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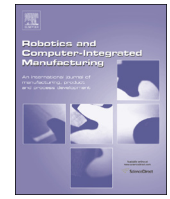

Markerless human–robot interface for dual robot manipulators using Kinect sensor

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ABSTRACT

Remote teleoperation of robot manipulators is often necessary in unstructured, dynamic, and dangerous environments. However, the existing mechanical and other contacting interfaces require unnatural, or hinder natural, human motions. At present, the contacting interfaces used in teleoperation for multiple robot manipulators often require multiple operators. Previous vision-based approaches have only been used in the remote teleoperation for one robot manipulator as well as require the special quantity of illumination and visual angle that limit the field of application. This paper presents a noncontacting Kinect-based method that allows a human operator to communicate his motions to the dual robot manipulators by performing double hand–arm movements that would naturally carry out an object manipulation task. This paper also proposes an innovative algorithm of over damping to solve the problem of error extracting and dithering due to the noncontact measure. By making full use of the human hand–arm motion, the operator would feel immersive. This human–robot interface allows the flexible implementation of the object manipulation task done in collaboration by dual robots through the double hand–arm motion by one operator.

1. Introduction

Human intelligence is necessary for decision-making and control in robot teleoperation, especially when the robot is in unstructured and dynamic environments, where objects are unfamiliar and changing in shape. Human–robot interfaces (Keum-Bae [1]) such as joysticks (Mitsantisuk et al. [2]; Hirche [3]; Takeshi et al. [4]), dials, and robot replicas have been commonly used to complete a teleoperation task. However, these contacting mechanical devices always require unnatural hand and arm motions.

Another means are available to communicate complex motions to a remote robot, and it is more natural compared with the use of contacting mechanical devices. This method is to track the operator hand–arm motion, which is set to complete the required task, by using inertial sensors, contacting electromagnetic tracking sensors [5], gloves instrumented with angle sensors, and exoskeletal systems (Kiguchi et al. [6]). However, these contacting devices may hinder natural human-limb motion.

Vision-based techniques are noncontacting and less limiting of hand–arm motion, and thus they often use physical markers that are placed on parts of body of the operator (Kofman et al. [7]; Park et al. [8]; Du et al. [9]). Numerous applications (Peer [10]; Borghese et al. [11]; Kofman et al. [7]) exist based on marker-based tracking of human motion. However, because body markers may hinder the motion for some highly dexterous tasks, and operators may become occluded, the marker-based tracking is not always practical. Thus, a markerless approach may be better for many applications.

Compared with image-based tracking that uses markers, the markerless method is not only less invasive but also eliminates problems of marker occlusion and identification (Verma [12]). For remote robot teleoperation, markerless tracking may thus be a better approach. However, the existing markerless human-limb tracking techniques have numerous limitations in that they may be difficult to use in robot teleoperation applications. Many existing markerless tracking techniques capture images and then compute the motion later (Yinghong et al. [13]; Peng et al. [14]; Suau et al. [15]; Rosales and Guo [16]). The robot manipulator could be controlled with the continuous robot motion by using markerless tracking. To allow the human operator to perform hand–arm motions for a task in a natural way without any interruption, the position and orientation of the hand and arm should be provided immediately. Many techniques can provide only two-dimensional (2D) image information of the human motion (Khezri et al. [17]; Dardas [18]), but the tracking methods cannot be extended for accurate three-dimensional (3D) joint-position data. However, an end-effector of a remote robot would

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require the 3D position and orientation information of the operator's limb-joint centers with respect to a fixed reference system. How to identify human body parts in different orientations has always been a main challenge (Yinghong et al. [13]; Varkonyi-Koczy [19]).

For robot teleoperation, several limited research have been conducted on markerless human tracking. Many techniques have used a human–robot interface based on hand-gesture recognition to control robot motion (Fong [20]; Ueda et al. [21]; Zhang [22]). Ionescu et al. [23] developed markerless hand-gesture recognition methods that can be used for mobile robot control where only a few different commands are sufficient, such as “go”, “stop”, “left”, and “right.”.However, for object manipulation in 3D space, achieving natural control and flexible robot motion by using gestures only is highly difficult. If a human operator wishes to use gestures, he or she needs to think of those limited separate commands that the human–robot interface can understand, such as move up, down, and forward. Rather than thinking of the required hand motions, a better method of human–robot interaction would be to permit the operator to focus on the complex global task in a manner similar to how a human naturally moves, such as grasping and manipulating objects in 3D space. With this goal, a method that allows the operator to complete the task using hand–arm motions naturally provides the robot with information of the hand–arm motion in real time, which are the hand and arm anatomical position and orientation (Kofman et al. [24]). However, to achieve the initialization, the human operator must assume a simple posture with an unclothed arm in front of a dark background, and the hand should be higher than the shoulder. However, precise results cannot be obtained by the method [24] under a complex background. In addition, the human operator encounters difficulty in working in the chill weather with an unclothed arm. Moreover, in the environment that is too bright or too dark, thus lighting also affects the result.

As the manipulation task becomes more complex, multiple robot cooperation would become a trend [25,26]. The vision-based methods mentioned above are difficult to use in the multi-robot interface, as they cannot solve the occlusion problem. At present, the contacting interfaces used in teleoperation for multiple robot manipulators often require multiple operators (Marin et al. [27]).

This article presents a method of dual robot manipulator interface using markerless Kinect-based 3D hand tracking of the human operator (Fig. 1). Markerless Kinect-based hand tracking is used to acquire 3D anatomical position and orientation, and then send the data to the robot manipulator by using a human–robot interface to enable the robot end-effector to copy the operator hand motion in real time. The natural means to communicate with the robots allows the operator to focus on the task, rather than thinking in terms of limited separate commands that the human–robot interface can understand, such as gesture-based approaches. Using the noninvasive Kinect-based tracking avoids problems, such as physical sensors, cables, and other contacting interfaces that may hinder natural motions. A marker occlusion and identification may occur when using vision-based approaches. In this way, the operator would feel immersive in the multi-robot environment, and that his hands are in the robot site.

Considering that the noncontacting way is unstable such as the error extracting and dithering phenomenon, this paper proposed an algorithm of over damping to manage the input data and thus the robot can move continuously.

The remainder of the paper is organized as follows. Section 2 presents the method of human motion tracking. The coordinate system of human hand is then detailed in Section 3. Section 4 describes data correction using over damping and Section 5 details virtual robot-manipulator control system. Experiments and results are presented in Section 6. Discussions are detailed in Section 7, followed by concluding remarks in Section 8.

2. Human-hand tracking system

Human hand tracking and positioning are conducted by continuously processing RGB and depth images of an operator performing the hand motion to complete a robot manipulation task. The RGB and depth images are captured by the Kinect that is fixed in front of the operator. In this paper, the human-pose-recognition method [28] is used to track the human skeleton.

The Kinect has three autofocus cameras: two infrared cameras optimized for depth detection and one standard visual-spectrum camera used for visual recognition.

2.1. Kinect coordinate system

Fig. 2 shows an operator standing in front of the Kinect and controls a robot. This algorithm defines the Kinect coordinate as shown in Fig. 2: axis X is upturned, axis Y is toward the right, and axis Z is vertical. The Kinect can capture the depth of any objects in its workspace. Fig. 2 shows that the index fingertip (I), thumb tip (T), and the part of the hand between the thumb and the index finger (B) have different distances away from the Kinect. I and T are closest, B is second, and U is at the end. The 3D position of B is used to control the position of the robot end-effector. I, T, and B are used to control the orientation of the robot end-effector.

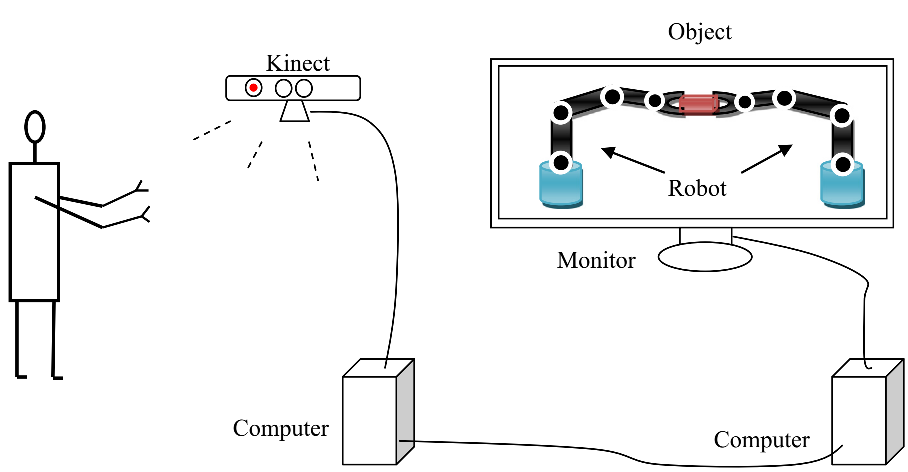

Fig. 1. Non-invasive robot teleoperation system based on the Kinect.