A TELEOPERATION EXPERIMENT TO CONTROL THE "PLATE AND BALL"

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Abstract: The paper presents an experimental setup, for a teleoperation experiment. It contains a physical controlled object and all the server and client software required to local or remote control of this object (through the Internet). The objectives are to share the teaching and research resources and to create a challenging control problem, i.e. control of unstable processes, with variable deadtime in the loop. The main result is the remote control system, satisfying the above mentioned objectives.

Keywords: teleoperation, Internet, control, deadtime, communication software.

1. INTRODUCTION

The paper describes an experimental setup, designed to remotely control a physical object ("plate and ball"), through Intranet or Internet, by students and researchers. The teleoperation experiment has two interesting properties: it can be remotely controlled (for teaching puposes and for sharing the research resources) and introduces some major difficulties in designing the controller, due to the behaviour of the network in the control loop (unknown and variable deadtime). Some other papers described previously such remotely controlled objects, used for teaching (Frangu and Chiculiță, 2002), (Chiculiță and Frangu, 2001, 2002). The controlled objects were stable slow processes, which are not significantly influenced by the network delay. In the present case, the controlled object is faster (values of time constants about hundreds of miliseconds), multivariate and unstable. This creates a very challenging control problem, for higher level than for undergraduate students in control.

The paper is organized as it follows: chapter 2 presents the experimental setup, chapter 3 presents the structure of the software, chapter 4 presents the possible experiments and some control issues, important for the purpose of this experiment. Chapter 5 presents the experimental results whereas the last chapter contains the conclusions and some ideas for further work.

2. DESCRIPTION OF THE EXPERIMENTAL SETUP

1.1 The mechanical part of the object

The experiment "the plate and the ball" is a frequenly used experiment for teaching the automatic control subject. The setup itself is composed of two rectangular rigid frames, assembled in a support-box. The frames have slightly different dimensions, such as the smaller one to be inside the larger. One of them rotates around the Ox axis, the other rotates around the perpendicular Oy axis, independetly with respect to the first. The frames are driven by two servomotors, controlled by a microcontroller. The latter receives the commands from the external world (from the automatic controller, synthesized by the researcher). A small sphericall ball can roll on the plate covering the internal frame. The purpose of the control action is to drive the ball to and to maintain it in the desired positiond. Accordingly, a control problem for an unstable, two variable system has to be solved.

The schematic structure of the frames is presented in figure 1. An image of the mechanical part appears in figure 2. The microcontroller circuit, controlling the servomotors, is presented in figure 3.

Some parameters of this part are: The actuators are standard servomotors, with a maximum torque of

3kg.cm, directly connected to the rotating axis. They are able of driving even larger boards. The step of the servomotor is 0.7 degrees, and the transient speed is 0.18 Sec/45°. The ball is 10mm in diameter and it weights 10 grams. The frames allow rotations of maximum 8 degrees on each axis.

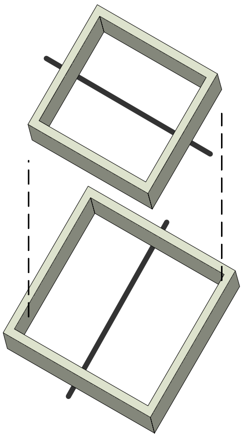

Fig. 1. Mechanical structure of the frames

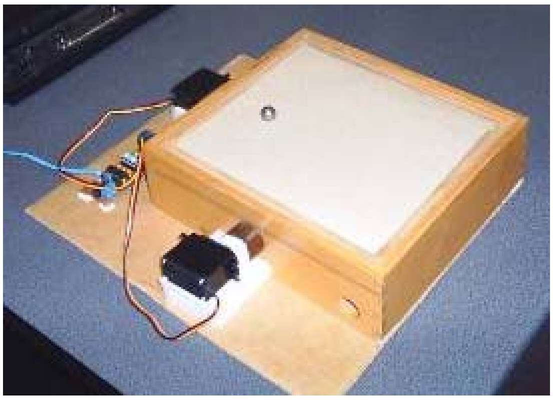

Fig. 2. The controlled object „plate and ball"

1.2 The computing part (hardware)

In order to control the object, the experiment needs a controller and a position transducer. In the simplest variant, both are performed by the human operator (manual regime). In this case, the command is transmitted to the servomotors through a joystick. For automatic control experiments, the roles of the controller and of the transducer are played by a computer and a video camera. For good image reasons, the surface of the plate has to dispersely reflect the light. It is not shiny, avoiding the patches of reflected light that could appear on the image. The USB connector of the camera is linked with the corresponding connector of the computer. The computer sends the commands to the microcontroller through the serial link. The commands can be provided by a local joystick, by a software implemented local controller or may be received through the network, from a client computer (Intranet or Internet). In this case, the local computer is connected to the network and it has the role of the server. The hardware structure is presented in figure 4.

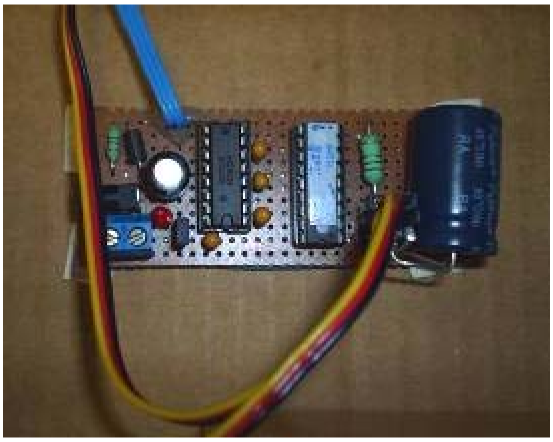

Fig. 3. The microcontroller

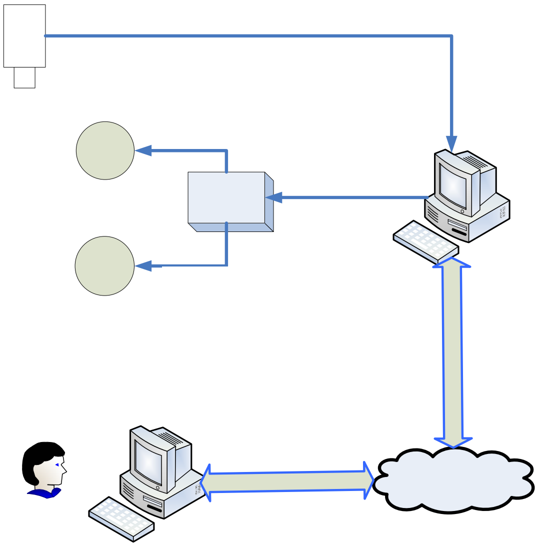

Fig. 4. Hardware structure „plate and ball"

Some technical parameters: the computer is PIII, 500MHz, endowed with USB, RS232, Ethernet. The command for the servos is assured by a PIC16f88 microcontroller interfaced to the PC through a MAX232 adapter. The image is captured by a Philips video camera running at 20fps, resolution 320x240.

3. DESCRIPTION OF THE SOFTWARE

The software is composed of three parts/modules:

1. Embedded software
2. Server software
3. Client software

The embedded software is running on the microcontroller attached to the platform. It is written in assembler and controls the two servomotors by means of PWM commands. The reference for the motors is received from the PC through the serial link. The expected packets are 4 bytes long containing a header, two position bytes, one for each servomotor, and a checksum.

The server software is running on the computer connected to the controlled physical device. Its functions are to acquire and process images from the camera, perform network communication and send the commands to the platform (references to the servos). The image is acquired from a USB webcam and depending on the selected mode, one of the following is done:

a) The image can be compressed in .jpg format and then sent through Ethernet.
b) The image can be processed on the server in order to recognize the position of the ball; then the coordinates only are sent through Ethernet.

The position of the ball is obtained by taking the image from the camera; in this experiment the surface was chosen white, and the ball is metallic, of a darker color. The ball is recognized as being the only dark object on the image. Even if the ball (in this case) is metallic and could reflect light, the reflection gives a white spot that is inside the dark contour that is elliminated using morphological operations.

Some attributes of the server depend on the type of the experiment. In local manual control experiments, the server has to capture the position of the joystick or mouse. In local automatic control experiments, the server hosts the controller. In remote automatic control experiments (Intranet or Internet) the server performs the communication only, it is the client who runs the controller.

The server software performs communication by means of UDP sockets. This type of communication was chosen versus TCP, because of the following reasons:

- UDP offers faster delivery times because it does not perform retransmissions;
- the packets are self-contained (independent of one another)
- the size of the packets is less than the maximum limit of the UDP packets of 64 Kbytes (the largest packet is the one containing a jpeg image, that is less than 30 Kbytes). If data packets larger than 64k are needed to be sent then using UDP could be more problematic that the use of TCP.

The communication with the platform is performed through an RS232 serial connection, which transmits the reference to the servomotors only.

The client software is a standalone application that communicates with the server using UDP. The client receives packets containing the image captured by the server or the coordinates of the ball as the server identified them. Either the image or the position of the ball is displayed to the user. The user interacts with the application by moving the mouse over the displayed image. If the mouse is centered in the middle of the image then the plane is horizontal; the angle of inclination of the experiment surface is given by the displacement of the cursor from the center of the image. The position of the mouse cursor is then sent to the server.

4. CONTROL ISSUES

As previously mentioned, the purpose of the controlled object is to allow remote experiments (teleoperation), in the field of automatic control. Similar software and hardware may be used for other kind of experiments, as in (Popescu e*t al*, 2002, 2003). For the sake of concretness, this chapter treats the control subject only.

Manual control is useful for a human operator that wants to learn how to control the unstable system, for instance for the researcher who has to design later a fuzzy controller. It is also useful for training or for verifying the abilities of the operators. The loop includes the controlled object and the human operator. The computer is still necessary, but it is used for transmitting the joystick command only. Both feedback and control algorithm are performed by the natural poperties of the operator.

The automatic control has teaching or research purpose (a multivariable control problem). Disregarding the placement of the computer running the control algorithm, the loop contains (at least) the controlled object, the video camera and the server computer. If the control is remotely performed, the client computer and the communication network are included in the loop as well. The main difference between local control and teleoperation is the propagation time through the communication channel, which is neglectable in Intranet but higher and variable when using the Internet. This time appears in the loop as a variable deadtime and it is the most important challenge to the control problem. The deadtime is not known *a priori*, it can only be estimated within a certain delay. However, its statistic properties may be determined, using the records, as in the example presented in figure 5 (from Oboe and Fiorini, 1997). The statistics can be exploited by the control algorithm.

Both control variants (manual and automatic) are supported by the teleoperation (remote) system, because different stages of the experiment will provide different pieces of information. The remote manual control, compared with the local manual control, will underline the effect of the communication channel propagation delay. The automatic control requires the use of multivariable control algorithms, together with variable deadtime compensation algorithms. This is the reason why the control problem adresses not only undergraduate teaching activities, but master or PhD activities as well.

According to the previous descripton, the laboratory experiments that can be carried on with this object are:

- local manual control (or Intranet);
- local automatic control (or Intranet);
- remote manual control (Internet);
- remote automatic control (Internet).

The camera is necessary in most of the experiments, but in local manual control.

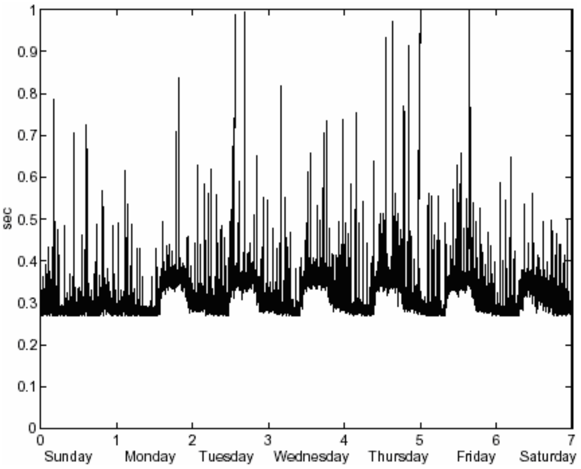

Fig. 5. Record of the network deadtime, from (Oboe and Fiorini, 1997)

5. EXPERIMENTAL RESULTS

The controlled object and the software were put together in a teleoperation experiment. The main result to be reported is the possibility to control the platform, both locally and remotely, through Intranet and Internet. It proved to allow both manual and automatic control. In short time, the human reaches the ability of controlling the experimental setup, in local manual control experiments. In teleoperation experiments, the server accepts the commands issued by the client and controls the movement of the platform. However, the control performance was not satisfactory, because of the variable deadtime. The delays that contribute to the value of the deadtime are presented in Table 1. It is obvious that the network propagation time (Internet) is the main contributor, creating the difficulty of the control. Its behaviour is similar to that presented in figure 5.

Table 1: Delays present in the loop (ms)

Camera acquisition	20
Image transmission	20
Video processing	20
Round-trip Internet delay	0..300
Serial link	1
Servo command	20

6. CONCLUSIONS AND FUTURE DEVELOPMENT

The presented experimental setup is able to remotely control the position, in manual or automatic control experiments. It allows to experiment a very challenging control problem, when a variable deadtime is present in the loop.

Future developments:
- changing the server software to be able to function as a http server and make the client run directly from a browser, without the need of an external applications of plugins;
- introducing a new transmission protocol, able to reduce the global deadtime in the loop;
- adopting different control algorithms, able to cope with the variable deadtime.

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