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Preliminary Drawing Test via Predictive Energy Bounding Algorithm for Time-Delayed Bilateral Teleoperation

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Abstract: This paper presents a predictive control approach in order to enhance the force tracking transparency which results comfortability in performing drawing task for the haptic bilateral energy-bounding Algorithm (EBA) teleoperation over communication channels in the presence of constant time delays. The proposed scheme (termed as Predictive EBA) combines the EBA with Smith predictor (SP) architecture which predicts the slave site states on the master site to improve force tracking transparency. If the knowledge about the contact location and slave/environment dynamics is well known, significant improvement in magnitude and phase of feedback force can be obtained. In order to show the effectiveness of proposed scheme a preliminary circle drawing task experimentation is attempted comparing the performance of original EBA with the predictive EBA in the presence of constant time delays.

Keywords: Teleoperation, Predictive Control, Transparency, Time Delays.

1. INTRODUCTION

Telerobotic systems are being used for past couple of decades for challenging and hazardous tasks in the known and unknown remote environments such as space, undersea, surgical operations, nuclear stations, etc. [1]. The time delay is one of the key factors to disturb the performance and stability of the whole teleoperation system [1]. Stability issues, therefore, have been researched well in the past [2].

On the other hand, transparency issue of bilateral teleoperation with time delays is investigated in [3]. EBA has been proposed for single-dof haptic teleoperation in [2]. Preliminary drawing results with EBA have been presented recently in [4]. Very limited approaches have been extended from single to muliple-degree of freedom (DOF) haptic teleoparaion such as passivity [5], wave variable [6] and LQG [7]. In order to improve transparency of single-DOF teleoperation, predictive control approaches [8-10] were investigated to reduce the effect of large time delays. These approaches also predict the slave states on master site and vice versa in order to avoid the delayed information from one or both ends. For better performance, all the models should be accurately estimated. Otherwise, for large time delays, the parametric uncertainty dominates the response. The above predictive approaches aimed to achieve non-delayed robust and transparent force and/or position tracking for single-DOF teleoperation. However, due to some limitations that are inherent in their schemes/controllers, some approaches may be lacking in robustness or others may become complex.

This paper presents a predictive control approach in order to enhance force tracking transparency of the haptic bilateral EBA for multiple-DOF drawing tasks in the presence of large constant delays. The proposed scheme (termed as Predictive EBA) combines the EBA with the SP architecture which predicts the slave site states on the master site to improve force tracking transparency. If the knowledge about the contact locations (to switch on contact mode using predictive control) and slave/environment dynamics is well known, significant improvement in magnitude of feedback force can be obtained. The proposed scheme utilizes two major advantages of the EBA and the SP: (1) the EBA provides robust stability regardless of the magnitude and variability of time delays as well as time varying non-linear dynamics of slave and environment. (2) the SP predicts a feedback force in advance, effectively cancelling out the time delay effect. Furthermore, there are benefits of getting improved force feedback because if the human operator gets reduced force feedback then he/she pushes more force on the master arm to maintain the contact that might result in the damage of marker pen attached at the end effecter of slave device. When marker pen gets more force input from the operator, then it suffers more friction in contact with the drawing board, this may spoil the accurate geometrical drawing. In case of predictive EBA, the operator gets the time advanced force feedback that makes operator cautious to put more force (that might damage marker pen). In addition to this, improved force feedback is obtained which helps in comfortability of drawing task.

The remaining part of the paper is organized as follows; Section 2 describes the proposed predictive EBA framework. Experimental setup and drawing task scenario showing improved force tracking transparency (causing comfortable task completion) of the proposed predictive EBA over the bilateral projected EBA are presented in Section 3. Finally, Section 4 presents conclusions and future works.

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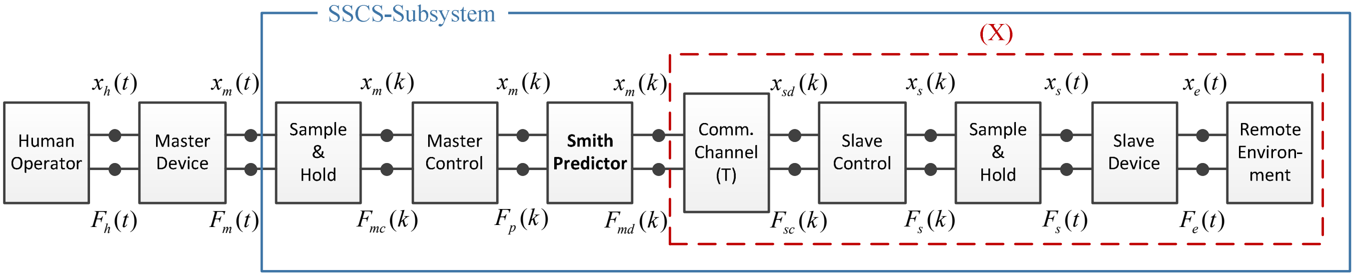


Fig. 1 Predictive EBA Framework for Passive Bilateral Teleoperation

2. PREDICTIVE EBA

The bilateral EBA [2] can provide robust stability regardless of the dynamics of network delay, operators, slave, and environment in bilateral teleoperation while the SP [11] can predict dynamics of a remote site. Fig. 1 shows a network representation of this system, in which the SP block is added between the bilateral EBA controller (Master Control) and the communication channel. Looking from the master site in Fig. 1, the configuration of the teleoperation system may be treated as that of a haptic interaction system because the subsystem {denoted as a dotted box (X)} from communication channel to a remote environment can be considered as a time-delayed virtual environment. In Fig. 1, the master position x_m is delivered to the slave site, and the predicted time-advanced slave force F_p via SP is input to the master controller. In Fig. 1, the slave force F_{sc} is transmitted to the master site and x_{sd} is the delayed master position transmitted to the slave. Fig. 1 shows a typical impedance type haptic interaction system if the SSCS-subsystem that is everything from the master S/H (sample & Hold) to the remote environment is represented by a one-port network. By assuming a passive human operator, the passivity condition can then be derived as in [2].

$$P_h(n) + \sum_{k=0}^{n-1} F_{mc}(k)\Delta x_m(k+1) + \varepsilon_0 \geq 0 \qquad (1)$$

where $P_h(n)$ is the dissipative energy of a master device, ε_0 is the initial energy, and $\Delta x_m(k+1)=\{x_m(k+1) - x_m(k)\}$. The control and bounding laws for the proposed predictive EBA are same as [2].

3. EXPERIMENTS

3.1 Experimental Setup

The practicality of the proposed predictive EBA performing drawing task in the presence of large constant time delays can be shown with the experimental set up in Fig. 2, where two PHANToM ™ devices (Sensible Technologies, Inc.) are used for master (ordinary force Phantom) and slave (high force Phantom) devices.

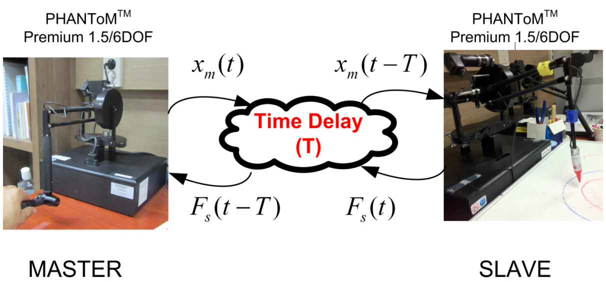


Fig. 2 Experimental Setup

The slave site used a PD controller for position tracking. The output (F_{sc}) of this PD controller is sent to the master through communication channel [2] that can be defined as

$$F_{sc} = K_p(x_{sd} - x_s) + K_d(v_{sd} - v_s) \qquad (2)$$

where K_p (0.1 N/m) and K_d (0.0001 Ns/m) gains are designed for suitable position tracking performance in the free motion. Through system identification, the values of mass and damping for the slave phantom are determined as M_s=0.0837 Kg and B_s=0.2 Ns/m.

The master and slave Phantoms are run by two different computers that communicate with each other via Internet. User Datagram Protocol (UDP) is used as a communication protocol. In order to implement the teleoperation with SP, Microsoft Visual C++ 6.0 in Windows XP is used to control the teleoperation system and to simulate the time delays using memory buffers that provide artificial time delay.

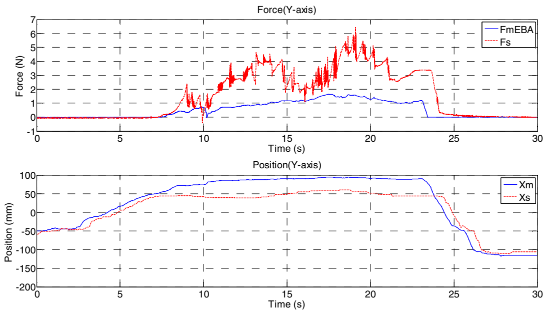
3.2 Experimental Scenario

Experiments are conducted for circle drawing tasks utilizing the proposed Predictive EBA with large time delay and comparing it with original EBA. In order to accomplish the 2-DOF circle drawing task, the slave device end effecter is attached with the marker pen tightly with the help tape. The drawing board is placed at some distance near the bottom of the marker pen to re-draw the circle by following already drawn desired circle trajectory when master device commands it, which can be seen in Fig. 2 and 3.

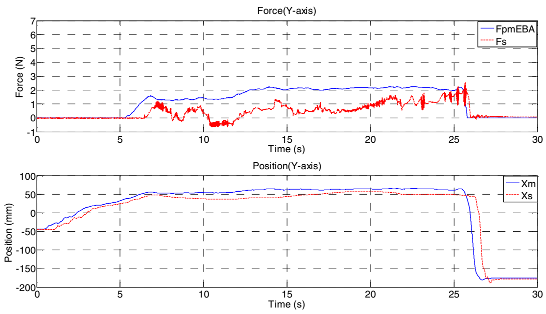
(a) (b)

Fig. 3 Circle Drawing tasks with 500 ms round trip time delays (a) EBA (b) Predictive EBA

Fig. 3 shows a typical performance comparing the non-predictive bilateral EBA with the proposed predictive EBA for the above-mentioned scenario with 500ms constant time delay. It is noted that only the axis normal direction force is transmitted to the master side for the current investigation, because the current predictive control uses the contact location which is not the case while predicting the surface frictional forces. Fig. 3(a) shows that the circle drawn by original EBA with 500ms time delay. The circle is not perfect. In the mean time the contact location is saved on the master side for predictive EBA to switch on. In Fig. 3(b) the circle is drawn by predictive EBA, the circular drawing is much better as compared to original EBA.



(a)



(b)

Fig. 4 (a) EBA vs. (b) predictive EBA with 500ms constant round trip time delay

Fig. 4 gives the force/position profiles of EBA vs predictive EBA. In Fig. 4(a), in case of EBA, the human operator gets 250ms delayed force feedback F_s and that is reduced in magnitude F_{mEBA} (force after master EBA). In case of Fig. 4(b), predictive EBA gives the time advanced force feedback with improved force feedback F_{pmEBA}.

4. CONCLUSION

Circle Drawing tasks are performed utilizing predictive EBA in the presence of constant time delays and the results are compared with original EBA. Predictive EBA helps in getting time advanced improved reflected force which results in comfortably in circle drawing task as compared to original EBA. In future, frictional forces from the other axes will also be considered and the work will be extended for variable time delays and multiple-DOF with more realistic tasks. Furthermore, the user study will be done as well.

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