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A teleoperation system to remote control robots

Abstract

This paper describes a master-slave teleoperation system that is developed to evaluate the effectiveness of using computer networks to control robot manipulators. The system is designed to examine different hardware and control techniques to develop and improve intuitive user interfaces for the natural control of the manipulators. In the presented system, a Cartesian manipulator, very popular in various computer controlled devices (e.g. CNC machines, 3D printers, etc.), is used. The versatile system configuration allows us to use different devices as master controllers – from standard computers to mobile devices and haptic tools.

Keywords: teleoperation, telepresence, robots, manipulators, Cartesian manipulators, haptic technology.

1. Introduction

Teleoperation is a common technique used in robotics. The first robotic machines were only constructed to give the possibility of performing operations at a distance. It is commonly assumed that the first such machines were manipulators developed by the Goertz group in the late 1940s at the Argonne National Laboratory [1]. The pioneering manipulators were designed and constructed to handle highly radioactive materials safely. They were used in the Manhattan Project – the construction of the first atomic bomb. Goertz's manipulators are classic examples of master-slave robotic systems. In other words, such manipulators (i.e. the slave part of the system) are controlled by overriding devices (i.e. the master part). The direction of control is always from the master unit to the slave one. In the first constructions, the slave and master units were mechanically or electrically connected.

Today, such controlling configurations can be realized in other forms [2]. Almost all modern robotic manipulators are controlled by different computer systems. Many of them are directly connected to computers that are interfaces between robotic systems and their human operators.

Such configurations allow only for building short distance teleoperation systems, which are highly unsatisfactory in many cases. As we well know, today computer networks are ubiquitous. Of course, it is natural to use computer networks to build long-distance teleoperation robotic systems. In practice, each such system has the following architecture. The manipulator is equipped with a computer to control the servos of the robot. These elements (i.e. the robot manipulator and the computer) form the slave part of the system, which can be linked through a computer network to a master controller. The master controller is a computer that ensures the interaction between humans and the robotic system. This architecture can be used both in long- and short-distance teleoperation systems. This is a very convenient solution because the master controller can be equipped with an operation system that is completely independent from the used one in the slave part of the system. The term "Master-slave" is also well-known in computer networks. In computer networking, "Master-slave" is a model of communication protocol in which one device or process (known as the master) controls one or more other devices or processes (known as the slaves). Today, more often various hardware and bilateral algorithms are implemented to ensure different forms of feedback control in teleoperation robotic systems. For example, haptic technology [3] was introduced to achieve force feedback. Of course in almost all systems, standard multimedia tools and techniques are also used to transfer visual feedback information from manipulator workspaces to operators. All these technologies are integrated to give the impression of telepresence in workspaces of the remote-controlled robots.

The robotic system described here is based on the master-slave architecture using computer networks, different master controllers and the aforementioned technologies to improve the skills of human operators who are located in faraway places.

2. Cartesian manipulator system

A Cartesian manipulator is a machine whose 3 principal axes of shift are at right angles to each other. The end effector of the manipulator moves in a straight line along each axis (x, y, and z). The manipulators of this type are the most common. They are used in CNC machines (Computer Numerical Control) as well as in 3D printers. The simple Cartesian manipulator uses 3 mutually independent servos. In the described system, 3 stepper motors are used as the servos. For almost all non-Cartesian coordinate manipulators, robot kinematics are usually very sophisticated, especially inverse kinematics [4]. Simplifying the problem, robot kinematics are a solution of the relationship between the servo positions and the position of the end effector of the manipulator. The solution is needed to plan and control movement of the end effector of the manipulator. The solution of the inverse kinematics of the robot allows one to calculate the parameters of servos to set the end-effector of the manipulator in the desired position in space [5]. The great advantage of the Cartesian manipulators is very simple kinematics. Programmers do not have to code any routines that implement complex mathematic equations. In practice, programmers should know only one factor: a number of steps of the motor per millimeter of movement. The manipulator of the described robotic system is displayed in Figure 1.

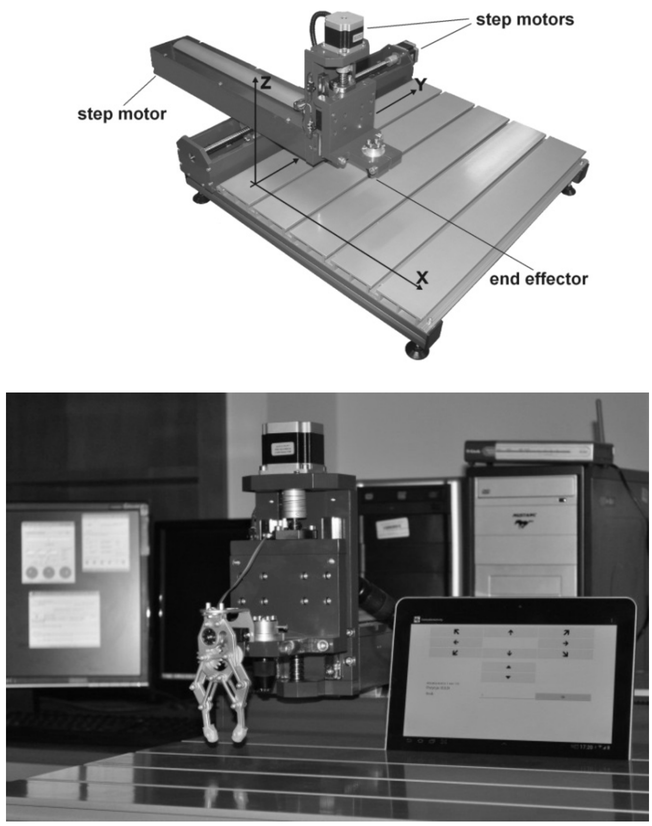


Fig. 1. Cartesian robotic manipulator

The manipulator motors are driven by a special controller equipped with 3 hardware drivers – see Figure 2. The controller is linked to the PC by LPT port; the LPT standard is still widely used in CNC machines. The interfaced computer (PC) is based on the Windows operating system.

The principle of the presented system is very simple. Current pulses from the motor controllers are applied to the step motors, and this generates the discrete rotation of the motor shafts.

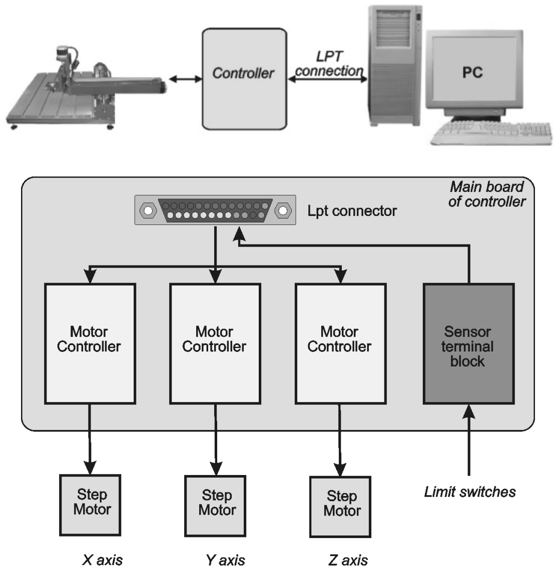
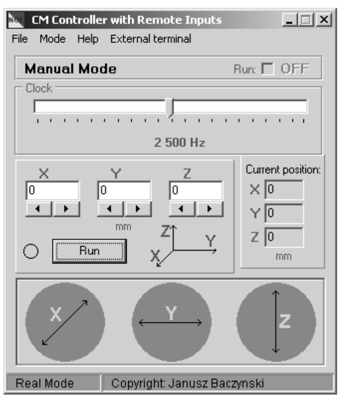
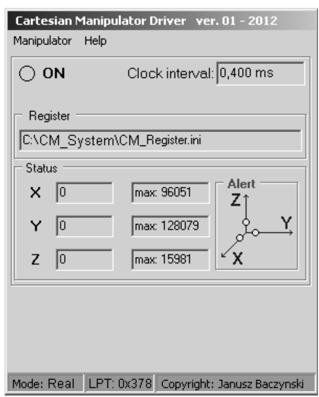


Fig. 2. Hardware configuration of the Cartesian robotic system

The motor controllers are stimulated by electric signals generated at the LPT output of the PC. The controller includes several inputs to read signals from limit switches, which are used to limit the workspace of the manipulator. The special software was devised to elastically control the manipulator in different ways. It consists of many different modules contained within separate files. Most of them are dynamic link libraries (DLL).



Application



DLL module

Fig. 3. Windows of the basic software modules dedicated to control the manipulator

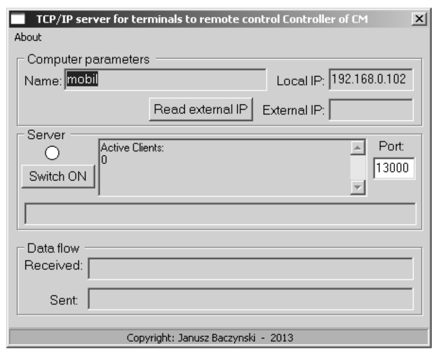
The basic module is named Cartesian Manipulator Driver. It generates signals to the controller via the parallel port LPT. The module has its own screen window for monitoring positions of the manipulator – see Figure 3. A separate program thread is dedicated to the controller timing. The timing is based on a high-resolution counter of the PC operating system. The Windows API includes a QueryPerformanceCounter function, which retrieves the current value of the high-resolution performance counter. In this way the elapsed time can be simply measured with an accuracy of microseconds [6]. In our system, the controller can be clocked by the LPT port with the frequency up to 10 kHz. This clock frequency of the stepper motor signals provides the speed of movement of up to 30 mm/s.

Generally, the Cartesian Manipulator Driver is always linked to the module named the CM controller. The CM controller is the application that can be a simple user interface. It allows one to move the manipulator end effector to the desired position using a mouse or by means of numerical coordinates entered in the appropriate edit boxes. The CM controller has a special option. It is able to link a DLL module that is the so-called external terminal of the controller. In other words, the external terminal can get remote access to the CM controller instead of the user. Figuratively, we can say that the external controller “can enter numerical data and click on the buttons in the window of the CM controller”. In this simple way, the various control modes and technologies can be realized.

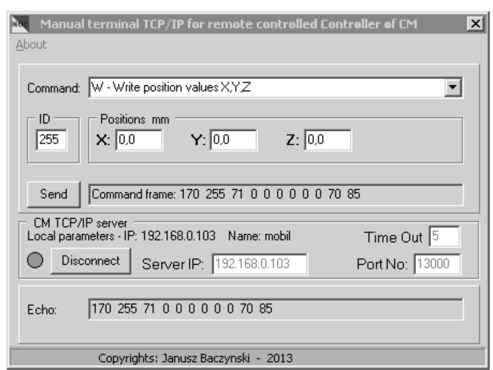
3. Teleoperation mode

A specially designed TCP/IP server is one of the basic versions of the external controller. The custom library can be linked to the CM controller and, in this way, the CM controller can respond adequately to requests sent from client applications. The server is able to recognize 8 commands needed to handle the controls of the window of the controller.

The presented mode of the work (see Figure 4) is the typical “master-slave” configuration, because the commands are sent in the direction from the master (client application) to the slave (server application). Of course the slave unit can send feedback information, but only for requests from the master unit. Both parts of the teleoperation system can be connected via a network (local or internet, wired or WiFi). In this configuration, there is no limit on the distance between the robotic manipulator and its human operator. The client application can be developed for any operating system. For example, the simple user interface has been designed for Android mobile devices – see Figure 1.



server application – DLL



Client application

Fig. 4. The client/server configuration to remote control the Cartesian robotic manipulator

One of the main problems in the control configuration is a time delay. Of course, the time delay occurs in every control system, especially in electro-mechanical systems. There are many reasons why this may occur in the described system. We can divide these reasons into 2 groups: “effects of electro-mechanical system” and “effects of computer network controlling”. In practice, for local area networks (LANs), the effects belonging to the second group are not noticeable. In the case of teleoperation over the Internet, the effects cannot be ignored [7–8].

We mainly focused on the problems connected with using the described system in the LAN: they are also present in remotely controlled systems with very large distances. An ideal tele-manipulator just like any master-slave system should execute all operations according to commands received from an operator. In other words, the manipulator should follow/replicate the movements of the human operator – directly or after proper transformation. It can be realized only by using a feedback loop. As mentioned before, our slave unit can send feedback information to the master part of the system. The information includes the current position of the tip of the end-effector. Also, the slave unit is able to send automatically an appropriate message about the result of the last operation. These data can be used differently. First of all, they are displayed in the screen window of the Cartesian Manipulator Driver – the data are represented numerically and graphically.

Such feedback can be described as “visual” only. Of course, it can be supplemented by an image from a video camera. This is the absolute minimum provided by almost every modern tele-operator or tele-presence system. However, using a force feedback is usually a good way to provide a more intuitive control of the manipulator. The force feedback technology is also widely used in different computer games, because the implementation of this technology allows one to develop applications with very intuitive interfaces [9–10].

Today, there are many tools to implement the force feedback mechanism. In the described system, we have used very well-known Phantom Omni® haptic device [11] – see Figure 5.

Fig. 5. The Phantom Omni® haptic

In our implementation, the haptic device has 2 roles. First, it is a convenient 3D joystick. Secondly, it generates a feeling of touch to the hand of the operator. Now, the adequate client application is still being developed for the haptic tool to control the manipulator also through the sense of touch. The 3D joystick allows one to control the manipulator with more freedom and a natural one-handed manner. Generating the respective forces to the hand allows one to feel virtual or real objects. The basic elements in the description of each workspace are its boundaries. The boundaries can be mapped by virtual walls. The creation algorithm of such virtual walls is relatively simple for the Cartesian manipulators: the workspace is linear. The use of the mechanism of the virtual walls reduces hand movements to within the allowed range.

4. Conclusions

The main aim of this work was to develop the master-slave tele-robotic system based on computer networks. The system is a multi-platform work environment to practise studying many different aspects of tele-operation robotic systems. For example, these studies include aspects such as the suitability of the described system for e-learning [12]. Furthermore, the system has the capability to research different algorithms for manipulating the robots at a distance with constant or variable time delays.

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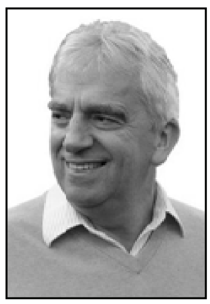

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