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REMOTE LEAD THROUGH TEACHING BY HUMAN DEMONSTRATION DEVICE

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ABSTRACT

Industrial robots are playing increasingly important roles in production lines. The traditional pendant programming method, however, is unintuitive and time-consuming. Its complicated operation also sets a high requirement on users. To simplify the robot programming process, many new methods have been proposed, such as lead through teaching, teleoperation, and human direct demonstration. Each of these methods, however, suffers from its own drawbacks. To overcome the drawbacks, a novel robot programming method, remote lead through teaching (RLTT), is introduced in this paper. In RLTT, the operator uses a device to train the robot remotely, allowing the demonstrators to use the mature lead through teaching techniques in a safe environment. In order to implement RLTT, the human demonstration device (HDD) is also designed to transfer the demonstration information from the human to the robot.

INTRODUCTION

Industrial manipulators are becoming more and more important in factory automation. Traditionally, the operators use teach pendants to program the robots by feeding input command sequence, such as position, velocity, and acceleration. This method is time-consuming and unintuitive. With increasingly complicated industrial tasks, this standard approach demands substantial time and efforts. To simplify the robot programming process, several methods have been proposed to program robots directly through human demonstrations.

Figure 1 shows the four current methods for industrial robot programming; namely, teach pendant programming, lead through teaching, teleoperation, and human direct demonstration. As previously mentioned, The teach pendant programming method is the most common method in industry, but it is unintuitive and time-consuming.

In the lead though teaching method [1, 2], the operator directly grasps the compliant joint or the handle mounted on the robot, then manually moves the robot arm to pass though a desired path or a sequence of successive points so as to define the task. The lead through teaching provides a convenient and intuitive path planning approach. Even an operator without any programming experience can train the robot. The lead through teaching method, however, requires physical contact between the operator and the robot. This poses a potential danger to the operator.

Teleoperation [3, 4] or virtual robot teaching [5] separates the workspace of human and robot. The operator manipulates the robot in a virtual reality environment by maneuvering a haptic interface. A sequence of robot commands are generated by recording the human motion/force on the haptic device. The remote operation ensures the operator's safety, but insufficient tactile feedback limits the applications. For instance, the teleoperation method may not be applicable for complicated industrial tasks such as surface polishing.

Human direct demonstration [6] enables the operator to naturally perform the example executions. Operators use their own bodies to demonstrate the task, and the motion capture suits record the demonstration. This approach especially fits in the humanoid or anthropomorphic robots. Since the body of robot is similar to that of human, the humanoid is capable of tracking faithfully the operator's motion/gestures [7, 8]. However, the dif-

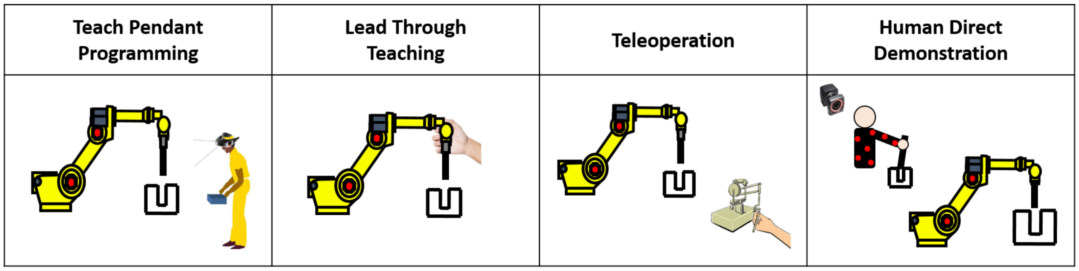

FIGURE 1: ROBOT PROGRAMMING METHODS

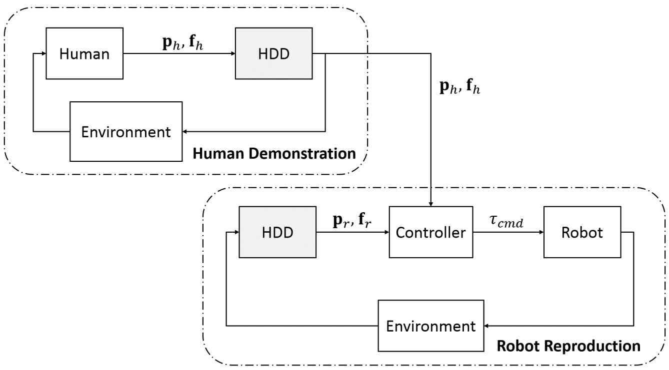

FIGURE 2: THE SCHEME OF REMOTE LEAD THROUGH TEACHING

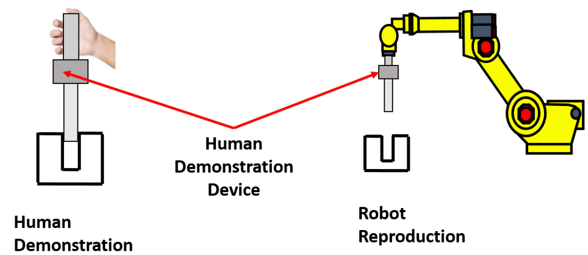

FIGURE 3: HUMAN DEMONSTRATION DEVICE ILLUSTRATION

ferent configurations between human and industrial robot make the mapping very difficult. Furthermore, the wearable sensors usually record the human motion only, but many industrial applications require the force information as well.

Since each of the current robot programming methods has its own drawback, a novel teaching method called remote lead through teaching (RLTT), is proposed in this paper. The human demonstration device (HDD) is designed to share the common reference between human and the robot, and RLTT enables the robot to reproduce the task from the demonstration data. RLTT preserves the properties of lead through teaching, and provides the operators a natural and safe demonstration approach. In the framework of RLTT, there are two phases, human demonstration phase and robot reproduction. In this paper, the work is focused on designing the HDD for data acquisition in the human demonstration phase.

The paper is organized as follows. Section 2 outlines the framework of RLTT. Section 3 discusses the design of the HDD and its prototype implementation. Section 4 presents the data acquisition results using the HDD. Lastly, Section 5 concludes the work.

SCHEME OF REMOTE LEAD THROUGH TEACHING

Figure 2 shows the scheme of RLTT. Considering the roles in robot programming, RLTT is decomposed into two phases, human demonstration and robot reproduction. In human demonstration phase, the operator uses HDD to naturally perform the task. At the same time, HDD records the operator's motion/force $(\mathbf{p}_h, \mathbf{f}_h)$ during the demonstration. The recorded data is stored for robot programming. In the robot reproduction phase, the previously stored desired trajectories are set as a reference signal for the system. The robot controller generates torque commands τ_{cmd} such that the state of HDD $(\mathbf{p}_r, \mathbf{f}_r)$ is tracking the reference signals. Under the framework of RLTT, HDD establishes an interface between the human operator and the robot.

The lead through teaching method exploits the information from the sensors on the robot end-effector to reproduce the demonstrated work. Similarly, RLTT enables the robot to reproduce the task by directly using the recorded data. The difference is that the sensors are installed in the HDD, instead of the robot end-effector. This difference leads to several benefits. Firstly, the human and robot workspaces are separated, thereby ensuring human safety. Secondly, the human working behavior is not altered too much, since the HDD can be regarded as an add-on of the tool. Thus, the operator can demonstrate the task naturally.

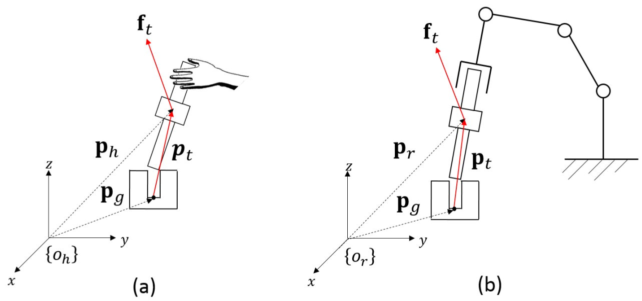

FIGURE 4: DEMONSTRATED DATA DIRECTLY UTILIZED BY THE ROBOT

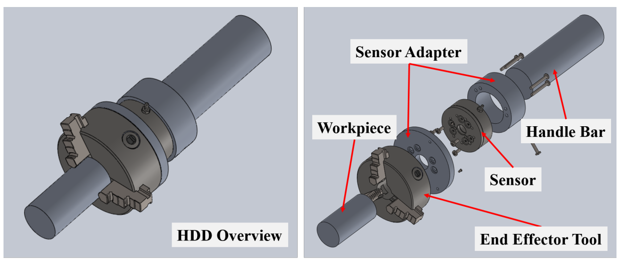

FIGURE 5: THE DESIGN OF HUMAN DEMONSTRATION DEVICE

HUMAN DEMONSTRATION DEVICE

The basic idea of the HDD is illustrated in Fig. 3. In the human demonstration phase, the HDD collects the demonstration data while the operator performing the task. In robot reproduction phase, the HDD mounted on the robot end-effctor sends the recorded data to the robot. Hence, it serves as the information messenger between human and robot, delivering the operator's relevant information to the robot.

To explicitly explain the function of the HDD, the peg-hole insertion task is provided as an example. As shown in Fig. 4(a), the operator tries to insert the peg into the hole. The pose of the HDD held by human hand is denoted as $\mathbf{p}_h$, and the goal position $\mathbf{p}_g$ is defined as the center of the hole. The successive motion/force $(\mathbf{p}_t,\mathbf{f}_t)$ of the workpiece relative to the HDD are recorded during human demonstration. In robot reproduction (Fig. 4(b)), the HDD is mounted on the robot end-effector. By taking the HDD and $\mathbf{p}_g$ as the reference points, the robot generates a trajectory $\mathbf{p}_r$ such that the HDD follows $(\mathbf{p}_t,\mathbf{f}_t)$ to reproduce the task.

Design of Human Demonstration Device

The structure of the HDD is briefly illustrated in Fig. 5, which consists of the handle bar, the sensor, the end-effector tool, and the adapters. The handle bar provides the place held by the human operator and mounted on the robot end-effector. A rapid release mechanism is placed on the robot end-effetor so that handle bar can be easily installed/uninstalled on the robot. As previously introduced, the HDD requires both force and motion sensing abilities. In this prototype design, a six-DoF force/torque transducer is fixed in the center of the HDD. The motion capture markers are placed on different surfaces of the HDD so that motion capture camera would not lose the tracking signal. The end-effector tool can be changed with various tools corresponding to the task requirement. For example, a gripper is placed for the peg-hole insertion, while a grinder is used for the surface polishing. The adapters are designed to protect the sensor and to link the handle bar with end-effector tool. Figure 6 shows the completed prototype of the HDD. The force sensor model is ATI mini 45 F/T transducer [9]. The PhaseSpace Impulse X2 LED markers [10] are placed on the top and body of the HDD.

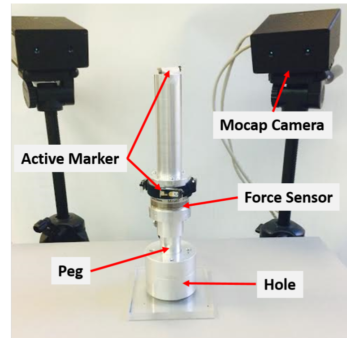

FIGURE 6: THE COMPLETED PROTOTYPE OF THE HDD

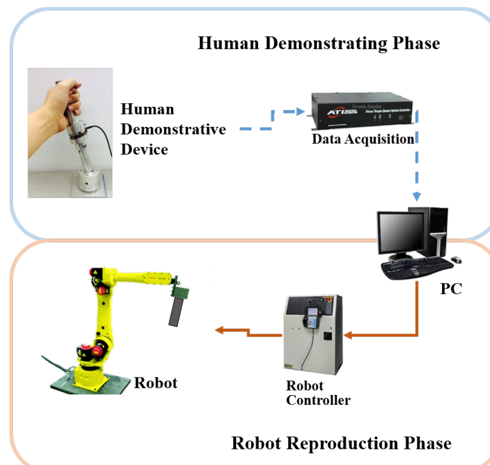

FIGURE 7: THE OVERALL HARDWARE STRUCTURE OF RLTT ROBOT PROGRAMMING

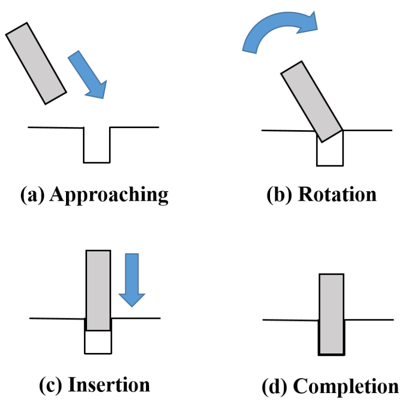

FIGURE 8: THE INSERTION PHASES

EXPERIMENT

Hardware Setup

The whole RLTT robot programming hardware framework is shown in Fig. 7. In the human demonstration, the operator holds the HDD to execute the task. The data acquisition board records and sends all the demonstration data to the computer. The operator can monitor the results in the PC. In the robot reproduction phase, the recorded data is deployed to the robot controller. The robot is driven in accordance with the recorded data so that it can follow the operator's demonstration to complete the task.

Experimental Setup and Result

The peg-hole insertion was selected as the experimental platform, because it was a common application that requires both force and motion for the task completion. In this experiment, the operator's motion and force during the demonstration were recorded by the HDD. The smooth trajectories and the contact force changes were expected in the results.

The demonstration trajectory and force during the peg-hole insertion task were shown in Fig. 9. The first plot illustrated the motion of the marker on the top of the HDD. The coordinate of the human workspace was shown in Fig. 4. The second plot showed the orientation of the HDD. The direction angles are the HDD relative to the basis axes. The third plot illustrated the force measured by the HDD.

As shown in Fig. 8, the peg-hole insertion was decomposed to four phases: approaching, rotation, insertion, and completion, where each phase was labeled under the bottom of the Fig. 9. The approaching phase was from 0s to 2s, where the operator held the tilted HDD to approach the hole. The position of the HDD decreased to a certain height and approached the entrance of the hole. The force was caused by the gravity and inertial. Notice that when the HDD contacted the hole in this phase, there was a support force compensating the gravity effect. The rotation

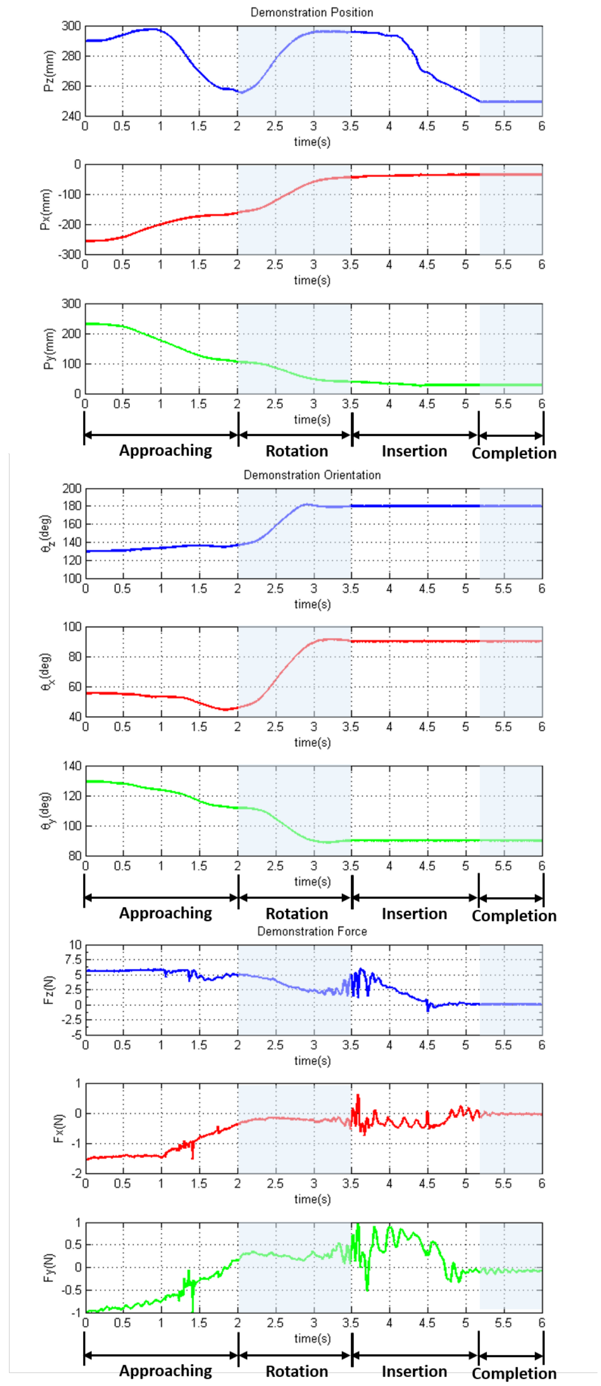

FIGURE 9: THE DEMONSTRATION TRAJECTORY AND FORCE

phase was the shaded area from 2s to 3.5s. The orientation of the HDD was adjusted to the insertion direction by the operator in this interval. Due to the orientation adjustment, the height of the marker increased until the HDD was perpendicular to the table. The insertion phase was from 3.5s to 5.2s. The HDD moved downward to the bottom of the hole, and the orientation remained the same. The force sensor reflected the fluctuation caused by the friction during the insertion. In the completion step, the HDD was in the static status, and the measurements remained the same. The experimental results clearly show the motion/force, which satisfied the expectation. Also, the results provided users with a insightful information of the demonstration.

CONCLUSION AND FUTURE WORK

This paper presented a new robot programming method called remote lead through teaching (RLTT). The key component of RLTT, human demonstration device (HDD), was designed, and its prototype was implemented in this work. The preliminary results of the HDD data acquisition was presented, where the operator's behaviors in different steps were clearly illustrated in the experimental results.

As discussed in previous section, RLTT has several advantages. For human, he/she is able to naturally demonstrate the task through a sensory device. For the robot, it directly exploits the recorded data to reproduce the task. Through RLTT, a more natural human demonstration data could be acquired, which provides LfD the possibility to teach the robot with the human-like skill. Therefore, a future direction of RLTT is the application to learning from demonstration(LfD) [11,12]. That is, the robot not only duplicates the motion and force from examples but also learns a control strategy from the demonstrations.

ACKNOWLEDGMENT

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REFERENCES

[1] Choi, S., Eakins, W., Rossano, G., and Fuhlbrigge, T., 2013. "Lead-through robot teaching". In Technologies for Practical Robot Applications (TePRA), 2013 IEEE International Conference on, pp. 1–4.

[2] McGee, H., Lee, E., Bauer, R., Swanson, P., Cheng, S., Tsai, C., and Sun, Y., 2002. Lead-through teach handle assembly and method of teaching a robot assembly, May 7. US Patent 6,385,508.

[3] Candelas Herías, F. A., Jara Bravo, C. A., and Torres Medina, F., 2006. "Flexible virtual and remote laboratory for teaching robotics".

[4] Calinon, S., Evrard, P., Gribovskaya, E., Billard, A., and Kheddar, A., 2009. "Learning collaborative manipulation tasks by demonstration using a haptic interface". In Advanced Robotics, 2009. ICAR 2009. International Conference on, IEEE, pp. 1–6.

[5] Kawasaki, H., Nanmo, S., Mouri, T., and Ueki, S., 2011. "Virtual robot teaching for humanoid hand robot using muti-fingered haptic interface". In Communications, Computing and Control Applications (CCCA), 2011 International Conference on, pp. 1–6.

[6] Calinon, S., and Billard, A., 2007. Learning of gestures by imitation in a humanoid robot. Tech. rep., Cambridge University Press.

[7] Ijspeert, A. J., Nakanishi, J., and Schaal, S., 2002. "Movement imitation with nonlinear dynamical systems in humanoid robots". In Robotics and Automation, 2002. Proceedings. ICRA'02. IEEE International Conference on, Vol. 2, IEEE, pp. 1398–1403.

[8] Calinon, S., D'halluin, F., Sauser, E. L., Caldwell, D. G., and Billard, A. G., 2010. "Learning and reproduction of gestures by imitation". *Robotics & Automation Magazine, IEEE,* ***17***(2), pp. 44–54.

[9] ATI Industrial Automation. http://www.ati-ia.com.

[10] PhaseSpace. http://http://www.phasespace.com/.

[11] Argall, B. D., Chernova, S., Veloso, M., and Browning, B., 2009. "A survey of robot learning from demonstration". *Robotics and autonomous systems,* ***57***(5), pp. 469–483.

[12] Billard, A., and Grollman, D., 2013. "Robot learning by demonstration". p. 3824. revision 138061.