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HMI of teleoperated robots

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Abstract. Automation of discrete manufacturing and service processes requires application of robots. In the article, we discuss the telerobot control, especially focused on applications in technical environment. The main task of HMI is to create the technology functionality clear, readable and comprehensible. HMI has to be designed with regards to human operator. HMI attributes can have an influence to: quality of performed tasks, time necessary to train the operators to perform particular work, create less stressful work environment with minimization of operators' exhaustion, increase of reliability and quality of performed tasks and thus reduction of operation costs.

Introduction

Robots are becoming more accessible to ordinary users who do not have technical education. This applies not only to household applications, but this trend is well seen in industrial production. Sophisticated robots become now easier to use especially particularly in terms of interaction with them. In the article, we discuss the telerobot control, especially focused on applications in technical environment. The main task of HMI is to create the technology functionality clear, readable and comprehensible. HMI has to be designed with regards to human operator. HMI attributes can have an influence to: quality of performed tasks, time necessary to train the operators to perform particular work, create less stressful work environment with minimization of operators' exhaustion, increase of reliability and quality of performed tasks and thus reduction of operation costs. All these issues are discussed, because it seems that this part of robotics will be very important in the future and not everybody pay the attention to HMI.

HMI and telecontrol

Easier tasks might be performed by industrial robots with program control, more difficult tasks require so-called adaptive robots and the most difficult tasks are for robots with artificial intelligence. Robots can perform the activity based on created program or program with a possibility of correction according to changes in environment or autonomously [7]. From the point of view of operator, the autonomous systems are advantageous. However, not all of the tasks can be performed by autonomous robots due to the high demands on system control (decision making) hence its complexity and high price. Semi-autonomous systems or systems with various forms of operator intervention to robot's activity are applied. In these

systems, it is important for operator's exhaustion reduction to increase level of robot control, that operator interferes to control only if necessary and in highest possible control level, so the robot can perform all routines automatically. It is important for the system of security inspection to be working during interactive control of robot, so the operator cannot input to perform a dangerous operation.

The complexity of autonomous action control by the robots is defined by the necessity of an external environment description – the working area of the robot. That is difficult during programming robot's actions in not determined conditions of the working area. Therefore it is necessary to use telecontrol of the robot [4,10,11,12,13]. It might be so-called mobile manipulator or stationary robot with regards to specific conditions in the working area. While teleoperating, operator has a chance to evaluate conditions in the working area and based on that to control robot's activity. Use of telecontrol is suitable when robot works in specific conditions (e.g. unknown and changing environment, cooperation with a human in the operation, cooperation with other robots, etc.). Telecontrol requires a feedback from working environment, for example inform of visual image, sound, position, orientation, motion dynamics, etc. In number of cases it is needed to use force-torque or tactile sensors.
It is necessary during telecontrol to:

- Define operation stages, which ones should be controlled by operator and which automatically.
- Minimize any risks of incorrect sequence during operation and ensuing dangerous consequences.
- Decide which sensor information is needed for operator to perform operation and recognize his reaction times, which is related to risk of instability caused by presence of human in control loop. It is necessary to deal with the mnemonic quality of the system design and an operator's "transfer function".

Control architecture

Control architecture is determined based on general requirements. It also depends on control objectives (position and its derivation, force, impedance) and chosen control (standard, adaptive, with UI elements).

The level of operator's participation in robot control depends not only on the complexity of operations, but significantly on system structure and telecontrol principles. During command, replicating and semi-autonomous manipulator operation, operator continuously controls motion of executive system. Supervised and dialog control allows operator to radically relieve of direct control of the simple and repetitive robot movements [7].

In supervised control, all information about system state is shown on control panel for the operator. Based on this information the operator makes decisions about further actions and sends appropriate control commands. The control system decides on the current control program of the activity with regards to control commands and autonomously performs preprogrammed required actions.

Dialog – interactive systems are another stage of telecontrol. Adaptive control is applied in interactive systems and control program can involve algorithms of artificial intelligence. Control system itself creates solutions, which are presented to operator for approval or asks him for decisions in situations, for which it cannot find solutions alone. Consequently, it checks operator's decisions so it can improve system security (it does not perform an unsecure operation).

Up-to-date use of telecontrol is for example in medicine, for drone control, for control robot in the water, underground, in space, etc. In technical practice, it is using in not

determined conditions in extreme environments, where it is necessary to perform complex movements, difficult operations, installation work with use of universal tools and equipment, etc. [5,6,14,15,16,17,18]. Telecontrol is suitable if: tasks are unstructured and not repeated, key parts of task require difficult manipulation (especially eye – hand coordination), object recognition or understanding of situation. The condition is that requirements of information security for operator and transmission of control commands cannot limit the communication line restrictions (bandwidth, time delay, interference).

The necessary condition for reliable operation during telecontrol is an appropriate information and communication system of the robot – Man Machine Interface MMI or Human Machine Interface HMI (Interface consists of hardware and software, that allows user inputs. Those are submitted as signals for the machines, which return desired result of action to operator) [1,8,9]. It is also used the name HCI - Human Computer Interaction [3]. It is a discipline dealing with the design, assessment and implementation of interactive computing systems in terms of users. It also studies main effects in connection with this interaction. Motivation and goals of HCI are to develop and improve: safety, utility, efficiency, effectiveness, usability and attractiveness of the system.

Information and action exchanges in the robot operation between the operator and the robot through a user interface are covered by HRI (Human Robot Interface) [2]. When designing the interface, the limited human sensory, motor and cognitive abilities should be kept in mind. Ergonomics deals with such kind of issues in order to create consistency among the technical solution, product function and adaptation to human abilities and needs. Use of ergonomics during system design leads to: a reduction in incapacity for work and occupational diseases, increase of work performance, reducing errors and spoilage, improve mental state of workers, minimizing signs of mental and physical fatigue. The main areas of ergonomics interest in terms of HMI design are focused on arrangement of control elements and indicators and appropriate use of color and sound. That results to good understanding of information about controlled process by the operator. HMI interface enables operator to take full advantage of his ability to control the process and reduces operator's workload.

Realization of HMI is connected with a sufficient amount of robot sensors and working environment sensors as well as HW and SW tools for information exchange to operator and for entering control commands for the robot and other equipment in working area. One of the options to create HMI is to use virtual or augmented reality. The general block diagram of telerobot use is shown in Fig. 1.

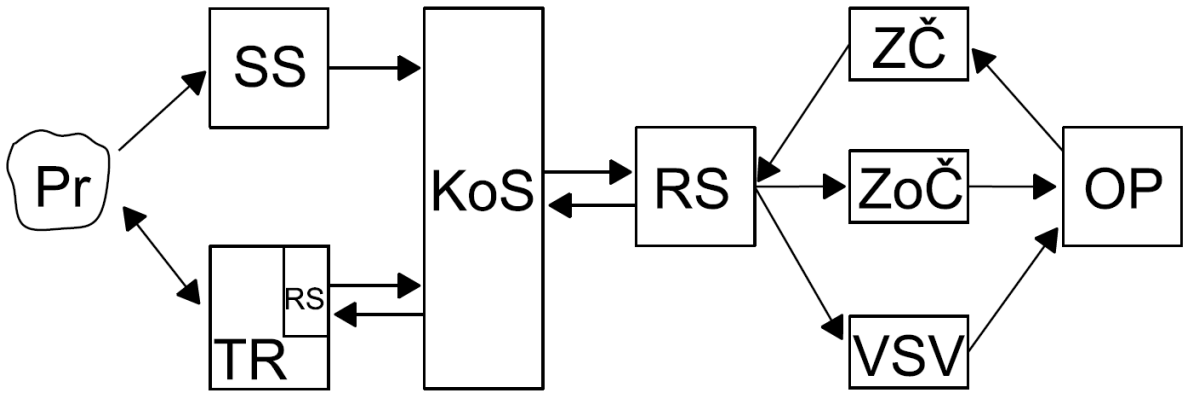

Fig. 1: Scheme of telecontrolled robot – Pr is environment, SS – sensor system, TR – telerobot, RS – control system, KoS – communication system, ZČ – input elements, ZoČ – display elements, VSV – sensory feedback, OP – operator.

If there is a sufficient amount of information from sensors (visual, sound, force-torque, tactile, position, speed, acceleration, orientation... [7,19,20,21]) presented to operator, it can lead to his feeling of physical presence at the same place as robot and sensors are. It is called telepresence. To ensure the perfect telepresence, the information transferred from the robot working area to operator should be for all human senses (in robotics in technical environment it is unlikely to utilize all 5 operator's senses).

The issues during telecontrol are caused usually by the possibility of communication failure, bandwidth limit of the communication channel, the communication delay, the possibility of noise and disturbances in information transmission. The main problem is also the high psychological stress of operator during telecontrol. Problems are caused by that operator is not moving in control workplace. Although robot is moving, the operator often has only a partial view of working area (has no stereopsis). He has to react to high number of various outputs. That highlights the importance of quality of HMI designated for this kind of control.

People obtain 90% of information from the surroundings by sight. Acquisition of visual information by technical resources is associated also to camera movement, focusing, resize the view angle or image spectrum, type of lightning, etc. [24]. For more precise scene recognition, there might be added another data to visual scene for operator from other sensors, e.g. about distance or temperature of different objects in scene, alternatively about forces and torques. An important role during system design belongs to optimal sensor deployment on the robot. It depends on complexity of addressed tasks, level of system intelligence, solo or group deployment of robots, etc. Visual systems are used with stationary cameras, cameras placed on special manipulators, cameras placed on robot's manipulators or the combination of above. Additional features for effective usage of visual system may be provided by special scene lightning. The information for operator is presented on screens or by video glasses. 3D view can be achieved also by augmented reality.

The use of sound is technically quite simple, but on the other hand the record of sound can be affected by other audio sources, which are unrelated to telecontrol activity. When the information transfer is bi-directional, it is the natural way of communication for the operator. The complexity of sound recognition is in accurate and reliable recognition of content and meaning of the communication – input of commands for performing activity. For complete sound and voice communication it is necessary to resolve the question of secure and reliable decode of commands from operator and also the speech synthesizer for exchange data from sensors to operator.

Other essential sensors for telecontrol are touch sensors, force sensors, torque sensors, position sensors, speed sensors and acceleration sensors [22,23]. This information can be provided to operator on display panels or some other data (force, torque, touch) directly by actuators of appropriate kinematic scheme at the operator's workplace. Feedback force-torque effect on operator needs a suitable kinematic solution of control elements at his workplace too. Within this kind of control, transformation of forces and torques size can be performed from the working area to operator. Such control increases the quality of telepresence, operation performance by the operator has high accuracy and decreases the risk of operator's exhaustion.

For mobile telerobots it is essential to be equipped in addition to above by sensors for localization and navigation. For technical environment, the essentials are mainly visual systems, optical systems, laser systems, ultrasonic sensor systems, or even GPS.

Depending on the complexity of the transferred information, the requirements apply to communication system. In complex applications, it is desired to have multi-channel system with high-speed information transfer with high resistance to interference. There are applications where cable connection between operator and the robotic system might be used,

but there are also ones where the wireless data transfer is required. Examples of telerobotic systems are shown in Fig. 2-4.

Fig. 2: Telerobot Scorpio - Ability of underpass the car, ability of explosive device disposal without the need of manipulation with it, possibility of remote control including the video transmission by radio signal, possibility of remote control including the video transmission through cable connection, simple control, obstacle avoidance and overpass, possibility of control and reconnaissance by visual systems, measuring of distance between obstacles and telerobotic system, detection of explosive device and measuring of distance between this device and muzzle of water gun and consequent disposal, possibility of simple implementation of additional extensions.

Fig. 3: Telerobot Teodor – main parameters: length 300 mm, width 685 mm, height 1 240 mm, weight 375 kg, speed max. 3 km/h, payload 350 kg, operation time 3-4 hours. Control station: weight 86 kg. Control panel: weight 9 kg.

Fig. 4: Mobile manipulator MT-15KM - all movements are provided by electric motors. Main parameters: rotation + 45°, main arm lift - 30° to + 105°, auxiliary arm lift + 105°, wrist rotation ± n x 360°, jaws opening max. 260 mm, weight 86 kg, payload - unloading 1,5 m - 15 kg, payload - unloading 0,5 m - 40 kg, installed power 475 W.

Conclusions

Telecontrol is still in focus of research institutions. Decision-making possibilities of the operator, processing the amount of information about the complex and changing environment, speed of evaluation the system state and the solution acceptance by a technical system are the things that still prefer operator's participation on control instead of fully-autonomous system. We can conclude the rapid development in all telerobotics subsystems. There is a signifficant increase of computing power, progress in sensor parameters, which improves HMI features, simplifies system control, reduces demands on operator training and exhaustion of operator during his work.

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