Teleplanning by Human Demonstration for VR-based Teleoperation of a Mobile Robotic Assistant

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Abstract

This paper focuses on the integration of local path planning techniques in a multimodal teleoperation interface, for the efficient remote control of a mobile robotic assistant. The main principle underlying this scheme is related to the continuous efforts in finding new ways to establish an efficient human-robot cooperation framework, where humans and robots take in charge the parts of the tasks that they can perform more efficiently. For the teleoperation of a mobile robotic platform, a simple application of this general principle could be to commit the human operator in performing the necessary global planning operations, which are more demanding in terms of complex reasoning and required "intelligence", while other more local tasks such as collision avoidance and trajectory optimization are dedicated to the telerobotic system. We propose an implementation of this principle within a mobile robot teleoperation interface integrating virtual reality techniques and Web standards. This paper describes the multimodal interface and the design principles followed, as well as the integration of a local path planning method. The method is based on wavefront expansion of a simple distance metric and the use of a trajectory modification technique similar to vector field approaches. This scheme, called "computer-assisted teleplanning by human demonstration", aims at providing active assistance to the human operator, enabling him to indicate in a natural way the desired global motion plan, for a more efficient teleoperation of a mobile robotic assistant.

1 Introduction

During the last five to ten years, robot teleoperation technology has been constantly evolving to in-

corporate new technological advances in many fields, including: (i) robot sensors and actuators, with the development of novel sensor-based control strategies, (ii) human-machine interaction, with the development of advanced multimedia interfaces including virtual reality (VR) techniques [7][9], as well as (iii) computer networks and communications, with the Internet being a typical example [8][11]. Telerobotics is a multi-disciplinary research field intersecting many scientific domains, such as those mentioned above, and having as a primary goal to establish an efficient communication and cooperation framework between humans and robots. The human operator and the telerobotic devices must be enabled to work together and collaborate efficiently towards performing the desired physical tasks. To achieve such a "synergy" between the human operator and the robot, the teleoperation (master or slave) control system should:

• Understand the "intentions" of the human operator and interpret his actions correctly. The human operator must be able to "indicate" in a *natural* manner the action plan that is to be followed in order to perform the desired physical task.

• Provide *active assistance* to the human operator, correcting his actions when necessary in order to deduce an appropriate robot action plan.

• Supply "rich" multi-sensory feedback to the human operator, to help him interpret *intuitively* the state of the remote task and the actual or expected results of current or planned actions.

We thus see that in order to enable such an intuitive human-robot interaction and cooperation, the use of multimodal teleoperation interfaces, exploiting multisensory displays and VR technologies, is of primary importance. Moreover, some "intelligence" is required for the interface to interpret correctly human intentions and deduce appropriate robot action plans. The basic principle of such a collaborative teleoper-

ation framework is to enable humans and robots to be in charge of the tasks and sub-tasks that they can accomplish more efficiently, depending on the specific situation and problem at hand and the related constraints. A simple application of this general principle for the teleoperation of a mobile robotic platform, could be to commit the human operator in performing the necessary global planning operations, which are more demanding in terms of complex reasoning and required "intelligence", while other more local tasks such as collision avoidance and trajectory optimization can be dedicated to the telerobotic system.

This paper proposes an implementation of this principle and its integration in a multimodal user interface for the teleoperation of a mobile robot. We start by describing in Section 2 the teleoperation interface, the design principles followed and their implementation. The system integrates VR techniques and Web standards to facilitate teleoperation through the Internet, and increase interactivity as well as intuitive operation of the system. Section 3 describes the integration in the teleoperation interface of a local path planning method, which is based on wavefront expansion of a simple distance metric and the use of a trajectory modification technique similar to vector field approaches. The method aims at providing active assistance to the human operator, enabling him to indicate in a natural way the desired global plan for a remote mobile robot. This scheme called *"computer-assisted teleplanning by human demonstration"* constitutes the first mode of teleoperation supported by the system, aiming at a more efficient "teleprogramming" of our mobile robotic assistant. This robotic assistant consists of a mobile platform equipped with a variety of on-board sensing and processing equipment, as well as a small manipulator, and is designed to perform simple fetch-and-carry operations in an indoor environment.

2 Multimodal Teleoperation Interface

2.1 Design Principles

In this section, we discuss and analyze some general guidelines and principles that need to be taken into account for the design of an efficient robot teleoperation system. Efficiency in remote operation and control of a robotic system concerns: (a) making "good use" of the available communication bandwidth between the master and slave systems, and (b) achieving a "synergy" between the human operator and the robot, by enabling the system to best exploit and integrate (in terms of speed, precision and error recovery) both: (i) the human operator capacity to take rapid decisions and intuitively indicate the most appropriate (coarse

or detailed) plan for system action (e.g. robot motion) in complex situations, and (ii) the robotic system capacity to perform, with controlled speed and precision, a variety of autonomous operations.

To approach towards these general targets, a set of requirements have to be specified and fulfilled by the teleoperation system and all its submodules. The final system design must converge towards the merging between a number of often contradictory modalities, in search of an "optimum" compromise and increased "efficiency". By *multimodal teleoperation interface* we mean a system that supports: (a) multiple computer-mediated human/robot interaction media, including VR models and tools, or even natural gesture recognition etc., and (b) multiple modes of operation, with a varying degree of robot autonomy and, respectively, human intervention. The latter is a very important issue for the design of a telerobotic system (see [15][10] for a comprehensive survey on the evolution of teleoperation systems). The *modes of operation* that we are considering for the teleoperation system include:

(a) *Direct teleoperation* control, based on on-line exchange of low-level commands and raw sensory signals.

(b) *Computer-aided teleoperation* of the mobile robot, with the master control system providing some form of assistance to the human operator, such as: (i) performing information feedback enhancement, like model-based predictive display, (ii) undertaking active control for some of the dofs of the system, substituting or complementing the human operator, or even (iii) providing some form of active guidance and model-based correction for the human operator's actions.

(c) *Shared-autonomy teleoperation control* of the robotic system, using a set of sensor-based autonomous behaviors of the robot. This mode of teleoperation control can be extended to incorporate a large set of intermediate-level, behavior-based, hybrid (qualitative/quantitative) instructions, such as: move through point A, B, C while avoiding obstacles, pass through door on the left, move at distance d from wall, follow corridor etc. These commands will trigger and make use of respective behavior-based control modes of the robot, incorporating automatic path generation functions.

(d) *Semi-autonomous teleoperation*, based on a set of high-level qualitative task-based instructions (such as go to location X, grasp object A on table B of room C etc.)

(e) *High-level supervisory control*, that is, simple monitoring of sensory feedback, and limited human intervention on specific complex situations, requiring difficult decision making and task planning.

Depending on the specific application and the tasks to be performed, a combination of these control modes will be used for on-line monitoring and remote control of the mobile robot. The system, however, should also support some or all of these control modes in an *off-line teleprogramming scheme*, where the human operator controls the robot task in a simulated environment and checks the validity of his actions before actually sending the commands (registered action plan) to the slave robotic system for real execution.

2.2 Implementation: VR-based Teleoperation

The human/computer interface for the teleoperation of the mobile robotic assistant comprises four main components:

(i) The *VR-panel*, where the 3D graphical models of the robotic system and its task environment are rendered. This simulation environment constitutes the first modality for inserting instructions (eg. motion commands) to the system in a natural and intuitive way. The input devices that will be used in the first place are: a joystick for virtual robot motion control, and a Spaceball for virtual camera navigation. Some form of sensory feedback information is also integrated in this virtual environment, like the actual robot position represented by a wireframe graphic model of the robot platform.

(ii) The *control-panel*, containing a 2D top-view graphical representation of the mobile robot environment (corridors, doors, rooms, obstacles etc.) and a command editing panel. The 2D model contains accurate map information of the whole indoor environment, where the robotic assistant will operate, allowing the user to obtain rapidly a top-view of any required region (using scrollbars or predefined region-buttons). The human operator will also have the ability, if needed, to directly edit commands that must be sent to the robot.

(iii) The *sensory-feedback*, where all the required sensory feedback signals will be displayed (for instance a sonar map, indicating the location of obstacles detected by the robot). A *visual-feedback panel* will also be integrated, displaying images obtained by the on-board robot camera. The refresh-rate of this video feedback will of course be reduced, since the bandwidth available for communication through the Internet is limited and real-time access to other more critical information, such as actual robot location and sensor status, is indispensable.

(iv) The *status panel* displaying information on the actual status of the robot in textual form, as well as messages about actions and events.
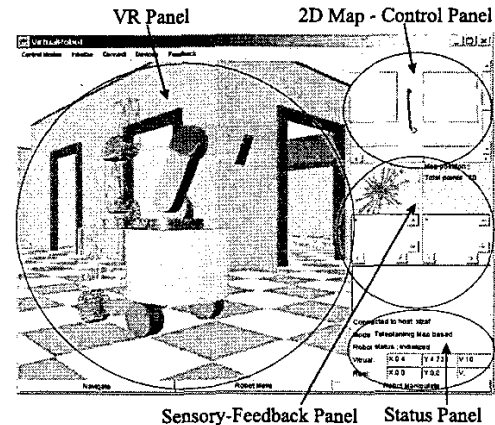

VR Panel   2D Map - Control Panel

Sensory-Feedback Panel   Status Panel

Figure 1: *Multimodal teleoperation interface for the mobile robotic assistant: First prototype implementation*

Figure 1 shows a snapshot of the first-prototype version of the human operator interface developed based on Java technology, in order to facilitate Web-based operation of the system. The 3D graphics rendering routines for the VR panel are implemented using the Java3D API. An enhanced version of this human/computer interface will constitute in the near future the Internet-based teleoperation control platform for our mobile robotic assistant.

3 Mobile Robot Teleplanning by Human Demonstration

Off-line teleprogramming is the first control scheme to be implemented on the real telerobotic system, since it constitutes the safest mode of operation in the presence of large and variable time delays. The main goal is to automatically generate a correct robot action plan from observation of the actions performed by the human operator within the VR or the 2D control panel. A solution consists of registering critical waypoints containing information such as robot position and orientation, navigation speed, acceleration etc. Interpolation between these waypoints by the local navigation module of the robot must result in the desired motion for the mobile platform.

According to the general teleoperation design guidelines and objectives, outlined in the previous sections, the human operator should be able to indicate in a natural and intuitive way the desired task plan, while the system should be "clever" enough to understand his intentions, interpret his actions and correct them appropriately to deduce a suitable robot

action plan, in the form of a series of robot commands (robot program). In this section we propose a method for providing active assistance to the human operator, having as a goal to facilitate such an intuitive human/computer interaction within a mobile robot teleprogramming control scheme.

The main idea underlying this teleoperation scheme is related to a more fundamental pursuit of an efficient human-robot cooperation framework, where the system combines in an "optimal" way the capacities of humans and robots. Many researchers are currently concentrating on establishing such a "synergetic and collaborative" control framework, like for instance the "shared intelligence" scheme proposed in [2] for the planning of telemanipulation tasks. For the teleoperation of a mobile robot, a simple application of this general principle could be to commit the human operator in performing the necessary global planning operations, which are more demanding in terms of complex reasoning and required "intelligence", while other more local tasks such as collision avoidance and trajectory optimization are dedicated to the telerobotic system. This section proposes an implementation of this principle, integrating a local path-planning method within the multimodal teleoperation interface presented above. The method is based on wavefront expansion of a simple distance metric and the use of a trajectory modification technique similar to vector field approaches. This scheme, called "computer-assisted teleplanning by human demonstration", aims at providing active assitance (collision avoidance and guidance) to the human operator, enabling him to indicate in a natural way the desired global plan for a remote mobile robot.

3.1 Local Path Planning

The problem of path-planning, that is, generating collision-free paths under particular task-related constraints, has attracted considerable interest for many years [1]. The two extreme approaches are: (a) *global planning*, based on a concise representation of the connectivity between collision-free configurations of the robot's workspace (usually in the form of a "connectivity graph"), and (b) *local planning*, which consists of searching locally around the robot for collision-free configurations, based on some heuristic that usually takes the form of a potential field guiding the search along the flow of its gradient vector field.

More recently, some research efforts have concentrated on integrating some form of motion planning technique within human/computer interaction systems. The goal is to develop "intelligent" interfaces that help users avoid unnecessary maneuvers, for in-
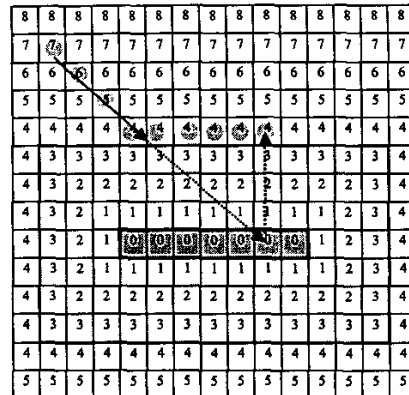

Figure 2: *Local path planning based on wavefront propagation of a distance metric*

stance avoid collisions when navigating within a virtual environment. In this context, a methodology was presented in [3] for supporting intelligent virtual camera control, incorporating a global path planning algorithm based on a room-to-room connectivity graph and global (static) numerical navigation function. Another method was proposed in [5], aiming also to facilitate user navigation within a virtual world, based on the integration of a probabilistic roadmap planner within a VRML interface for architectural walkthrough applications.

The drawback of using global path planning approaches is that they require an expensive precomputation step for the construction of the connectivity graph, while this step has to be repeated in case of a dynamically changing environment. Moreover, the graph search may also be time consuming, which may be inappropriate when real-time human-computer interaction applications are considered. We propose to integrate a simple local path planning method within a mobile robot teleoperation interface. This method is based on the automatic creation of a distance map based on a 2D top-view representation of the indoor environment constituting the robot workspace. This 2D map is constructed using a wavefront propagation algorithm for a standard Manhattan (L2) distance metric, considering a typical 8-connectivity for neighboring pixels. This is illustrated in Figure 2, where we see a commanded trajectory towards an obstacle (*distance* = 0), and its modification following the gradient of the distance function until an acceptable threshold is reached (for the case of Figure 2, this threashold level equals 4).

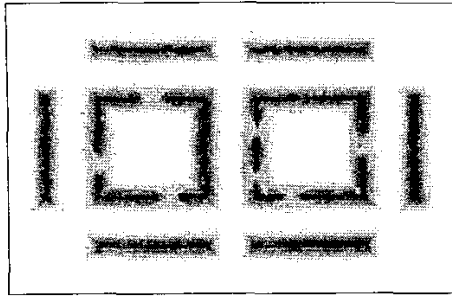This method intends to unburden the human opera-

Figure 3: *Distance map for active collision avoidance*

Active anti-collision and guidance

Automatic Waypoint Generation

Figure 4: *Computer-assisted trajectory teleplanning*

tor from precisely and accurately inputing the desired trajectory to be followed. Instead, only an approximate global plan (room to room navigation) may be needed, while the system is in charge of dynamically correcting the input path, to deduce an appropriate trajectory for the mobile robot.

3.2 Integration within the Teleoperation Interface

The method has been implemented using Java, and integrated within the multimodal teleoperation interface presented in Section 2. Fig. 3 shows a typical example of a distance map computed for an indoor environment (consisting of a couple of rooms, doorways and corridors). Fig. 4 demonstrates the implementation of this local path-planning method, for on-line anti-collision and guidance (following corridors, passing through doorways etc.). The arrows in this figure (4-a,b,c) indicate the points where the algorithm intervenes to modify and correct the motion imparted by the human operator, and provide active assistance. Motion input can be provided by the human operator either using a standard mouse-drag procedure, or using other 2D devices like an e-pen digitizer. In the future we will consider human interaction using vision-based algorithms for natural gesture recognition.

An automatic waypoint generation module is then in charge of computing a set of optimal waypoints that will constitute the commanded robot motion plan (Figure 4-d). This can be performed either using some simple heuristic (like comparing simulated robot heading through neighboring points) or using some general optimization algorithm, taking into consideration constraints related to the motion control method employed by the mobile robotic platform. The system also supports previewing of the final planned trajectory (and even waypoint editing), in 2D and/or in 3D (VR) mode, in order to give to the human operator a realistic idea of the motion that is to be executed
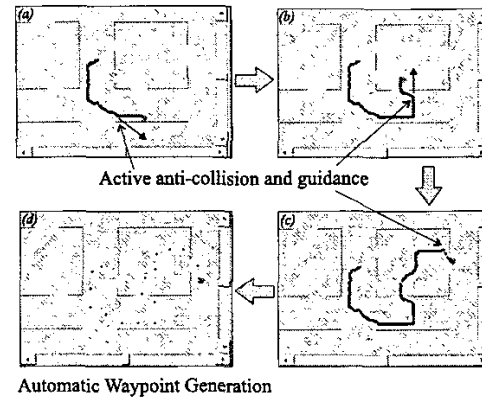
by the slave robot, prior to sending the deduced motion plan to the remote site for real execution (in the form of a list of waypoints with additional task-related information, such as landmarks).

4 Hardware Configuration of the Mobile Robotic Assistant

Initial experiments are currently being performed using the multimodal VR-based teleoperation interface, with the local path-planning function active, for the remote control of an integrated mobile robotic assistant. The hardware configuration of the mobile robotic system consists of: (a) a mobile platform, manufactured by Robosoft and equipped with a ring of 16 ultrasonic sensors, (b) a vision system mounted on a pan/tilt platform, and (c) a small 5 dof manipulator arm, manufactured by Eshed Robotics, also integrated on the platform.

The robot platform is equipped with on-board computational power consisting of a VME-based controller (running on a Motorolla 68020 CPU processor), and a Pentium PC communicating via a wireless Ethernet link with the off-board central control server. Figure 5 shows photos of the robotic platform, with the manipulator arm mounted on it. This work is performed in the context of a research project, called "HygioRobot"[1], aiming at the development of an integrated mobile robotic system and the investigation of its use to perform assistive operations in a hospital environment [13][14] (for a survey on health-care robotics see [4, 6, 12]). The whole system should be fully operational for a complete series of experiments by the end of the year.

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[1]Participating partners are: National Techninal University of Athens, NCSR Demokritos and University of Pireaus
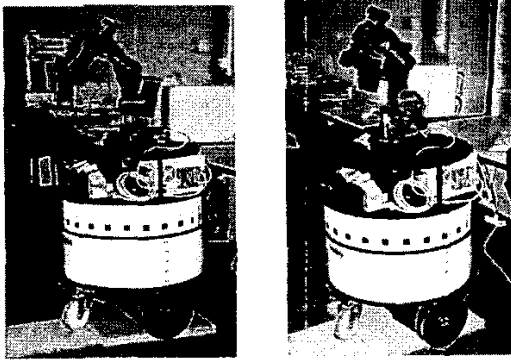
Figure 5: *Integrated mobile robotic assistant*

5 Conclusion

This paper focused on the design and implementation of a multimodal teleoperation interface, integrating VR models and Web standards, for the remote control of a mobile robotic assistant. We proposed to incorporate a local path planning technique within the user interface, based on a simple wavefront expansion algorithm of a standard distance metric. The method intends to facilitate global planning of the desired trajectory by the human operator, and enable intuitive interaction and efficient teleoperation. Active computer-mediated assistance is provided to the human operator in the form of collision avoidance and active guidance, enabling him to indicate rapidly and in a natural manner the desired motion plan, without having to accurately input the precise mobile robot trajectory.

This mobile robot teleoperation scheme, called computer-assisted *teleplanning by human demonstration*, is inspired by a more fundamental pursuit for an efficient *human-robot collaboration* framework, a general target on which many research efforts are now focusing, intending to achieve a better synergy between humans and robots and exploit in an "optimal" way their capacities.

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