# COMMUNICATION AND DATA SHARING IN HUMAN-ROBOT HETEROGENOUS TEAMS

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Abstract: Nowadays, there exists a great interest in development of mobile and teleoperated or even autonomous robots, which could replace humans in dangerous tasks. Information management and system architecture in these can stand for a difficult issue even with a single teleoperated robot. Considering a system of multiple human and robot entities working together in teams at different locations, complexity of information management rapidly grows. This paper sketches an information exchange and handling design in heterogenous human-robot teams, employing teleoperation of semi-autonomous robots and humans in rescue test-cases. The paper addresses analysis of the system design as well as particular tasks specifics connected with this issue. 

Keywords: human-robot interaction, communication, data sharing, system architecture, telerobotics

## 1. INTRODUCTION

Many life-dangerous missions encompass human rescue teams therefore a lot of efforts are dedicated to development of mobile robots tailored for such a task. Proper system design enables replacement of humans by robots, or simply enables assistance to humans in highly dangerous situations. This leads to requirements for concepts of creating heterogenous teams of robots and humans, whereas both kind of these entities work together, at the same level and support each other. Remote-controlled (teleoperated) robots bring combination of human intelligence and manoeuvrability with the precision, robustness and durability of robots. The following stands for a part of the PeLoTe[1] project attempting to join together not only one (teleoperated and/or semi-autonomous) robot, but the whole team of robots assisting to human teams in rescue mission scenario.

These heterogenous teams are globally controlled and coordinated from remote operating center by a human operator.

Basic background for the previous concept is setting up a virtual working environment and being the key issue for sharing knowledge amongst a team of different-natured entities. The virtual working environment provides primarily a map of the real environment to users (e.g. basic structure of the building) with all additional information relevant to the mission. These data (e.g. entity position, relative localization of other entities, its' actual status, actions to be executed - route to follow, environment structural collapses, dangerous areas, etc.) are dynamically modified during mission execution. The execution itself is controlled via remote operating center by teleoperator (or teleoperators), who has access to all the actual information about the mission being under way. In other words, the operating center is responsible for mission coordination. Environment description, its' shape, structure and the above

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mentioned properties are kept in a multi-layered map of the environment using Standard for Rescue Maps (SRM), which has been suggested within the PeLoTe project (PeLoTe Report D2.1, 2003). One of major properties of the multi-layered map is capability to display actual positions of all the mission entities. Thus, the teleoperator knows actual positions of all in the scene, in a case of danger the teleoperator can organize mutual support from other entities, can guide the entity by commands, (e.g. guide the rescue staff how to find an exit from dangerous area). Another option is to set some specific orders not only by voice but also through the Graphic User Interface (GUI). The teleoperator is expected to have available real-time video and audio streams from the scene provided either by a remote robot or just to see the situation in the workplace mediated by human rescuer camera (Suomela, *et. al.*, 2003), (Kantor, 2003). Although the teleoperator can execute and modify control commands, the core planning of the systems' activity (to head to and finally achieve the mission goal) is aided by integrated planner system.

## 2. Virtual Environments & Common Presence

*Virtual environments* (VE) are computer–based (mainly 3D) spaces which can be provided to observers via various media, e.g. by head–mounted displays, monitors, etc. Special cases even take into account text presentations only, as this defines the case in text–based virtual environments. The stimulus field depicting a 3D space and its' coupling with the user of a VE leads to what we call *immersion*. Immersion can be described objectively and should be distinguished from presence. *Presence*, in contrast, is a psychological phenomenon. It can be defined as the *"participant's sense of being there' in the virtual environment"* (Slater, *et. al.*, 1994). (Biocca, 1997) has noted that "*users experiencing presence report having a compelling sense of being in a mediated space other than where their physical body is located...*".

As this project has been focused on building common presence through localization in heterogenous teams, i.e. each entity involved in a rescue mission has information on real working environment through the mediated virtual environment. It was already mentioned that not only human entities are considered, but also robotic entities are involved in the rescue team. Both kinds of entities use the same working VE, but different representation. Robots definitely proceed better with formalized and numeric information, while human easily understands contexts, uncertain data and also visual cognition is much easier, thus friendly Graphical User Interface (GUI) is required by a human (Monferrer and Bonyuet, 2002). In this context it seems to be of highest importance to find a proper solution of information presentation via GUI and flexible data representation (SRM) suitable for both the kinds of entities.

The way of gathering and finally presenting the knowledge about the environment heavily influences the sense of common presence and can bring substantial increase here, thus it should lead to better orientation in the environment, higher safety and better performance of the mission.

## 3. Communication & Data Sharing

Proper design of communication in teams of collaborating entities fulfilling cooperative tasks is indispensable to achieve desired performance of the given task. Communication between two or more parties is called conversation. Conversation is a joint process of sharing information (data, symbols or context) and control. Humans usually use linguistic communications (in spoken or written), context of communication is set up by face to face contact or exchanging some personal identification (e.g. exchanging greeting type of message). Communication between robots is based on computer networking principles. If a virtual circuit is established, it denotes a structure for controlled and mostly error-free information transfers from transmitter to receiver and whose identities are known each other priory. When humans and machines (computers, robots, etc.) communicate their conversation is usually mediated by an interface in a form of "dialog" (Fong, et. al., 2001). Some interfaces (e.g. command line) offer powerful and flexible way of communication with high costs of learning. Nevertheless, humans mainly prefer some kind of GUI. These GUIs tend to be more user friendly (especially for novices) than command line interfaces while these make some assumptions about previous experience. Regardless the form of the user interface, it is a way of mediation a man-machine dialog and information exchange.

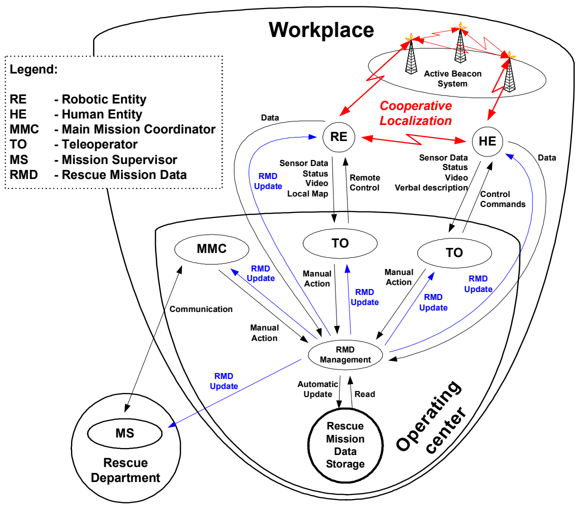


Fig. 1. Design of the communication model

Here we address issues overall architecture and structure of communication and data sharing among modules of the PeLoTe System, see Fig. 1.
Concerning two generic types of entities: human (HE) and robot (RE) we distinguish four following cases for communication setup:

- HE to HE – This communication is done usually by voice. Optional information can be transferred to HE from teleoperating center by transferring data in a graphic form to Graphic User Interface (GUI) of the HE.
- HE to RE – This is the most complicated type of communication. It needs a support of speech recognition tools translating the speech into symbolic information for robots. Solution of automatic speech recognition problem is out of the main scope of this work, thus it is not dealt with here. Another, substitute and even more robust solution is to utilize the HE in teleoperating center as a mediator, that can simply transfer voice to data by retyping commands on keyboard or selecting required commands using pointing devices.
- RE to HE – Robot can use for communication with HE speech synthesis program or transfer the information to HE's GUI. The speech synthesis will desire preliminary setup of the possible communication scenarios (dialogues) for known situations. Design of a general-purpose dialogue capable of handling unexpected cases in communication might be a hard problem.
- RE to RE – The communication between RE entities is given strictly by predefined data and command protocol.

From the above summary three types of information flow (within a group of HEs and REs) are coming out:

*Verbal* – HE`s doesn't need any special tool for understanding the voice commands, while RE`s requires some special tools for this task.

*Data* – RE`s can exchange information by transmitting pure numerical and symbolic data in a given format, while HE`s requires from RE`s data interpreted to visual or verbal form.

*Visual* – Graphical User Interface (GUI) allows to HE`s easy understanding special kind of information like: the map of the environment, actual locations of cooperating entities, identification numbers, actual operating state of each entity, etc.

## 4. Information Exchange among PeLoTe Modules

The basic setup of the PeLoTe system incorporates functional modules enabling the necessary featuring of the whole system. This in minimal setup includes:

- TC – Teleoperating Center which provides oversight of the system performance and current system status as well as enables manual control of particular system components (entities) by human (tele)operator (e.g. a malfunction case).
- Robot(s) representing the instances of autonomous and nonliving entities.
- PAS/PENA – Personal Assistance System / Personal Navigation System, which serves as PeLoTe-to-human in-scene type of interface enabling communication, information sharing and provides localization for the entity.
- CoLo – Cooperative Localization System, besides mutually interlinked PeLoTe components another integrating subsystem takes the advantage of presence of multiple entities and/or other landmarks in the scene at time. Cooperative localizations provide highly reliable information on the entities' position in the scene.

Nevertheless, the core unit of the PeLoTe communication system relies on the PeLoTe Server. The following Fig. 2 presents the domain of the Pelote Server, whereas the shared information is stored in the PeLoTe server and provided by applying Server Services to client applications on request. The TC, robot and PAS modules are considered client applications. As the proposed architecture might fail in its' functionality in the cases of communication interrupts with the server or in cases of requirements for fast responses. These possible malfunctions can be overcome and robustness of the system substantially improved by establishing direct communication between modules (e.g. direct control of robotic entity by human using PAS system or direct drawing from TO GUI to PAS GUI and so on).

The communication issues and data sharing among software modules of the PeLoTe system require a deeper study. The core constrains for the design of communication/data sharing mirror in:

(1) What data should be exchanged without overloading communication links?
(2) How to visualize the data provided to human entity to achieve clear and easy interpretation?

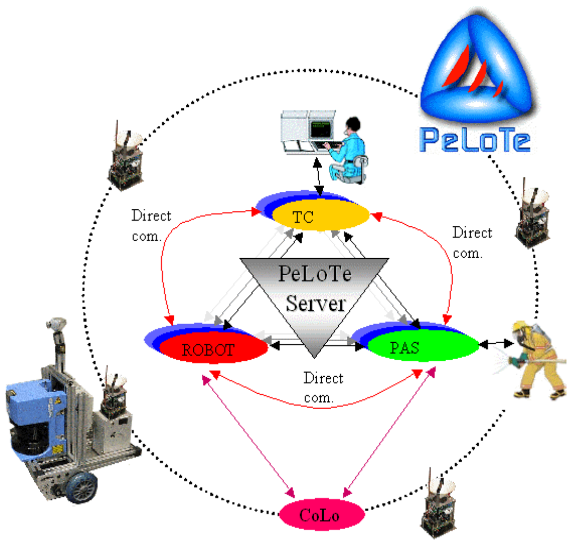


Fig. 2. Interactions among PeLoTe modules

Teleoperating Center software module provides functionalities which have been driven to fulfil the original targeting of the PeLoTe system on rescue applications to maximum robustness, simplicity, capability to bridge communication dropouts or to stay with narrow bandwidth links. Some of the listed processes are running autonomously, while other ones require responses of a human operator, thus user-friendly GUI is a substantial component of the TC.

### *4.1. Teleoperating Center (TC)*

General description of TC and GUI at TC has been designed respecting two major types of interactions. These are TC-to-robot and TC-to-human, mainly making-use of proper GUI for this case. GUI at TC provides to human teleoperator following functionalities, which stand in overview and control of entities involved in the mission:

- Automated path / activity planning for multiple entities towards given goal
- Semi-automated path / activity (re)planning and plan modification
- Global map (environment) keeping at various levels (layers):
  - Visualizes actual positions of all controlled entities
  - Visualizes path (activity) plans for all entities
  - Detailed information about entities (internal status)
  - Correction of entity actual position
  - Video transmission and control panel
  - Audio transmission and control panel

Main interactions of TC with a robot can be wrapped as:

- Human teleoperator can remotely control robot entity
- Human (either teleoperator or in-scene actor) can control robot directly by joystick
- Human can control robot by higher level commands (e.g. go to specified position)

### *4.2. Personal Assistance System (PAS)*

The PAS system consists of two components: (1) the PENA system provides localization services for the human entity as well as for the teleoperator (TO). The other part (2) comprises mainly communication and interfacing services (e.g. in-scene actor GUI, evaluation of entities' status, audio and video streaming and etc.). In general the PAS provides to teleoperator (TO):

- Actual position (given by PENA system)
- Entity status evaluation and info
- Audio communication (bi-directional)
- Video streaming (scene to TO)

Interactions of GUI at PAS with in-scene actor provides to human user (HE) the following functionalities:

- Global and local map of the environment
- Shows actual positions of all entities
- Shows own path plan
- Video from chosen entity
- Possibility to overtake manual control of a selected robot
- Communication with TO (bi-directional audio, TO to HE alphanumeric/symbolic

Standard needed interactions of PAS with any in–scene Robot may incorporate:

- Human TO or in-scene HE can overtake direct robot control by joystick
- Human TO can speak with another humans (e.g. victims) through the robot
- Robot provides to human operator audio and streaming video from the scene
- Robot provides to human operator (either TO or in-scene HE): its' actual position and status information

### *4.3. Robot*

Considering the used robots being fully autonomous this concept does not require any on-board GUI for proper operation. The robots are strictly elements of the systems' communication system with no other direct interaction with humans.

The existing interactions of the robot are to TC (what denotes data from robot available to teleoperator). The other type or interaction exists to in–scene HE which is provided via their local GUI interfaces (in fact via the PAS system). Therefore the major existing interactions are:

- Streaming video images (robot to TC, resp. TO or HE)
- Audio communication (bi-directional)
- Robot localization (robot actual position)
- Robot status information

### *4.4. Cooperative Localization System (CoLo)*

Each of the acting entities uses primarily a stand-alone localization system to determine its' position in the environment. Nevertheless, any localization system suffers from particular limitations (random or cumulative errors, limited reliability, etc.). To improve robustness and precision of the localization process, the advantage of multiple entities and other landmarks has been taken and a Cooperative Localization (CoLo) system has been designed. The main principle used in CoLo is based on radio-controlled ultrasonic beacons serving as landmarks placed at known positions. Ultrasonic beacons are deployed around the workplace satisfying a criterion to reach good area coverage. The beacons are responding to coded radio signal with ultrasonic pulses. The detection of the time-of-flight of the ultrasonic pulses allows calculation of the beacon-to-beacon distances. Since each entity has on-top-mounted beacon, the pose of the entity is identical with this beacon. The localization problem is then solved as a triangulation task. Initial localization step is done by entity itself via calculation of distances to beacons followed by triangulation algorithm for actual position estimation (rough position estimate). The second step of the localization procedure stands in sending the distance measurements to the CoLo module, which maintains actual position of all entities at once, globally optimizes the calculations, and through the server services makes this information available to each single entity.

## 5. SYSTEM DESIGN

To improve the coordination between team members sharing of information became essential. In order to achieve the previous, application of centralized software architecture is one of possible vehicles to achieve proper functionality. The hereunder chosen approach employs a client/server principle.

The centralized software architecture means that all data communication passes through the server (exceptions will be explained later). Hence, the server is able to trace the current status of the system. In such architecture, the server only responds to requests from the clients and it will never send an update to a client without a previous request. Therefore, it is a task of the clients to update data in the server and to ask for new information. Whenever a client needs some periodic update, it should pool the server.

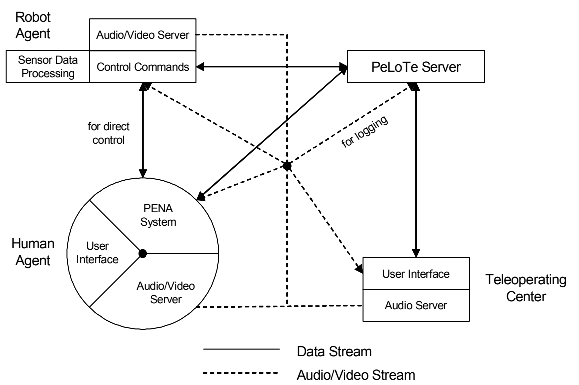


Fig. 3. Client/Server architecture of the PeLoTe system.

The server does not take care about the communication: if it is broken, the concerned clients have to re-establish it. However, the system is robust against such communication failure, since direct communication between clients is also supported.
Exceptions from the centralized architecture: Audio and video data can be requested directly by the clients. These data do not necessarily pass through the server. Furthermore, a human member in place can control and/or teleoperate a robot directly.

The clients can be divided into following categories: user interfaces for the remote coordinators (teleoperating center) and agents for the humans and robots in the team (environment). The teleoperating center contains the user interface of the remote coordinator and is connected to the server. The human team members have their personal navigation system and a similar user interface. The software of the robot team members includes sensor data processing and navigation control. Each client should register itself in the PeLoTe server before it can participate in the system. Since, the server is able to trace and to spread information from it.
Fig. 3 summarizes the system architecture and the flow of information and control between the agents and the server.

### *5.1. PeLoTe Server*

The PeLoTe server is the core of the system and was designed to support following main features: multitasking and multi-user capabilities as well as portability (platform independent). The structure of the server is modular with the communication between the modules being hierarchical. The modules are organized in levels (see Fig. 4).

- Only one module belongs to the first level, the Kernel.
- Every module has to communicate with exactly one module in a level just one step below (exception is the Kernel module).
- No communication is allowed between modules of the same level.
- A module can communicate with any module of a higher level.

This modular hierarchical concept allows extensions of the server in an easy way. Only a module in a lower level has to supply an interface for the communication. The Kernel module is the heart of the server being the central point for data sharing and control of remainder modules. It is responsible for the configuration management (manages the current status and configuration of the entities and environment), persistence (creates and maintains log files and save the configuration of the system) and, authentication and authorization of clients.

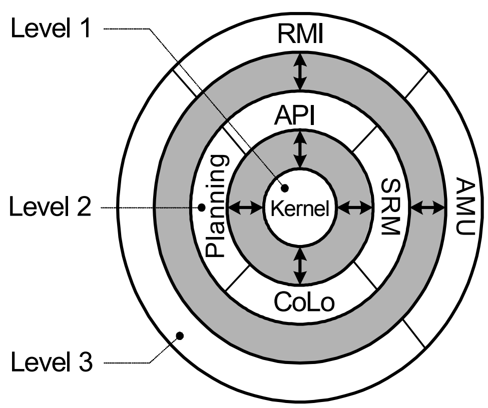


Fig. 4. Modular architecture of the PeLoTe server. The inter-modules communication is a rooted tree with the root being the Kernel module.

The API (Application Programming Interface) module allows third party software to communicate locally with the server. The RMI (Remote Method Invocation) module is an extension to the API that allows remote communication using Java RMI. Thus, a client can call a remote object in the server in an easy and standard way. The Planning module is responsible for the path planning of the multiple entities and the CoLo module performs the cooperative localization tasks. The SRM module deals with the tasks concerning the standard rescue map. The AMU (Automated Map Update) module denotes an extension of the SRM.

## 6. Conclusions

The contribution presents a brief overview of the communication and data-sharing problems encountered when establishing a heterogenous team of living and nonliving entities (humans and autonomous robots), which are operating mostly at the same level and/or being optionally teleoperated. As the sketched problem is subject to running research in the presence and heterogenous robotics fields, the above- mentioned issues as a part of it aim to sketch the analysis and possible approaches to design of the communication infrastructure in such a system.

Major features (and constrains) of the design were identified in limited communication bandwidth, substantially different nature of the information transfer, and possibility of the system backup in a case of malfunction, interfacing different-nature entities as humans and robots, and many others. Therefore, this contribution sketches basic concepts and approaches to communication schema design and concentrates onto the centralized client-server architecture. Although the systems design and implementation is still under development, the first experimental tests and functional principles have been verified. The presented design will serve as a backbone communication system in a rescue-mission type of real experiment with heterogenous team of rescue entities (rescue robots and firemen), which could definitely be considered for a final proof of its' design functionality.

## 7. Acknowledgements

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