Steffen Planthaber*, Daniel Kühn, Kerstin Rohde, and Christian Hartberger

Future Control Stations for Heavy Machinery

From Telepresence to Autonomous Systems

Abstract: Robots and industrial vehicles are becoming more and more autonomous. Currently, the robots are not able to carry out all tasks autonomously, but the number of those tasks is increasing. Semi- autonomous robots are changing the requirements of control stations for their surveillance and control. These new technologies will provide the possibility to have a single operator command and supervise multiple (semi-) autonomous systems. This requires new control stations, which support remote control and also commanding autonomous actions, like executing a movement command to a specific position. Here, we provide a concept that combines classic and future control stations, that can already be used with the current state of the art in robotics.

Keywords: Robotics, Remote Control, Control Station

1 Motivation

Humans and robots are increasingly complementing each other in a wide variety of scenarios, in order to simplify work procedures or to make them possible in the first place. Machines or robotic technology are already being used for safety-relevant

***Corresponding author: Steffen Planthaber,** German Research Center for Artificial Intelligence
Daniel Kühn, German Research Center for Artificial Intelligence
Kerstin Rohde, Götting KG
Christian Hartberger, Götting KG

tasks that are dangerous for humans, such as defusing or detonating hazardous objects. The same applies to the use of robots in extreme and unstructured environments, which include disaster areas (e.g. after earthquakes, explosions or similar). If autonomous execution of work is not possible, teleoperation of robots is an option. Due to continuous improvement of the existing technology, it can be assumed that this combination of man and machine will be used in many more applications in the near future.

When a robotic systems are dispatched to a landscape, a large amount of data is automatically recorded. This data is collected in the control stations. By building up environment maps or using live-streams from cameras installed on the robots, the systems' movements and actions can be monitored. When a robotic system takes over tasks, it must be possible for humans to grasp the overall situation at a glance. If human intervention is required, the operator has the option to control the machines or the robot as if he/she were on site and thus, can contribute his/her experience and cognitive abilities. In the future, human operators will be able to immerse themselves in the situation on site (immersion) and intuitively operate the systems, regardless of the size or type of robotic system, by using state-of-the-art teleoperation methods and cross-system interfaces. This is where the move from pure teleoperation to telepresence is made. Telepresence enables the execution of complex tasks that cannot be performed autonomously by the system (Shared Autonomy[2]) without putting people at risk.

The control stations and concepts presented here, can be combined with each other. They start with simple control stations, which are virtually a one-to-one copies of the machine in use in terms of the control system available. This is followed by a immersive control station concept for controlling heterogeneous robot teams including construction machines, which can be performed by a single person. Furthermore, an abstraction of the stationary control station to a mobile control station is discussed and presented. It should be noted that each control station has its own sensory feedback.

2 State of the Art

In the field of telepresence and control stations for the control of heavy construction machinery, solutions are often used in which the operating elements are the same as those found in the machine. Generally, these control stations or teleoperation solutions are tailored to one system / type of system. These control stations often resemble those of an office workstation.

Sandvik is a technology group in the mining and aggregate mining sectors. With the automation and teleoperation solutions developed by Sandvik, it is possible to control several machines simultaneously from a safe environment, even underground.

Spohn & Burkhardt GmbH & Co. KG specializes in control tasks in the field of crane systems. A special feature of crane systems is that an unobstructed all-round view is required. Depending on the requirements, whether container ports or mobile cranes, in power plants or on drilling rigs, the Remote Control Desks are set up accordingly (see following Fig. 1).

Fig. 1: The Remote Control Desk from Spohn is a multifunctional control station for cranes. Picture source: https://www.spobu.de/produkte/steuerstaende.html

Caterpillar Inc. offers several teleoperation options. The operator works remotely with familiar controls and machine displays. This "Virtual Operator's Cab" can be set up at a central office or on-site at the job site. The operator's inputs are sent directly to the machine electronics using a special radio transmitter/receiver. This allows the equipment to be controlled in real time. Operators can switch back and forth between different machines.

There are many more of these types of commercially available control stations around the world. Efforts to provide operators with an alternative experience and control while working are more common in the scientific domain. A group of Mechanical and Electrical Engineering students from ETH Zurich have gone the next step in developing a teleoperation environment compared to the industrial systems shown (see Fig. 2).

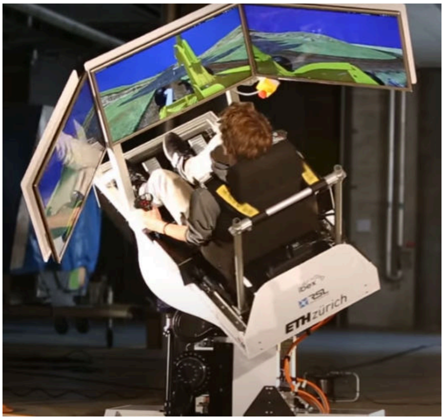


Fig. 2: The ETH teleoperation system can provide a user experience similar to a real excavator cockpit. Picture source: https://ibex.ethz.ch/

The so-called Ibex teleoperation system is equipped with two position-controlled eccentrics, which are used to control the roll and pitch angle of the cockpit. The angles approached in the teleoperation system come directly from the teleoperated system. This is made possible by several sensors mounted on the excavator. These sensors provide real-time speed and acceleration data that is mimicked in the cockpit, which should allow the operator to control the excavator more precisely.

Visual feedback from the cameras is reproduced on the screens from the excavator. The excavator is equipped with multiple communication systems so that, on the one hand, additional sensors can be added as needed, but also redundancy is provided so that communication to the system is always available.

3 Control Stations

In the Robdekon research network, Götting KG converted a Linde E25 forklift for teleoperation. DFKI GmbH developed an semi-autonomous excavator and a mobile robot, other partners provide even more systems[1].

The control stations and systems within the network all provide the same remote control interface and protocol.

1 https://robdekon.de

At Götting KG the forklift was equipped with four network cameras, which provide an all-round vision as if from the driver's cab. The camera streams are transmitted to the teleoperation stand via WIFI. The controls of the teleoperation stand are transmitted via CAN bus to an industrial PC (IPC). There, a ROS[3] node takes care of the translation of these control commands into a standardised communication protocol [1] and the transmission via WIFI to the vehicle. On the vehicle, the drive/steer commands are translated into the vehicle's drive/steer commands on a Raspberry Pi 4, which also runs a ROS node, and transmitted to the vehicle PLC via CAN bus. Conversely, this ROS node delivers the current vehicle data from the CAN bus to the teleoperation station using the standartized interface.

DFKI fully robotized an Menzi Muck 545 excavaor to have all robotic features for autonomous control and also teleoperation.

In principle, it is possible to teleoperate any vehicle in the Robdekon network using the following control stations. This means that the excavator located at the DFKI, can be controlled from the teleoperation stand at Götting KG in Lehrte-Röddensen, provided that the camera streams can also be transmitted with acceptable latency. This also allows to select the most appropriate control station for a given task, e.g. when the task requires remote control, a classic control station can control the system, when the task can be completed autonomously, another control station can be used.

3.1 Classic Control Station for industrial applications

The classic teleoperation stand from Götting KG (see figure 3) is designed to enable a driver with little training to operate his familiar work machine remotely. For the driver, this offers the familiar picture with control elements in industrial quality such as steering wheel, foot pedals and two joysticks, which can be mapped to the vehicle functions. All input devices with a wide input area are interpreted as axes with floating point numbers between 0 and 1 and single buttons as boolean values. This makes it possible to control common commercial vehicles (e.g. forklift, excavator, wheel loader, tractor or truck). In addition, screens are mounted in such a way that they provide an all-round view similar to the view from the vehicle cabin. If the vehicle to be teleoperated is equipped with appropriate sensor technology, it is also possible to provide force feedback to the driver, i.e. the seat is moved by actuator technology in a comparable way to the seat on the vehicle itself. In addition, acoustic signals are transmitted from the driver's cabin so that the teleoperator can perceive additional information such as beeps, engine sounds or other noises from the vehicle environment. This

Fig. 3: Teleoperation of a forklift via Götting Control Station

reinforces the impression that the driver is directly in the vehicle and facilitates teleoperation.

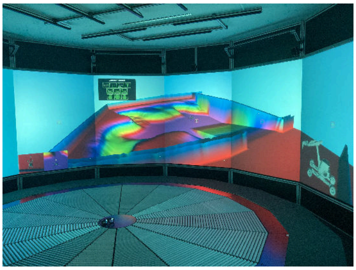
3.2 Immersive Control Station for Shared Autonomy

On the other end on the spectrum of control stations, the DFKI created an immersive, Virtual Reality (VR) control station that can be used with an exoskeleton.

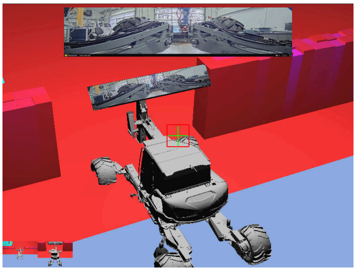
This VR control station is capable of multi-robot control. Compared to the remote control of the classic control station, the VR control station relies on a shared autonomy concept that requires the robots to be able to finish their tasks they got from the control station on their own. For example when the robot is capable of moving to a goal position autonomously, the VR control station can just send the goal command by clicking into the robot- generated map.

Classic remote control is possible using the VR control station. Either game controllers, joysticks, VR controllers, or the exoskeletons can be used as input devices. When using the VR controllers or the exoskeleton, a direct mapping of movements can be utilized to control robots. This can be either the robot base platform, which e.g. moves the robot forwards, when the VR controller is moved forward and stops when the controller is on its original position, or a robotic arm which mimics the movement of the controller. For the control of large scale arms (like on excavators) workspace scaling is possible which translates a small movement of the controller to a bigger movement of the target.

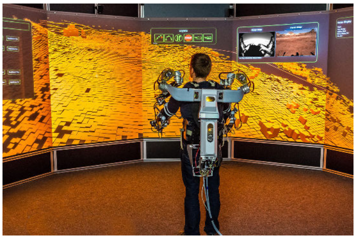
Additionally, the immersive control station allows to walk through the virtual environment, which was created by the robots on an omnidirectional treadmill. This allows for inspection tasks for a human operator in the current map of the robot without the need for the human to enter hazardous areas.



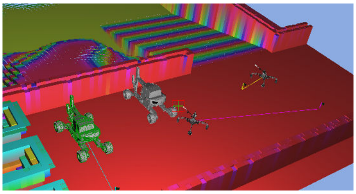
(a) VR Control Station: Seven 3D Displays in 180° Configuration and Omnidirectional Treadmill



(b) Camera Images Augmented into the Virtual Reality



(c) Exoskeleton Input: Exoskeleton arm can be used as cursor or mapped input to a robot part to be moved



(d) Multi Robot Control Example

Fig. 4: Immersive Virtual Reality Control Station: Excavator Robot Control in Hazardous Environments With Supporting Scout Robots

3.3 Mobile Control Station for Quick Intervention

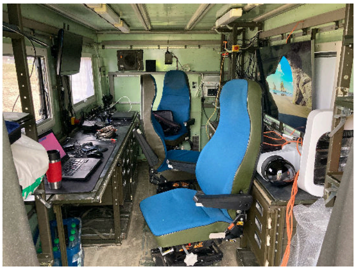
Currently, the autonomy level of robotics used in reality for these kind of tasks require experts on site to maintain the robots (charging/refueling, battery replacement, or general maintenance). Often, these experts are also the same people who control the robot. So having a remote control via the internet is often not the best solution, especially when a direct line of sight to the robot could be established. Seeing the robot helps the operator to estimate the state of the robot. If no line of sight is possible, the VR visualization, even when only displayed on a normal computer display, can also help to estimate the robot state.

The goal of the Project was also to create a functional Prototype of a future control station that is usable with the current state of the art in robotics. This means to be able to use these kind of robotic heavy machines in critical situations or hazardous areas in the near future. As a decent communication infrastructure cannot be expected in all use cases, a mobile control station was created that can be used close to the deployment site of the robots.

(a) Overview

(b) In Operation with survaillance Camera and Antennas on the roof

(c) Entrance Door



(d) Robot Remote Operator looking to the Right (Monitor), Scientific Staff/Developers looking to the left (window)

Fig. 5: Mobile Control Station: On site Excavator and/or Robot Control with Three Workplaces

The mobile control station is a mobile container that contains all the infrastructure needed to operate robot teams as described above. Minimal effort is required to make the control station shipping ready, as it features fixed seats and contents, except e.g. portable laptops. A deployable mast (4m, not in the images), can be used to elevate the communication antennas and a surveillance camera with optical zoom to keep the robots in sight.

3.4 Outlook

In the future we aim to further improve the mobile control station with a combination of the classic and the immersive control station. The goal is to have joystick controls in the mobile container and also equip it with the telemetry-based software from the immersive control station in order to provide the operator with a 3D model of the robot and its environment. Furthermore, we aim to add the multi-robot functionalities to this new control station.

This way, the mobile control station will be capable of controlling and monitoring multiple semi-autonomous robots directly on site, while there is still the possibility to remote control a selected robot using the joysticks like in the classic control station in case a task cannot be completed autonomously.

Due to the common interface, it will still be possible to hand over the controls of robots to other control stations via the internet.

Acknowledgment: Funded by the German Federal Ministry of Education and Research, grant number: 13N14675.

References

[1] Leon Cedric Danter, Steffen Planthaber, Alexander Dettmann, Wiebke Brinkmann, and Frank Kirchner. Lightweight and framework-independent communication library to support cross-plattform robotic applications and high-latency connections. In *International Symposium on Systems, Artificial Intelligence, Robotics, and Automation in Space (i-SAIRAS), 15th, October 19-23, Online-Conference*, 2020.

[2] Stefanos Nikolaidis, Yu Xiang Zhu, David Hsu, and Siddhartha Srinivasa. Human-robot mutual adaptation in shared autonomy. In *2017 12th ACM/IEEE International Conference on Human-Robot Interaction (HRI*, pages 294–302, 2017.

[3] Stanford Artificial Intelligence Laboratory et al. Robotic operating system.