Collaborative Teleoperation Design Requirements and Development Issues*

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Abstract

Collaboration is the creation of shared understanding that facilitates augmentative, integrative and debative capabilities, and it is a fundamental part of an effective decision making and problem solving in complex environment. This paper introduces a collaborative teleoperation concept to deal with task complexity, high cost, need to enhance quality and safety, and the distribution of resources in terms of time, space and functionality. The new concept is supported by the use of shared virtual environment enhanced by reality to facilitate interaction, decision making, collaborative control, monitoring, discussion, document sharing, and other activities while interacting and manipulating real facilities jointly or individually. This concept uses the Internet and the Web as platform and location independent environment to enable geographically dispersed teams that may compose of human members, and intelligent and autonomous machines. The dispersed team can perform collaboratively shared and individual tasks at specific single or distributed locations as if they are all were interacting with each other in the same physical place. In addition, this paper introduces the functional and design requirements along with development and research issues for having an efficient collaborative teleoperation.

1 Introduction

One of the fields that is gaining a lot of attractions and momentum in the current era of technical development is teleoperation field as a kind of technology to achieve necessary remote operation, where environment, equipment and devices can be accessible, monitored and controlled over vast distances for different purposes. Remotely operated facilities (equipment, devices, other resources) have been desired for use in various environments and applications to extend human ability to perceive, reason with, and project his intelligent actions in an environment that is too distant, hazards, and high cost. It is important to have such ability in places that are inaccessible to people and places that are dangerous to people to go in, and places where resources are available. It is also vital for certain operations or processes that need special skills, expertise, special equipment that are not available on-site either because it is unique or because it is very expensive along with time and space constraint. Application area of teleoperated systems may include radiation sites, nuclear and toxic waste cleanup, underwater that involve inspection, exploration, maintenance, etc. variety of space applications, medical diagnoses, manufacturing and micro-manipulation, remote surveillance, remote diagnosis and maintenance of machinery, resource industries, military applications, construction, etc. [3,5-15,20,24,28]. The common characteristic of these different application areas is that most of them are highly variable and involve operating in unstructured, partially structured, unknown or dynamic work domains. These are defined as classes of environments in which system surroundings at the remote site cannot be known and modeled in advance with sufficient precision. These tasks require a highly flexible and intelligent control mechanism through well-balanced and coordinated human-machine interaction where human operator capabilities are extended into the scene using visual, haptic and other sensory devices [3-6,10,13]. An ideal system to perform these tasks at remote sites would be one that has the same capability as a human. To recognize what task has to be performed and what steps should be taken to carry out the task, and which has the flexibility to perform physical manipulations like human. However most systems that perform remote operations/manipulations require human intelligence where humans are more flexible and more capable of interacting meaningfully with the environments especially if it is unstructured or dynamic. In general, current teleoperation implies continuous perceptive and cognitive of human operator involvement in the control of remotely teleoperated system to decide how task should be carried out.

The quality of communication technology and infrastructures of networking is forcing a rethinking of the physical structures and spaces needed for living, working and learning. There will be less need to be in any particular physical location. Collaborative tools, virtual reality tools, dynamically linked tools, and advances in languages also mean profound change as the Internet becomes a robust environment. Due to its low cost, flexibility, worldwide availability along with its media rich interface that can

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make teleoperated resources accessible to a broad range of users regardless of geographic location and the platforms they are using. The Internet provides substantially increased effectiveness by making wide range of tasks and applications possible. These powerful channels for data transfer and multimedia interaction are ways of extending our capabilities to communicate and work across barriers of distance and time, restricted access, scheduling difficulties, and limit of one personal expertise, exploring and contributing to wide range and new kind of applications. It provides remote access to experts at specific field/topic/problem solving, inter-linked resources, distributed investigations and virtual communities. Also, mobility and portability create and support new styles of collaborative work.

2 Motivations

Most of the developed and currently in use teleoperation systems had focused on having a single operator at local site controls a single process, such a process may be, a device, robot, machine, etc. at a remote site. Several researchers have considered the problem of having one user controlling multiple robot [31]. Most telerooperated systems in use today are controlled entirely manual, requiring constant attention of human operator. With manual control, operator's sensorimotor skills and his ability to maintain situational awareness limit teleoperation and contribute to errors. Cognitive fatigue due to the nature of many tasks and available technology and techniques all results in a variety of operator errors that contribute to degrade his performance [1, 28, 30]. The number, type and resolutions of sensors available at the remote site also directly influence the operator's ability to perceive and create an illusion of physical presence at the remote environment and to identify possible hazards. Increasing sensory information and involving the operator continuously with low level details of a task and continuous tracking resulting in extremely high workload that leads directly to fatigue, stress and inability to perform other tasks. Time delay in communication between local and remote site can occur due to a large distance between them, or to a low speed of data transmission, or to computer processing at different stages, or to all of the above. In any events, time delay beyond a couple of seconds affect operator's patience enormously and make direct teleoperation impractical or impossible [28]. Also, operator performance will be degraded and difficulties will be enormous when the remote mechanisms tend to have a complex structure with large degrees of freedom to be controlled and the task environment is unstructured. In general, it would be practically impossible for one person to deal with all type of tasks alone.

The complexity of many environments or missions may require a mixture of capabilities that is impossible to find it in one person or one machine. Also, there are tasks that compose large-scale complex system, or distributed independent units that collectively participate in the overall functionality of the system. Additionally, time constraints may require the use of team based concept to work simultaneously on different aspect of the mission in order to accomplish the objectives successfully within the required time frame. Having dispersed collaborative team working together or interacting as individuals is becoming attractive with increased interest due to its promising results in industrial, commercial and scientific applications. These systems are highly desirable in realizing advanced teleoperation system that aims to achieve high level tasks. Collaborative teleoperation systems can accomplish tasks that no single operator/equipment teleoperation system no matter how capable, is spatially limited, and associated with complexity and variety of task requirements.

There is growing need for humans to perform complex and large-scale remote operations to achieve remote intelligent actions at a distance. Also, there is a need to elevate teleoperation to a new level of task performance capabilities by adapting new paradigm that improve performance, functionality, operability and usability of remotely operated facilities and integrating distributed resources through the use of information and communication technologies. Resources may include but not limited, machines, robots, information system, research facilities, manufacturing lines, space facilities, autonomous systems, human, etc. In additions, the issues of quality and safety, high cost, task complexity, environment conditions, the uniqueness of research and experimental facilities, the availability and distribution of other resources and human experts demands for new approach. Such demand is powering and supporting the direction to have collaborative teleoperation system. Such system aims to fulfil the need by having effective problem solving and facilitating augmentative, integrative and debative capabilities for geographically dispersed team while sharing and coordinating worldwide distributed resources in terms of workspaces, facilities and expertise to achieve their shared goals.

This paper presents collaborative teleoperation concept that uses the Internet and supported by the use of shared virtual environment enhanced by reality to facilitate awareness, interaction and job sharing. This concept aims to enable geographically dispersed teams that may compose of human and, intelligent and autonomous systems, that can be co-located or distributed in different physical locations, to work individually or collaboratively, synchronously or asynchronously to achieve an assigned task.

3 Collaborative Teleoperation as New Concept

In collaborative environments, researchers/users/operators along with autonomous machines multiply their output by having synergistic cooperation while reducing costs through improved facilities and capabilities sharing and save in time to perform task and to achieve common goals. Also, such systems improve operational efficiency and quality by distributing knowledge functions such as information processing, performing more complex tasks and enabling parallel performance of operations. Communication and collaboration can take place over varying dimensions of time, space and capabilities. Capabilities represented by intelligent behaviors can be expressed by entities, such as human with types of functions to be performed at specific place/location. Internet based teleoperation with tools supporting human communication and interaction with real world, will inevitably lead to many useful applications and can make teleoperated resources accessible to a broad range of users regardless of geographic location. Objectives to be achieved through a shared understanding and the creation of new prospect of performance around a shared goal that represent the exponential product of the collective interactions among the collaborative team members while accessing a shared space/task environment. Such understanding and outcome can not be achieved by the sum of individual capabilities of team members.

In the context of the presented work, the term "collaborative teleoperation" is used to describe,

1. many to one (group of users to one process whether it is simple or complex),
2. many to many (many users to many processes whether they are distributed or integrated in terms time and space), and
3. one to many (a team member that can access more that one machine/device within a single task environment or within multiple task environment).

control architecture. The user group may consist of human and autonomous machines/systems and some of them can be collocated physically within the same task environment depending on the application need.

The new concept provides real time access to remote facilities and enables geographically dispersed team, interact among themselves through shared virtual environment representing task environment (Fig.1). It enables team members to collaborate on a joint work by remotely accessing equipment, manipulating data, manipulating objects, remote diagnostics and analyses, and simultaneously control, monitor, view and discuss results as if they are all were interacting with each other in the same place. The shared facilities may include integrated processes such as, nuclear power plant (decontamination and decommissioning), space exploration, manufacturing, military operations and command systems, medical surgery, rescue operations, fire-fighting, intervention operations, joint research facilities, educational facilities, software systems, etc. Also, it may include very expensive equipment and unique facilities (e.g. large electron microscope, synchrotron light sources, various types of particle accelerator, etc.).

The basic issue of collaborative teleoperation systems is the structure of the operational team that is making it. A collaborative team should consist of at least two members with decision-making capabilities to enable negotiation, coordination and cooperation. Collaborating team members can work together synchronously or asynchronously and can be physically co-located or distributed. Team members can vary in their degree of interdependence, i.e., to have dynamic cooperative relation among them. Each member of the team should have the capability to implement an assigned task individually and cooperatively. The control of single or compound facilities at one site can be shared between teams members located at different location. It is possible to have some team members collocated and working with the facilities of the task environment as required and cooperating with others members that are physically outside the task environment. Collaborative teleoperated team may include one or more intelligent and autonomous systems such as an autonomous mobile robot, but not limited to, as a member in the team. Intelligent and autonomous systems as team members should be enabled to interact and communicate with human members and among themselves. They can collaborate in achieving specific task while they may monitor and control specific system or acting as a local command and monitoring base for a group of machines or processes that are part of the task environment but not members of the collaborative team. Three levels of interactions are considered possible among distributed operational team members. These levels of interactions are human to human, human to machine, and machine to machine interactions. Task environment can be distributed at different physical location that are integrated through the network and the results between them is piped according to the need, and it can be one common physical location for all activities of the team. Depending on the type of task and mission, the facilities to be controlled at remote sites are considered slaves if they are not autonomous even if they have some intelligent capabilities under supervisory control scheme.

Human member in a team should be integrated as an inside part of the teleoperated system architecture with his powerful creativity, cognition, perceptual and problem solving capabilities, i.e., having the operator augmented into the system. This leads to have quality systems that are capable to respond, interact flexibly with dynamic environments and develop new behaviors as required while insulating human from the hazards at the work environment. Such structure support different level of control with seamless transfer between them. A collaborative control approach to be employed that defines a role for each team member and accordingly assigns authority for decision-making capability within the overall control structure. Cooperative relations among team members can be dynamic. Communication, negotiation, and coordination toward achieving intelligent actions at a distance should inspire cooperation. When there is a dispute among participating members of team at specific control session in selecting suitable action among a group of actions, a voting mechanism can be applied to optimize the selection process of the suitable action. A team member that holds higher role at that instant can judge the final result. The leader of a team or a group should do task description. Also, an intelligent mediation is needed to monitor a sequence of autonomous tasks,, and decide between continuing their execution or requesting human intervention for new command and objectives. Members in the team should not apply their decision-making authority according to their role before engaging in a constructive dialogue with other team members. Such decision-making authority can be used to resolve deadlock that is blocking the whole operation of the system and to resolve conflict that is affecting the safety and the integrity of the remote facilities and task environment. Access control and security are critical issues that need to be considered for any remotely controlled and operated facilities.

The presented concept is associated with the creation of multi later virtual environments to support awareness and enable multiple simultaneous users interacting and cooperating within a task environment through advance and modular user interface supported by heterogeneous integrated human media technologies. Each layer of the virtual environment represents a task environment in which it tracks and displays team members once they logs-in to the task environment. Also, it facilitates flexible level of communication and interaction through various sensing capabilities and the integration of human media technologies to facilitate

4 Functional and Design Requirements

The focus on the need for methods and techniques, which maximize bandwidth usage, optimize human machine interaction and control architecture, maximize information transfer through rich and quality information feedback, and minimize cognition load, facilitating the understanding of the remote environment and improving situation awareness.

1. The need to have a generic architecture. It should be open system architecture to facilities the addition of new features and tools, and it should be shared by different applications with each domain or between classes of domains. The application architecture should show some degree of dynamic configurability, in order to accept different system configurations that can easily adapted and optimized for a particular system environment without requiring major rework. Such architecture should make the integration of real facilities easy like plug-in modules with the application domain.

2. Easy to use, operate, maintain, and capable Web based collaborated environment that is consistent over different platform and operating systems to enable efficient, robust and reliable teleoperation in unknown, unstructured and dynamic environment. Standard and interoperability are very important issues and pose quite a challenge to all applications in this field.

3. Intuitive, coherent and integrated user interfaces represent a trade off between ease of use and the capacity for complex task. It should maximize quality information transfer. It should be designed to maximize the usability of wide range of users. User interface should allow the operator to have complete control over the system. The user interface should represent the system in an abstracted hierarchy that details the structure of the system at different level of abstraction. The need to facilitate team members perception through proper information transfer and a better situational awareness, and to have variety of command generation tools that enable and speed up efficient and accurate motion command generation.

4. It should support flexible reconfiguration and wide range of environments and applications by defining a comprehensive set of reusable user interface components that support both mobile and static reality applications. Allowing participant of collaborative team to communicate over multi modal graphical, textual, video and audio media, etc. new physical hypermedia user interface that guides users through a presentation, while giving them the freedom to follow their own trails through the operation. Visual communication capabilities will effectively enable team members communicate spatial experiences with proper resolution and depth over distances

5. The system should allow each team member to access, interact and control a single or multiple remote operational sites while collaborating with other operators in achieving a common goal.

6. The design of a distributed system supporting real time collaboration should handle human factors. The need for methods to understand and model human capabilities, limitations, performance, and reliability, as part of the overall engineering and design optimization of complex systems

7. The collaborated environment should support access to remote equipment/device/process/human with the ability to control, monitor, share, manipulate data and objects, diagnosis and analysis, analyze results, data setting, etc. Location independent for the team members to access remotely distributed resources in terms of physical facilities such as, devices, equipment, robots, and processes or in terms of expertise. The system should support effective and reliable interaction with the remote environment. Interactivity refers to how well the system can be steered either for static or dynamic situations.

8. Scalability. The environment should be scalable toward the number of devices/equipment, number of sites, number of users that are participating in a collaborated task, total number of users in a single team, etc. Also, scalability reflect the ability not only to function well in the re-scaled situation, but to actually take full advantage of the new environment/situation
9. To have multi layer virtual environment, each reflects individual and separated task environment. The virtual environment represents the environmental model of a task without the necessity to have it in accurate dimensions. Each user will be immersed in the virtual environment that he is targeting once he logged in. A shape of a user (person/Autonomous system) that identify him to be displayed. All users accessing the same task environment can recognize each other through the virtual environment. It will facilitate and enhance awareness between team members and interaction through seamless communication capabilities while working jointly or collaboratively with the real processes.
10. Human-factors issues, including human performance efficiency in virtual worlds which is likely influenced by task characteristics, user characteristics, human sensory and motor physiology, multi-modal interaction, and the potential need for new design metaphors. If virtual systems are to be effective and well received by their users, considerable human-factors research needs to be accomplished.
11. Security concerns along with user authentication, privacy, confidentiality, access control, accountability and integrity of data communication.
12. Events tracking and logging capabilities. This will be helpful to track illegal access, faults, and malfunction of any parts of the system. Also, it will be useful to evaluate system performance, system management, enhance problem solving through learned lesson from previous problems, and training purposes for new staff
13. Resource management, and locating resources dynamically. In a collaborative environment, different team members may require to access a single resource, such as, a device at the same instance. To solve such problem and any other types of possible deadlocks, a resource manager will take this responsibility by providing a mechanism for finding who is in control of each device and for transferring the control to other team member who has requested a device. Also, if more than one member is willing to access the same device, there is a functional need to manage and coordinate their actions.
14. The need for safeguard functions and, conflict and deadlock solving mechanism along with action coordination capabilities to enhance safety and performance. The system should have the ability to recognize any deadlock or danger or when an unknown situation arises that may constitute emergency or danger. It should inform human operator about it and enable him to engage in a direct control seamlessly to overcome that situation. Interactive exception handling aid will be necessary to help the remote site to ask for assistance from the human operator, or to enable human operator to check or interfere with the ongoing remote site functions at its detail level.
15. The need to have the capability to describe, formulate, decompose, and allocate task and problems to be solved, and synthesize results among team members
16. Each user should have the capability to monitor different view of the task environment through various sensory information and provides appropriate motion commands accordingly. Monitoring and motions commands should be coordinated and synchronized with other users when there is a shared task.

5 Development and Research Issues

Regardless of the domain of application, team based collaborative teleoperation concept gives raises to a number of critical and fundamental issues according to different situations while processing tasks at a single or distributed remote environments. Such issues affect the performance and need to be addressed properly.

5.1 Collaborative Control

Communication, negotiation, and coordination toward achieving intelligent actions at a distance should inspire cooperation. Each member of a team should be enabled to act and to achieve its own goal in cooperation with other members thereby achieving the goal of the entire system. When there is a dispute among participating members of a team regarding specific shared control session in selecting suitable action among a group of actions, a voting mechanism can be applied to optimize action selection process. Intelligent mediation is necessary to enhance flexibility and performance while assuring safety. To optimize cooperation among distributed team members, three levels of interactions are considered possible, human to human, human to machine, and machine to machine interactions. In this aspect, performing a task collaboratively needs mutual sharing of information and coordination that enables to produce an efficient solution. In such system, the main issue is to study the distribution and the collaborative resolution of a given task, and to study how to integrate various level of autonomy.

With respect to collaborative control, various levels of control are considered possible with some focus on shared control. But, shared control concept in the view of this paper specify the following levels of control,

1. A team member is responsible for controlling some variables or subtasks while the remote system/device simultaneously control others. The remote system is part of the facilities and not a team member,
2. Two or more team members are accessing and controlling different remote devices in the same task environment and work together to realize a common task.
3. Two or more team members are accessing the same remote device while controlling different or common parameters of the device during the execution of a common task.

The motion commands from multiple simultaneous members need to be coordinated/aggregated as necessary into the required stream of motion commands related to the common task. Motion Commands can be generated through interaction in a graphical environment to enable proper action selection.

5.2 Autonomy and Real Time Interaction

A higher level of autonomy at the facilities part of task environment would lessen the impact of operator by reducing the communication between the local and the remote site and the need for intelligent mediation, and allow for decentralized control. The operator can thus provide higher levels of control to the remote system. The problem is how to add intelligence so as to move the teleoperated system forward on this spectrum. Teleoperation should be more robust and better able to accommodate varying level of autonomy (e.g. adjustable autonomy) and interaction. Intelligent mediation to monitor a sequence of autonomous tasks, and decide between continuing autonomous tasks execution or requesting human intervention for new command and objectives. How to handle human-machine interaction? How to design the user interface? How to handle dynamic control and data flow? Are important questions that need to be addressed during the design phase. There is a need to engage humans and machines in constructive dialogue, not merely simple interaction, to exchange ideas and to resolve differences. Dialog leads to coordinate and negotiate a better solution, optimize action selection, and find ways to cooperate in implementing it.

5.3 Awareness

In real world, shared physical workspaces and the resources they contain act as a stage and offer advantages for rich person to person interaction. It is not only the information available within such space is important, but also the ways that interaction over the information is facilitated. Understanding workspace awareness is determining what awareness is and how it works. Awareness involves not only states of knowledge but also dynamic processes of perception and action. The aim of the awareness is to help collaborative team members to manage and optimize their interaction. It will give them enough clues about each other, their task engagement and the real time progress of any shared task. This information is useful for many activities of collaboration, such as, synchronizing and coordinating actions, managing coupling, negotiating about task, anticipating other's actions, and finding opportunities to assist on another. If these attributes can be brought to a dispersed team, the quality and productivity of distributed collaboration can be greatly improved. Work-space awareness needs to be maintained through a rich variety of sensory information. When awareness is difficult to maintain, collaboration becomes more difficult too.

5.4 Collaborative Team and Autonomous Systems

Each team member within a collaborative teleoperation system is an intelligent entity that has it own existence and act rationally and intentionally with respect to its own roles and goals and the current state of its knowledge. When defining group architecture, whether the decision making system is centralized, hierarchical or distributed. Team based approach is advantageous with flexibility, efficiency, multi-functionality. A distributed autonomy oriented multi-user system has defective aspects, such as, optimality, coherency, synchronization, etc. that need to be addressed properly. Autonomous and decentralized systems have two essential and contradictory characteristics, autonomy and cooperation. It is important to reconcile these two features for the benefit of collaborative work. Also, it is important to understand the impact of Interaction among team members and how it affects the behavior of the team as a group. Issues such as heterogeneity, communication, coordination, resource and deadlock solving, control architecture, autonomy, group intelligence, knowledge representation, and real world implementation are among the main issues that need to be addressed.

5.5 Virtual environment and collaboration

Merging virtuality and reality in unique and innovative ways will take new meanings and its implication is extensive. Users of the system are immersing themselves into shared multi layers virtual environments, that create illusion of physical presence at the remote site supported by sensory devices that can develop a better understanding and appreciation of reality. This will extend distributed team members capabilities at different locations to inhabit and shape a common synthetic environment. Team members can move between the layers of the virtual environment seamlessly according to the task need. The appearance and capabilities of graphically represented task environment as space, equipment and people are displayed and tracked when they are logged in to the system. Shared synthetic environments are a representational container that can empower a broad range of uses.

5.6 Integrated User Interface

An important factor for the acceptance of remote services and cooperative applications is the presentation of the user interface. The design of a good user interfaces for teleoperators is a demanding task because of the requirement for real-time reproduction of motions, actions, monitoring, analysis, etc. Many interfaces overwhelm the user with multiple displays while simultaneously demanding high levels of cognition and motor skill. The user interface should represent the system in an abstracted hierarchy that details the structure of the system at different level of abstraction. The lowest level of any such hierarchy involves the physical characteristics of the system and the top level is the system goals. In between there will be various levels to deal with state of the sensors and actuators, the behaviors that use these states, and the relation between behaviors. The operator interface should support both high and low level commands, to allow the operator maximum flexibility in sending efficient command sequences.

5.7 Human Factors

Human cognition, collaboration, and performance depend on context. How a problem is represented influences the cognitive work needed to solve that problem. There is a continuous need to develop and evaluate human-computer interaction designs, methods and technology for networked systems that support real-time control, monitoring and anomaly detection, diagnosis, failure impact assessment and malfunction procedure evaluation. Human factors usually have impacts on how user interface structures user's task and on the design of the user interface itself. Human factors considerations should be seen as an important accompanying discipline to autonomous functions, rather than alternative. This leads to have a balance between considerations on human factors and the types of functionality that will be embodied in the remote process

5.8 Interactivity and Time delay

The primary constraint that should be considered is the communication link. In particular, bandwidth directly restricts the quantity and quality of information available to the operator for decision making. Time delay affects the reliability of remote operation. Beyond a certain delay, manual control of a teleoperated system becomes highly error prone or impractical. Since the developed system is Internet based, data transmission through the Internet is often irregular and unreliable. Consequently, the system must be designed to handle potentially unbounded delay or loss of data. In addition, the available network bandwidth varies greatly, depending on network hardware and network load. Thus, the amount and type of information that can be exchanged between a remote system and a user is severely limited. Communication time delay and data loss is the most serious problems facing real time application over the Internet. These problems that affect usability, performance and safety need to be addressed properly and solutions need to be introduced to overcome it. Different ways to minimize the serious impact of the time delay on real time system should be investigated. Also, there is a need to design new approaches that minimize bandwidth usage, provide sensor fusion capability, optimize human-computer interaction, and use of predicted display efficiently with augmented reality.

5.9 Integration of Human Media Technologies

In current multimedia systems, users have to carefully choose appropriate communication media and expressions which computers can accept, and to adjust their communication manner to suit computer and network systems requirements. There is a need to have a counter approach in designing new multimedia information space on information networks that enable human to access information infrastructure in a natural manner and accelerate intuitive communication between human and information space, and also amongst human beings through information space. It expands the communication bandwidth of human beings, and may achieve great progress in usability of information space by representing the various kinds of information in a familiar style. Human-centered approach is the most essential issue in order to make greater use of information networks in the future. Human media technology enables us to make effective communications through multimedia information space.

5.10 Security

The goal of any security design is to provide maximum security with minimum impact on legitimate users accessing the resources. Access to remote instrumentation and resources via open networks, whether for monitoring, control of experiments, or collection and manipulation of data, requires that authentication and access control mechanisms be in place in order to provide safeguards against unauthorized access, and to assure confidentiality, data integrity, non-repudiation, etc. Event tracking and logging will be also essential to enhance security performance. The need to focus on access control among a team members and between interactive teams. This will rise the issue to develop a hybrid security strategy when team members or teams belong to different organizations.

6 Conclusions

New collaborative teleoperation concept has been presented in this paper. The new concept allows solving many of the problems associated with applications that are distributed in time, space and functionality and need to extend human and autonomous system intelligent actions to different remote locations. Also, it arises many research and development issues that need to be addressed and studied and concluded with efficient solutions. Collaborative teleoperation can provide an effective framework for collaborative teams to work efficiently, jointly solve problems, sharing task implementation through collaborative control, and to create robust teleoperation systems.

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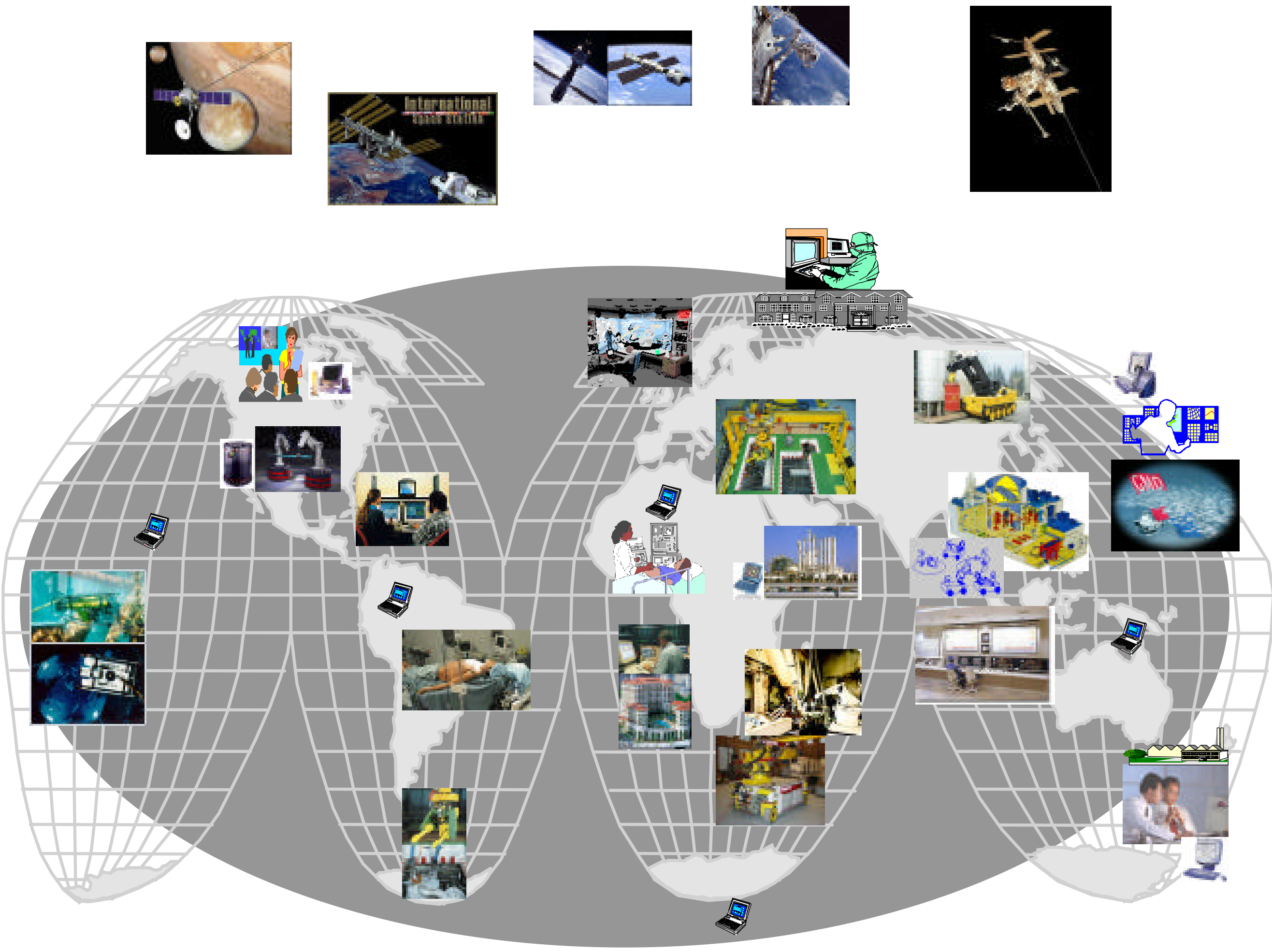

Fig. 1 Illustrates the distribution of resources and Internet infrastructure
to support collaborative teleopeation