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A remote handling rate-position controller for telemanipulating in a large workspace

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ABSTRACT

This paper presents a new haptic rate-position controller, which allows manipulating a slave robot in a large workspace using a small haptic device. This control algorithm is very effective when the master device is much smaller than the slave device. Haptic information is displayed to the user so as to be informed when a change in the operation mode occurs. This controller allows performing tasks in a large remote workspace by using a haptic device with a reduced workspace such as Phantom. Experimental results have been carried out using a slave robot from Kraft Telerobotics and a commercial haptic interface as a master device. A curvature path following task has been simulated using the proposed controller which was compared with the force-position control algorithm. Results obtained show that higher accuracy is obtained when the proposed method is used, spending a similar amount of time to perform the task.

1. Introduction

Previous works [1,2] have found that depending on the requirements in a teleoperation task, there is a specific configuration that offers better performance. Two control modes are usually used for guiding a remote robot: position control and rate control.

Several works have been carried out to determine how task performance is affected by the control mode. In [3] the authors found out that the position control can be 1.5 times faster than the rate control when the master and slave workspaces are similar. In contrast, the rate control reaches better performance when the slave workspace is larger than the master's.

In general, position control has been proven suitable for tasks where short and precise movements are involved. Moreover, rate control has shown better performance for tasks that involve long and precise movements in an extremely rigid environment [4]. Manual operation of a crane can be an example of rate control. The crane itself is the slave device which is commanded by the operator using several joysticks (usually one for degree of freedom). These joysticks serve as master devices. Movements of the joysticks define the speed and direction of the different crane degrees of freedom. On the other hand, position control is frequently applied in robotics applications where movements of the slave are expected to imitate the movements executed by the master device. As mentioned, this kind of control is better when the master and slave have similar workspace, which means a direct kinematic relation between the master and slave devices.

At the present time, the current commercialized teleoperation systems do not allow combining position and rate control. In fact, when there is a substantial difference between the device workspace, rate control or position control workspace indexing is used. Indexing the workspace of the master consists of performing unlinking when the master reaches its mechanical limit. The master device is then relocated to a new position where it will permit the guidance process to continue. The problem with indexing is that it generates disorientation on the operator due to the changes in the references frames. Productivity of the system is thereby affected due to the downtime in getting accustomed to the new references.

Although some rate-position approaches have already been developed for mobile robots [5] or virtual haptic applications [6], there is no development specially designed for telemanipulation systems. Other typical scaling and indexing methods require the user to press a button in order to swap from one method to another, in contrast with the proposed algorithm. Due to these features, the proposed method is considered more intuitive for users since they can shift between control modes more naturally.

The present paper is organized as follows: Section 2 explains the proposed method in detail, Section 3 describes the developed test-bed for assessing the method, Section 4 presents the results obtained from the experiments carried out and finally, conclusions are provided in Section 5.

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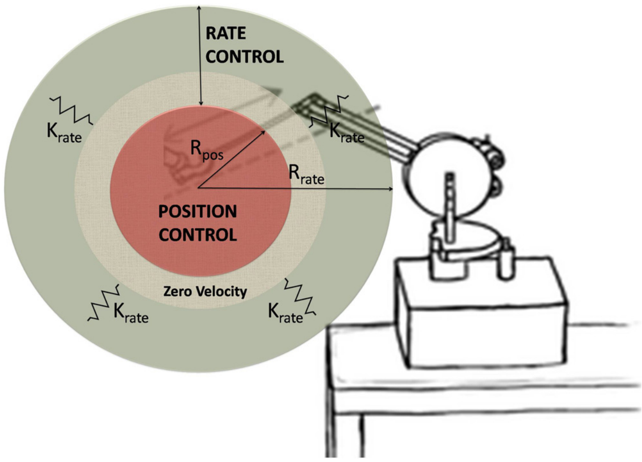

Fig. 1. Definition of the position and rate control areas within a haptic interface.

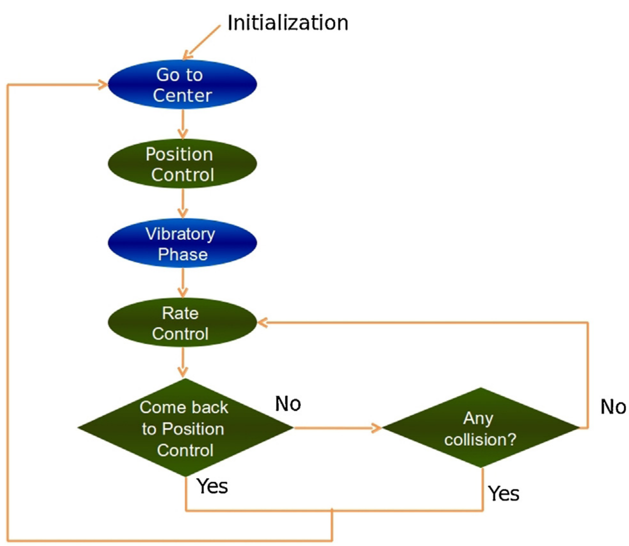

Fig. 2. State machine diagram used for implementing the Position-Rate control.

2. Description of the rate-position algorithm

A new algorithm which is able to swap from position control to rate control was designed. Only haptic information is used for informing the operator about the transitions from position to rate control. Pressing a button while tasks are carried out is then not required.

Haptic workspace has been divided into position and rate control areas as shown in Fig. 1. It means that accuracy is obtained when the slave robot is manipulated using the position control and large displacements can be carried out using the rate control. Therefore, accuracy can be gained in a large workspace by using a small haptic master.

2.1. States of the control algorithm

Different states have been defined in order to implement transitions from position to rate control and vice-versa. In Fig. 2, it is depicted what the main states are and how the controller evolves between them. Some states display haptic information to the user notifying about any change occurred in the control mode. Additionally, state transitions have been defined to assure the system stability.

2.1.1. State: 'go to center'

This state displays forces to bring the user to the workspace center. It is usually activated after entering the position workspace coming from the rate control area. During this transition, the slave robot holds its position and it is not affected by the master displacements.

In addition, this state is also important for the initialization of the system, since it allows to define the zero point of the master. During this initialization, the master is held in the center for around 5 s in order for the user to know where the zero point is.

Once the haptic device reaches the workspace center, this state is held for 0.5 s in order to stabilize the master device and synchronise both robots. As synchronization error is close to zero, the controller automatically goes to the next state:*Position Control*.

2.1.2. State: 'position control'

In this state the user can manipulate the slave robot in position and perceive the interaction forces with the environment. The accuracy of the movements can be adjusted according to the features of both robots and the task.

The controller checks whether the position of the master device is within the position control area. The distance from the zero point of the master device to the current position is calculated and compared with the radius of position workspace, see Eq. (1). In case the user goes beyond the position workspace, the controller moves to the next state: *Vibration phase*.

$$d = \sqrt{x^2 + y^2 + z^2}$$
$$d \leq R_{pos} \quad (1)$$

2.1.3. State: 'vibratory phase'

This *vibratory phase* informs the user when a transition from position to rate control occurs. It generates a vibratory stimulus to inform the user that a new operation mode is activated. The use of haptic information avoids using buttons to switch from position to rate control, making the teleoperation more natural. Furthermore, the vibratory stimulus plays a key role since the user knows that a new operation mode is being used, avoiding unexpected behaviours of the system. A damped oscillatory signal is used for generating the vibratory stimulus, where A is the amplitude, C the decay rate parameter and w is the angular frequency of the signal.

$$F_{vib} = A \cdot e^{-C \cdot t} \cdot \sin(wt) \quad (2)$$

2.1.4. State: 'rate control'

This state allows telemanipulating the slave robot using rate commands. A force feedback proportional to the rate command is displayed to the user according to Eq. (3). Parameter K describes the spring used for displaying force feedback, d is the current position distance measured from the center of position workspace, R_{pos} is the radius of the sphere which bounds the position control and D_{hys} is the distance which is considered as hysteresis area.

According to Eq. (4), the further the user is from the position sphere, the faster the slave robot moves.

$$F_{rate} = \begin{cases} K_f(d - R_{pos} - D_{hys}) & \text{if } d > R_{pos} + D_{hys} \\ 0 & \text{if } d \leq R_{pos} + D_{hys} \end{cases} \quad (3)$$

$$\dot{x}_{rate} = K_{vel}(d - R_{pos} - D_{hys}) \quad (4)$$

As shown in Fig. 1 a hysteresis area is defined in order to avoid force glitches in accidentally changing the controller from rate control to position control or vice-versa. In this area, no velocity commands are sent to the slave robot and no force feedback is displayed to the user.