Towards the assisted teleoperation systems

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Abstract—This paper describes the proposed humanoid robot teleoperation system capable of task learning through teleoperation. The system is based on the task rule extraction from the data acquired by monitoring a human operator during the teleoperation process. The basic information about teleoperation systems, history, applications and current trends are provided in the first part of the paper. The second part of this paper is dedicated to the architecture and software implementation of the proposed system. The last two sections are dedicated to the conducted experiments and conclusion of the project and the possible improvements considered for the future work.

Index Terms—Teleoperation, humanoid robot, learning. (key words)

I. INTRODUCTION

Teleoperation systems are extremely important in human’s modern life. Nowadays the teleoperation systems are not only considered to be used in hazardous environments or to move toxic materials. Teleoperation systems are widely used all around the world in various applications from space applications to entertainment applications. To have an ability to control something remotely has a strong impact in the business sector as well, as it is lowering the costs. There is a strong demand for teleoperation process improvement, and the main trend is to reduce the operator’s share on the control process and increase the teleoperator’s share or any other “virtual operator’s” share instead. Increasing the autonomy of the teleoperator leads not only to reduce the amount of work needed to be done by a human operator but also gives us the opportunity to operate in places, where it was not possible earlier (time lags, weak and unstable connectivity, etc…). In this paper, the Smart Teleoperating System is described. STS is a teleoperation software capable of learning through teleoperation. In the first chapter of this paper, the basic introduction to teleoperation is given. Third section provides some details of the applications of teleoperation system. The current trends in teleoperation development are described in the fourth chapter. Fifth chapter is dedicated to the description of the proposed Smart Teleoperation System and its main features, experiments and research results.

II. TELEOPERATION AND ITS HISTORY

Teleoperation has very rich history dating to 1940s. Since then it led to many practical applications and brought a human ability to interact with remote environments using manmade machines, allowed us to manipulate toxic and very hazardous materials, explore the space and to perform many others fantastic things. In order to understand teleoperation, some of the basic terms and concepts need to be clarified. The concepts and terms provided in the following words appear in the well known articles related to teleoperation [1, 2, 3, 4, 5, 6, and 7].

Robot: Robotics historians agree that the first public use of the word robot was around 1921. It was introduced by the Czech writer Čapek in his R.U.R (Rossum’s Universal Robots) play to describe are artificial people. Initially he wanted to use the word labor derived from the word labor, but finally he listened to the advice of his brother and changed his mind and used the word robot, derived from a czech word “robota” which means “work” in english. There are lots of definitions for the term “Robot”. For example, any automatically operated device that replaces human effort, though it may not resemble human beings in appearance or perform functions in a humanlike manner. By extension, robotics is the engineering discipline dealing with the design, construction, and operation of robots [4].

Operator: A human operator is the person who takes the control actions needed and monitors the operated machine [4].

Teleoperator: Teleoperator is the teleoperated machine (robot). It is a machine that enables a human operator to move, to sense and to manipulate objects mechanically at a distance [4]. Most generally any tool, which extends a person’s mechanical action beyond his/her reach, is a teleoperator.

Telerobot: Telerobot is a subclass of a teleoperator. It is a robot that accepts instructions from a remote site, generally from a human (also other robotic or computer system might be accepted) operator and performs actions at a distant environment through the use of its sensors or other control mechanisms. Usually it has various sensors and effectors for manipulation and mobility, plus a means for the human operator to communicate with a telerobot or other robots or humans at the distant environment.

Teleoperation: Teleoperation means to operate a robot using human intelligence, which requires the availability of adequate
human-machine interface. Simply, the teleoperation means to operate a vehicle or a system over a distance [13]. Distance can vary from tens of centimeters (micro manipulation) to millions of kilometers (space applications).

Today, in the "normal teleoperation", there is no direct visual contact with the controlled system. The visual feedback is usually made by a camera-display combination. Controlled commands are sent electrically by wire or radio/wireless. On the other hand in the “Remote operation/control”, the operator has the most of the time straight visual contact to the controlled target. Control commands are sent electrically by wire or radio as well. When the connection between the manipulator and operator is mechanical, the term "remote manipulation" means mechanical manipulation. In telemanipulation, the connection is electrical. Between the basic mechanical manipulation and high-level supervisory control, there are several systems of different technical levels included under the term teleoperation. Figure 1 illustrates the information flow in a teleoperation system.

**Figure 1: The general information flow in a teleoperation system [8].**

The main function of the teleoperation system is to assist the operator to perform and accomplish complex, uncertain tasks in hazardous and less structured environments, such as space, nuclear plants, battlefield, surveillance, and underwater operations [9, 10, and 11].

The autonomy level of the teleoperator in the teleoperation process can be classified into the three main control classes.

1. Closed loop control (Direct teleoperation): The operator controls the actuators of the teleoperator by direct (analog) signals and gets real-time feedback. This is possible only when the delays in the control loop are minimal (up to 100ms). A typical example of this is a radio controlled car.

2. Coordinated teleoperation: The operator again controls the actuators, but now there is some internal control loop in the teleoperator. However, there is no autonomy included in the remote side. The remote loops are used only to close those control loops that the operator is unable to control because of the delay. A typical example of this is a teleoperator for whom the speed control has a remote loop and, instead of controlling the throttle position, the operator gives a speed set point. Digital closed loop control systems almost always fall into this category.

3. Supervisory control: Most of the control part is to be found on the teleoperator side. The teleoperator can now perform part of the tasks more or less autonomously, while the operator mainly monitors and gives high-level commands. The term "task based teleoperation" is sometimes used here, but it is more limited than supervisory control [12].

By increasing the sensory and effector equipment on the teleoperator side and improving the graphical user interface, so the human operator gets more and more information from the distant place, we move from standard teleoperation to telepresence, virtual presence or augmented presence operation.

Telepresence: In 1987 Sheridan described telepresence as the “ideal of sensing sufficient information, and communicating this to the human in a sufficiently natural way that she feels herself to be physically present at the remote site.” Sheridan also called telepresence a “compelling illusion” and “a subjective sensation.” In the field of robotics, telepresence refers to a remotely controlled system that combines the use of computer vision, computer graphics and virtual reality [14].

Virtual presence (or Virtual reality): It is the same like telepresence, except the environment where the operator feels to be present (and all the sensor information) is artificially generated by a computer system.

Augmented presence (or Augmented reality): It is a combination of real world sensor information and virtual reality. A typical example of this is a real camera image with additional computer generated virtual information or using a virtual sensory information.

**A. History of the teleoperation systems**

In the beginning of the teleoperation research times, the priority was to develop remote mechanical control system to be able to manipulate the toxic and for a human very dangerous materials. So, it was extremely necessary to develop mechanical systems with high dexterity to be able to solve the dangerous object manipulation tasks. On the other hand, high possibility of endangering a life of human or environment intoxication by a dangerous material led to distance increase between operators and teleoperators. All these factors influenced the further development of teleoperation systems. Some sorts of information and instruction transfer system development were required. The first master-slave system was proposed by R. Goertz in late 40s of 20th century for the very first nuclear reactor. It was a mechanical manipulator controlled using wires and belts with the operator’s direct view over the teleoperator. The main disadvantage of such system was that the operator had to cope with the parasite inertias being formed during the force transfer between the operator and manipulator, which led to additional operator’s strain production. The second manipulator developed in 1954 by R. Goertz and his team solved all the problems mentioned earlier. It was the first electro mechanical manipulator with feedback servo control. After this, the teleoperation of manipulators and vehicles spread out rapidly to new branches where advantages of teleoperation techniques could be utilized [19].

**III. APPLICATIONS OF TELEOPERATION**

There are many ways how the teleoperation or telerobotic systems can be used in the real world applications. Today, the application field of the teleoperation is extremely diverse covering the space exploration areas, toxic waste manipulation, mining, forestry, medicine and many more. The most of the space exploration projects has been conducted
telerobotic space probes. Telerobotic telescopes are widely used for space-based astronomy where the Hubble Space Telescope is an excellent example. The first lunar vehicles Lunokhod 1 and Lunokhod 2 were telerobotically operated and even more recent Mars exploration rovers Soujoner, Spirit and Opportunity were operated telerobotically. The most recent and advanced planned rover to be sent to Mars is called Curiosity. The Internation Space Station (ISS) uses a two armed telemanipulator called Dextre. Marine remotely operated vehicles (MROVs) are widely used to work in water too deep or too dangerous for divers. In addition, a lot of telerobotic research is being done in the field of medical devices (da Vinci surgical system). To handle radioactive materials, various remote manipulators are used. To handle radioactive materials the most recent iRobot’s “Warrior” robots are used in Fukushima. Telerobotics has been used in art, education and entertainment fields as well. The TeleGarden is an art installation that allows web users to view and interact with a remote garden filled with living plants. A few notable uses of the teleoperation in humanoid robotics are selected and described in the following subchapter.

A. Use of teleoperation in Humanoids

Robonaut 2, the latest generation of the Robonaut astronaut helpers, was launched to the space station aboard space shuttle Discovery on the STS-133 mission. It is the first humanoid robot in space, and although its primary job for now is demonstrating to engineers how dexterous robots behave in space, the hope is that, through upgrades and advancements, it could one day venture outside the station to help spacewalkers make repairs or additions to the station or perform scientific work. R2 operators have several choices for how to control the robot. Station crew members will be able to operate R2, as will controllers on the ground. However, one of improvements over the previous Robonaut generation is that R2 does not need constant supervision. In anticipation of a future destination in which distance and time delays would make continuous management problematic, R2 was designed to be set to tasks and then carry them through autonomously with periodic status checks [15]. In 2003, there was some research done on Robonaut task learning through teleoperation [16]. The main result of this work was a proof of concept. It was demonstrated that a few teleoperated trials of a task are sufficient for extracting a canonical representation of the task. The representation was canonical in that it described the motions and sensory triggers for behavior state transitions in such a way as to enable successful completion of the task with differing boundary conditions. The small number of trials is important since shows that a skill can thus be “programmed” into a robot through teleoperation without the usual trajectory planning / calculation and without direct calibration of sensors and actuators [16]. Another application of teleoperation using humanoid robots is described in another article from May 2002, where a teleoperated humanoid robot drives a lift truck [17]. The teleoperated humanoid robot platform consists of a humanoid robot (HRP-1), and a remote control cockpit system to operate the humanoid robot. HRP-1 is 1600mm high, 600mm wide, and has 99kg of weight excluding batteries. It has 12 DOFs in two legs and 16 DOFs in two arms including hands with 1 DOF grippers [17].

The recent work on teleoperation and humanoid robots has been done in Russia, and some of the materials can be found on Roscosmos and Androidnaya Tekhnika company’s websites. The new S-400 humanoid robot is similar to Robonaut 2 robot. While R2 robot is already utilized on ISS, S-400 is planned to be launched to space in 2014. The S-400 robot has no legs, just like R2, and is designed to connect to a crane operated on the space station. SAR-400 would be remotely operated by the controller wearing a head mounted display, jacket, and gloves that would relay the movements directly to the robot’s body. One of the most fascinating things is that the S-400 robot has tactile feedback. According to the Androidnaya Tekhnika Company, the producer of the robot, S-400 uses a remarkable technology that relays pressure from the surface to the manipulator’s gloves. With the help of the robot, the operator can literally feel the surface. In addition microprograms for supervisor technology will be used for work in remote locations. The robot will be given the vector of movement or the objective will be set and the robot will itself decide how to fulfill it.

IV. CURRENT TRENDS IN TELEOPERATION

The abilities of teleoperation systems are being improved from year to year. Since the electro mechanical manipulator was developed, the teleoperation systems have spread to different areas of applications from military to the entertainment industry. So what is going to happen to the teleoperation systems as we know them today? The course of the development is to lower the human’s share of control and transfer it to the teleoperator. The following picture describes the actual trend of teleoperation systems.

![iRobot's User Paradigm View of Autonomy Levels](image)

Figure 2: iRobot’s user paradigm view of autonomy levels. [Robotics Summit Virtual Conference & Expo, June 2011]

It shows the need of the transfer from manual teleoperation to task and mission autonomy of the robots. The figure 2 appeared on the Robotics Summit Virtual Conference & Expo in June 2011 and was presented by iRobot Company.
According to the Figure 2 above, the main problem nowadays in teleoperation and robotics is that robots are not able to perform their tasks or missions autonomously. In addition, one or more operators are needed to control one machine and perform basic tasks. This is the reason why the future of the robotic systems is dependent on the robots autonomy.

According to the iRobot company, the transfer from today’s situation of 100%-90% human’s share on the control to 1% human’s share may happen in 10 years assuming the actual level of investment in this research field. In that case, one operator would be able to control 50 and more robots in a real time, while today we do need n operators to control one robot. This will lead to significant lowering of expenses, errors during the task solution and human fatigue. Human fatigue may be very dangerous in teleoperation tasks and may endanger the mission or even a human life.

On the other hand, the expenses are the most important factor in these days for the business.

Autonomous robotic systems of the future will be able individually or collaboratively solve given tasks with no or only a little intervention of human to control process. In the following chapter, the proposed smart teleoperating system with the ability of learning from the operator during the control process is described.

V. SMART TELEOPERATING SYSTEM

We propose a teleoperating system framework capable of operating humanoid robots, wheeled and flying vehicles and with a capability of learning from teleoperation and automatization of the previously performed tasks, collaborative work of various robots during the process of task or mission solving. The following picture describes the overall architecture of the Smart Teleoperating System (STS).

![Figure 3: The basic smart teleoperating system architecture describing the information flow between the STS, operator and teleoperator.](image)

The main architecture consists of three main parts: Human operator, teleoperators and some cloud service or single master computer (Virtual Assistant). As it was mentioned earlier, the teleoperators might be humanoid robots, wheeled or flying vehicles. The proposed System is capable of serving one or more human or other non-human operators (other virtual assistants). Virtual Assistant consists of 4 main function parts. The Standard teleoperating service provides human machine interface for the operator and provides commands transmission to the teleoperator. Then there are services for learning from teleoperation, optimizing the obtained knowledge and storing it into the database. On the right side of the picture 3, there is a main block that provides assistance to the operator during the teleoperation process. So basically the system can run in three modes at the moment: Manual teleoperation, learning, assisted teleoperation.

During the manual teleoperation mode, there are no or only the little interventions to the operation of the robots and all the work has to be done by a human operator. Learning mode provides an ability of the system to learn from the teleoperation. Firstly, the task properties like the name of the task and objectives have to be defined using a user-friendly graphical interface. Then the operator has to define which of the inputs and outputs need to be monitored by the system for further rule extraction of the control. Then these input and output variables are fuzzified. All these I/Os can be selected using the graphical interface. Then the human operator performs the tasks and gives system flag messages when the action needs to be monitored and when the system should stop monitoring the operator’s actions. In the first stage, basic fuzzy rules are extracted from the monitoring process. After collecting more training data, the fuzzy memberships of the input and output values and also the weights of the individual rules are optimized, and finally the task is stored to the database. The process is repeated for various tasks. Then a human operator can connect the tasks to sequences and build the missions using intuitive graphical user interface.

In the last stage, the Virtual Assistant can be fully utilized in the teleoperation process of the robots. Human operator just picks up the tasks or missions that need to be performed and puts them to the mission stack. Virtual Assistant will distribute the tasks to the robots, and if there is an action required from a human operator, the systems simply asks for a help. This is how the main architecture of the proposed system works. Unfortunately, there are a lot of problems in the real-world applications. In the following subchapters, the main teleoperation framework and some of the experimental results are presented.

A. STS Framework

The robotic platforms for the current research are Aldebaran Nao, the humanoid robot and AR-Drone, the flying vehicle. STS framework is designed to work with these two platforms at the moment. The GUI of the STS framework is shown in the following picture. Robot NAO can be manually controlled using a PS3 controller. Operator simply selects the joints that need to be controlled. Then using the analog sticks of the controller, the robot is operated. In addition, the framework allows the operator to see what robot sees using the robots embedded cameras, apply any filter for the image processing

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The content provided is a natural language representation of the text, formatted to maintain continuity and coherence as closely as possible. The diagram and figure references are included as described in the original text.
or utilize other source of information (overhead cameras, images from the flying vehicle, etc...). Operator can trigger any preprogrammed robot behaviors by pressing some combo buttons on PS3 controller and interact with the environment by using text to speech.

The image processing plug-in. The plug-in outputs can be seen in the previous pictures in the middle image boxes of the STS framework. It shows the error of the ball or cone in that case and the change of the error position from the middle of the image. The input variables for the learning system were defined as the horizontal and vertical position of the cone related to the center image position. Output variables are the operator’s actions performed using the controller (Nao head pitch and yaw). Input and output variables were fuzzified. Membership function of the input and output variables were created manually using STS framework GUI. Learning process trough teleoperation is triggered manually by the operator. The STS monitors the operator’s actions and cone position, error and change of the error in time. The rule is extracted from the every action that leads to the error lowering. For example, the cone in time \( t \) is “low left and low down”, the error in \( t+1 \) was lowered and the operator’s action was “output” (low right, low up) then create this rule. After a few moments of teleoperation, the system is able to track the cone automatically without the operator’s intervention using the extracted rules. However for more smooth action the further optimization is required using the training data collected during the teleoperation process and utilizing optimization algorithms. For this experiment, the genetic algorithm optimization was used. The process can be found in [18].

The same experiment was conducted for teaching a robot to track a cone and navigate to it. The cone tracker from the previous experiment was used and the operator focused only on the robot navigation using PS3 controller to control the legs of NAO robot. The rules for the “walk to cone” were extracted by the same way as in the previous experiment including the head angle source of information in addition. The significant lowering of the amount of operator’s interventions was achieved during the second experiment, as the robot was able to track the cone automatically (learned from the previous experiment) and the operator could focus on walking operation only.

VI. Conclusion

Increasing the level of autonomy of the robots is very important task. Teleoperation gives us the ability to control the robots in the environment dangerous to a human and enables us to manipulate toxic materials and so on. In some cases, it is technologically not possible to operate the robot manually. If there is no or very weak connectivity, the mission and sometimes the teleoperator itself is lost. This is the reason why we focus on learning through teleoperation and increasing the task and mission autonomy of robots.

The experimental results show that the proposed architecture of the system able to learn through the teleoperation works well. We were able to extract the rules based on the operator’s actions during the teleoperation process. As the proposed system is based on the plug-in architecture, there is a possibility of extending the functionality. Learning process is incremental. After teaching the STS the tasks individually, operator can connect these tasks in a sequence or in parallel run to build a mission. The future work will be focused on further experiment work, increasing the functionality of the system, improving the
graphical user interface so it is more intuitive and testing more optimization algorithms to improve the overall performance of the STS.

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