REMOTE CONTROL OF MOBILE ROBOTS FOR EMERGENCIES

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Abstract: In emergency situations, rescue teams combined of humans and robots in place, as well as tele-operators to coordinate the activities from a remote location need to complement each other. This contribution addresses specific aspects of the tele-operator to remotely control the robots. Aspects to be analyzed are related to remote sensor data acquisition, as well as to data transfer in the distributed system of remote and in place team members. Appropriate user interfaces for the tele-operator are to be provided, filtering the input information. The use of telepresence methods in this context provides an intuitive user interface for the remote operator and the team members in place. It enables a quick overview of the situation in order to select under time pressure most appropriate strategies.

Keywords: mobile robots, telerobotics, teleoperation, man /machine system, man/machine interfaces, remote control, telematics

1. INTRODUCTION

Robots offer good potential to support rescue teams in emergency operations, in particular for first monitoring and for exploration of the damaged area. Thus the risks for rescue personal in dangerous environments could be significantly reduced (Andresen, 2002, Casper et al., 2000, Murphy et al., 2000). Here joint teams of humans and robots are analysed, combining the cognitive and adaptive capabilities of the human rescuers with agility of remotely controlled small mobile robots.

Typically a search and rescue team is thus composed of

- firefighters, interconnected with robots and teleoperators by radio links,
- robots , which are in general remotely controlled, but might use also autonomous control features,
- teleoperators, outside the emergency area in order to plan and coordinate the team as well as to provide access to database information.

The coordination and control of such teams is analyzed at the example of a typical scenario for emergencies in more complex environments, such as factories, hospitals, large office buildings. Information about the current position of all team members in the area is the basis to plan future activities.

This contribution reviews in chapter 2 the necessary infrastructure and describes the key components for such a search and rescue team. A more detailed description of the rover control interface for the firefighters and the teleoperators on basis of tele-presence techniques follows. The test plan and the achieved results are summarized in chapter 4.

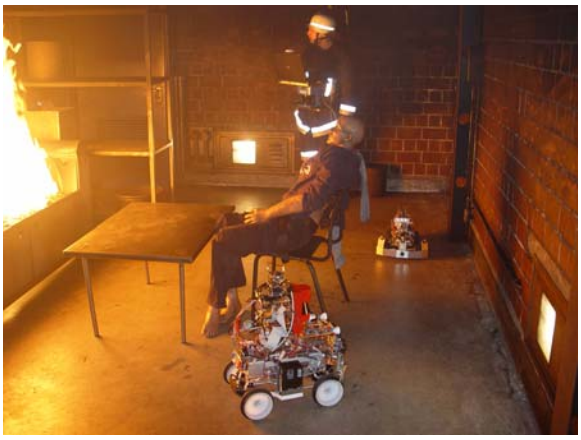

Fig.1: Robots guiding a firefighter during tests to persons to be rescued

2. SYSTEM ARCHITECTURE

In order to identify user needs for tele-presence methods in the search and rescue field, questionnaires had been distributed to professionals in that field (cf. Baier et al., 2005). This provided the basis to develop an appropriate architecture for a cooperative control and information system within the EU-project PeLoTe (Building *Pre*sence through *Lo*calization for Hybrid *Te*lematic Systems), reflecting user needs.

2.1 Requirements Analyses by Questionnaires

Different professional organisations in the area of search and rescue, related to fire fighting (for urban areas, as well as for factories, airports, nuclear plants,…), to disaster relief, and to police/military context had been contacted. First inputs were acquired by questionnaires. Later on the basis of about 21 returned questionnaires more detailed interviews were initiated to provide more evidence on how to interpret the obtained results.

Robots are considered as an interesting tool to reduce risks for the humans. While research focussed earlier a lot on autonomous robot behaviours, meanwhile tele-operated rovers, supported by some partially autonomous behaviours, are considered as a more realistic approach. Rescue team tracking systems and a homogeneous display of all rescue team members on basis of reasonably accurate localisation methods were anticipated as an essential improvement. Warning systems (based on robot sensors for unexpected dangers, such as poisons, toxic gases, defects in carrying structures) are considered as particularly useful. Beyond the objectives of that project, there is still a huge demand for provision of robust telecommunication links.

2.2 Data Flow Architecture

Rescue personnel, mobile robots and remote coordinators are to be integrated by tele-presence methods into a cooperative system. Different information streams related to voice, video and sensor data are to be exchanged between the team members (cf. Fig. 2). After trade-offs with event based architectures, a centralized client server architecture had been selected. The supervisory control (Parasuraman et al., 2002 and Sheridan et al., 1992) system enables remote control of the rovers by the teleoperators as well as by the rescue personal in place. An essential background for decision making is the knowledge about the position of each team member of the rescue team. Thus localisation system inputs (cf. Suomela et al., 2003 and Kulich et al., 2004) enable to integrate and display information from different sources on the graphical user interface (Schilling et al., 2004) by a layered map. This way an intuitive information display results, enabling quick reactions in time critical situations. Good localisation of team members provides the basis for efficient planning, too. Thus software tools for systematic path planning in order to efficiently cover all rooms in a building to search for people are integrated.

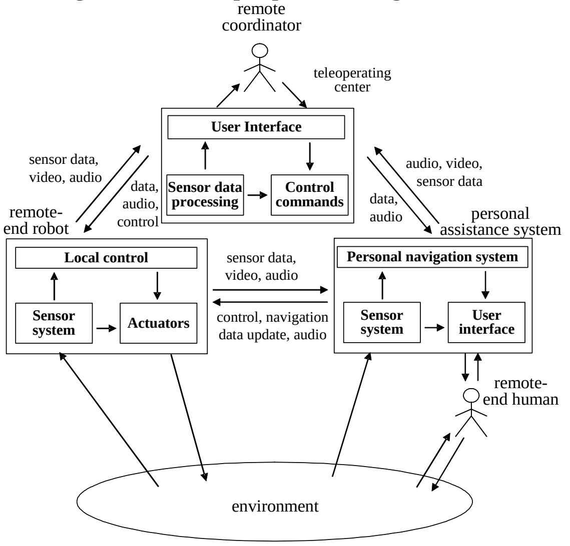

Fig.2: Schematic of the information flow between team members

2.3 The Robots

Several agile small rovers based on the standard MERLIN vehicles have been used in that context. MERLIN (***M***obile ***E***xperimental ***R***obots for ***L***ocomotion and ***I***ntelligent ***N***avigation, cf. Schilling/Meng, 2002) is the name for a family of small rovers (length ca. 50 cm, weight range 5 to 15 kg) with a modular electric design, employing tracked and wheeled locomotion systems (cf. Fig.3). It was designed to accommodate different sensor configurations according to specific mission needs.

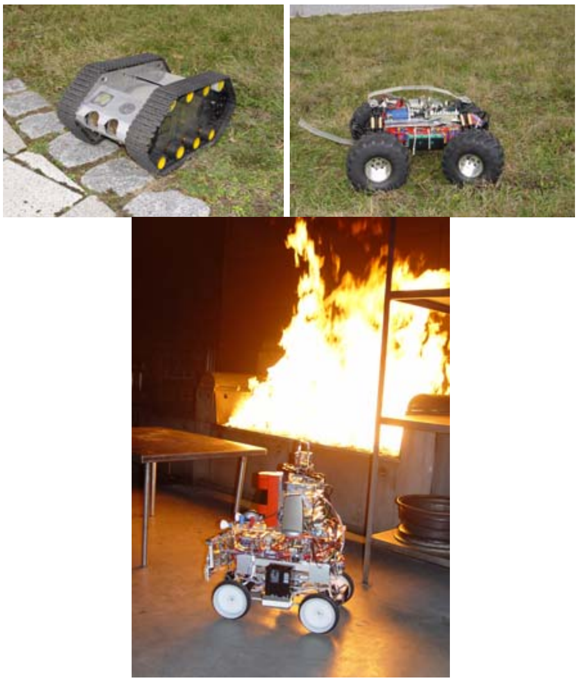

Fig.3: Modular MERLIN vehicles for different rescue scenarios, in tracked and wheeled versions, as well as a fully equipped MERLIN (below) with sensors for rescue purposes.

Several autonomous functions have been implemented on MERLINs in the context of cooperating robots addressing convoy driving and cooperative navigation tasks (cf. Gilioli/Schilling, 2003). In the search and rescue context, the standard usage is remote control of the rovers by the humans in the team, in order to explore a potentially dangerous environment or to investigate narrow areas not accessible for humans. Beyond this, some autonomous functionalities have been considered as helpful to relieve the human team members from work load:

- autonomously following an human team mate to reach the work environment,
- autonomous detection of obstacles, in order to issue a warning to the tele-operator,
- autonomous localisation by the on-board sensors.

3. THE TELE-CONTROL SYSTEM

Both, humans in place and remote coordinators need to access the system in different ways:

- they need to control the robot, by means of way points in a map or directly by means of a joystick.
- sensor data as well as the location should be displayed in a two-dimensional map (graphical representation of the search and rescue map).
- path planning and re-planning needs is to be initiated by the teleoperator.
- the a-priory map needs to be manually updated in case of changes, e.g. if destructed areas have been detected.
- manual position corrections for human and robot should be enabled.

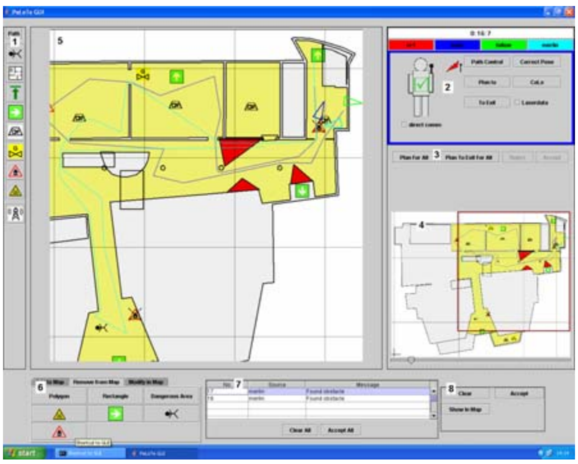

Fig. 4: Graphical User Interface for Supervisor including a priori and up-to-date information, as well as possibilities to control the team and update the map manually.

In order to achieve these interactions, a graphical user interface (GUI) was designed and implemented. The starting point was the user requirement analysis (Driewer, *et al.*, 2004). An interview session with fire fighters provided useful suggestions for further improvements. Two experiments with different test groups, fire-fighters and non-fire fighters, helped to improve and verify the design of the GUIs.

A screenshot of the current version of the GUI for the supervisor is presented in Fig. 4, which was used for the final test in November 2004. The two-dimensional map shows the building structure with the location of related objects, e.g. exits, alarms (global - 4 and zoom - 5). On the left side buttons allow fading in or out of a certain layer (1). The actual data and properties of every entity are shown in the window in the right upper corner (2). Below buttons for the planning and re-planning for the whole team are located (3). The buttons left below enable the user to update the map according to the changes reported from the environment (6). A message window at the bottom of the GUI shows messages from the team members in the emergency area, humans and robots (7). The operator can accept or reject the changes suggested by these messages (8), e.g. changes to the map.

Map changes will only be done by the operator, not by team members in the scene. It is hard for the operator to track changes if they are done autonomously by the robots or manually from the emergency area. Moreover, the human rescuers do not have the time and are too stressed to input updates. In the current GUI design the operator needs to read the messages, interpret them, make the necessary changes and invoke modifications in the mission planning, if necessary. This means more work for the operator, but enables the operator to keep track on all adaptations and to react appropriately to contradictory inputs. Video images from the scene can be obtained from all team members equipped with cameras and can be displayed on a separate screen. The operator keeps also continuous audio contact with human rescuers.

Fig. 5: Graphical User Interface for a rescuer in the emergency area, including similar information such as the supervisor's GUI and an personalized laser view according to his field of view, that visualizes the local map in front and the path to walk.

Fig. 5 provides the GUI for the human in place. It contains a similar two-dimensional global representation of the search and rescue map (3) and buttons to fade in and out certain layers (1). Additionally, it includes an individually centered view of the laser data (4). The window shows the measurement points of the laser, an proximity alarm if the human approaches nearby obstacles, the blue dot representing the own position and the blue line showing the next path element. This view together with the localization and mapping system (Saarinen, *et. al.*, 2004) provides an excellent way of navigating fast through environments with low or non-visibility conditions. An arrow (5) visualizes the direction in the map. The panel in the right bottom corner (6) displays own properties and control buttons, e.g. for the following robot.

Even though the design of the GUI for the supervisor and the human in place is different, the implementation is similar. The GUI can be started as teleoperating system or as personal assistance system, which also initiates the navigation system, called PeNa (**Pe**rsonal **Na**vigation system).

The GUI is implemented in Java to achieve platform independency using the Swing library for the GUI components and Java Advanced Imagine (JAI) for the visualization of the map.

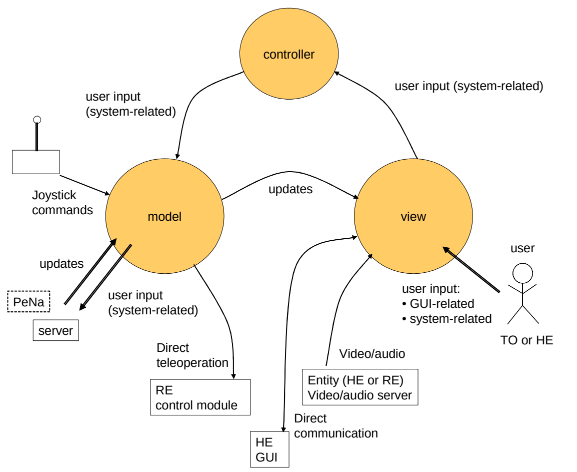

Fig. 6: Principle structure of the GUI application and its interfaces.

The GUI implementation (cf. Fig. 6) consists of several components that are organized according to the MVC (Model-View-Controller) paradigm (Buschmann et al., 1996).

The model manages the connection to the server via Java RMI (Remote Method Invocation), i.e. gets updates (position, status and sensor measurements) and messages (map updates, requests) from the entities and sends control data to the entities as well as map updates to the common map, which is maintained in the server. It also reads in joystick commands and sends it directly to the robot via socket connection, if the operator decides to directly control a robot (cf. Fig. 7). The operator is able to control the robot via onboard camera, or with a user-centric laser view (similar to user-centric view in the GUI for the human in place). The laser view provides an excellent addition or even alternative to the camera image. This is especially useful in dark areas or at low-bandwidth conditions.

If the GUI is started for the human in place, the model contains also the interface to the PeNa system, i.e. gets the position and other sensor data of the team member from PeNa directly instead from the server.

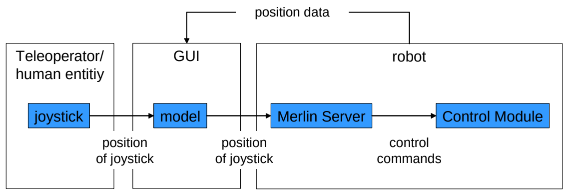

Fig. 7: Direct teleoperation mode via joystick.

The view manages the graphical output (the actual visualization) of the changes in the model and GUI-related inputs from the user (e.g. map updates, invocation of planning etc.).

The controller interprets system-related user inputs (mouse and keyboard) and commands the model and/or the view to change as appropriate.

Additional to the client-server architecture direct communication is possible via sockets between the tele-operator’s GUI and the GUI of the human in place (cf. Fig. 8). The operator can show directly a position in the map (as an additional mouse pointer for remote control). This provides an augmentation to the discussion via audio link.

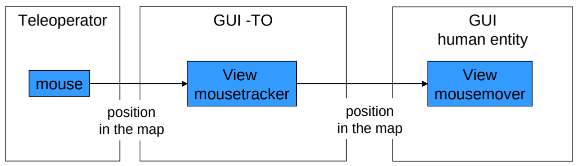

Fig. 8: Direct communication between GUIs.

4. THE TEST SCENARIO

The PeLoTe system and the developed GUIs were verified in two tests: one in an office-like area with many corridors, the other area included narrow corridors as well as open spaces. According to test results, updates have been entered, leading to new system versions.

The test environment was prepared to simulate the challenges of a search and rescue mission (see Fig. 9). 24 test participants, voluntary fire fighters, students and staff members carried out an experimental mission in this area. Six teams performed the mission with the system and six teams without the PeLoTe-system in order to provide data for comparison. Every team consisted of two test participants: one supervisor and one human rescuer in the emergency area.

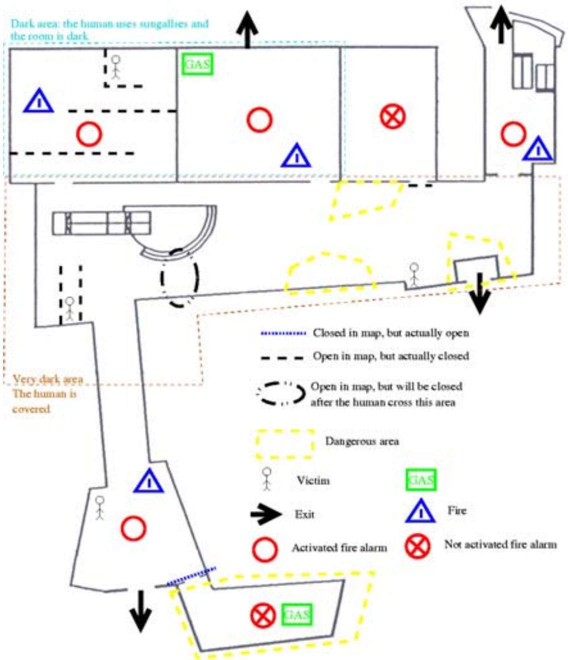

Fig. 9: Experimental area for final experiment

The teams with the PeLoTe system had also one robot that was exploring the area on its own under control of the supervisor and one robot that was following the human in place. It could be used for direct (joystick) teleoperation in areas, where the human could not reach (dangerous or blocked). Before the mission the teams with the system had about 30 minutes time to train and practise with the system.

The following task was given to both groups:

- Four victims, simulated by dolls and crying, needed to be rescued to a safe exit.
- Four fires, represented by symbols in the area needed to be found and put off (by touching the symbol).
- Five dangerous areas, represented by symbols and barriers, had to be avoided.
- Two gas valves and six fire detectors, represented by symbols needed to be checked.
- Structural collapses were simulated by moving obstacles during the test run. The map in the beginning of the experiment was not correct, some ways were blocked, and others were open in the real environment. Map changes should be marked by the supervisor.
- Some areas were darkened to simulate low visibility conditions. In part of the environment a blanket was used to cover the participants, which simulates no visibility conditions. The supervisor should help the human in place to navigate through these areas and to plan the complete mission.
- There was no strict time limit given, but the test teams were instructed to leave the area after about 25 minutes.

The teams without the PeLoTe system had a paper map and audio communication available. They were also carrying a backpack with additional load in order to compare with the current weight restrictions of the localization system. The PeLoTe teams had the same map visible on the GUIs.

The left chart in Fig. 10 emphasizes the supervisor judgement of the system being a good support in performing tasks as finding fires, finding victims and getting along, as well as a good support for saving victims. The right chart displays that the supervisors were only very little distracted by the system in performing all tasks.

The humans in the emergency area evaluated the system as a great support in getting along. For finding, fires and victims as well as rescuing victims they assessed the system as less supportive as the supervisors, but they felt not disturbed, too. The humans in place feel a lot more the current drawbacks of the system (heavy weight, restricted movement, less attention due to the screen …) as the supervisor. Therefore, the supervisors appreciated the system more in comparison to the humans in place.

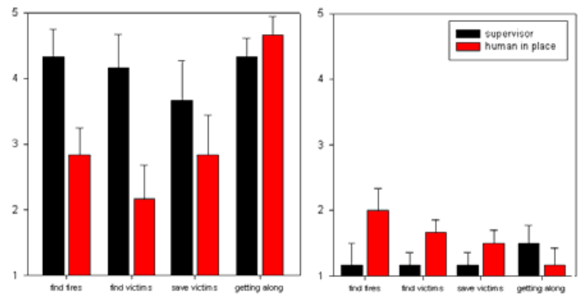

Fig. 10: The teams testing the PeLoTe system judged the system as supportive (left chart) and felt only little distracted (right chart).

5. CONCLUSIONS

The system was tested with both, fire fighter and non-fire fighters. Both groups performed well with the system. The fire fighters confirmed that the system or components of the system can be very useful for search and rescue tasks. In the final demonstration, in a fire training house, interviews documented the appreciation for the system's potential for emergency applications.

The localization system together with the visualization of the position in the graphical user interface allows quick and safe movements in dark or unknown environments only after a short training period. The graphical user interface for the supervisor displays the position of the team members, all relevant available information and enables the operator to maintain a good overview even in complex situations.

The robots were used to explore areas, which were blocked for humans, or for a faster search of the area by parallel activities of all team members.

During the experiment it has been demonstrated that information about location of all team members is a key to improve the performance of the teams. The human in place felt connected and the teleoperator could provide better support whenever needed. Teams without the system moved often randomly and needed to touch the walls to stay in contact with the environment. People with the system moved more secure and the operator was able to plan the mission more efficient. The robots helped to investigate the area faster and enabled also access to dangerous areas.

By using more complex input devices, such as small haptic joysticks for control, possibly the interaction could be further improved. The user interfaces for both, the supervisor and the human in place might take further advantage from using virtual or augmented reality, other senses as the visual (sound and touch) and by an improved display technique for the human in place, e.g. integration of the display in the helmet or an arm-mounted display.

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