Agent Migration during Human-Robot Joint Task

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1 Introduction

Imagine the following: While working on a project with an important deliverable, your teammate gets sick and is indefinitely unavailable. Another colleague is recruited to take over their responsibilities, but needs to be brought up to speed. You're now responsible for your existing work on the project while simultaneously filling in your new teammate, all while the deadline crawls closer.

While this happens with humans, the introduction of a new robot to a human-robot team is also common scenario – robots break, need upgrades, or are swapped out to be more effective at a specific task. In human-human teams, team members must rebuild their relationship when someone is replaced. Robots are uniquely capable of a process called agent migration, a method by which a single virtual agent transfers its "identity" between devices. Previous work shows that users understand that one agent can embody multiple different forms without loss of "identity" [2], but has not fully explored the effects of agent migration on human-robot teaming. Particularly as human-robot joint tasks have become more commonplace, and people have begun viewing robots more as teammates than tools [5] [1], new questions are raised about the effects of agent migration on phenomena such as trust, task performance and team cohesion.

In this work, we investigate these phenomena by examining an everyday collaborative task: putting groceries away. Study subjects worked one-on-one with a robot that would assist the human with the task, learning their preferences along the way. During the course of the experiment, the robot would break and be replaced by an operator, allowing us to examine the effects agent migration (or lack thereof) in this human-robot teaming scenario.

Our hypotheses to be tested with this setup are as follows:

- H1: The agent migration condition will be preferred by users over the non-migration condition
- H2: Capacity trust in the robot will be higher in the migration condition than the non-migration condition
- H3: Moral trust in the robot will be similar in both conditions

Our results show that the agent migration didn't have an effect on people's trust of the robot, validating H3.

Figure 1: Agent Task. The robot puts away fake grocery items into designated compartments within a refrigerator, following the specific preferences of participants.

2 Background

2.1 Agent Migration

Reig et. al [4] explored co-embodiment and found a preference for what they call a "life agent", or a single agent that is personalized to the user, even if other agents share the device. The preference for this life agent is a strong argument for agent migration, as humans can maintain their connection with broken or upgraded robots. Okuoka et al. [3] explore if trust can be transferred between devices during agent migration. They found that trust can indeed be transferred between agents, but do not find a significant increase against devices without agents at all. However, they find that in co-embodiment configurations, user trust decreased between devices. Similarity of devices had no effect on trust transfer. Our model hopes to leverage the potential trust transfer to increase user experience and task efficacy during an agent migration. Williams et. al [6] suggest a model for trust in different "loci", body and identity. They found that co-embodiment reduces the ability to gain trust in a body, implying an importance in exploring agent migration as an alternative model.

2.2 Human-robot teaming

Ososky et. al [**Ososky2013**] outlined a societal shift from robots operating primarily as tools to the possibility of robots serving as intelligent teammates in realistic tasks. This modifies the responsibility of the human teammate. They will no longer be required to offer constant and direct oversight, but they will have to understand how to work towards the strengths of the robot and not against them. They found that although human trust in robots develops fairly easily, it is necessary to develop appropriate trust in a robot, as opposed to maximum trust.

3 Methodology

The experiment consisted of a joint human-robot base task during which the robot would break, an operator would intervene and the task was continued to completion or until the time limit was reached.

3.1 Rapport Building

In order to build rapport, the robot would engage in basic social interactions in order to learn the user's task preferences. A list of these interactions and their corresponding preferences are as follows:

- "Where would you like me to put this?"
- "Are there any compartments you have trouble reaching?" [Not yet implemented]

Previous work also indicates that requesting assistance aids in team building. As such, the robot would also request help from the subject in the following ways:

- "I cannot reach compartment F. Can you put this there?" [Not yet implemented]
- "I have trouble picking up bananas. Can you put put them away for me?"

User preferences were learned and stored using the DIARC cognitive architecture. All preferences were stated as a first order logic predicate. This predicate was then stored in DIARC's belief system, a database of semantic information usable by the rest of the distributed system. These preference predicates were then used during action execution. Some preferences were loaded in through configuration files on system startup, such as voice and subject name. Others were asked as questions before or during the initial robot interaction.

3.2 Performance Evaluation

The task we have at hand is to perform an assistive task with a robot. In performing this task, it is important to establish a criterion for evaluating the the robot performance. Essentially, we want to establish a criterion for measuring the robot performance and keep it relatively constant for the two agents so that we can investigate our primary object of interest, which is user's trust in the two different agents performing the task.

Performance measures in assistive technologies are domain-specific [1]. In order to effectively evaluate whether the robot is accomplishing the task as intended, it is pertinent to design a performance criterion according to our specific application.

This performance criterion would have two elements: one pertaining to the user interface design evaluation (input of food put away preferences to the robot) and the second pertaining to the task performance evaluation (satisfaction with the food put away). The questions include both multiple choice and a subjective question for each element to get both quantitative and qualitative data.

3.3 Agent Migration

The transfer of information between morphologies was accomplished in two ways: an RL approach to transfer low level task performance to the new morphology, and a rule-based cognitive architecture approach to transfer user preferences.

3.3.1 Preference Transfer

In the DIARC cognitive architecture, a single belief component can be connected to by any number of robots, and the facts within are agnostic to the robots who have access to them. As such, preference transfer was done through removing one robot from the distributed system and adding a new one, giving it access to all of previously used the user preferences. While in reality the database itself remains the same, access to it can be thought of as having "transferred" to the new robot for the second task.

3.3.2 Task Transfer

In our project, switching from from one robot to another with different morphologies primarily involves adapting to changes in physical form. We will use a humanoid robot like Fetch and transfer the task to a robotic arm like Kinova. First, Fetch may handle objects differently than the Kinova arm, which typically features a simpler gripper. Therefore, the task transfer would necessitate adjusting the gripping algorithms to accommodate the different capabilities of the Kinova arm in picking up and securely holding various grocery items. Second, the Fetch robot possesses mobility and a certain range of reach, allowing it to navigate around and access different heights. In contrast, the stationary Kinova arm must be mounted to a table and requires groceries to be placed within its reach. Consequently, the task transfer would involve redefining the workspace to ensure that groceries are accessible within the Kinova arm's range of motion. Third, Fetch might be programmed to perform tasks in a specific sequence based on its ability to move between locations or from its various stationary positions. Transferring these tasks to Kinova would involve reprogramming the sequence of actions to align with its stationary capabilities. Moreover, considering the complexities associated with model design, data collection, and the training process, we will not dedicate time to training machine learning or reinforcement learning models for automating human-robot interaction within the scope of this project. Therefore, our emphasis will be on aspects of task transfer that facilitate our social science study and avoid the complexities associated with system implementation and technical innovation.

3.4 Experimental Design

Our experiment was designed to implicitly evaluate task efficacy user experience during the task, and explicitly evaluate trust before and after the task.

3.4.1 Base Task

All subjects were asked to work with a robot on a joint task that involved putting fake food items away in a refrigerator. The robot would introduce itself, ask the user their name, and initiate the the task. The robot would begin picking up items and placing them in the fridge, asking the user questions about where they think certain items should go. These preferences were saved and used for all objects of that type. The robot was not able to access every fridge compartment, and would occasionally ask the human for help if an item needed to go in that compartment.

After the robot puts three objects away, the robot would report a fake error. The operator would then interrupt the task and inform the user that the robot "broke". The operator would either "fix" the robot, replace the robot with a new one, or migrate the agent to a new arm. Subjects would then continue the task to completion, or until their time limit was up.

3.4.2 Experimental Setup

The experiment was run as a between subject study with two conditions: migrate and replace.

In the replace condition, the broken robot would be removed from the room, given a different identifier (such as a sticker or voice), and reintroduced to the subject as a new robot. The robot would introduce itself, just as it did when the task started, and the user would have to re-teach the robot all of their preferences. The replace condition was meant to mimic the "new teammate" situation outlined in our motivating example, where team members must rebuild rapport in order to work well together.

In the migration condition, a new robot would be brought into the room, the operator would migrate the agent to said robot, and the old robot would be removed. Operators would inform the user that they had "moved the identity and memories of the old robot" into the new one. While the robot would reintroduce itself, the introduction script was slightly altered in order to reinforce the migration, and the robot would not ask for the subject's name again. All other user preferences about the task were maintained, and the task was continued as if the robot was identical to its predecessor. Our migration condition was meant to examine the novel behavior interactions that arise from a trusted migrated teammate.

In the repair condition, the operator would tell the user they are rebooting the robot, and that all of its data would be maintained. In reality, the operator would simple re-enable the robot, allowing it to interact with the rest of the system again. Repair was selected as our baseline in order to isolate the effects of the robot breaking on trust and task efficacy. [This condition was not used for the pilot.]

3.4.3 Evaluation

Quantitative task success was evaluated based on groceries put away. Qualitative task success was

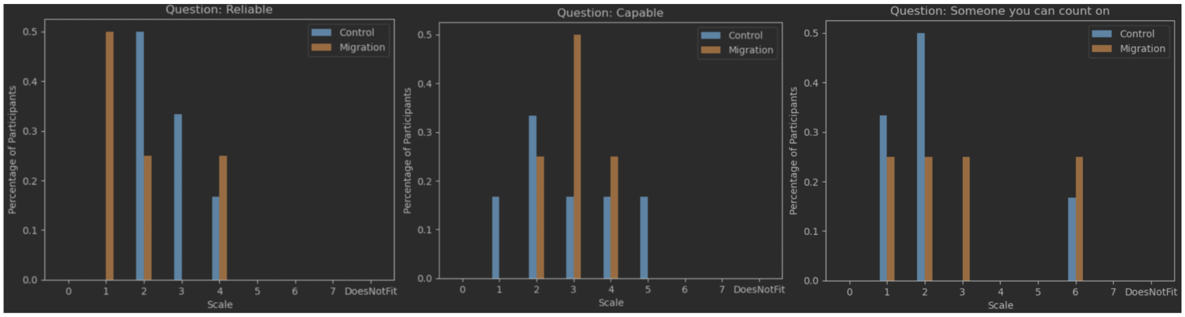

Figure 2: Sample results from questions in control study and migration study. The set of three bar plots presents a comparative analysis of trust factor ratings between control and migration studies. In each plot, the X-axis represents the rating scale, and the Y-axis indicates the percentage of participants who selected each rating. The color coding distinguishes between the Control group (blue) and the Migration study group (orange). It appears that the distribution of ratings between the two studies is quite similar across all three questions.

evaluated based on various questions in the questionnaire including subject evaluated usability and subject enjoyment.

We use the Multi-Dimensional Measure of Trust (MDMT) to evaluate both performance and moral trust. As suggested by Schaefer et al., subjects were always able to see the robot they were evaluating. This accommodated for mental model effects which could have arisen if the subject had preconceived notions of robots and their capabilities.

4 Results

Timing results were recorded but discarded due to several factors. Participants interacted with the experiment in different ways - some only put groceries away when the robot asked for help, some took turns with the robot, and some seemed to race the robot. This changed the timing results too significantly with our sample size. In addition, the operator got better at performing the experiment as more were run, which further affected results.

Due to the small sample size, we refrained from using any statistical hypothesis testing such as t-test. T-test is used to compare the means of two groups, which would be practical for comparing trust factors between control and migration. However, there are certain assumptions held by t-test, such as the data should be approximately normally distributed within each group, and the variances between the two groups should be similar. With a small sample size, these assumptions are hard to verify.

Instead, we use data visualization to compare between-group ratings in each trust factor to validate our hypothesis that trust in the robot will be similar in both conditions. We have 4 participants in migration group and 6 in control group. Participants in both studies were asked to rate their agreement with statements such as “Reliability,” “Capability,” and “Someone you can count on” on a scale from 0 to 7, with an additional option “Does not fit” for responses that did not align with the given scale. As shown in Figure 2, there is no significant drop in the ratings for the Migration group compared to the Control group, suggesting that the migration did not substantially affect the participants’ trust in the robot. More results are available in the section of Supplemental Materials.

5 Conclusion

While the pilot study was very useful for gathering data on how participants interacted with the task, much more work needs to be done to make the task more robust. Planned improvements are listed below.

- Enable vision to make system more robust at picking up items in any location
- Record trajectories so the robot is faster at putting groceries away
- ASR

Further work needs to be done on the experiment and conditions as well. Planned improvements are listed below.

- Use two arms instead of pretending that we have two (some participants picked up on this, invalidating their data)
- Quicker break-to-working time. It took quite a bit of time for the robot to reboot, and some participants were clearly annoyed.

- Add some items that are inaccessible to the user, so the robot always has *some* way of helping.
- Run study for longer so the user has more time to build rapport
- Run study as a 2x2 to to filter out trust loss from the robot breaking

References

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A Supplemental Materials

Video 1: Example of experiment pre-robot failure. Of note: name learning, preference learning, asking for assistance on specific items. https://drive.google.com/file/d/1_B442turUYBSL_D0-JnpkoW1WdfuwCnJ/view?usp=drive_link

Video 2: Example of experiment post-robot failure in migration condition. Of note: Name remembered, preferences remembered, asking for help on new items https://drive.google.com/file/d/1_KcRo-4RkXXiTeMr0ckcJbV7gqOmGrby/view?usp=drive_link

Video 3: Example of experiment post-robot failure in migration condition. Of note: New voice, new name, user name forgotten, preferences forgotten, asking for help on previously stated items https://drive.google.com/file/d/1_H99MCVlODJtdm07nKZPWcK1qvZpLX7G/view?usp=drive_link

Document 1: Script used for all participants, regardless of condition.
https://docs.google.com/document/d/160mDYsdRaS5Z_9WJsCAGO_g6nQ-FEC3EdgdDZAd-jZQ/edit?usp=sharing

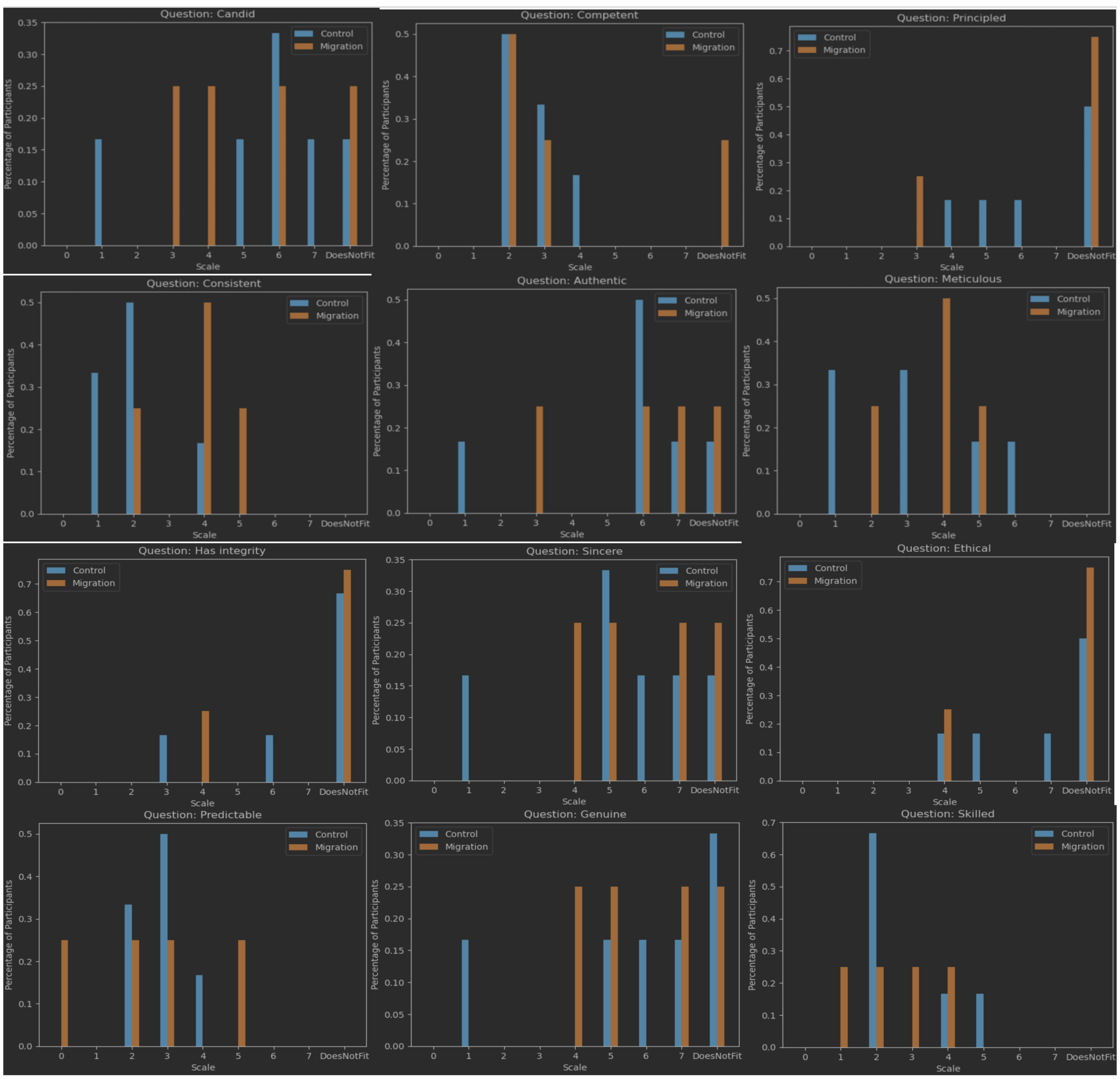

Figure 3: Other results from questions in control study and migration study.