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Skillful Manipulation Based on High-speed Sensory-Motor Fusion

Taku Senoo, Yuji Yamakawa, Satoru Mizusawa, Akio Namiki, Masatoshi Ishikawa and Makoto Shimojo

Abstract— **This video introduces the demonstration of skillful manipulation using a high-speed robot system. The system consists of visual and tactile sensors at a rate of 1 kHz and a high-speed hand-arm manipulator. The high-speed sensory-motor fusion improves not just the speed of existing robot manipulations, but robotic skills by introducing the features peculiar to high-speed motion. Based on such a concept, new variations of skillful manipulation were achieved.**

I. INTRODUCTION

In recent years, many robotic manipulation systems have been developed. However such systems were designed with a primary goal of the emulation of human capabilities, and less attention to pursuing of the upper limit in terms of speed for mechanical systems.

To achieve such dynamic fast motion, we have developed a high-speed manipulation system. This system consists of a multi-fingered hand with tactile sensors, a wire-drive arm, and a stereo active vision system. The cycle time of sensor feedback and control processing is set at 1ms. Therefore the robot can react quickly to target motion in unpredictable conditions.

Moreover new strategies for high-speed manipulation are developed utilizing the feature of high-speed motion. Several tasks show that high-speed active control enables stable and robust manipulation. In addition such a high-speed control strategy can be applied to various complicated manipulation. This result indicates that high-speed manipulation improves robotic skills.

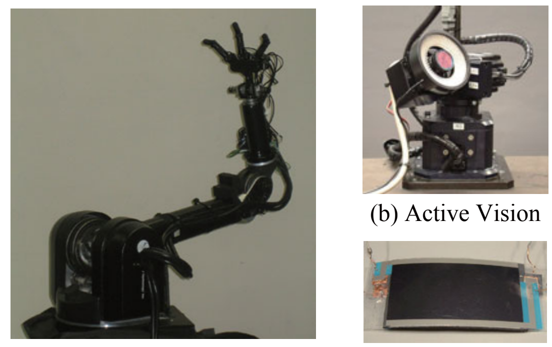
II. SYSTEM CONFIGURATION

A. Motor System

The hand [1] consists of three fingers and a wrist. It has 10-DOF in total. A small harmonic drive gear and a high-power mini actuator are fitted in each finger link. The design of this actuator is based on the new concept that maximum power output, rather than rated power output, should be improved. The hand can close its joints at 180 [deg] per 0.1 [s]. Its maximum velocity is 300 [rpm], and the maximum output is 12 [N].

The arm is a wire-drive manipulator (Barrett Technology Inc.). The manipulator has 4-DOF consisting of alternately revolution and bending motion. High-speed movement with maximum velocity of the end-effector of 6 [m/s] and maximum acceleration of 58 [m/s^2] is achieved.

The hand-arm system is shown in Fig.1 (a).



(a) Hand-Arm System (b) Active Vision (c) Tactile Sensor

Fig. 1. System configuration

B. Sensory System

Figure 1 (b) shows a column parallel vision system (CPV) [2] mounted on the 2-DOF (tilt and pan) active mechanism. The CPV has 128×128 pixel photo detectors and an all pixel parallel processing array. Various visual processing (moment detection, segmentation and so on) are achieved within 1 ms because execution is in parallel.

The tactile sensor [3] is a sheet-like object as shown in Fig.1 (c). The sensor consists of the two outer electrically conductive films and the inner pressure-conductive rubber. The sensor can measure the center position of a two dimensional distributed load and the total load within 1 ms. The sensor is attached to the top link of each finger.

III. SKILLFUL MANIPULATION

A. High-speed Manipulation

A high-speed robot system improves not just the speed of existing robot manipulations. Pursuing the upper limit in terms of manipulation speed, we have developed appropriate new control for high-speed manipulation. Here stable and robust manipulation by introducing the features peculiar to high-speed motion are presented as shown in Fig.2.

1) Dribbling: The hand dribbles a small ball between two fingers [4]. The dribbling period is around 100 ms. In this task, new concept called ”dynamic holding” is proposed. This means that high-speed active control enables the maintaining of periodically stable motion. Through dynamic holding states, there is an increasing possibility that novel transition of contact state is achieved.

T. Senoo, Y. Yamakawa, S. Mizusawa and M. Ishikawa are with Dept. of Creative Informatics, Graduate School of Information Science and Technology, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan. Taku_Seno@ipc.i.u-tokyo.ac.jp

A. Namiki is with Dept. of Mechanical Engineering, Graduate School of Engineering, Chiba University, 1-33 Yayoi-cho Inage-ku Chiba-shi, Chiba 263-8522, Japan. namiki@faculty.chiba-u.jp

M. Shimojo is with the Dept. of Mechanical Engineering and Intelligent Systems, Univ. of Electro-Communications, 1-5-1 Chofugaoka, Chofu-shi, Tokyo 182-8585, Japan. shimojo@mce.uec.ac.jp

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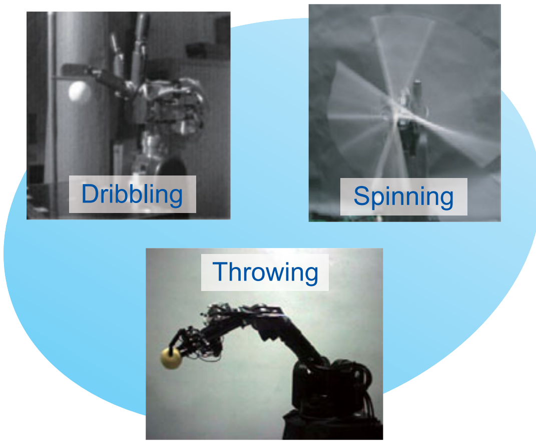

Fig. 2. High-speed manipulation

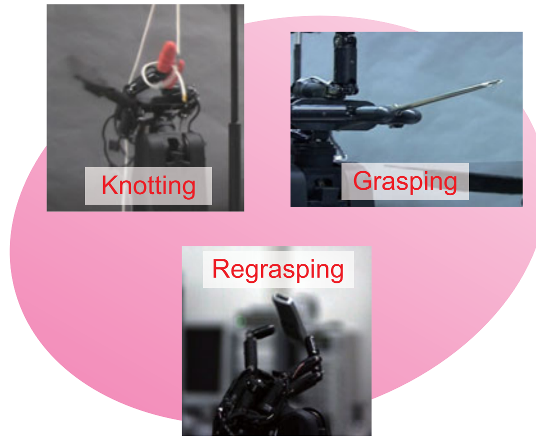

Fig. 3. Complicated manipulation

2) Pen Spinning: The hand repeats alternately the rotation of a pen-shaped object using left and center fingers and using right and center fingers [5]. The spinning strategy is based on the feature that rotational motion is stable when its speed is fast. Moreover the contact force and the timing of shifts about the axis of rotation are controlled in real-time by tactile feedback.

3) Throwing: The hand-arm manipulator throws a ball towards the target [6]. The release control with three fingers is designed so that the error of the ball direction is reduced using the apparent force, which is generated by high-speed arm swing. In order to achieve high-speed arm swing a kinetic chain algorithm is also presented, which is a mechanism to explosively radiate kinetic energy.

B. Complicated Manipulation

Such new control strategies for high-speed manipulation can be expanded to more complicated manipulations. We achieved skillful handling of more practical objects as shown in Fig.3.

1) Knotting of a Rope: Manipulation of flexible objects with robotic hands is a difficult issue. We have challenged to knot a rope as a simple example [7]. By high-speed sensory feedback control, the hand can dexterously control a flexible object regardless of its unpredictable moiton. Moreover a new strategy of motion for robot hands corresponding to mathematical elements of knot theory is presented.

2) Grasping with Tweezers: Considering robots work in human society, it is important for robot hands to handle a typical human tool. We achieved grasping a rice grain and a screw with tweezers [8]. High-speed visual servoing enables the control of force between a finger and a tool in real-time. This result means that a robot hand can handle many objects of various sizes with a tool.

3) Dynamic Regrasping: A new type of regrasping using high-speed performance is developed [9]. The dynamic regrasping consists of throwing and catching unlike with previous one while keeping a contact state. We achieved dynamic regrasping for objects of which mass distribution is not uniform and different-shaped objects.

IV. CONCLUSIONS

These videos show that high-speed sensory-motor fusion has great potential to produce new control strategies and new robotic skills. Integrating high-speed dynamic manipulation as shown in this video and conventional static manipulation, more suitable robotic work for practical use would be realized.

These experimental results and other manipulations are shown on the web site [10].

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