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Original article

Multi-LeapMotion sensor based demonstration for robotic refine tabletop object manipulation task☆

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Abstract

In some complicated tabletop object manipulation task for robotic system, demonstration based control is an efficient way to enhance the stability of execution. In this paper, we use a new optical hand tracking sensor, LeapMotion, to perform a non-contact demonstration for robotic systems. A Multi-LeapMotion hand tracking system is developed. The setup of the two sensors is analyzed to gain a optimal way for efficiently use the informations from the two sensors. Meanwhile, the coordinate systems of the Mult-LeapMotion hand tracking device and the robotic demonstration system are developed. With the recognition to the element actions and the delay calibration, the fusion principles are developed to get the improved and corrected gesture recognition. The gesture recognition and scenario experiments are carried out, and indicate the improvement of the proposed Multi-LeapMotion hand tracking system in tabletop object manipulation task for robotic demonstration.

Keywords: LeapMotion sensor; Muti-sensor fusion; Tele-operative demonstration; Gesture recognition; Tabletop object manipulation

1. Introduction

For intelligent robots, tabletop object manipulation is one of the most common task. It combines the capabilities of the robot in vision, image procession, object recognition, hand-arm manipulation, etc. However, the real indoor environment is much more complicated than experimental scenarios. The vision of the robot sometimes can hardly provides enough information for successfully executing some difficult tasks, such as pick, place or assemble some small objects [1]. In these cases, if two objects are too close to each other, it will be difficult to correctly segment them; moreover, some occlusion cases often occur in real indoor environment. So, tele-operative demonstration method is an efficient way to overcome these problems [2,3].

These demonstration methods have already been used on industrial robots for some years. For instance, the controller with buttons or a six-dimensional mouse are used to control the robot and tell the key positions and orientations, so that the robot can plan the trajectory and correctly reach each key position with desired orientations and perform a smooth movement [4]. However, the interface of this kind of demonstration method is not efficient for an intelligent robotic system. And in most such systems, the robot only records position and orientations without interpreting gestures, so these systems are not applicable to more complex tabletop object manipulation tasks. A more natural method based on a kinesthetic interface is used for demonstration. One can drag the robotic arm to follow his actions, such as the researches on humanoid robots by Hersch et al. [5] and Hwang et al. [6]. However, this method also aims at the trajectory tracking

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rather than at gesture recognition. Furthermore, this is a typical contact control method in which a human works within the same environment as the robot. Therefore, it is hardly used in human-unfriendly environments. For this reason, non-contact tele-control methods are more appropriate for these situation. For example, some mechanical based [7–9], optical tracking based or vision based master-slave-device and tele-operation system [10–12] are developed for robotic systems. Comparing with the mechanical devices, the optical and vision tracking systems are lower cost and easier to be mounted in difference environment.

For hand gesture recognition, a highly efficient way is using data glove that can record the motion of each finger [13,14]; some kinds of data glove can even measure the contact force of a grasping or pinching action [15]. However, beside the high cost of data glove, they lack the capability to track position of the hand. Therefore, extra approaches are added to track hand positions [16,17], such as inferred optical tracking [18], which also increases the complexity of the system.

Some scholars only use the vision based method for both the hand tracking and gesture recognition. But the performance of the gesture recognition is much effected by the lighting and background conditions [19–21]. Thus, some aiding methods like skin color and pure color background are used to improve the recognition accuracy [22,23]. Some other scholars use RGB-D data from Kinect for gesture recognition [24]. However, the Kinect sensor is developed for body motion tracking, In the research of Kim et al., it has been proved that the accuracy of hand motion tracking using Kinect is much lower than LeapMotion sensor, which is particularly designed for hand motion tracking [25].

The LeapMotion[1] sensor, developed by Leap Motion Inc., is a new non-contact finger/hand tracking sensor. It has a high tracking accuracy and provides plenty of software interface for pose and gesture recognition. Some preliminary studies have been carried out for robot manipulation. Zubrycki et al. use a LeapMotion sensor to control a 3-finger gripper [26], GuerreroRincon et al. develop a interface to control a robotic arm [27], Marin et al. report the first attempt to detect gestures from the data combination of LeapMotion and Kinect [28,29]. These use single LeapMotion for hand tracking and gesture recognition, however, due to the occlusion problem between fingers, single sensor can perform well only when the palm is with a ideal orientation.

In this paper, a multi-LeapMotion hand tracking system is developed to overcome the limitation of the aforementioned drawback of single LeapMotion. The tracking space and working area are analyzed to gain an appropriate setup for two LeapMotion sensors. With self-registration, a coordinate system are established. Based on the definition of the element actions, an algorithm to calibrate the delay and combine the data from the two LeapMotion sensors is proposed to improve the stability for both the hand tracking and gesture recognition. To developed a tele-operative demonstration system, a Kinect sensor and a 7-DoFs (Degree of Freedoms) robotic arm with a 3-finger gripper are combined with the developed Multi-LeapMotion hand tracking system in ROS (Robot Operation System).[2] Functional experiments are performed to indicate the results of combined hand tracking and gesture recognition. At the end, a scenario experiment is performed to show how this proposed system is used in a robotic system.

The rest of this paper organized as follow: the design and setup of Muti-LeapMotion hand tracking system is described in section II; the data fusion algorithm of the two sensors is shown in section III; in section IV introduces the scenario setups and experiments; at the end, some conclusion, discussion and future works are given in section V.

2. Design of the Muti-LeapMotion hand tracking system

2.1. Setups of the Muti-LeapMotion sensors

For high accuracy gesture recognition, one LeapMotion sensor can work well when the palm rotates less than 60°. The coordination of LeapMotion sensor and the orientation of palm are defined as shown in Fig. 1. The initial orientation is defined as the palm flat to the sensor. The rotation angle of palm is defined as the angle between palm normal vector and the −Y-axis of the sensor. However, for this optical based sensor, one of the most common problem is occlusion. Therefore, when the rotation angle of the palm closes to 90°, the fingers might be occluded by other fingers (defined as "finger-occlusion"). Furthermore, when the palm turns over and closes to 180°, the fingers are occluded by the palm when the hand performs grasping or fisting gestures (defined as "palm-occlusion"). That obviously impacts the gesture recognition. Thus, in this paper, we use one more LeapMotion sensor to cover all the blind zone and overcome the aforementioned problem.

Another very common problem for the optical sensors is aliasing. When the target object is too close to the background objects, the tracking and recognition accuracy will be reduced. These will happen when a LeapMotion sensor is mounted faceto-face to the operator. Therefore, we setup the two LeapMotion sensors in a plane orthogonal to the operator's arm. Fig. 2 shows three optional ways to setup the two sensors.

face-to-face: This setup method is good for recognizing the gestures when the hand is flat to the bottom sensor or turns over and closes to 180. But it can hardly solve the finger-occlusion problem when the hand rotates close to 90°. Moreover, the aliasing case will happen when the up mounted sensor is too close to the tabletop.

orthogonal-setup: This setup method is good at solving the finger-occlusion problem when the hand rotates close to 90°. But when the hand turns over to 180°, the palm is vertical to the side sensor. In this case, the finger-occlusion occurs to the side sensor, and simultaneously, the palm occlusion happens to the bottom sensor.

[1] http://www.leapmotion.com.

[2] http://www.ros.org.