Bulletin of the *Transilvania* University of Braşov
Series I: Engineering Sciences • Vol. 5 (54) No. 2 - 2012

A REVIEW OF CURRENT APPLICATIONS IN TELEOPERATION OF MOBILE ROBOTS

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Abstract: *Teleoperation means to operate a robot or a system from a distant location. Teleoperation is useful when the operating environment is dangerous, impractical or when achieving a specific vehicle for inspection environment is too expensive. Mobile robots can be considered as an example of teleoperation system because they can be remotely controlled to perform certain specific tasks. This paper is a review of existing teleoperated mobile robots and reports the current progress in this area.*

Key words: *teleoperation, mobile robots, robot control, communication, sensor, virtual reality.*

1. Introduction

Teleoperation, from Greek origin, is composed of the prefix *tele*, which means "at a distance" and *operation*, meaning perform a task. Thus teleoperation extends the human capability of manipulating an object at a distance by providing the operator similar conditions to those of a remote location [4].

The most common application areas of teleoperation are: space exploration, underwater vehicles, forestry, mining, agriculture, surveillance, rescue, surgery, volcanos exploration, landmine detection, domestic environment, entertainment.

A teleoperation system is usually a master-slave system. The master device is controlled by the operator and the slave device is placed in the remote side.

Mobile robots can be considered as an example of teleoperation system because they can be remotely controlled to perform certain specific tasks [1]. They have been designed to explore the planets, to navigate in hazardous environments or to inspect some places restricted to humans.

Mobile robots can be categorized into three categories according to their operating environments: land (based) robots, aquatic/underwater robots, and aerial (air, flying) robots [7]. The most popular used in teleoperation are wheeled mobile robot (WMR) and unmanned aerial vehicle (UAV) [39].

Although the purpose of a mobile robot is to be autonomous, there are many situations when the control must be switched to human operator for solving particular problems. So did the idea of telerobotics (teleoperation of robots).

The key components needed to develop telerobotics applications are the following: control (algorithm and real time implementation), sensors (world sensing and information processing), and wireless communication [9]. These components are illustrated in Figure 1.

The purpose of this paper is to analyze the most important systems used in teleoperation

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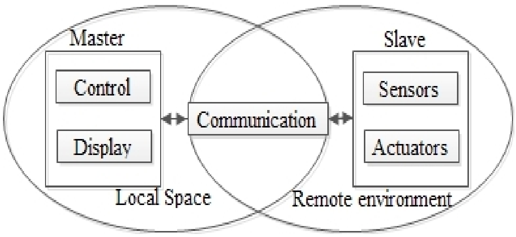

Fig. 1. *General block diagram of a mobile robot teleoperation system*

and to present an overview study of current systems. As a conclusion, some directions for future research in development of a new and innovative system are presented.

2. Teleoperation Control

There are a lot of devices used to control the remote system (mobile robot) in teleoperation, such as joystick, mouse, keyboard, haptic device, depth-camera (like the Xbox Kinect), touch-screen. Some of these are used just to send commands and other to control the mobile robot.

2.1. Haptic devices

To enhance the operator perception of the mobile robot workspace, the developers use haptic interfaces. They can offer force feedback or tactile feedback (reproduce tactile parameters). Some devices with force-feedback are showed in Figure 2.

Lee, S., et al. [17] demonstrated that the added haptic feedback in teleoperation significantly improves operator performance in several ways (reduced collisions, increased minimum distance between the robot and obstacles) without a significant increase in navigation time. The user's action is used directly to determine the speed and turn rate of the robot. Authors combine two kinds of forces (an "environmental" force and a "collision-preventing" force) and whichever is the larger is chosen as the feedback at a given moment during control.

Mitsou, N.C., et al. [23] also showed that combining haptic devices with teleoperated mobile robotic systems, the task of remote navigation in unknown environments is easier. They presented a visuo-haptic interface based on a virtual spring-type joystick model, used to teleoperate a mobile robot in exploring polygonal environments.

Horan, B., et al. [13] introduced a novel approach to multipoint multi-hand haptic teleoperation of a mobile robot, so that the operator can utilise one hand to achieve intuitive haptic control of the mobile robot while utilising the other hand to intuitively control the orientation of the robot's onboard camera.

Farkhatdinov, I., et al. [10] presented a new force feedback rendering scheme, taking into account not only the distance between the robot and its environment, but also the speed of the robot and that improves the quality of motion control.

Fig. 2. *Force-feedback devices* [10], [16]

Nadrag, P., et al. [27] considered a haptic teleoperation of an assistive mobile robot, used for exploring a domestic environment. The experiments have been performed on a robot (Lina robot) controlled with a Phantom Omni device, but their opinion is that force feedback not seem to have benefits, except that the feedback information is useful for the user.

2.2. Touch screen devices

Recently, touch-screen interfaces have been used in the field of mobile robot teleoperation because they are more intuitive for controlling robots (Figure 3).

Kato, J., et al. [14] developed a multi-touch interface with a top-down view from a ceiling camera for controlling multiple mobile robots. They used a tabletop panel with a top-down view from a ceil-mounted camera projected on it.

Hashimoto, S., et al. [12] proposed a touch-based interface for remotely controlling a robot that allows the user to manipulate each part of the robot by directly touching it on a view of the world as seen by a camera looking at from a third-person view.

Paravati, G., et al. [29] presented a solution to control mobile robots by using customizable haptic and multi-touch gesture interfaces on handheld devices. The user can interact with robots using touch and hand gestures and the images from a camera allows user to control the robot manually or automatically.

Seo, Y.H., et al. [33] proposed a touch-based control of a mobile robot using a smart phone. By touching the screen of the smart phone, a series of points obtained from designated curve traces are analyzed and provide control of a robot.

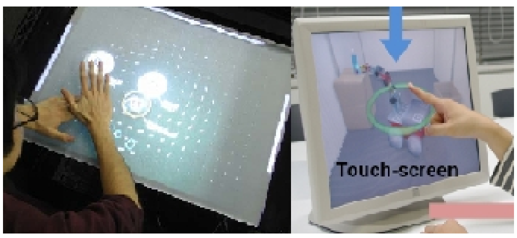

Fig. 3. *Touch-screen interfaces* [14], [12]

Stone, R., and Wang, M. [36] showed that the multi-touch interface is more effective than a joystick controller for telerobotics.

2.3. Other teleoperation control techniques

The current progress in speech recognition offers the possibility to the operator to control the remote environment by establishing a dialogue between human and the robot. Wang, B., et al. [38] presented a mobile humanoid robot platform which is able to understand humans' speech commands in teleoperation environments and showed that proposed voice control method makes the robot more intelligent and user-friendly.

Cossell, S., et al. [8] used a Kinect camera coupled with a compression algorithm to stream a forward facing 3D range image to a remote operator who uses it to drive a mobile robot. They demonstrate how a Kinect data stream can provide a remote real-time 3D visualisation of an environment that can be used for remote teleoperation of a mobile robot.

3. Sensors

The mobile robot can be equipped with a variety of sensors, wich can be classified as follows:

- *proprioceptive* sensors - measure values internal to the system (robot);
- *exteroceptive* sensors - acquire information from the robot's environment [35].

The sensors capture data from the surrounding environment and send them to operator over the communication channel, so that he can understand what happened in that place and can decide what to do next. In [28] are presented the main types of sensors proposed in literature for mobile robots. They are divided in two groups: internal and external sensors.

Visual sensors are very popular in telerobotics because they can provide a large amount of information about the remote workspace. Many researchers have used visual sensors in their works. Han, S., et al. [11] used a CCD camera to teleoperate a mobile robot. Kenyon, S.H., et al. [15] used a CMOS camera as a primary sensor for a reconnaissance robot, while Shin, H.C., et al. [34] proposed a stereo vision process on FPGA with two CMOS cameras to obtain the disparity image.

In order to create the three dimensional mapping of the environment, Bernshausen, J., et al. [5] showed the advantages using a combination between a 3D PMD camera and a normal CCD camera. The PMD (photonic mixer device) camera is a 3D measuring system, which is based on a time-of-flight principle.

Sonar and laser sensors are most commonly used to measure the distance from an obstacle, providing information about object surrounding the robot.

Livatino, S., et al. [20] proposed an alternative to the use of video technology in robot teleoperation, represented by the use of laser sensor technology and also compared this two technologies in terms of performance.

Linda, O. and Manic, M. [19] introduced SOFAMap, an algorithm developed for a rotational sonar sensory system to alleviate some of the deficiencies of the traditionally used multisonar array.

Sasaki, Y., et al. [32] described a tele-operated mobile robot system which can perform multiple sound source localization and separation using a 32-channel tri-concentric microphone array.

4. Communication

To achieve a functional teleoperation system, communication between robot and operator must take place under optimum conditions and information provided must be of good - quality.

There are a variety of possibilities to communicate with a remote location today: transmission lines, radio waves, wireless, infrared. In the past years wireless communication was preferred due to its advantages like: mobility, low cost, easy installation etc.

Ahnn, J.H. [2] used two kinds of communications to remotely control a mobile robot: one for wireless communication between the robot and a remote Base Station, another for serial communication between the remote Base Station and a GUI Application, PC.

4.1. Internet

The Internet is a good media to control systems from distance and teleoperation over Internet have been widely used.

However, the Internet has a number of limitations, such as restricted bandwidth, arbitrarily large transmission delays, delay jitter, and packet lost or error [30].

Many researchers developed systems that operate through World Wide Web. Moutaouakkil, F., et al. [25] presented a new architecture for remote control formed by an intelligent and distributed architecture based on the multi-agent aspect. They summarized some robotic systems and interfaces used to control devices via Internet.

Time delay is the main problem in Internet communication and many techniques have been proposed to compensate this effect.

Azadegan, M., et al. [3] presented a delay-independent robust stability criterion for teleoperation system which is independent of network’s time-delay and any admissible uncertainties.

Zou, Z. [39] also mentioned the time delay problem and showed some techniques used in literature. The author studied the controller design for the wheeled mobile robot (WMR) and unmanned aerial vehicle (UAV) haptic teleoperation over the Internet.

Lee, D., et al. [16] proposed a novel haptic teleoperation control framework for multiple unmanned aerial vehicles (UAVs) over the Internet, consisting of the three control layers. Their goal was to enable a remote human user to teleoperate N UAVs via a single master haptic device over the Internet.

4.2. Wireless technologies

Seo, Y., et al. [33] used Bluetooth communication to transmit data between the mobile robot and a smart phone. Other researchers used Zigbee technology [29].

Mobile telephony has improved greatly in recent years and it is able to provide data transmissions. Montúfar-Chaveznava, R., et al. [24] presented a simulation system to control a Pioneer mobile robot with a cell phone, using phone tones or by sending text messages.

Ryu, J.G., et al. [31] proposed a robot that can be operated and conduct surveillance of the environment around itself anytime/anywhere using wireless communication networks such as CDMA (Code Division Multiple Access) Networks.

Shin, H.C., et al. [34] used wireless LAN (IEEE 802.11g) to teleoperate a gesture recognition mobile robot.

The GPRS network can be used in teleoperation to transfer data because it has some needed characteristics, like mobility and wide coverage [22]. The operator can control the mobile robot from large distance through a mobile phone with an Internet connection.

Mufioz, N.D. [26] presented a strategy for using the cellular network, and specifically the general Packet Radio Service, to teleoperate a mobile robot.

5. Virtual and Augmented Reality

Virtual and augmented reality techniques are becoming widely used in teleoperation because they can improve the operator efficiency in robot manipulation. One of the most important reasons for using this techniques is related to the notion of immersion, which means that the operator feels like being physically present in the remote environment. He also can interact with the objects and navigate through that space. Augmented reality is used to enhance the feedback information, so the operator can more accurately interpret the received data.

Stereo visualization is an important element for immersion. Stereoscopy technique gives the impression of depth, so the human operator can see objects like they have three dimensions. There are a lot of display systems with 3D visualization, presented in [28].

More studies show how stereoscopic viewing improved performance, providing advantages for operators such as: a higher depth perception and so an increased sense of presence, better distance estimation, and obstacles perception accuracy [6], [20].

Martins, H., and Ventura, R. [21] proposed a teleoperation methods using a head mounted display (HMD), so the operator is capable of perceiving rectified images of the robot world in 3-D, as transmitted by a pair of stereo cameras onboard the robot.

Tang, X. and Yamada, H. [37] presented a control system of a teleoperated robot used in constructions by introducing virtual reality technology and adding a virtual space display using computer graphics.

Lera, F.J., et al. [18] showed how augmented reality interfaces can improve the performance of operators controlling a mobile robot. They have made experiments with 8 peoples with no previous experience tele-operating robots and they took into account some parameters like: time to do the exercise, precision, distance traveled to destination.

6. Conclusions

In this paper, a state-of-the-art based on the various applications of teleoperated mobile robots is presented, looking at the area of control, sensors and communication methods that are available today.

The purpose of this study is to highlight current progress in teleoperation of mobile robots and to be a base for future research that will be performed by the authors for development of a new system to teleoperate mobile robots.

Authors will propose a multi - modal interface for teleoperation of a Pioneer 3 DX mobile robot. The operator achieves the control of the remote mobile robot by means of a virtual robot, which navigates in a virtual environment.

The new system must improve the operator perception of the remote environment by providing video and force - feedback. Using augmented and virtual reality techniques, he will have a better control over the real robot, which will performed specific tasks, according to human needs.

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