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Vision-based virtual force guidance for tele-robotic system ☆

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ABSTRACT

In order to improve operator performance and understanding within remote environment, a vision-based virtual forced guidance control methodology for tele-robotic system is presented. The remote operation of the construction robot is achieved by manipulating the graphic robot in a virtual environment. Based on binocular vision, the ground surface is modeled as an elevation map, and the task objects are recognized from video images and reconstructed using the Power Crust algorithm. The virtual guidance forces consisting of a pair of attractive force and repulsive force from the objects and obstacles are used to enhance the multi-task manipulation of the tele-robotic system.

1. Introduction

Tele-operation technologies have been widely used in tele-robotic systems in hazardous environments, such as outer space, deep oceans, and nuclear plants. In conventional remote operation systems, there are limitations on the number of installed sensors and the volume of transmitted data. As a result, limited information is available to the operator on site and the task efficiency is significantly influenced [1,2].

Virtual reality technology provides operator with the intuitive cue for the perception of the working fields at the remote site, which could potentially enhance the system with greater efficiency and facility [2]. Moreover, it provides the operator with a “live” virtual representation of the scene instead of the delayed video images [3]. For example, Qingping Lin introduced a virtual tele-presence interface operation approach, which greatly improved the efficiency of tele-presence operation of underwater robots by providing the operation with a 3-D virtual representation of the underwater environment [4]. However, the virtual environment is commonly built upon a “beforehand” modeling method with hypotheses that the position, size and contour of task objects have been known in advance. Besides, the operator has to judge the relative posture between the end-effector of robot and the task object with vision-only information. It is not applicative for unstructured environment and increases the operator’s workload and stress.

Force or haptic feedback is proved to be a valid method for improving the safety and efficiency of tele-robotic system [5]. As psychophysiology reveals that tactile stimulus incorporated with vision data brings about faster response time compared to vision-only stimulus [6,7], many more studies on vision-force hybrid servoing and impedance control strategy show the trend of incorporating haptics and vision with manipulation. However, in these cases, the high cost of force sensors plays critical roles, and the direct relationship between visual data and haptic force is less studied [6]. Moreover, the direct force signals which have time delay and noise in transmission are only generated when the robot interacts with the environment [8–10]. According to the feedbacks of tele-operation, operators are more concerned about the relative posture between robot and environment. The force sensors could not provide valid information under the free-moving phase of robot. A virtual collision-preventing force was generated according to the relative position between robot gripper and the environment

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obtained with a trinocular camera [11,12]. Similarly, haptic feedback was computed from the range information obtained by a sonar array attached to the robot, and delivered to an operator's hand via a haptic probe [13,14]. However, in those mentioned methods the haptic feedback was mainly used for collision prevention, instead of improving operational efficiency of tele-robotic system.

To improve the operational safety and efficiency of tele-robotic system, a force guidance control methodology is presented in this paper. The visual data captured by a binocular vision system is utilized not only for generating the virtual environment of working fields in real time, but also for providing the operator with force guidance data which includes the attractive force from the task object and the repulsive force from the obstacles. The human decision-making, the safety and the manipulation performance of tele-robotic system are improved by combining visual data with the virtual force feedback.

The rest of the paper is structured as follows: in Section 2, we describe structure of tele-robotic system with force guidance, involving a bilateral section–master and slave. Then we describe the 3-D reconstruction of task object and ground surface by the stereo vision camera in Section 3. Based on the artificial potential field theory, Section 4 shows the Generation of guiding forces, including the attractive force from task object and repulsive force from obstacles. In Section 5, comparison experiments are shown under the circumstances of force guidance and other situations. Finally, Section 6 concludes the paper.

2. Architecture of the tele-robotic system with force guidance

Fig. 1 shows the block diagram of the tele-robotic system with vision-based force guidance. The system involves a bilateral master and slave. The master is controlled by an operator and mainly consists of two force feedback joysticks and a screen with computer graphics (CG). For force feedback joysticks, Microsoft SiderWinder2 force feedback joysticks are adopted, which are capable of delivering around 100 different forces and 16 programmable buttons (8 action buttons plus 8-direction hat). The slave is composed of a construction robot and a stereo vision camera called "Bumblebee". The construction robot has four hydraulic actuators controlled by four servo vales through a control computer (PC1), and the "Bumblebee", which is a calibrated camera system as a product of Point Grey Research Inc., is mounted on top of the robot and its optical axis is perpendicular to the floor. This camera provides real time stereo image capture for applications such as tracking, building virtual reality model, human machine interface and mobile robotics. It can accurately measure the distance of the robot to the object in its field of view at a speed of up to 20 frames per second.

By means of the stereo camera "Bumblebee", the task objects in images are recognized and their contour information is extracted with a feature point based on stereo matching algorithm. Moreover, the terrain's height information of working field is also calculated according to the dense stereo matching results of binocular vision. Therefore, the task objects and the terrain are able to be rendered in the 3-D virtual environment on a graphic computer (PC2) with this information.

The operator performs remote operation of the construction robot by the joysticks with the assistance of the 3-D virtual scene in front. Operational signals for the servo valves of the robot are then generated by PC1 which processes the operational information from the joysticks. The displacements of hydraulic cylinders of the robot are detected by on-site displacement sensors mounted to hydraulic cylinders of the construction robot and input to PC2, inducing the corresponding movement of the graphic robot in the virtual world. With the information of the relative posture between robot and environment, the virtual forces, including the attractive force from the task object and the repulsive force from the obstacles or ground surface, are calculated in PC2 and fed back to the operator. With the assistance of these forces, the operator is able to control the robot approaching target quickly and avoiding collision with obstacles automatically.

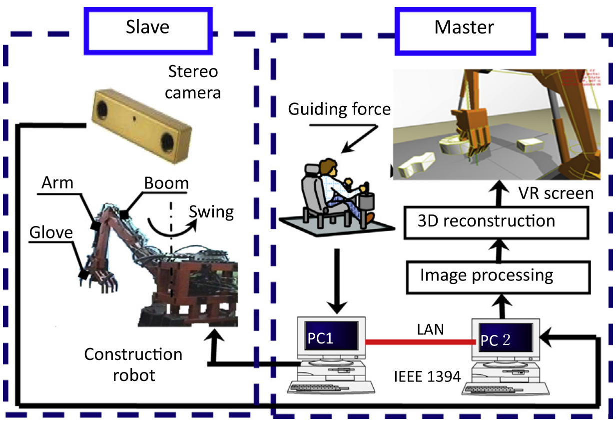

Fig. 1. Construction tele-robotic system with force guidance.