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GENERAL ERGONOMIC CONSIDERATIONS OF DESIGN OF A TELEROBOTIC SYSTEM

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Abstract. *Designing the man - telerobot system requires a multidisciplinary approach. Ergonomics has an important role in almost all stages of the designing of this complex system. One of its main role consists in optimization of sensory, mental and physical workload of operators.One of the first steps in designing of a system that contains a teleoperator consists in determining the optimal distribution of functions between operator and telerobot. This distribution of functions is dependent on the types of interactions between mentioned entities, which are considered in this paper. Interface components also need to be designed in accordance with the ergonomic principles. Conclusion of the paper is that depending on the specific task that needs to be done depends the design solution of the telerobotic system.*

Keywords: ergonomics, teleoperators, human - telerobot interaction, interface, teleoperation

INTRODUCTION

Teleoperation has a long tradition in mobile robotics (Steinfeld). Teleoperation is a term that refers to the remote control of technical devices. The origin of teleoperation is connected with the invention of the radio technology and the patent (1898) of Nikola Tesla, who developed the first teleoperated device, a radio-controlled boat(Viinikainen). However, this term is usualy used for mobile and robotic applications where the operator is at certain distance from the remote manipulator. In teleoperation, anoperator interacts with the world via a telerobot (Stanton et al.).The first robotic teleoperation tasks, such as manipulating nuclear material, can be classified as remote or remote operation.

BILATERAL TELEOPERATION SYSTEM

When a teleoperation system possesses force feedback option in relation to the operator, it is called a bilateral teleoperation system. The bilateral teleoperation has rapidly developed for the purpose of the remote handling of radioactive materials. The first bilateral teleoperation system was based on the mechanical manipulation. One of the first contemporary bilateral teleoperation systemwas built in 1940s in the United States (Viinikainen).Byusing this bilateral teleoperation system, with the radioactive materials wasmanipulated safely. Thissystem consisted of the mechanical manipulator, wichwas controlled by an operator behind a lead glass. The master control device that was used by the operator was identical to the manipulator (slave) on the other side of the glass. Movements of the master control device were transferred to the slave manipulator by a mechanical linkage. Through the mechanical linkage, the operator also could feel the forces that acted on the slave manipulator.

The term "remote manipulation" emphasizes that the controlled system is at some distance from the operator. Today, in most cases, there is no direct visual contact with the controlled system. The visual feedback is usually made by combination of a camera and a display. When the connection between an operator and a manipulator is mechanical, the term "remote manipulation" means mechanical manipulation. In the mechanical manipulation, the commands are transmitted mechanically or hydraulically (pneumatically) to the execution part of a teleoperator. In that case,visual feedback is usually direct, but can be also via a monitor. Commands also can be sent electrically by wire or radio (wireless). Electrical actuation and software based control systems make possible that the teleoperation distances be significantly greater than the distances that are allowed by mechanical linkages.

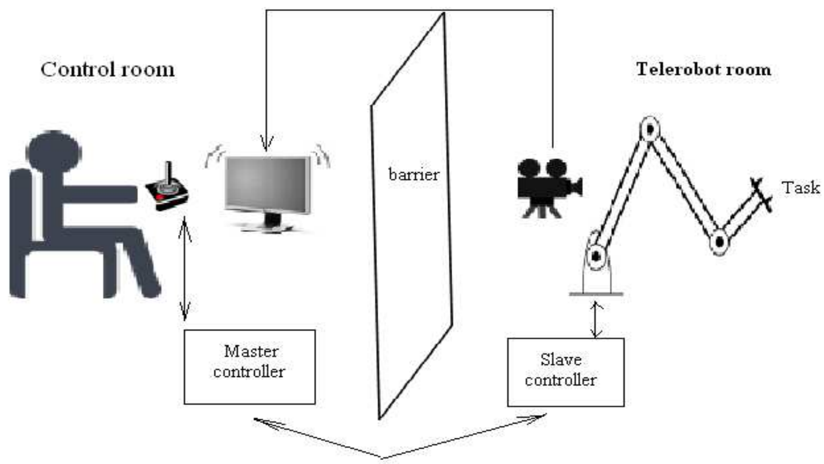

Figure 1. Example of a modern control system with a teleoperator.

The main drawbacks of the electrically based teleoperation systems are the cost caused by the overall complexity of the systems, as well as the technical challenges caused by time delays in the communication links. Basic components of the modern teleoperation system are presented in Figure 1.

Stability and transparency are the two major challenges of the modern bilateral teleoperation systems. The term "transparency" refers to the degree of telepresence in a teleoperation system (telepresence means that the information about the remote environment is represented to the operator in a natural manner). In a system with the perfect transparency, the operator of the system should feel as he performs the task directly, without telerobots between him and the task. Perfect transparency is of course almost impossible to achieve, but a good degree of telepresence guarantees the feasibility of the manipulation task. The stability and transparency requirements of the bilateral teleoperation systems often become troublesome with the fact that stability and transparency demands tend to have contradicting effects to the systems. Often, an improvement of transparency makes the system more unstable.Also,increasing the stability impairs the level of transparency (Viinikainen).

TYPES OF HUMAN - TELEROBOT INTERACTION

Interaction of one man and a single telerobot is very common. However, this is not an unique example of the interaction, which can be found in the theory and practice (Yanco and Drury). Practically, there are many types of interactions between a human and a telerobot. In the Figure 2, various possibilities of interaction between mentioned entities are represented. Arrows indicate commands flow between the humans and teleoperators. A maximum of two humans and two teleoperators are shown in each figure (A-H), but the same concepts is valid for "many" as for "two".

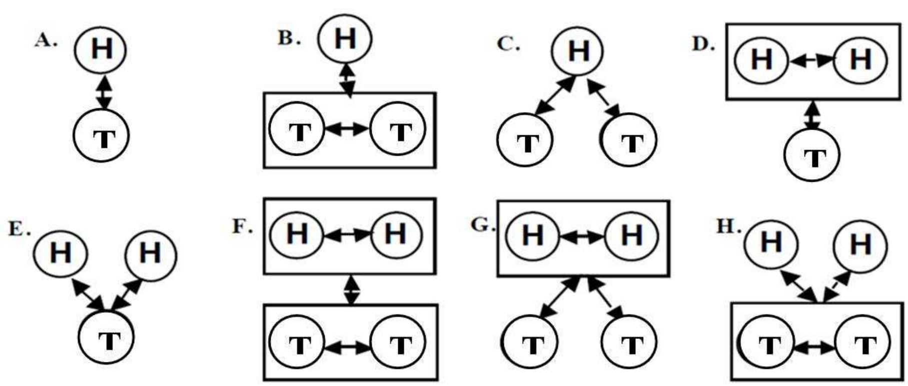

Figure 2. Types of interaction in the human - telerobot system (based on Yanco and Drury)

Several questions appear during a consideration of the interactions, which are represented in Figure 2. For example, if there are multiple human operators (represented with H in the figure), are these humans agreeing on commands before providing the teleoperator - telerobot(s) direction, or are they independently issuing commands that teleoperator(s) (represented with T in the figure) need to analyze and give the priority? Also, if there are multiple teleoperators, are they each receiving and acting on commands independently, or are all teleoperators receiving all commands and coordinating among themselves to determine which teleoperator(s) should respond to which commands?

In the most simple case of bilateral teleoperation that is shown in Figure 2A, one human gives commands to one teleoperator, which sends back the sensor information to the human. An example of this case is one person who directs a bomb-disposal teleoperator. In this case, and all others that will be mentioned below, the humans need the appropriate level of awareness about the interaction, in order of understanding the locations of the entities, distances between objects, activities, as well as surroundings of the teleoperators. Similarly, in some cases, the teleoperators need certain kind of awareness, so to have the knowledge (on the machine level) about the humans' commands and to have the possibility to act in order of modifyingthe initiated action, to eliminate possible human error. The humans and teleoperatorsalso may need othertypes of interaction awareness, depending upon the type ofinterconnection that may apply.

Figures 2B and 2C show the case where one human controls two teleoperators. In Figure 2B, the human is giving a command to a group of teleoperators, which coordinate among themselves to determine which teleoperator should performswhich part of the command. An example of this case is when anoperator gives a command to a group of teleoperators, to find human victims in a partially destroyed building.Figure 2C shows one person directing two teleoperators, which work independently. This case could happen in emergency services in the future, where one operator might want to direct multiple teleoperators to different parts of a hazardous waste spill, to receive as much information about the environment as quickly as possible.

In Figures 2D and 2E multiple people are controlling one teleoperator. In Figure 2D, the people coordinate among themselves to issue one command to the teleoperator. An example of this situation is when a pilot and anoperator for controlling of the sensors data coordinate to direct an unmanned aerial vehicle to a convenient position for viewing enemy targets. Besides the human - machine awareness, these people need the human-human awareness, so to be in possibility to complete the task efficiently. In Figure 2E, the humans act independently, and send different commands to the same teleoperator. The teleoperator should make decisions aboutpriority of the commands before carrying them out. A possible example of this type of teleoperator is a waiter telerobot, which is directed by one person to bring a drink to one table, while another person requests that the drink bedelivered to another table. The teleoperator must make a decision which order should be delivered first.

Figures 2F-2H represent the cases where multiple humans manage with the multiple teleoperators. Figure 2F illustrates a team of operators directing a group of teleoperators. The humans make an agreement about one command.The teleoperators then process that command,and they make a decision what teleoperator will carry out what part of the command, or the whole command. For example, the teleoperators can decide that the teleoperator that is nearest to the target will be executor of the command.

In Figure 2G, a team of operators issues different commands to different individual telerobots. The operators agree which instruction should go to which telerobot, and each telerobot acts independently to fulfill the command (thus, no coordination is needed betweentelerobots). This situation may happen in the urban search and rescue action if multiple operators work together to direct individual telerobots to different parts of the destroyed area.

Finally, Figure 2H shows the case where operators do not coordinate before issuing different commands to a group of telerobots. Telerobots make the priority among different commands, and they divide the commands among themselves before their realization.Such a situation may occurs when telerobots receive their orders from multiple, non-coordinating humans from different locations. Similar situation may happen when the communication between operators is hindered.

OPERATOR'S INTERFACE

Control of teleoperators require a master human interface device that can provide haptic input as well as the output, which reflects the responses of a slave robotic system. For that purpose, the force-reflecting hand controllers can be used.Unlike conventional input devices, forces on a controlled device (the efector part) are sensed and "reflected" back to the operator, which handles with the device. For example, the back-driven motors are used to make the control to resistin relation to further forward motion of the execution part of a teleoperator, which is in a contact with an obstacle.In addition to the forces, displacements at the end effector of the manipulator are also transferred to the control, which will cause the tactile, kinesthetic and proprioceptive sensations of an operator.

However, most force-feedback devices are not hand held, or mounted on a panel. Rather, most of them are large master robot arms. However, activation of control devices of a telerobotic system also can be performed using the sense of sight (Klarin and Zunjic). At the present time, the production of master human interface devices with small dimensions presents a design challenge.

An operator receives the information from the teleoperator by the senses. Besides the tactile and visual senses, one of the possible ways of receiving the information in the execution of certain teleoperation tasks is by the sense of hearing. Input devices that are used in the execution of teleoperation tasks should have the properties of the kinesthetic displays. These displays should produce sensations of the mechanical energy flow. Particularly, electric motors can provide force feedback against the limbs of the body,so as to mimic the forces that originate from the physical interaction between the teleoperator and real world objects. Ergonomic data regarding the capabilities and limitations of the senses can be used to provide guidelines for the design of display technology, which will be used by operators.For example, haptic displays need not to be designed with theproperties that exceeds the capabilities of the sense for detection of the information. The haptic input device should adequately represent any movement of the operator during the interaction, but also, to adequately reflect the teleoperator's actions.

Visual displays for monitoring of teleoperation tasks should also meet certain ergonomics characteristics. Some of these recommendations for designing and arrangement of visual displays in the human - teleoperator system are(Park and Woldstad):

·Select dimension of the display based on the task being performed. Consider a multiple 2D display format, if the task demands frequent use of focused attention.

For 3D perspective displays, ensure visual enhancement cues to aid depth perception.

As a visual enhancement cue, a single line is not sufficient to aid depth perception. Design a visual enhancement cue which has a volume in 3D space.

Take into the consideration the task difficulty when selecting the level of visual enhancement.

For 3D perspective displays, ensure that the movement of the control and the resulting change in the display are in the same relative location. Keep lateral displacements to <15°.

Provide the hand of the human operator with the proportional force of the manipulator (force feedback). As an alternative, consider a display of force feedback.

CONCLUSION

It is not advisable to address the role of the human in the teleoperation system only from the aspect of technological automatization.It is necessary to perform careful consideration of human capabilities and constraints in parallel with the level of a teleoperator autonomy. This is especially important when an operator is located at the long distance from the teleoperator (for example, when controlling is performed through the web connection). Such consideration should be performed in the phase of early development of the system.In that sense, a comprehensive analysis of the operator's task can be performed. Experts in the field of the ergonomics should be involved in this process, in order of avoiding the mistakes in the functioning of the system and to achieve the optimal interaction.

After considering the task that needs to be done and redistribution of functions between men and telerobot, it is necessary to perform the basic design of the system. At this stage the ergonomic experts should provide a variety of information, which are necessary for telerobot design (e.g. in connection with the problem of scaling of forces etc.). After that, follows the stage of designing of the interface, which should be fully compliant with the characteristics of operators. At the stage of testing and evaluation of the system, ergonomic experts can give suggestions for improvement, if certain shortcomings are identified. Therefore, multidisciplinary cooperation between experts from different scientific disciplines is required, starting from the stage of establishing goals and performance specifications, in order to obtain the efficient man - telerobot system.

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