Human–Robot Collaboration with Augmented Reality

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Abstract. This paper presents an implementation of human-robot collaboration by using augmented reality technique for providing necessary information to human operator. In this research, human operator and a robot arm share the same workspace in virtual object assembly task. The virtual objects are created in the form of 3D computer graphics that is superimposed on the real video image. While working in assembly task, the robot will assist the human operator by loading the virtual objects. Furthermore, a task planner controls all robots' operations accordingly to human actions. Using augmented reality, human operator will receive robot's task plan in the form of computer graphics during assembly task. The computer-generated information will support human operator's decision for a suitable next step action.

Keywords: Human - Robot Collaboration, Augmented Reality, Task Planning.

1 Introduction

During recent years, augmented reality technology, which presents computer graphics information superimposed on real time video image, gains more interests. Previous research works implemented augmented reality to provide necessary information in the form of computer graphics to the operator during working with real objects [1],[2],[3]. Augmented reality is also used in human-robot collaboration task. Human operator will receive the augmented task information while working with robot [4],[5]. However, human and robot do not share the same workspace in previous related research works.

Hence, this paper presents the development of human-robot collaboration with augmented reality system in the common workspace. The task presented in the research is a virtual object assembly. During human- robot operation, human will obtain virtual objects, graphics instruction, and robot's action information through augmented reality technique. Moreover, robot will receive control commands from human operator to assist in transferring virtual objects.

2 System Overview

This research allows the collaboration between human and robot in virtual assembly task. The virtual objects which are used in this task are in the form of 3D computer

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graphics and rendered on the detected marker plates. During assembly process, the operator will receive all graphics information which is 2D guidance texts, 3D symbols, and 3D virtual objects through LCD display. In addition, the operator can allow or decline the assistance from robot in transferring marker on which virtual objects are superimposed.

2.1 System Configuration

Figure 1 shows the system configuration developed in this research. It consists of an operator, 5 DOF robot arm, computer, LCD screen display, video camera, and maker plates. During virtual object assembly, the operator and robot will move virtual objects on marker plates as system guidance. USB video camera is used to capture image of the workspace. The computer is responsible for image processing, task planning management, rendering all graphics on LCD screen, and controlling robot operation. The robot performs as an operator's assistance. Its operations depend on task plan and operator's decision commands.

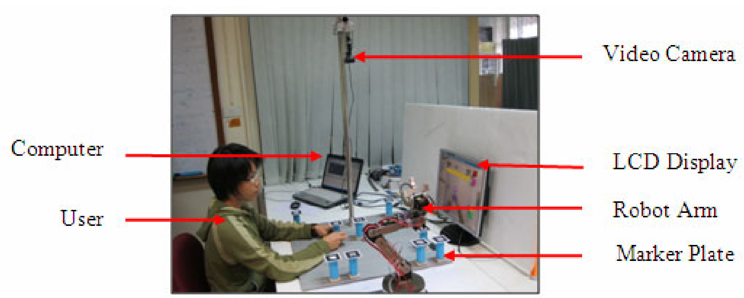


Fig. 1. System Configuration

2.2 System Data Flow

From data flow diagram in Figure 2, this system consists of 4 main components which are vision manager, graphics manager, task manager, and robot manager. First, ARToolKit [6] software library is used in the vision manager to process captured video images and obtain positions and orientations of targeted marker plates. Then, the vision manager sends targeted objects' positions and orientations to the task manager. The task manager is responsible for generating action plan using STRIPS planning algorithm in assembly task. Next, the robot manager computes forward/inverse kinematics, reads robot's joint angles, and sends commands to control the robot's movement. The last component is the graphics manager which generates 2D and 3D computer graphics to present all guidance information and virtual objects on LCD display to the operator.

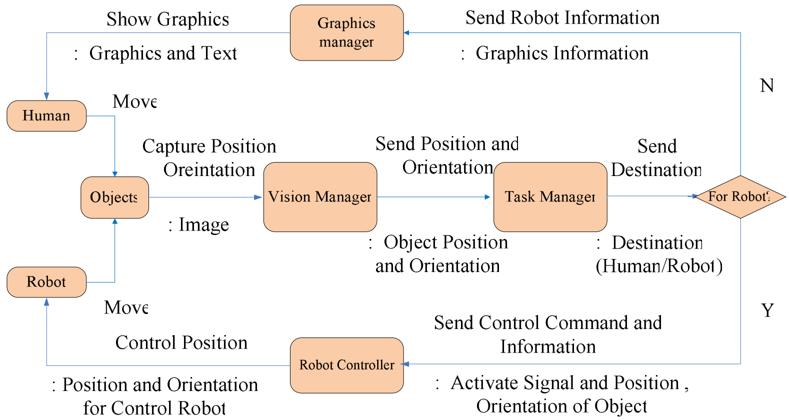
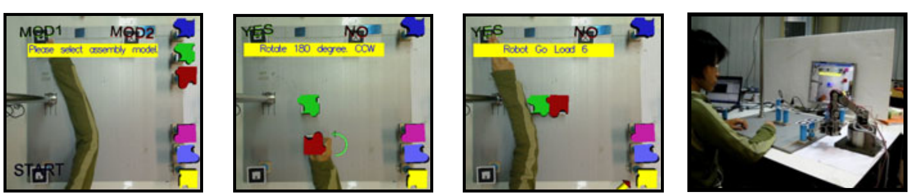


Fig. 2. System Data Flow Diagram

2.3 System Operation

When system starts, it presents graphics instructions so that the operator can select the assembly model as shown in Figure 3(a). After selecting the assembly model, several virtual objects are rendered and superimposed on the markers. The system then generates a task plan of selected assembly model. That plan is interpreted to manage system states, present graphics information, and control the robot. The 2D graphics shows suggestion texts and information related to robot action while 3D graphics presents assembly guidance arrows such as suitable positions and orientations of virtual objects over the real video image on the LCD screen as shown in Figure 3(b) and 3(c). During the operation, robot will assist the operator to transfer targeted object after "Yes" virtual object is selected as shown in Figure 3(d). The operator can decline any robot action by selecting "No" virtual object. If the operator does not follow the suggested task plan, the system will generate a new task plan for that assembly task automatically.



(a) Model Selection (b) Rotation Guide (c) Robot Selection (d) Robot Operation

Fig. 3. System Operation

3 Experimental Results

There are 3 experimental sets to evaluate the proposed system in the areas of system performance, usability, and values for specific task.

3.1 System Performance

Robot's repeatability is one of the system performances. At least 6 targeted positions in the robot workspace are tested for obtaining the robot's repeatability in both x and y axes. This experiment results indicate that the repeatability errors in x and y axes are 0.52 and 0.35 millimeters, respectively. Next, the graphics update rate is about 17 fps with the image resolution of 640 x 480 pixels. This system has ability of tracking the targeted markers which are moved with velocity less than 10 centimeters/second.

3.2 Usability

After using the proposed system to do virtual assembly task, questionnaire is used to collect user's satisfaction on the system's usability. The results indicate that most of users are satisfied with the system's usability. Using graphic arrow helps the users to understand the virtual object's direction more easily. Hence, the usability of guidance arrows indicating the virtual object's orientation got the highest satisfaction score with 92 percents. However, most users did not pay much attention at the suggestion text during operation. As the result, the usability of suggestion texts got the lowest satisfaction score with 74 percents.

3.3 Values for Specific Task

This proposed system is applied in a virtual assembly task. In this task, the users were asked to assemble the virtual object as a given picture on the instruction sheet. This assembly task is set in three conditions as assembly with/without any system's information and assembly with system's information along with robot's assistance. The goal of this experiment is to reduce the operation's time when the users work with this system's assistances. Since the 3D virtual objects are mostly complicated, this task is difficult for the user who does not have much skill in 3D graphics assembly. Therefore, assembly without any system's information took the most averaged assembly time at 182 seconds. With graphics guidance information, it can reduce averaged assembly time into 64 seconds or 64.84 percents of assembly time obtained from system without graphics guidance information. The averaged assembly time with system's information and the robot is 144 seconds or 20.88 percents of assembly time obtained from system without graphics guidance information. The speed of this operation depends on the robot's speed. After the experiments, the questionnaire is used to collect the user's satisfaction. The results show that most of the users are pleased with this proposed system for the virtual assembly task. Because of using guidance graphics overlaid on real time video during assembly task can reduce the operating time. Therefore, the ability of system's suggestion assisting user to assembly faster got the highest satisfaction score with 87 percents. Since the robot must work with human operator, it is set to operate at the low speed. Some users are not satisfied with this operation speed so the satisfaction of robot's assistance got the lowest score with 81.33 percents.

4 Conclusions and Future Works

The human- robot collaboration with augmented reality for virtual assembly task was proposed. The system's assistance using augmented reality and the robot can reduce the operation times of the virtual assembly task. Furthermore, the use of augmented reality in the assembly task can save cost and training time. The virtual objects in assembly task can be changed into various object's models by importing from the CAD applications. Moreover, the graphics guidance can help the user to understand the assembly task more easily so the assembly time is reduced.

Based on the experimental results, there are many issues that can be developed to improve the system performance and usability. Since the operator does not pay much attention to read graphic texts during operation, the augmented guidance information should be graphic symbols instead of texts. The assembly time of operating with the robot can be reduced by increasing the robot's speed. However, the change of robot's speed should be considered along with human's safety. For more natural communication, the interaction between robot and human can be improved by using gesture or speech recognition.

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