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Design and Control of a Two Degree of Freedom Teleoperated Manipulator

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Abstract. This paper deals with the problem of position-tracking of bilateral teleoperated manipulators ,especially that performs difficult and critical tasks such as under water works usually done using ROV manipulators. A workspace-control system was developed to aid the operator in controlling and driving the slave manipulator .The proposed control technique referred to replacing tradition, master robot that was used for human input commands, with workspace station, consisting of a computer , mouse or joystick as an input device. A wireless UDP network was held between the master and slave manipulator . A PD controller with two different software architecture were applied. We proved experimentally that with parallel executing of two loops in the software architecture, we could achieve total delay time in the system around 90 milliseconds and get a good position tracking of the slave manipulator with system stability even with presence of network delays .

1. Introduction

Teleoperated manipulatoris a robot ora manipulator that is controlled remotely by a human operator. A teleoperation system usually composed of a master station , slave robot, and a communication channel to passing data between the two systems. Slave robot usually located in the task area, which could be unreachable or hazardous area for human operator. Master station or system is placed at the operator site .Teleoperation is utilized in wide variety of applications such as under water tasks, telesurgery, space exploration handling of radioactive sources in reactors [1-3].

As data is transmitted over the delayed network channel between the master and slave subsystems, a time delaysalways causes a serious problem that can destabilize stable system oraffecting the tracking performance of the whole teleoperated system [4-6]. Many researchers proposed different control methods to solve the problem of time delays ,and to enhance the tracking performance. These approaches have been reviewed in [4 , 7]. One of the common control schemes are the PD (proportional derivative) [8]. Also, more advanced approaches are proposed todeal with the uncertainty in teleoperation systems, such as robust control, adaptive control, and other control schemes [9-14].

Most teleoperation works depend on operator's skill. The operator's effort is higher in special works when the slave environment area is hard and had many hazards or with poor knowledge like under water tasks with ROV manipulators. Under water tasks, or tasks that require two degree of motion at same time i.e. linear motion control with constant orientation. The operator usually controls the slave joints, as well as orientation of the end-effector. So, the manipulator's control is not easy, even if the operator is an expert.

This paper presents a computer-based master control system to solve the problem of performing a difficult teleported task, and achieve good position tracking of slave manipulator under delayed networks .The new master system consisting of a computer ,mouse ,or joystick as an input device . The new system enables the operator to control the slave manipulator in workspace not in joint space.In addition, the workspace-control system provides the operator with a virtual simulated graph of slave manipulator. A PD controller with enhanced scheme for a UDP wireless communication channel has been implemented to develop the teleoperation system and the system performance areverifiedby experiments.

2. System descripetion

2.1. The slave manipulator

The slave manipulator which used in implementing the system is a SCARA robot (Selective Compliance Assembly Robot Arm). Many researches proposed to achieve the precise control of SCARA robot[14 ,15].In the experiments we fixed the vertical arm and performed the experiments on only the waist and elbow links (Axis1,Axis2).

2.2. The master device

Not like most of teleoperated systems that have a master manipulator used for generating angles commands and simulating feedback forces on slave environment ,we introduces alternative master system called (workspace control system).This system replaces the master manipulator with a joystick for input commands, and a computer for solving the forward and inverse kinematics of the slave arm . Then the controller calculates motors torque for each joint and send to slave local controller over the wireless network communication channel. The slave controller then controls the slave arm joints motors and returns the posture of the slave arm back to the master computer, which displays the slave arm status graphically.

2.3. Network media and protocol

In our setup we implemented a UDP (User Datagram Protocol) wireless network .Teleoperation system using UDP protocol is a better solution , as it does not require long acknowledgments packets , shorter timeouts , and shorter data frames . This makes UDP protocol faster than TCP/IP. With the choice of preferring fast communication over guaranteed data delivery, the problem of data packets loss appears, whichis considered a common problem in any digital network. Among the three common policies always applied when data packet is lost,we count on "using previous data packet" .

3. Control algorithms

It's known that, the trajectory tracking of the robotic systems is the best method for testing any control algorithm, and for a teleoperated delayed system, it was proven that its stability is highly dependent on system delay time [1].So, a model free PD control algorithm has been applied. Butwith different software and networking architecture, which reducestotal system delay time. These algorithms areshown in figure (1,2). In the first algorithm the PD controller, and the communication processes were in one loop, so the communication performance was affected by the time consumed in the controller calculations. This affects the controller performance and system overhaul delay time. In the second algorithm we made two different loops in the program work simultaneously. One for communication process and the other for whole controller calculations, inverse and forward kinematics, input device interface, and visual displaying .This reflects positively on the controller performance, stability ,and system delay time .All software programs are developed using Labview programming language.

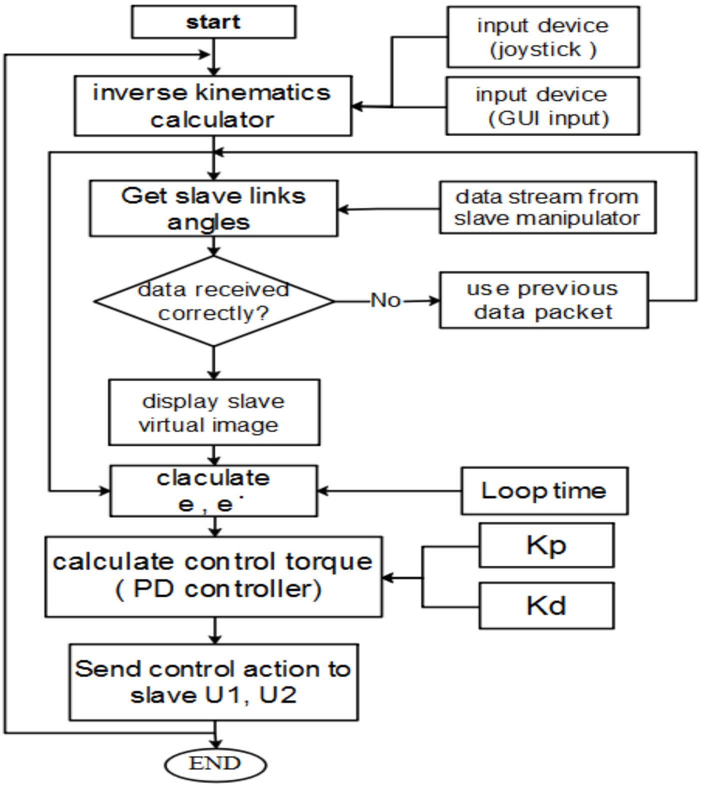

Figure 1. One loop software architecture

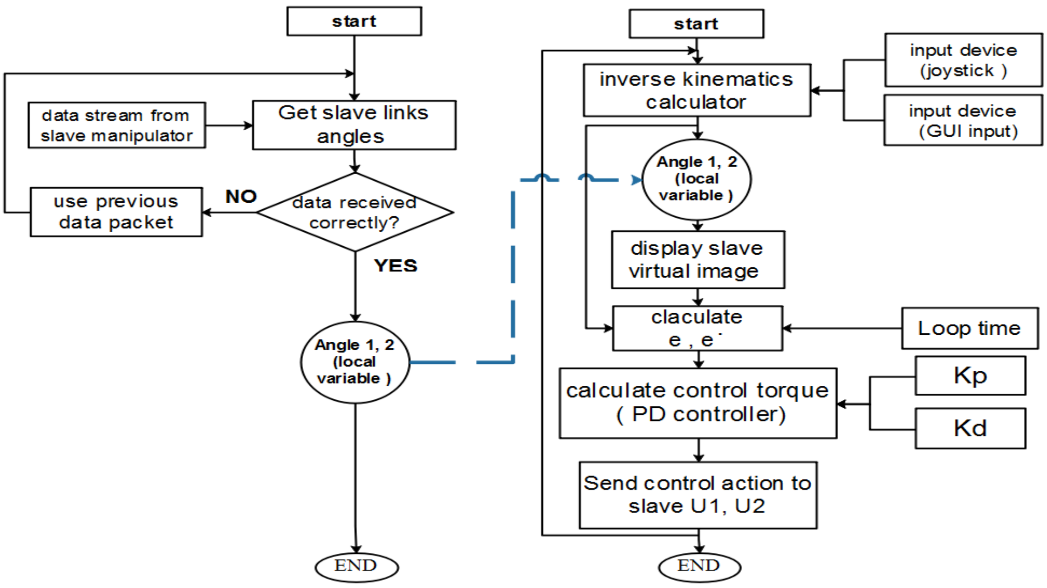

Figure 2. Two loops software architecture

4. The PD controller

The goal of the PD controller is to get a good tracking of slave manipulator with the operator input commands. For the two link used from SCARA robot the following parameters of joints are considered $\theta = [\theta_1\ \theta_2]$, where$\theta_1$ is the angle of joint1 and θ_2 is the angle of joint2. And considering the state variables asθ (t) and$\dot{\theta}$ (t). and the tracking error vectors are e(t) and$\dot{e}$ (t) as:

$$e(t) = \theta(t) - \theta_d(t) \quad (1)$$
$$\dot{e}(t) = \dot{\theta}(t) - \dot{\theta}_d(t) \quad (2)$$

Whereθ_d and$\dot{\theta}_d$ are vectors of the desired joint position and velocity, respectively.
The motors control torque for the PD controller is defined by:

$$U(t) = K_P e(t) + K_d \dot{e}(t) \quad (3)$$

WhereK_P and K_d are the proportional and the derivative gains of the controller, respectively. The block diagram of the bilateral teleoperated PD controller is shown in Figure 3. it is different from traditional PD control block diagram , as we can see intermediate block representing the delay times in the way to and from the slave manipulator (T_{in} ,T_{out}). These delays decrease the values of the constant control gains of the system. These gains should bekept within theiraccepted amount, as if they passes the critical limit the system becomes unstable. These values of gains are usually experimentallydetermined.

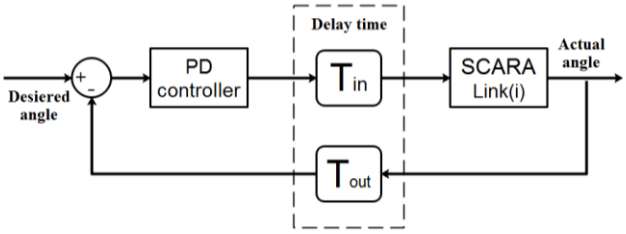

Figure 3. Bilateral telemanipulation block diagram.

5. Experimental results

The experimental results of the PD bilateral control algorithm are shown in this section , the different software and communication schemes performance will be compared, and the total average system delaysare computed. In the experiments, the controllers are tested with a sign wave input, and a step input signals. As mentioned earlier, experiments are performed on only two links, axis1, and axis2. A sinusoidal input trajectory with amplitude of 57.3° or1.0 rad, and a frequency of 0.16cycles/Sec was applied to all control algorithms. The desired trajectory becomes : $[\theta_d = \sin(0.16 * 2\pi t)]$for each joint.

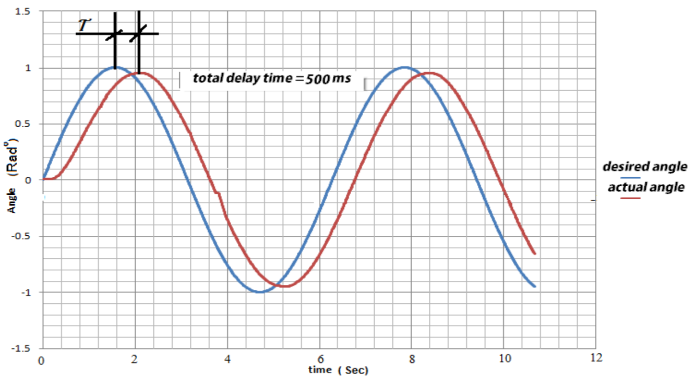

Figure 4. The trajectory tracking of PD controller with first scheme

The trajectory tracking of PD controller with first scheme is shown in Figure 4. In this Figure, The blue line describes the desired trajectory and the red line describes the actual trajectory. The proportional and derivative gains used in the experimentare 2 ,8 respectively. In Figure 4.we can see the lag between input and output signals, or we can called it sent wave and reflected wave . The total delay time between them was nearly 500 milliseconds. As the desired and actual angle measurement logged at master computer side, also assuming equal communication delay time for sending and receiving, so the actual delay time between master and slave time was (total delay time /2 = 250 ms). It is shown that the system is stable and tracking has been achieved with reasonable error and actual delay time round 250 milliseconds. A step input response of 1 rad for the first scheme is shown in Figure5 , shows a total delay time near 400 milliseconds..Figure 6 shows the trajectory of PD controller with second algorithm The blue line describes the desired trajectory and the red line describes the actual trajectory. The proportional and derivative gains used in the experiment are 2 and 8 respectively.

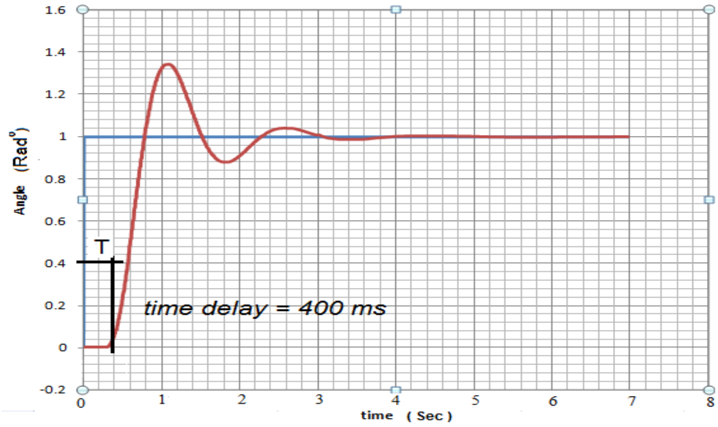

Figure 5. Step response for the first scheme

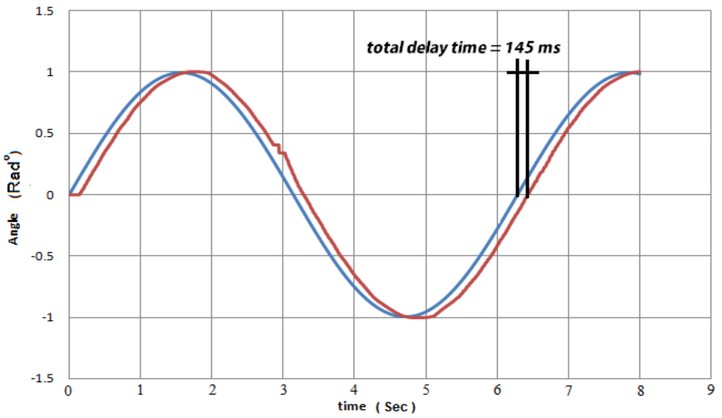

Figure 6. The trajectory of PD controller with second algorithm

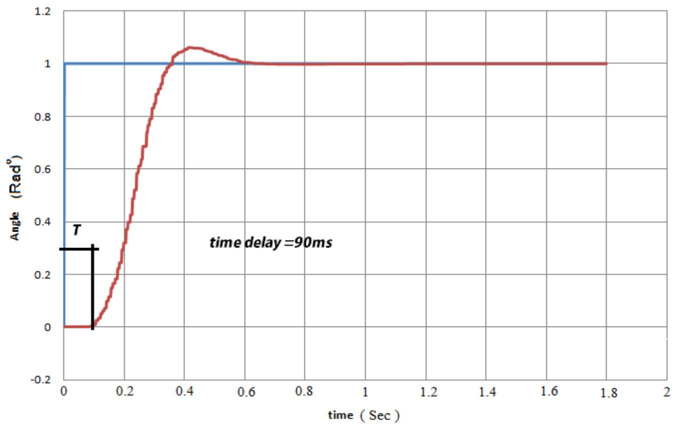

Figure 7. A step response for the second scheme.

As seen in figure 6 the total delay time was nearly 145 milliseconds. So the actual delay time between master and slave time was (total delay time /2 = 73ms) . It is shown that the system is stable and tracking has been achieved with reasonable error and actual delay time round 73 milliseconds. A step input response test for these scheme is also shown in Figure 7.It shows total delay time near 90ms .

6. Conclusion

A workspace control technique and PD controller with two parallel loops software architecture for simultaneous execution of the program tasks is developed to solve the problem of remote manipulation of critical and difficult teleoperated tasks that needs high precision and tracking of the slave manipulator under predefined path with fixed orientation. Thiswas very difficult before with joint space technique even with good trained and experiencedoperators. The developed system has achieved a good tracking characteristics and provided robust stability against network delays . Also we enhanced the communication channel between master and slave performance ,and achieved total delay time in the system round to 90 milliseconds .We used mechatronics laboratory SCARA robot as a testing platform, and the experiments done with only two joints. The ROV manipulation could be a good real industrial application ,where the operator will benefit by the new workspace and computer aided technique in performing critical underwater tasks..

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