Kinesthetic Teaching of Position-Controlled Robot Manipulators Using Disturbance Observer

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***Abstract*— Manufacturing robots very often require re-programming tasks due to the frequent change in the production process. Kinesthetic teaching is one of the efficient ways to re-programming the task for robots. In this paper, the interaction is estimated by the disturbance observer based on the position controllers at each joint without additional sensors. Then, the compliant motion is created in the direction of the observed disturbance. The experiment demonstrates the capability of kinesthetic teaching through the physical guidance.**

I. INTRODUCTION

The production process is changed frequently in small or medium-sized enterprise for a flexible manufacturing system. Programming the new tasks to the robots in the industrial field typically consumes time and requires expert engineers [1]. It states that convenience in re-programming for robots can affect productivity. Kinesthetic teaching is one of the efficient ways because non-experts can program tasks to the robot and save time for re-programming robots [2]. Kinesthetic teaching allows operators to implement robot motion without the background knowledge of kinematic structure for the robot by guiding the robots posture with physical human-robot interaction.

To track the physical guidance by the operator for teaching tasks, only if the compliant motion is allowed, kinesthetic teaching is performed as the guided motion recorded. In the industrial field, the position-controlled manipulator is widely used. And, using force/torque sensor or vision sensor causes additional cost on the industry side [3] [4]. Therefore, the compliant motion of position-controlled manipulator without additional sensor can be the most effective method for kinesthetic teaching.

This paper presents a kinesthetic teaching method which builds on the disturbance observer (DOB) introduced in [5] to a sensorless position-controlled manipulator. Compliant motion is created from the interaction through DOB which is implemented at each joint. Thus, The kinesthetic teaching guidance can be able to record the task while the robot in motion and replay it later on.

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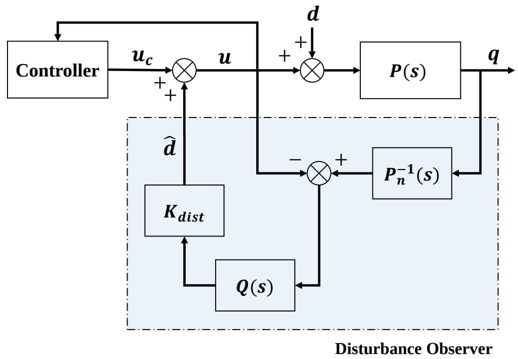

Fig. 1. Control scheme of proposed method with DOB

II. METHODOLOGY

A. *Disturbance Observer*

Most of the conventional research about DOB has been studied to reduce the effect of disturbance [6]. Otherwise, our approach interprets the use of the disturbance to achieve the compliant motion with only using an encoder instead of additional sensors [5]. The external forces from the physical guidance and the modeling errors between the real system and the nominal system can be estimated by the DOB. According to this approach, the estimated disturbance is added to the control input and it reflects the control of rotation motor. As a result, the output of the system facilitates to move the robot manipulator in the direction of the disturbance for the compliant motion.

The estimated disturbance is treated at each joint as shown in Fig. 1. In this figure, $P(s)$ represents the real system, $P_n(s)$ represents the nominal system, $Q(s)$ represents the first order low pass filter, d, q and K_{dist} represent a disturbance, the measured angle of joint, and the weighting gain, respectively. The object of DOB is the real system $P(s)$ including the uncertainty. Let us assume that the transfer function of the first order system for the motor can be described by

$$P_n(s) = \frac{K}{s+K}, \tag{1}$$

where K is parameter of the transfer function. Using this nominal model, the estimated disturbance $\hat{d}$ is obtained by

$$\hat{d} = K_{dist}Q(s)(P_n^{-1}(s)q - u). \tag{2}$$

Finally, the plant input based on proposed DOB is computed as follows.

$$u = u_c + \hat{d}. \tag{3}$$

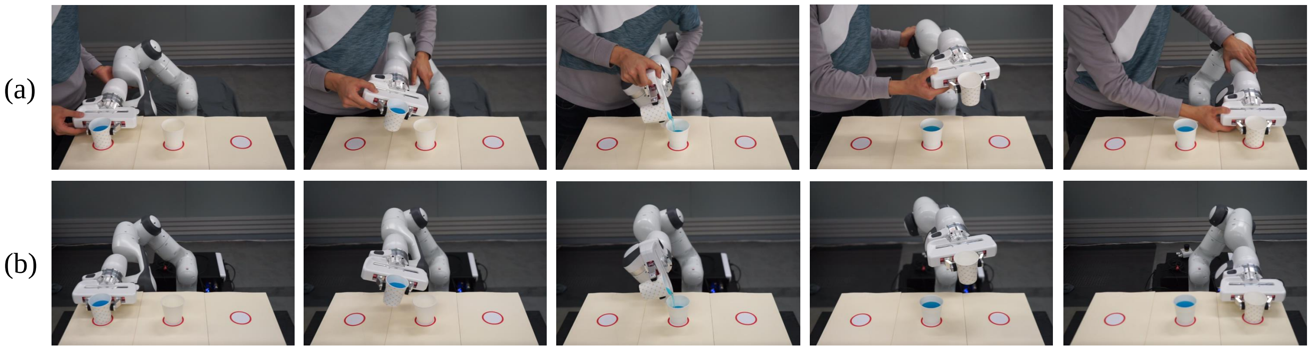

Fig. 2. (a) Snapshots of the kinesthetic teaching to program pouring a water scenario, and (b) replaying the task

Through adding the estimated disturbance to the control input, the motor angle rotates to the direction of the external force. The gain K_{dist} represents depending on how much the estimated disturbance is taken into account for proposal control.

B. Kinesthetic Teaching

The goal of kinesthetic teaching is that new tasks are programmed through the physical guidance. The proposed kinesthetic teaching consists of two modes: guidance and replay. Firstly, the guidance mode is a process of programming the task to the robot with the human hand. During programming the task, the physical guidance is treated by the controller in Fig. 1 with allowing compliant control based on DOB introduced in Section 2A. Secondly, replay mode is a process to perform the robot task programmed at the guidance mode. So, the robot should track the given joint trajectory in the replay mode. During performing the task, the estimated disturbance does not reflect to control.

For the guidance mode, the controller is designed as follows:

$$u_c(t) = u(t - \Delta t), \tag{4}$$

where u_c is the control input, u is the plant input, Δt is the sampling period.

III. EXPERIMENTS

A. System Overview

The proposed approach is verified experimentally by a 7-DOF arm manipulator from FRANKA EMIKA called Panda, equipped with a 2-finger gripper. The remote computer, which is installed the Ubuntu 16.04 operating system with robot operating system (ROS), is connected to a Panda controller desk with 1000 Hz sampling time.

B. Pouring a Water Scenario

The performance of the kinesthetic teaching is tested in pouring a water scenario while trajectories of each joint are recorded in the joint space. The experimental setup is described in Fig. 2. There are three locations to place, an empty cup and a cup filled with water.

As shown in Fig. 2, the scenario proceeds in the order of lifting the cup, moving to another cup, pouring water, and placing the cup down in the target place. Thus, the tasks are composed of several motions and require a combination of all the joints of the manipulator to be used to success the scenario. The scenario also validates that the proposed kinesthetic teaching performs reliably and stably by not spilling water.

As a result, following the operator's physical guidance, the manipulator performed the pouring a water scenario. Kinesthetic teaching was well conducted, and the programmed task was performed as shown in Fig. 2-(b). The proposed approach, which is carried out in position-controlled mode, is correctly controlled and has a high task reproducibility.

IV. CONCLUSIONS

In this paper, we presented the proposed approach with DOB that allows a position-controlled manipulator to program task using kinesthetic teaching and to make the compliant motion. The external force is taken into account as the estimated disturbance and each joint is actuated in the direction of the estimated disturbance to implement compliance capability. Only encoder sensors are used and the force/torque sensor is not required. The experimental results verify the method of kinesthetic teaching.

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