Next Generation Human-Robot Telematic Teams

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Abstract

The contribution investigates new methods and tools for design of next-generation telematic systems based on hybrid teams of cooperating robots and humans. The contribution presents selected issues of building the feature of presence in such systems, deals with human-robot integration and cooperation issues together with drawbacks and benefits of the technology in question. The presented approach is focused onto investigation of a search and rescue type of tasks and provides evaluation of results obtained in proof-of-concept experiments.
Keywords: telematic system, human-robot cooperation, personal navigation, search and rescue.

Problem Description

Bidding to make the human activities easier and to become more powerful leads to focusing on development of specific technical tools for extension of human natural abilities. These cover mainly devices and tools that enable further improvements on the level of humans' sensory and perception system, providing him/her completely new, or normally unavailable, observations.

One of possible ways to achieve the previous goal is to apply so-called wearable computing technologies opening possibilities to access desired information at any time and any place. So far, many daily working activities can endanger the human. To avoid this, (semi)autonomous machines - robots - can be used as substitutes for the living entities. Nevertheless, overtaking the danger from humans not always brings purely positive gain into the overall performance: the robot needs not to be capable of execution of the desired maneuvers or operations, or is not capable to obtain complete survey of the working environment.

Therefore, as ideal cut still remains a proper combination of the "classical" human approach to solve the given task being at once supported by a robot. Extension of human capabilities towards those, robots typically have, forms the topic investigated in this contribution and is shown in the Fig. 1.

In the case a human is expected to be equipped by a communication (Mazl 2005) and sensing system (Saarinen 2004 and Saarinen 2005), similar to ones robots rely on. Selected robotic principles can also be applied to these humans as activity planning and/or optimization, human navigation and localization tasks, etc. In particular, this means, the mechanical part of a standard robot is to be substitute by a human body, and simultaneously also bringing his/her cognition into the problem solution. This qualitative step opens possibilities to build hybrid teams of cooperating humans and robots. Synergies in these teams belong to central advantages of this setup; complementary

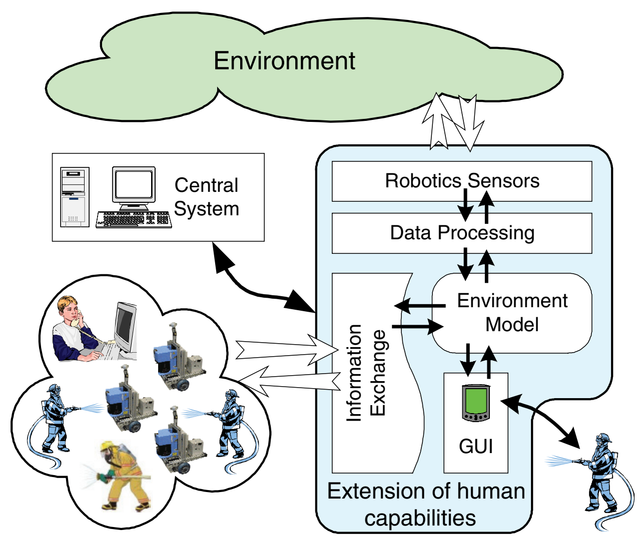

Fig 1: Supporting system for human sensing, communication and data sharing.

properties of diverse types of entities (robots and humans) result into substantial improvements in the final performance of the whole system. The major advantages of the human-robot support principles in question stand mainly in specific applications, where classical perception schemes fail (or are substantially limited). These could be e.g. rescue mission in spaces with low visibility, or

situations where local optimization is required with respect to global efficiency of the system.
Therefore, this contribution elaborates experiences with design and development of hybrid human-robot telematic teams and related necessary technologies to verify the investigated principles in laboratory conditions in missions of investigated in “Presence thru Localization for Hybrid Telematic Entities” (Pelote 2006). The mentioned system was designed as a test-bed with emphasize on applications in search and rescue activities; the fire-fighting scenario has been chosen for demonstration of the project results, regardless the system can be applicable also to any similar inspection-like tasks (Driewer 2005 and Pelote 2006).

Extension of Human Capabilities

One of the mentioned project targets has been design of a support system aimed at best possible extension of human perceptual abilities in the situations, where the human is expected to undertake decisions in stressing situations. This fits into the overall concept of integration diverse types of entities like humans and robots into a homogenous team. Then, team existence allows setup of an efficient scheme for data exchange and sharing, all leading to team member cooperation.

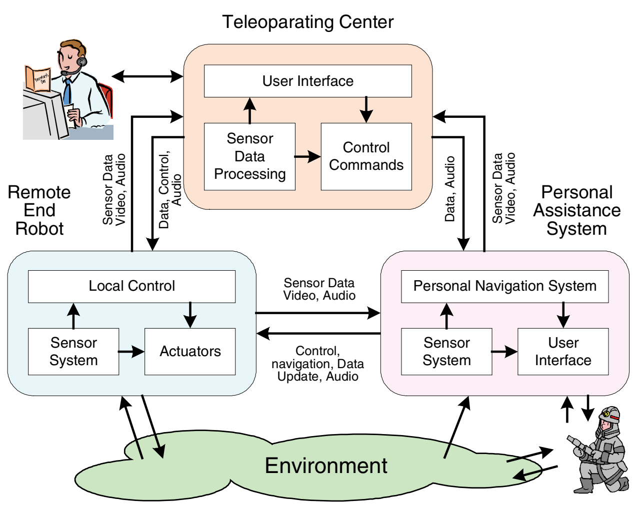

Fig 2: Information flow between the different team members (human and robot) involved in a rescue mission.

While robots can perform their communication via native interfaces, the human desires a specific interface to participate in the communication traffic within the robot community. The interface shall allow him/her to establish a bidirectional communication in a form proper to the nature of the task solved and well adjusted to the human abilities (Pavlicek 2005 and Rekimoto 1998). Such a Personal Assistance System (PAS) dedicated for interfacing a human to the rest of the system (Fig. 2) plays key role in the system design and definitely belongs to wearable technologies itself. The PAS system (Saarinen 2005 and Driewer 2004) has been composed of multiple parts, all together targeted to improve human actors’ perceptual capabilities and to establish communication with the other members of the community. The PAS system can also be understood like a multipurpose interface enabling the human to process sensor data, visualize system state information and to provide the human data of a robotic kind and origin in understandable form like maps, planned trajectories, etc.
From the users’ point of view, the PAS system brings key functionalities in:

- processing, evaluation and visualization of sensor data
- indoor localization relative to the map and gives positions of other team members
- information sharing between other team members (human-to-human and robot-to-human)
- capability to influence/modify the environment map
- audio-visual and intuitive communication interface to the user,

all together contributing to mutual symbiosis of humans and robots in mixed communities (Schilling 2004).

Target Usage

The mentioned PeLoTe system was designed to study the issues of building presence in hybrid teams of robots and humans but with emphasize on applications in search and rescue activities for emergencies or catastrophes. Nevertheless, the theoretical background has been constituted with respect to applicability of used general principles for building of hybrid teams. The humans and robots as the complementary partners can effectively fulfill many kind of tasks, moreover the extension of human capabilities open a new areas where can be utilized methods of robotics. Since it is possible to localize a person in general environment (even in indoor) and the information about its positions spread over other team members, the overlying system for activity planning can find globally optimal solution for coordination of partial actions (Kulich 2005 and Kulich 2006).
In the future, the self localization of humans definitely provides wide variety of possible applications. Imagine that carrying just a portable device with a localization system and environment map enabling people to find their way through unknown urban areas, highly complex building structures, or to guide around passing several tourist attractions. Special applications for visually impaired people, rescue, exploration and/or military missions are straightforward in this context.
Moreover, the cooperation between mobile robots and humans can be used in industrial context e.g. for moving objects or mounting products by several robots and human workers at once.
The hereunder discussed fire-fighting scenario has been chosen for demonstration of the project results, regardless the system can be applicable also to any inspection or guarding tasks.

Specifically, a special kind of exploration task is indicated for usage with teams of robots and humans. The humans are in this case often requested to share sensed information with exploration robots, e.g. in a sweeping tasks. If human is equipped by special devices providing him/her novel features, it can be considered for a telematic entity, what opens completely new areas of usage.
On contrary to the teleoperation of robots, humans will not be controlled or operated from a remote place. The "teleoperator" provides support, help, knowledge or supervision to the human to keep him in the task scenario only but also releases his own abilities to be applied for the task solution. This kind of technology can be useful for people that repair or maintain equipment. Moreover, after certain modifications the concept could also be used in medical area. A specialist can support and supervise another one during complicated operations, in order to share its expertise and knowledge. Another application area is education and training of staff. The teacher can supervise the students during their execution of task and point out mistakes and answer questions from a remote place.
The difference to the traditional way of support (telephone or email) is the telepresence of the operator. Whereas, traditionally the human in place has to tell everything to the supporter, with telepresence methods the operator gets the information directly by means of transmission of sensor data, camera images, audio and so on. The teleoperator can even provide direct help with special interfaces as pointing to object with a laser pointer remotely or fading in additional information in augmented reality user interfaces.

System Prototyping

Description of the Experimental Setup

The proposed system sketch has been implemented for experimental environments and tested in an extensive evaluation process.
The test was executed in two phases. The first phase served as a general test for the soft- and hardware as well as an input for the next prototype of GUIs (28 test participants). The second phase (24 test participants), provided evaluation of the system, including performance, user feelings, interaction, feeling of presence and spatial awareness. Test tools were observations and questionnaires: PANAS questionnaire (Watson 1998) and MEC-Spatial Presence Questionnaire (Vorderer 2004).
Half of the test participants used the system with two robots (Ruangpayoongsak 2005) teamed with a human. The other half experienced the same mission in a traditional way, being equipped only with a standard printed map and audio communication available. Each of the rescue teams was coupled to single supervisor coordinating the whole mission.
The tests in the second phase were designed as a course simulating challenges as in a fire fighting scenario (Fig. 3) in a given indoor mission area. The experiment area was simulating a rescue course having dolls and sounds of victims, symbols for fires, fire detectors, gas valves and barriers denoting dangerous areas. Certain obstacles were moved to simulate structural changes during the test run.
The tasks to fulfill the mission were:

- to rescue four victims (simulated by fetching a doll to the next secure exit),
- to put off fires (by touching the symbol),
- to check fire detectors, if they are activated or not,
- to identify and avoid dangerous areas, and
- to explore the whole mission area.

The human rescuers were not allowed to enter any dangerous area, otherwise the mission would be considered as completely failed. The test environment contained areas with diverse visibility conditions, ranging from full visibility to complete non-visibility, i.e. some areas were dimmed by darkening the windows (low-visibility). For part of the environment a blanket was used to cover the participants and allowed to achieve zero-visibility conditions. The teams using the system trained in a different area for about 30-40 minutes prior to the experiment with the goal to get acquainted with the technology used.
The activity of the participating robots was assigned as: the former robot was dedicated to follow the human in place and could be used for direct (joystick) teleoperation in areas, which the human can not reach. The latter robot explored the area on its own (in a semi-autonomous way) under control of the supervisor. Both, robots and humans contributed steadily to updates of the information (current content of the map of the mission space) in the system.
To avoid negative influence on the comparison team results, the groups without the system support were also carrying all the system devices, but not using them. This was aimed to compensate influence of the additional weight and motion restrictions originating from the localization system prototype used.
All teams had an a priori map available, which was only partly correct. The PeLoTe system supported teams used the map on the GUI, while the teams without the system relied on a paper map.

Evaluation Methods

Several evaluation tools provided measure for comparison of the teams with and without the system.
To evaluate team performance in the experiment, the following measures were used:

- completion of the tasks
- mission time
- personal questionnaires for team members to judge on their performance during the mission

For presence evaluation purposes, the previously mentioned questionnaires/ tests were applied subsequently to the conducted experimental trial:

- adapted version of the MEC Spatial Presence Questionnaire

- memory test (spatial awareness test), where the test in which the participants had to recall and identify the objects observed and the path through the mission space.

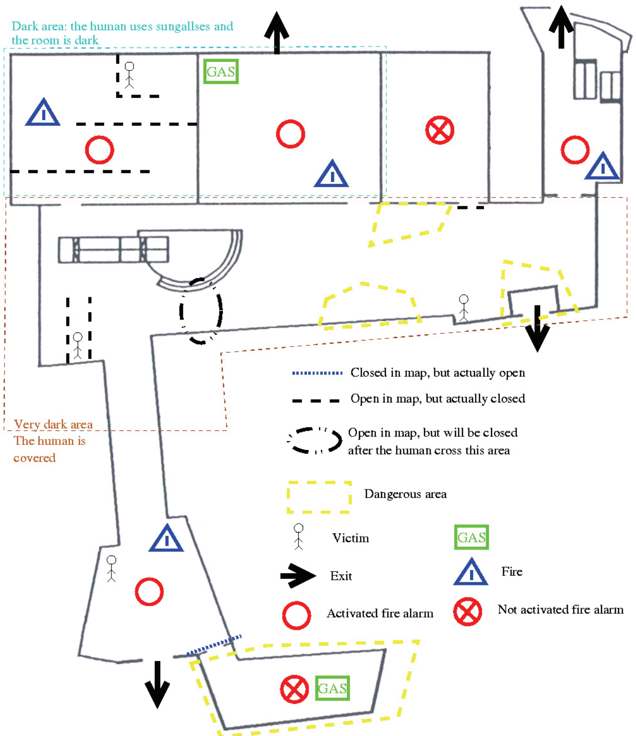

Fig 3: The experimental area showing the different challenges for the test participants: rescue victims, put fires off, move in dark areas, avoid dangerous areas etc.

Evaluation of user feelings was done on the basis of:

- PANAS questionnaires
- other additional questionnaires gave also hints about the feelings

Interaction of the users with the system relied on:

- observations
- conclusions from different questionnaires

For all the different items it was important to observe the remote coordinator as well as the human in place and their interaction with the robots. From these observations important conclusions could be drawn. These interpretations are especially important to explain e.g., differences and relation between teams and/or certain behaviors. Finally, these observations gave hints how to improve the systems in the next.
The following section summarizes the experiments and system performance in a quantitative way.

Results Comparison

The following diagrams depict comparison of behaviors and subsequent evaluations for various teams in the experiment. The evaluation is principally done with respect to certain features of the particular mission as: space coverage, fire allocation, dangerous region avoidance, victims rescue and mission time. While the Fig. 5 shows the performance results without the PeLoTe system

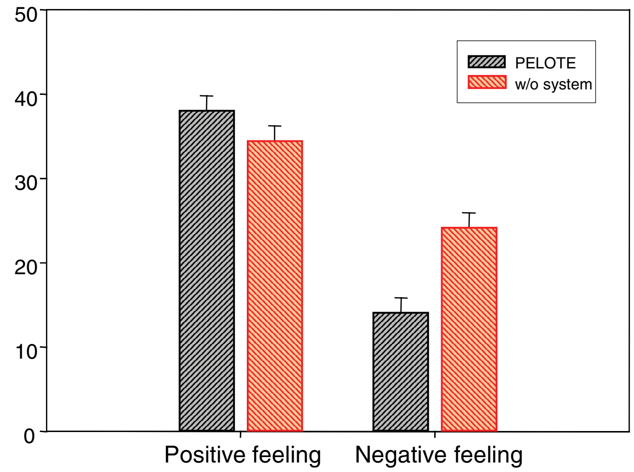

Fig 4. Results of PANAS questionnaire. The both, black and red columns show the comparison of positive and negative feelings for the PeLoTe teams and the teams without the system.

support, the Fig. 6 denotes the performance results of the teams without use of the PeLoTe system. The teams 7, 8, 9, 10 and 12 were built of professional fire-fighters, the other ones only volunteers. The last column always contains average of all the teams with or without the PeLoTe system.
As can be recognized from the these figures, the needed average time for a mission execution was a little bit longer in the case of PeLoTe teams, while the teams without the system completed the mission earlier. The main reason of the difference is seen in the fact, that manual teleoperation of a mobile robot loads the human actors and therefore slows down the mission execution. Nevertheless, an indirect payback for this behavior was identified in much better and detailed exploration dangerous areas as the teams could send the robot inside.
In all other performance issues, the teams using the system performed better. These teams achieved a higher coverage of the area as five percent of the environment was reachable exclusively by the robots, not accessible for the humans. Moreover, the teams using the system were substantially more organized in their mission. This was achieved due to ability to estimate their mission activity plans more into future if having an up-to-date map in the GUI and the systems planning tools available. In principle, their missions were more systematic and people felt less confused or lost under the non-visibility conditions.
In average, the teams with the system put off more fires, found more dangerous areas and rescued more victims. Specifically, each group with the system successfuly rescued all four victims. Rescuing victims was obviously the task, which had the highest priority after not loosing the own life by stepping in dangerous areas.
There was indicated no significant difference in performance between non-firefighters and fire-fighter team

members. Nevertheless, the non fire fighters were mostly technically skilled persons, typically used to work with computers. In opposite to that, the fire fighters had more training experiences to perform in dark areas.
From observation of the tests in place and at the teleoperating center it was obvious that teams with the

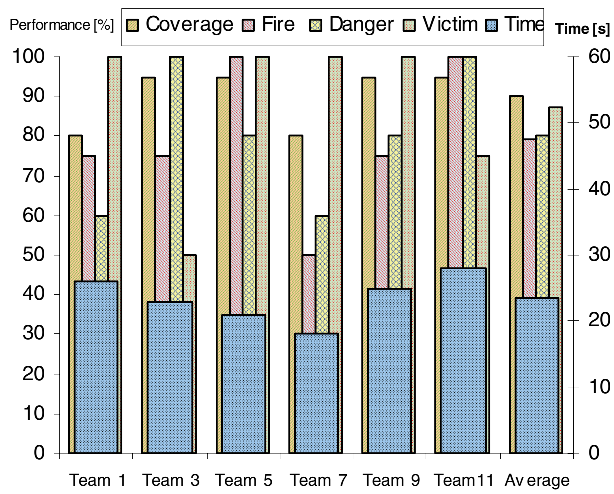

Fig 5. Performance measures (left y-axis) and time of mission execution (right y-axis) of teams **without support** of the PeLoTe system.

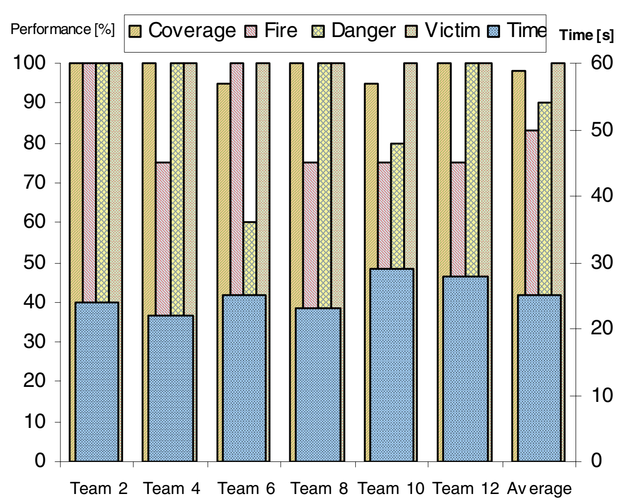

Fig 6. Performance measures (left y-axis) and time of mission execution (right y-axis) of teams **supported** by the PeLoTe system.

system were less stressed and therefore much more organized. The supervisor was able to support the rescuer in mission with more useful information and more efficient guidance. Without the system the supervisor quickly felt helpless and disorganized. The humans in place without the system felt alone and indicated often that they are lost. The communication between both sites was often louder and more stressed than in the PeLoTe use cases. This view could also be verified from the PANAS questionnaire results, which evaluates positive and negative feelings of the test participants. As seen in Fig. 4 both, teams with and without system, indicated the same amount of positive feelings. Nevertheless, the teams with the system mentioned that they had more negative feelings during the test (e.g. worried, nervous, confused).
Finally, a test was carried out in a real fire training house, where fire and smoke were applied under safe conditions (Fig. 7).

Fig. 7. The system test-case experiment in a fire brigade-training facility.

Conclusion

The presented PeLoTe system can be considered as an experimental platform for verification of theoretic foundations required for building of advanced heterogeneous human-robot communities. The humans and robots following the sketched principles are able to effectively share knowledge, data and mutually communicate within these communities in order to fulfill joint tasks. By using these principles the humans acquire capabilities to act as a robot from a certain point of view while as an integral part of a robotic system they can receive, gather and distribute/share different-natured data along all the community.
The PeLoTe system was designed with respect to study of principles for building presence in semi-virtual working environments with hybrid teams of humans and robots. The performed experiments successfully proved that the given system principles bring various advantages in search and rescue mission tasks as well as formulate challenges for next developments in the field of human-robot systems. The system was prototyped according to the design and evaluated by test users with different level of skills in the field of search and rescue missions. Despite of the PeLoTe system is still in phase of the prototyped solution and does not provide full possible user comfort, it was reviewed positively not only by non-professional users but also by the fire fighters in user's questionnaires.

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