robot somewhere, e.g., by requiring a large tablet [4].

INTERFACE DESIGN AND IMPLEMENTATION

For all interfaces the user holds a handle with a common 2-axis thumb analog joystick attached (as found on console game controllers). The joystick communicates with the robot using a standard 802.11g connection.

For our work we re-think and explore the joystick-input to robot-movement mapping. We designed and implemented three input-output mapping schemes: *robot-centric*, *human-centric*, and *human-robot-centric*.

Robot-Centric Interface

The *robot-centric* interface is a direct mapping from the user's joystick input to the robot's movement, e.g., as with common toy remote control devices: pressing the joystick forward moves the robot forward and pressing right turns the robot to the right (Figure 2, top left). Note the inherent mapping problem: the person's right / left will generally not match the robot's, and for accurate control the person has to do the mental translation in real time.

Human-Centric Interface

The *human-centric* interface uses the person's position and orientation as a frame of reference for input-output mapping (Figure 2, top right), e.g., pressing forward moves the robot in the direction the person is facing, and pressing right moves the robot to the person's right. This design is an attempt at improving *robot-centric*'s input-output mapping problem. We use a Motion Analysis global tracking system to track the person and robot for calculating movements.

Human-Robot-Centric Interface

As a combination of the *robot-* and *human-centric* mappings, we designed *human-robot-centric* to use the vector between the person and the robot as a control frame of reference (Figure 2, bottom). Pressing forward / backward moves the robot away from or toward the person along the vector, and pressing left / right moves the robot in an arc around the person. Thus control is movements in polar coordinates relative to the person.

H*uman-robot-centric* is an extension to our prior work [7], as we use the person-to-robot cable as a visual cue to the user of the input-output mapping (Figure 2); we disable the previous autonomous movement behavior.

We implemented two versions of this interface. First, similar to *human-centric* we used a Motion Analysis global tracking system to enable tracking. For the second we used a retractable cable between the person and the robot from prior work [7] to serve as a visible indicator of the frame of reference. In this case, the light tension on the retractable cable made the joystick naturally tend to face in the robot's direction: the joystick's control axis directly matched the *human-robot* vector, simplifying control. Additionally, this method did not require global tracking as the robot can sense both the length and direction of the cable [7], robustly providing polar coordinates of the person's location.

EXPLORATORY STUDY

We performed a study to explore how people use our collocated-robot direction interfaces, with a focus on user experience over effectiveness: we believe this is important given our end-user assistive robot target task. As such, our study design and analysis uses qualitative methodologies, participant feedback and experimenter observations as primary data to identify interaction themes [5]. For brevity we use the following abbreviations below: RC (*robot-centric*), HC (*human-centric*), HRC (*human-robot-centric*), and HRCC (*human-robot-centric* with cable).

The only hypotheses behind our study were we expected the *robot-centric* to be slower, and, we expected differences to emerge between the with- and without-cable cases.

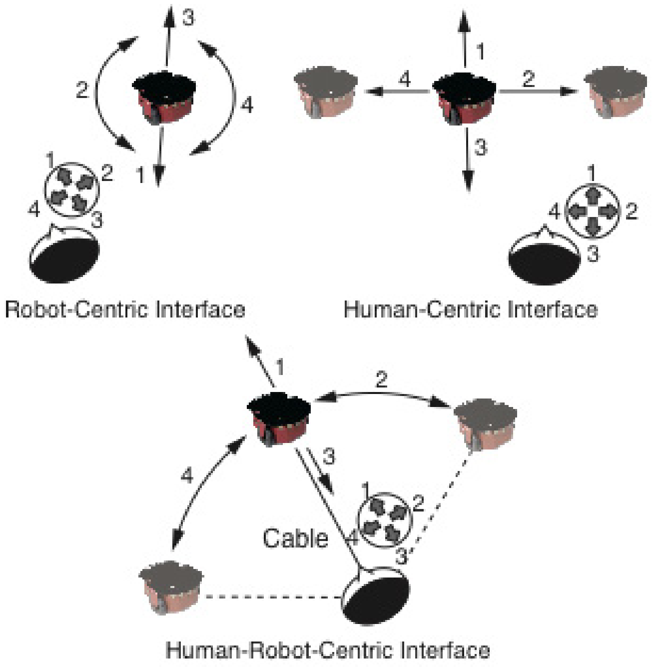

Figure 2. Three input-output mappings. *Robot-centric* translates the joystick input to robot-local movements. *Human-centric* robot movements are based on person's location and orientation. For *human-robot-centric* the vector between the person and the robot forms the movement frame of reference.

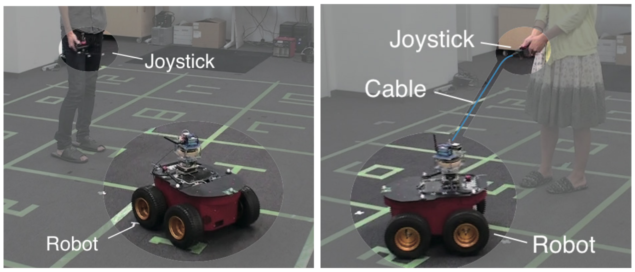

Figure 3. Users holding the joystick and handle for robot control.

Tasks – The primary task was to direct a wheeled robot (Pioneer 3 DX, Figure 3) to a series of locations on a floor grid. The grid was 4m by 3m, with 4 by 3 cells numbered 1 to 12 (Figure 4); participants were initially asked (but not reminded) to stay in the center squares 5 and 8. The target locations were fixed across participants: start at 1, then proceed to 12, 10, 3, 2, 6, 4, 6, 8, and end at 1; participants verbally declared when they had reached each target. Task completion time was recorded.

Procedure – We recruited nine participants from a university in Tokyo, Japan. Participants were not paid for their time, and their major was computer science or HCI; 3 female / 6 male, aged 22-26 (M=23.4, SD=1.5). Participants completed a pre-test demographics questionnaire, were given full instruction on the experiment and all interfaces, and completed the primary task once per interface type RC, HC, HRC, HRCC, order counterbalanced across participants. We administered a questionnaire after each condition which asked the participant to rate the interface on: whether it was easy or fun to use, and whether they felt in control. In addition we used the Godspeed [1] scales (III and IV) to target robot likability and perceived intelligence. All questions above used 5 pt Likert-like scales. Finally, we administered a post-test questionnaire which consisted of two open-ended questions asking for additional "positive" or "negative" comments regarding the experiment.

Qualitative Results

Here we present themes which emerged from the post-test free-form questionnaires using open coding.

Perception of Animacy – Some (P7,9) found that with the cable "it felt like it was alive, like a dog" (P9), and "just by having the string, friendliness emerged." Others (P3,9) reported that "with the robot on the string I felt that it was a little cute" (P9). P2 reported that "the method for moving the robot like a remote control car felt inorganic, but the other movement methods felt more alive."

Perception of Safety – Two participants in particular commented on how the cable impacted their sense of safety: "I think that after getting used to it [HRCC], it would be the #1 method that could be used comfortably without worry" (P4), and "I don't know why, but when operating with the leash I felt safe and relaxed" (P6).

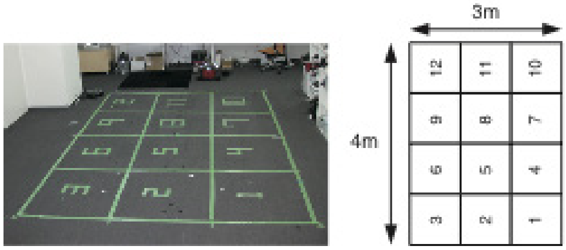

Figure 4. Environmental setup

Participant Movement About the Space – Although asked to stay in the center of the space, most participants were observed to move around during interaction. Generally, participants appeared to do this to optimize the input-output mapping, e.g., P6 said "it was easy to do when I could see the string. Mid-task I would move myself to help the string line up with the robot." In contrast, for the HC case only, participants were observed to do the entire task with minimal movement or body rotation: P7, P9 noted that for HC "if I moved the robot to the target without moving myself it was easy" (P9). This included the participant controlling the robot while it was behind them: they would turn their head but not their body and leash control.

General Comments on the Interface Designs – Overall, participants reported that the interfaces were relatively easy to use, e.g., "the coordinates were easy to imagine" (P6) and "the control methods … were intuitive" (P1). Some found it difficult to do fine movements (P1, 7). Most comments were regarding HRCC, e.g., P2 found that "as it is easier to…understand the rotations for the experiment with the string, it was easier to move the robot" (P2). In contrast, P7 found the HRCC and HRC mappings to be slightly confusing as the left / right movements arc around the user: "when I move the joystick right it moves along the circumference, and I lose my bearings a little." P7 further compared HRCC and HRC: "even in the case without the string I imagined the string in my head for operation;" in this case HRCC was first. Experimenters informally noted that experience with HRCC seemed to impact performance with HRC; although we have insufficient data for statistical analysis, we found that average task completion time for HRC was 105s faster if it followed HRCC.

For RC P7 noted that "it was difficult to understand the rotation direction, so as a result without intending to I had to do a lot of backing up". For HC, while P7 commented that it was "a clever design", P6 noted that "instead of using 'face direction' or 'gaze direction', as it took 'controller direction' [due to tracking the controller] it was easy to carelessly proceed in the wrong direction."

Feedback on Implementation – a common implementation-related comment (P2,4,5) was that "the controller response time was a little slow, so I felt it was a little difficult to operate"(P2). P1 found that "although the string helps make the movement direction obvious, it often got in the way," and P3 found that “things like the robot’s noise and unexpected movements were a little scary.”

Quantitative Results

Average completion time was: HRCC 288.6s, HRC: 332.4s, HC: 210.8s, RC: 266.8s. We found a trend on how the interface type affected task completion time (log transform), $F(3,24)=2.740$, $p=0.066$. Post-hoc pairwise comparisons (Bonferroni correction) show a trend for HC being faster than HRCC ($p=0.079$); no other effects were found.

For the questionnaire results, no effect was found of interface type on how easy, fun, or controllable participants rated the robot ($p > 0.1$). On the Godspeed questionnaire, there was a significant effect of interface type on how “friendly” participants rated the robot $\chi^2(3)=10.28$, $p=0.016$. Mean ranks: HRCC 3.61, HRC 2.22, HC 2.28, and RC 1.89. Post-hoc Wilcoxon tests (Bonferroni correction) found trend-level support for HRCC as being rated more friendly than HRC ($T=0$, $p=0.1$, $r=-.40$) and RC ($T=1$, $p=0.078$, $r=-.41$) but not for human-centric. No further effects were found for the other interface combinations.

Interface type had a significant effect on how “pleasant” participants rated the robot, $\chi^2(3)=10.24$, $p=0.017$. Mean ranks: HRCC 3.39, HRC 1.78, HC 2.44, RC 2.39. Post-hoc Wilcoxon tests (Bonferroni correction) found trend-level support for HRCC being rated more pleasant than HRC ($T=0$, $p=0.096$, $r=-0.4$). No other effects were found.

We found trend-level support for interface type effecting how “competent” participants rated the robot, $\chi^2(3)=6.92$, $p=0.075$. Mean ranks: HRCC 3.39, HRC 1.78, HC 2.44, RC 2.39. Post-hoc Wilcoxon tests failed to find further effects.

DISCUSSION AND FUTURE WORK

Emotional Impacts of Physical Link – The study results suggest that the mere existence of the physical link (i.e., a cable) between the person and the robot can have an important impact on the user’s interaction experience, even though it may not be the most efficient interface. Our data suggests that the cable may influence the user’s sense of safety and control, and may increase anthropomorphism, zoomorphism, and animacy, perhaps impacting perception of robot pleasantness and friendliness.

Mapping Comparisons – While we cannot conclude strongly about interface effectiveness, our data suggests that *human-centric* may be best. While this is perhaps the obvious result, we were surprised at participants’ behavior of not moving for this case only. Perhaps this is due to the use of controller direction instead of the gaze or head direction, introducing complexity into the input-output. Further, *robot-centric* performed better than expected. We suggest that this may be an effect of prior training, given how common such interfaces are with toys, and for future work intend to explicitly control for this variable.

Standalone Systems – We believe it is useful to highlight that both the *robot-centric* and *human-robot-centric cable* interfaces worked well without requiring global or environmental sensors. These technologies could be integrated into dynamic unstructured environments for robust robot control, using existing technology.

Cable Impact on Visualizing Control – Our results suggest that there may be an effect on users from interacting via a cable-based interface, e.g., that they later visualize the cable when it’s not there. We believe that this should be further explored, for example, if training with a cable interface can impact how other joystick methods are received. This could be useful for improving control in situations where a cable could not be used, such as over long distances.

Use in Real-World Crowds – Given our target task of a person taking a robot with them for, e.g., grocery shopping, these interfaces must be tested in busy, dynamic, and unpredictable real-world crowds.

Sensitive to Response Time – Several participants complained of the control delay from input to robot output, even though this was not particularly noticed by the experimenters: post-test we determined that this was due to the low-acceleration cap we imposed on the robot for safety. For future work we should re-think how to maintain safety while having fluid and responsive control.

In this paper we presented interfaces which explored new mappings for fine-tuned joystick control of a collocated robot, and detailed results from a study which explored how people use these interfaces. In particular, we discovered how a physical cable link between the person and the robot can have important implications on user experience.

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