Autonomy Mode Suggestions for Improving Human-Robot Interaction^{*}

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Abstract – Robot systems can have autonomy levels ranging from fully autonomous to teleoperated. Some systems have more than one autonomy mode that an operator can select. In studies, we have found that operators rarely change autonomy modes, even when it would improve their performance. This paper describes a method for suggesting autonomy mode changes on a robot designed for an urban search and rescue application.

Keywords: Human-robot interaction (HRI), adjustable autonomy, mixed initiative, collaborative control.

1 Introduction

The term "adjustable autonomy" refers to switching between a robot's autonomy modes or levels. Ideally, a robot should always know the current situation and adjust its own autonomy mode appropriately. In the urban search and rescue (USAR) task, a robot must safely navigate through a rubble pile or collapsed building while discovering victims who may be trapped and injured. Currently, robots with autonomous and semi-autonomous capabilities lack the perception and cognition for this difficult task; the USAR task requires some human control and decision making.

In usability studies of robotic systems for USAR, we found that typical users did not use robot autonomy modes effectively. For example, one subject navigated the robot to an area where it was surrounded by walls in the front and its two sides. The operator knew that he was having difficulty driving the robot in this area. The robot system had an escape mode, in which the robot will autonomously drive itself out of a tight space into an open space. However, the operator did not switch into this mode; instead, he ended up spending several minutes trying extricate the robot from this tight space before succeeding. (For more information about this study, see [1]).

We have also observed users choose an autonomy mode that puts the robot, the environment, and possibly victims in harm's way. For example, a fire chief testing a Holly A. Yanco Computer Science Department University of Massachusetts Lowell One University Ave, Olsen Hall Lowell, MA 01854 USA

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robotic system was frustrated when the robot would not drive forward. The operator saw nothing in his video screen. He decided to switch the robot from safe mode, in which the robot will not allow an operator to drive into an obstacle, to teleoperation mode, which has no sensor mediation. After the switch, the operator drove the robot through a Plexiglas panel. The panel was not visible in the video window, but the robot's sonar sensors had detected the obstacle. In fact, the presence of the obstacle was being signaled in the interface's sensor window, but the operator did not see it [2].

Common reasons for poor mode selection and switching include confusion about robot autonomy and thinking of the robot as a tool [3]. In spite of familiarization exercises beforehand, most users rarely switched between autonomy modes and did not use robot autonomy at times when it could have helped navigation. Users who switched autonomy modes more frequently tended to be more successful at navigating through the test arena. Since the goal of the USAR task is to find and rescue victims, it is important to navigate efficiently and cover as much area as possible.

Teleoperation of a robot requires intense mental attention. Robot autonomy alleviates some of this burden, which preserves valuable human cognition for the higher task of finding victims. Collectively, these observations inspired an idea that the USAR interface could do more to encourage autonomy mode switching.

We have developed a system of mode suggestions that is part of a project to improve human-robot interaction in USAR interfaces [4]. HRI studies have revealed that users of USAR human-robot systems spend too much time trying to gain situation awareness, which detracts from the task of finding victims [1,5,6]. Most of the dozen USAR interfaces we have studied do not convey essential information in an intuitive fashion. Some interfaces present an abundance of sensor information in a way that is not easily processed or understood by a typical user.

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We observed that users tend to focus all of their attention on the video display to the exclusion of other sensor information. Our interface design (described more fully in [4]) exploits this fact by "fusing" useful information onto and around the video display. In the design of our user interface, we deliberately sought to make the controls and displays as intuitive as possible.

The developers of the INEEL human-robot system advocate training during which a novice user can learn to trust the robot's autonomous navigation [7]. When disaster strikes, however, time for formal training may not be available. In addition to assisting a user, mode suggestions can teach the user about a robot's autonomy levels. A mode suggestion identifies situations where a mode switch could be useful. As an operator becomes more comfortable with the robot system, switching modes should become more natural, even if suggestions were not offered. Additionally, if a user developed a high level of trust in the suggestion system, there could be an opportunity to automate some of the suggested switches.

In this paper, we describe the development of a system that can suggest mode changes. Our system is built on top of a robotic navigation system developed by INEEL [7,8], described in section 3.

2 Related Work

Horvitz [9] cites "inadequate attention to opportunities that allow a user to guide the invocation of automated services" as a key problem. We have developed a user interface that addresses this problem by incorporating a mode suggestion system. Our mode suggestion system detects and informs the user of opportunities where an autonomy mode switch or autonomous behavior could benefit the USAR task.

Scerri's theoretical model of adjustable autonomy is based on "transfer-of-control strategies" [10]. Goodrich's perspective on adjustable autonomy allows for the possibility of automation initiating and terminating itself, but his experimental system, like Scerri's, is based on a model of transitions between human and robot control [11]. The conceptual model of the robot system upon which ours is based is a human-robot team in which control is truly shared. The INEEL system's autonomy modes represent a sliding scale of autonomy, which varies the proportion of human and robot control.

Fong et al. [12,13] describe a model of "collaborative control" in which the robot regards the human as a resource and asks the human operator for advice when the need arises. Our system offers suggestions to encourage the user to take advantage of robot autonomy. As Bruemmer et al [3] found, strategic switching between autonomy modes results in better human-robot performance.

3 INEEL's Autonomy Modes

The INEEL robot control architecture [8] consists of a sophisticated interface (see figure 1) and a robot navigation system consisting of multiple autonomy modes. The four primary modes are teleoperation, safe, shared and autonomous.

<u>Teleoperation Mode</u>: In this mode, the user controls the robot directly with without any interference from robot autonomy. In this mode, it is possible to drive the robot into obstacles.

<u>Safe Mode</u>: In this mode, the user still directly controls the robot, but the robot detects obstacles and prevents the user from bumping into them.

<u>Shared Mode</u>: In this mode, the robot drives itself while avoiding obstacles. The user, however, can influence or decide the robot's travel direction through steering commands.

<u>Autonomous Mode</u>: The robot is given a goal point to which it then safely navigates.

The system also has two autonomous behaviors: escape and pursuit.

Escape: The robot gets out of a tight situation autonomously.

Pursuit: The robot follows a specified target.

The INEEL system makes no distinction between its autonomy modes and autonomous behaviors; everything is a mode and presented identically on the UI, in the bottom right corner of figure 1. We think there is an important conceptual difference between autonomy modes and autonomous behaviors that is reflected in our interface design. For example, safe mode is an autonomy mode that is generally applicable in the USAR environment. Escape is more properly considered a behavior since it is triggered by temporary environmental conditions. It does not make sense to stay in an escape mode once the environmental trigger has lapsed.

4 Suggesting Autonomy Modes

We have incorporated a mode suggestion system into our interface, shown in figure 2. The current design consists of a mode indicator bar located just below the video display. (Again, we are exploiting the typical user's tendency to focus primarily on the video display.) The mode indicator bar changes color to indicate the current autonomy mode. Mode suggestions appear as buttons at different positions along the mode indicator bar. A mode



Figure 1: The INEEL interface. The four autonomy modes and two autonomous behaviors are selected using the six vertical buttons in the lower right corner of the screen.

suggestion button has both color and a text label to indicate which mode is being suggested. We intentionally use color and position to make it easier for the user to assimilate the mode suggestion. The text label was added to compensate for color blindness or forgetting the color map.

The mode suggestion component of our interface uses information from the robot and the user to determine when a suggestion should be made. The system running on the robot detects and reports obstructions, resistance to movement, and bumping of objects. It also detects environmental features like "box canyons." The mode suggestion system also reasons about sonar and laser readings when determining whether a mode suggestion is appropriate.

It does not make sense to present the user with multiple suggestions at once. Instead, when multiple conditions are met, the system decides which suggestion is most appropriate. (An example of mode suggestion arbitration is discussed below.) Additionally, a mode suggestion has a timeout (currently 30 seconds) associated with it. If the current mode suggestion is not preempted by a better suggestion, and the user does not choose to accept the suggestion, the suggestion will time out and disappear. The mode suggestion system compiles data on its suggestions: which suggestions were made, what conditions prompted a suggestion, and whether or not a suggestion was taken by the user.

4.1 Implemented Mode Suggestions

This section describes two mode suggestions that we have implemented in our system.

4.1.1 Teleop→Safe

In the urban search and rescue task, it is critically important that the robot not bump into obstacles and cause a secondary collapse. Since safe mode provides protection against bumping into obstacles, it is almost always more desirable than the teleoperation mode. There are special circumstances where the teleoperation mode can be useful. For example, erroneous sonar sensor readings, which happen for a number of reasons, could indicate a blockage in front of the robot. In this case, the autonomy mode could prevent the robot from moving, even though



Figure 2: Our interface for controlling the robotic system. The mode indicator and suggestion area is displayed directly below the video window. In the screen shot, the robot is in teleoperation mode (indicated by the color red), and the system is suggesting a change to the safe mode (indicated by the color green).

the video display and the laser ranging sensor show that nothing is blocking the robot. Switching to the teleoperation mode temporarily could get the robot by this impasse.

When the user switches to the teleoperation mode from any other mode, the system suggests safe mode as a better alternative. It could be the case that the user is an expert operator who prefers the teleoperation mode. Such a user would find the suggestion an annoyance. We deal with this possibility in two ways. The user can disable the *teleop* \rightarrow *safe* mode suggestion through an interface setting. If the user continually declines the *teleop* \rightarrow *safe* suggestion, the system learns to make the suggestion less frequently or not at all.

4.1.2 Any Mode→Escape

Strictly speaking, escape mode is really a robot behavior; it is used to extricate the robot from tight spaces. Once the robot is free, the previous autonomy mode is restored automatically. We believe that this suggestion should improve operator performance as we've observed several situations where using the escape mode would have saved several minutes of navigation attempts.

The suggestion system uses sonar and laser ranging sensor data to determine if the robot is stuck. Being "stuck" is defined as close readings on three sides of the robot. Close readings on two sides usually indicate a hallway or corner; if we suggest escape too often, the operator is likely to ignore all future escape suggestions.

The INEEL robot system computes a large amount of status information to send to the user interface. There are status messages that report on obstructions, bumps, and resistance to motion. We plan to investigate if this status information could be used to improve our suggestion system.

4.2 Arbitrating Mode Suggestions

The system must be able to arbitrate between mode suggestions. For example, if the robot is in a tight spot and the user switches to the teleoperation mode, the system must arbitrate between suggesting safe mode or escape mode since the conditions for both have been met simultaneously. Since the robot being stuck is the more pressing concern, the system will suggest escape mode. The system will not provide multiple suggestions because that would only create confusion. Heuristics will be used to build a suggestion hierarchy for arbitration.

4.3 Tracking Acceptance of Suggestions

The operator does not need to accept the system's suggestions. We are improving our suggestion algorithms by tracking when users accept or decline the system's suggestions. We record the suggestion, the conditions that triggered the suggestion, the user's choice, and, if the suggestion was accepted, how long the user took to accept the suggestion.

Tracking acceptance will allow us to create a measure for how much operators trust the system. As trust increases in the system, we will investigate how we could automate the switch in some situations.

It is also possible that some mode suggestions will become less useful as an operator becomes more skilled with controlling the robot. One of our objectives is to teach users about the different autonomy modes through the use of suggestions, so that an experienced user may have enough knowledge to choose their own modes effectively.

5 Discussion and Future Work

Our autonomy mode suggestions can be thought of as training wheels for users who are unfamiliar with robot autonomy. We think the concept of mode suggestions is a useful way to make progress toward automatic adjustable autonomy. As previously intimated, the mode suggestion system can learn which suggestions are helpful from how the user takes or ignores them. Eventually, the system could learn which suggestions the user always takes. Ultimately, the user could choose to have some autonomy mode switching occur automatically.

In addition to mode suggestions, we are also investigating automatic adjustable autonomy. Many USAR human-robot systems use wireless communication because a tethered connection restricts the mobility of the robot. However, wireless communication between the interface and robot system is often unreliable. We are using the mapping and localization capabilities of the robot system to create an autonomous "backtrack" behavior that the robot activates automatically when the wireless communication fails. The robot uses its generated map to backtrack along its previous path until communication restores. The backtracking behavior could also be implemented as a mode suggestion, triggered when the robot's battery level drops to where the robot will need all of the remaining power to exit the area.

Automatic mode switching could also be used to enforce robot and environment safety. For example, if the user continually bumps into obstacles while in teleoperation mode, the system will suggest safe mode. If the user stubbornly refuses the suggestion and continues to bump things, the robot could switch to safe mode automatically. This is an example of automatic adjustable autonomy.

We have not yet tested our system against the INEEL system. Since our system uses the INEEL system's autonomy modes, it is a natural basis for comparison. We believe that effective mode suggestions should improve a user's performance, as found by Marble et al [3].

6 Acknowledgments

This work is supported in part by NSF IIS-0308186. Thanks to Doug Few at INEEL for providing us with the code for the INEEL robot system, which includes the autonomy levels used in our suggestion system.

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