Configurable Human-Robot Interaction for Multi-Robot Manipulation Tasks

(Extended Abstract)

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ABSTRACT

Multi-robot manipulation tasks can be complicated, due to the need for tight temporal coupling between the robots. However, this is an ideal scenario for human-agent-robot teams, since performing all of the manipulation aspects of the task autonomously is not feasible without additional sensors. To ameliorate this problem, we present a paradigm for allowing subjects to configure a user interface for multi-robot manipulation tasks; using a macro acquisition system for learning combined manipulation/driving tasks. Learning takes place within this social setting; the human demonstrates the task to the single robot, but the robot uses an internal teamwork model to modify the macro to account for the actions of the second robot during execution. This allows the same macro to be useful in a variety of cooperative situations. In this paper, we show that our system is highly effective at empowering human-agent-robot teams within a household multi-robot manipulation setting and is rated favorably over a non-configurable user interface by a significant portion of the users.

Categories and Subject Descriptors

I.2.9 [**Robotics**]: Operator interfaces

General Terms

Algorithms

Keywords

human-robot interaction, multi-robot manipulation, programming by example

1. INTRODUCTION

Human-agent-robot teams [1] fill an important niche in robotics since they can accomplish tasks that robots cannot complete autonomously, forming a team unit that is greater than the sum of the parts. Ideally the human users focus on the difficult cognitive and perceptual tasks, the robots manage the planning and execution of repetitive physical tasks, while the agents handle the most cumbersome information processing tasks. At the core of designing an effective social system that includes human, agent, and robot teammates is the question of communication between the biological and synthetic entities—how to create a user interface that empowers rather than hinders teamwork and social learning?

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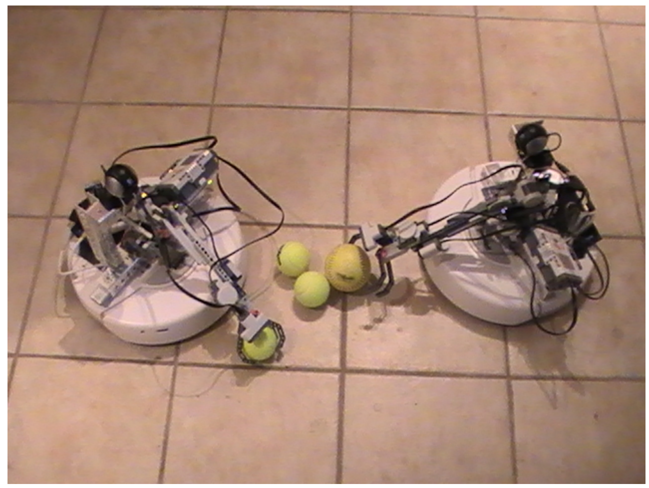

Figure 1: Two HU-IE robots cooperating together to clear the environment of objects and deposit them in the goal location.

Here we focus on the problem of multi-robot manipulation; the human user guides a team of robots to lift and clear clutter in a household environment. Since some of the objects are too large to be raised by a single robot, the robots must work together in tight temporal coordination to lift and transport the clutter to the goal area. Coordination failure leads to dropped objects and slow task completion times. The users must also effectively control the multiple degrees of freedom that the robot offers (wheelbase, arm, and claw).

2. USER INTERFACE

The user views the environment and interacts with the HU-IE robot team through our configurable user interface (IAI: Intelligent Agent Interface). A rudimentary agent is embedded within the user interface to support teamwork by managing information propagation between the team mem-

Figure 2: State representation of a recorded macro

bers; it governs the information that gets sent to the robots and displayed on the user interface. Additionally it contains a macro acquisition system that allows the user to identify four key subtasks which are abstracted and used to create robot behaviors which the user can deploy during task execution. All commands to the robots are issued through an Xbox 360 gamepad, using a button to switch between robots.

3. MACRO ACQUISITION

During the macro acquisition phase, the robot's state space trajectory is recorded, paying special attention to the initial and final states of the trajectory. The state includes the following features in absolute coordinates: drive start/end position, arm start/end, claw open/closed. Additionally, the status of all of the key sensor systems (cliff, wall, and bumper sensors) is logged. The agent also notes the current location of known movable objects in the environment and whether the user is teleoperating the second robot. The state space trajectory is then used to create an abstract workflow of the task which can be combined with the teamwork model and the path planner to generalize to new situations. To build the workflow, the state space trajectory is separated into drive, arm, and claw segments. Adjacent drive and arm segments are merged to form one long segment. The terminal position of the robot is retained in both absolute coordinates and also the relative position to the nearest object or robot.

After the macro acquisition phase, there is an acceptance phase during which the operator is given a chance to verify the macros' performance. When the human operator is satisfied that the macro was performed correctly then the macro is accepted and mapped to one of the Xbox 360 buttons. During the acceptance phase, the macro is evaluated in multiple locations on the map and with the HU-IE robot arm at different angles.

If the macro representation was not accepted by the human operator, the system attempts to modify the macro using a set of taskwork rules. For instance, during the initial phase, it is assumed that the terminal positions are of key importance and that the robot should use the path planner to return to the same absolute position. In the second demonstration, the system used the recorded sensor date to identify the most salient object located near the terminal position and return the robot to that area. If an object is dropped during the acceptance phase, it is assumed that the drop is the principal reason for the macro non-acceptance and the macro is repeated using the same abstraction but with minor modifications to its positioning relative to the object using the ultrasonic sensor. For simplicity of user interaction, macro acquisition is done by teleoperating a single robot but during actual task execution many of the macros are actually executed in mirror mode, using the preprogrammed teamwork model. One of the most common macros developed by both expert and novice users was a macro for driving the robot to the goal.

4. RESULTS

The users were asked to clear objects from a cluttered household environment and transport them to a goal area using two robots guided by the configurable user interface. We evaluated the performance and quality of the IAI system Macro Mode on a variety of measures, including usability of the macros, speed of task completion, number of object drops, and user satisfaction. Two indoor scenarios, a training scenario, and One macro recording phase were employed in our user study. The user was asked to execute each of the scenarios using our Intelligent Agent Interface Macro Mode.

The macros created by users varied in length and complexity, with a general trend that game skill correlated with shorter macros and longer periods of user teleoperation. This can be contrasted with the pattern of novice macro usage that shows a heavier reliance on macros. Overall, we found it encouraging that the configurable aspects of the user interface were more heavily used by novice users.

From observation, we noted that the users created macros to help them with parts of the task that they struggled on during training; for instance, users who experienced more failed pickups would often focus on creating a good object pick up macro. In a post hoc comparison to users from a previous study who used a non-configurable version of the same user interface, macros appeared to confer a slight time advantage. The most significant results were in the user rankings of the interface which enthusiastically (70%) preferred the configurable user interface; overall, the interface scored high ratings in the post-questionnaire user ratings.

5. ACKNOWLEDGMENTS

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6. CONCLUSION AND FUTURE WORK

In this paper we demonstrate a macro acquisition system for learning autonomous robot behaviors by example; by separating taskwork and teamwork, we can generalize single robot macros to multi-robot macros. We plan to extend the teamwork model in the future by having the system learn user-specific teamwork preferences separately through demonstrations on a non-manipulation task. Users expressed a significant preference for the configurable autonomy of macros over the built-in autonomous functions, and gave the user interface high overall ratings. Adding a configurable user interface to a human-agent-robot team empowers the human operator to structure his/her user experience by expressing task-specific preferences for the amount of interdependence vs. autonomy between human and robot. This is consistent with the coactive design model for human-agent-robot systems.

7. REFERENCES

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