Improving Multi-Robot Teleoperation by Inferring Operator Distraction

(Extended Abstract)

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ABSTRACT

A high-quality human-robot interface is essential for the success of search and rescue operations in urban environments that are too challenging for fully-autonomous operation. Teleoperating multiple robots greatly increases the complexity of the human's cognitive task, since the operator's concentration is divided among multiple robots. Thus, simply adding more robots to the system does not necessarily expand the effective coverage region nor increase the rate at which the operator can search. We present CoOperator, an agent-based human-robot interface that infers operator distraction and identifies any robots that are not currently being effectively managed. A CoOperator agent assumes control of such a robot and moves it along a search path that complements the operator's explicit teleoperation. The CoOperator agent seamlessly cedes control to the user whenever direct commands are given and resumes directing the robot if the operator's attention shifts. We demonstrate that our agents significantly improve multi-robot teleoperation through user studies on four urban search and rescue scenarios with a team of three simulated Pioneer 3DX robots.

Categories and Subject Descriptors

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

General Terms

Human Factors

Keywords

human-robot interaction, urban search and rescue, multi-robot control

1. INTRODUCTION

Teleoperating a team of Urban Search and Rescue (USAR) robots is a challenging task for a single human operator since the user must make intelligent control decisions while being presented with a simultaneous barrage of visual information from the sensors of multiple robots.The goal of a fully-autonomous robot team for real-world search and rescue tasks remains elusive; our research focuses on agent-based approaches that partially automate the task and complement the human operator's control to enable a more effective search and rescue strategy.

During cognitively demanding tasks, the human operator's attention is typically focused on controlling a single robot; in such periods, the other robots in the USAR team are under-utilized. The key contribution of our work is to automatically infer (from observable features) which robots in the team are currently being neglected by the user and to manage those intelligently during such periods.

Cite as: Improving Multi-Robot Teleoperation by Inferring Operator Distraction (Extended Abstract), B. Lewis, B. Tastan, and G. Sukthankar, *Proc. of 9th Int. Conf. on Autonomous Agents and Multiagent Systems (AAMAS 2010)*, van der Hoek, Kaminka, Lespérance, Luck and Sen (eds.), May, 10–14, 2010, Toronto, Canada, pp. 1505-1506

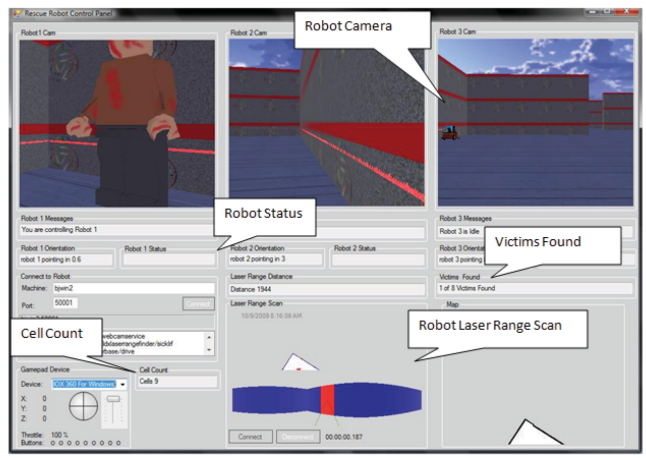

Figure 1: The CoOperator agent-based interface for multi-robot teleoperation. The human operator controls a team of three robots, each of which sends a first-person perspective of the environment from its onboard camera. The CoOperator agent infers operator distraction and identifies whether a robot is not being effectively managed. These under-utilized robots are guided along a path that complements the human's explicit teleoperation.

2. COOPERATOR AGENT INTERFACE

The CoOperator interface is designed to assist the human operator in managing, controlling, and navigating multiple robotic agents through the disaster scenario.

It augments basic teleoperation interface in several important respects. First, it monitors each of the robots in the team and determines which ones are suffering from operator neglect. This is non-trivial since a robot in wander mode receives no explicit instructions from the operator yet can be effectively exploring the environment. We employ a Hidden Markov Model to infer operator neglect from the robot's observable state. Second, the CoOperator agent assumes control of robots while they are unattended. Specifically, it overlays a higher-level goal on the wander behavior to ensure that the robot explores a series of waypoints in its assigned region of the disaster zone. This is done by mapping the immediate environment and employing A* to find efficient routes between waypoints. Third, it transparently and responsively cedes control to the human operator whenever the user sends the robot an explicit teleoperation command.

2.1 Inferring Operator Distraction

We employ a Hidden Markov Model (HMM) [2] to infer, based on observable state, whether it is likely that the given robot could be a good candidate for CoOperator control. A similar inference approach was successfully employed to infer cognitive load in human-agent teams [1]; however our observed features and user task are quite different. We use a straightforward model for the operator's (hidden) cognitive state, as it applies to a particular robot. The three states are: (1) **A**ctive, referring to a robot that is under active teleoperation control; (2) **M**onitored, for a robot that is moving without explicit control, but that is acting in a manner consistent with the user's higher-level goals; (3) **I**nactive, for a robot that is not currently being monitored by the human operator.

The CoOperator agent moves an unattended robot to various waypoints in its assigned regions in the disaster scenario and initiates a directed exploration in the local neighborhood of each waypoint. At the start of the scenario, the region is roughly partitioned among the robots in the team, based solely on gross geometric characteristics (i.e., without detailed map information). Given this partition, each robot independently generates a set of waypoints that cover its assigned space. The basic idea is to exhaustively explore the region near each waypoint and then move efficiently to the closest unexplored waypoint.

For path planning, the CoOperator agent employs a standard discretized A* search from its current location to each of the unexplored waypoints. Unexplored waypoints in the robot's assigned zone are given priority over those assigned to other robots. The robot then follows the efficient route to the next waypoint without specifically searching for victims; any victims that are fortuitously encountered en route are tagged.

3. RESULTS

Four indoor scenarios, consisting of different topological configurations of connected rooms were employed in our user study. These were presented to the eight users in a random order. The CoOperator agents were enabled on two of these four runs, and the operator was restricted to manual mode on the other two runs. The participant had 15 minutes on each scenario to locate the victims.

We measured performance using two metrics: (1) the time taken to find all of the victims in each scenario, bounded by 15 minutes; (2) the area covered by the robot team during a given scenario, as measured in terms of unique discretized cells.

Our study revealed that in the majority of runs, the agent-assisted CoOperator condition significantly accelerates the robot team's progress. We can attribute this to the fact that the robots controlled by the CoOperator agents continue to search with minimal human supervision while the inactive robots in the manual condition (whether stationary or wandering) are less effective.

We also analyzed our data according to the second metric, map coverage. Here we found that the number of map cells explored by the robot team in each of the different scenarios correlates less well with the experimental condition. The difference is that the CoOperator agents direct the inactive robots to efficiently explore the space in a directed manner, resulting in a faster rescue of victims.

An overwhelming fraction (90%) of the participants expressed a clear preference for the agent-assisted (CoOperator) mode of teleoperation. 10% of the participants stated that CoOperator made no difference. None of the participants felt a negative impact from using CoOperator in these tasks. This validates our belief that allowing the inactive robots to operate effectively under minimal operator supervision is highly valued.

4. CONCLUSION AND FUTURE WORK

Developing an effective human-robot interface is an important part of creating a competitive USAR team. In this paper, we describe RSARSim, our simulation environment for prototyping and evaluating multi-robot teleoperation paradigms. RSARSim was used to develop and evaluate the CoOperator, an agent assistant for multi-robot teleoperation. The CoOperator explicitly infers the operator's neglect level and increases the autonomy of the robots. In our user study, the majority of the participants were able to locate victims more rapidly using the CoOperator and relied on it as part of their search strategy. In future work, we plan to improve our inference technique to use more features and states. By modifying our simulation to artificially introduce distractions, we can use RSARSim to gather sufficient labeled data to learn the parameters used in our user neglect model. Additionally, we plan to make the robot map coverage more efficient by improving the robot allocation strategy and using an exploration transform to identify better waypoints.

5. ACKNOWLEDGMENTS

This work was supported in part by DARPA grant HR0011-09-1-0023.

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