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Development of an Automatic Dishwashing Robot System

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***Abstract*— In this paper, we introduce an automatic dishwashing robot system, which consists of two 7-DOF manipulators, novel grasping system with hook structure, sensing system and the controller. We introduce each component of the system and experiments are performed to illustrate the effectiveness of the developed robot system.**

I. Introduction

With the development of the robot technologies, robots are expected to execute various tasks in many fields of human environments. In the backyard of the restaurant, hotel, hospital etc., many workers want to be supported by the assistive systems for realizing the tasks for washing the dishes and clearing away them. Though the dishwashers have been used in many restaurants, hotels, etc., the tasks for setting the dishes in the dishwasher, taking them out of the dishwasher and clearing away them are very tough works for the workers.

In this paper, we will apply the robot technologies to the backyard of these fields for realizing the tasks of washing the dishes and clearing away them by integrating with the existing dishwasher, which is commercially available. Though the existing dishwashers are designed under the assumption that they are used for human workers, the hardware of new robot system for integrating with the existing dishwasher should be designed as human-like structure. Therefore, in this research, we develop a robot system for washing the dishes and clearing away them, which consists of two 7-DOF manipulators, grasping system like human hand, sensing system and the controller.

This paper will discuss the automatic dishwashing robot system, and is organized as follows: in section II, we discuss the summary of the developed robot system and the experimental results of the processes required for realizing automatic dishwashing robot system is described in section III. Section IV summarizes our contributions.

II. Automatic Dishwashing Robot System

In this section, we introduce prototype of automatic dishwashing robot system, which consists of two 7-DOF manipulators, novel grasping system with passive hook structure and active fingers, vision sensing system, controllers and dishwasher. Fig.1 shows the developed automatic dishwashing robot system.

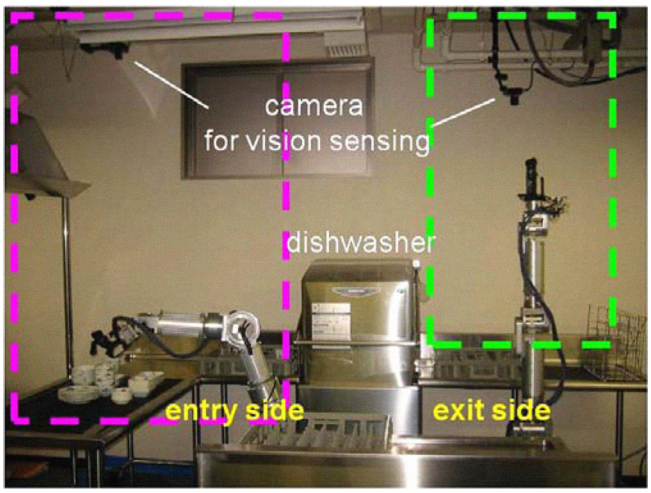
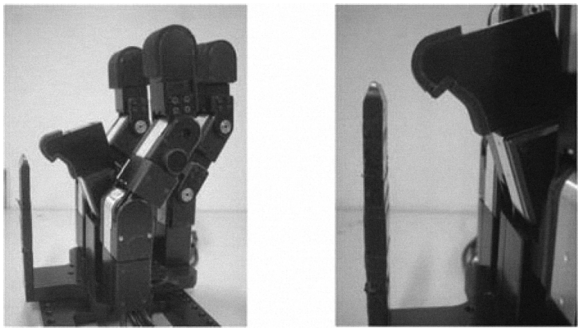


Fig. 1. Automatic dishwashing robot system



(a) Hook-structured hand (b) Hook part

Fig. 2. Prototype of hook-structured hand

A. 7-DOF Manipulator

In the development of the manipulator as shown in Fig.1, we consider the high power and the light weight manipulator. From the safety point of view, the light weight manipulator is very useful for using in the human environment. However, the high power is also required for handling the many kinds of dishes. The development of such manipulator with high power and the light weight is challenging issues, and if we could develop it, it could be applied to not only the backyard

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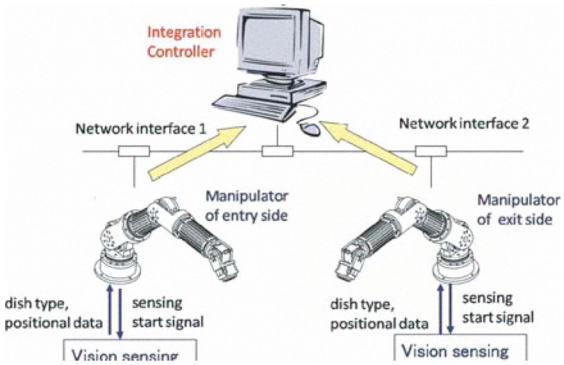
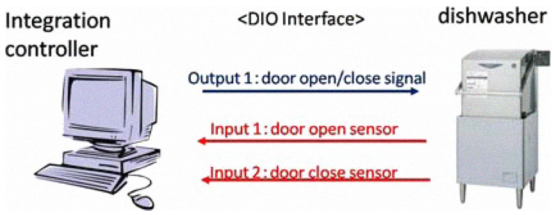


(a) Interface with manipulation system and sensing system



(b) Interface with dishwasher

Fig. 3. Interface of integration controller

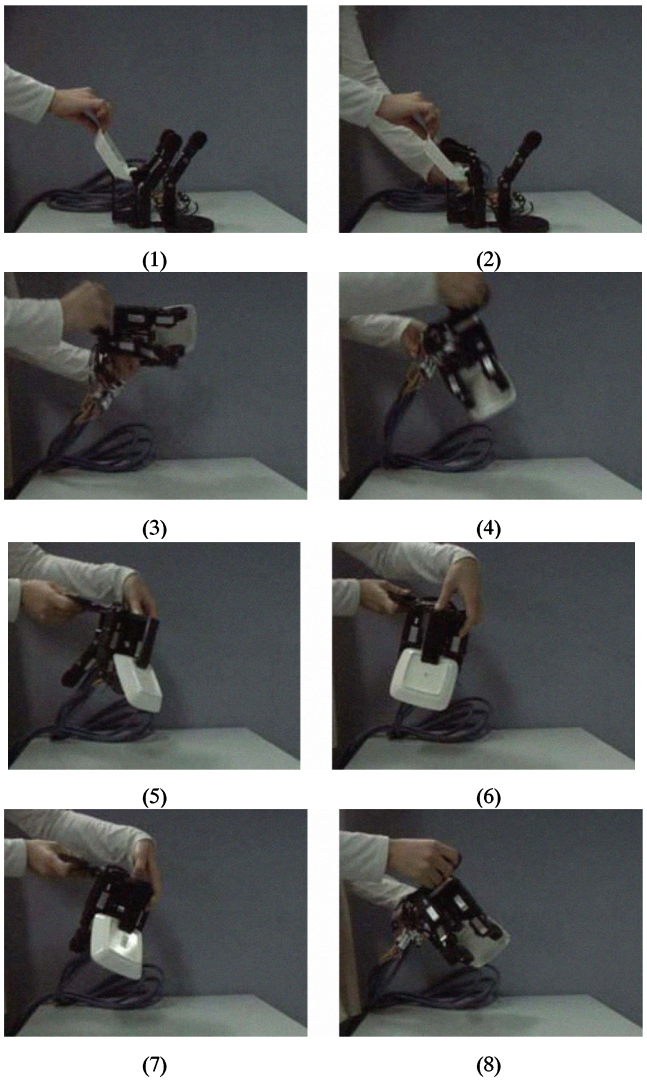


Fig. 4. Grasping against disturbance forces

of the restaurant but also the many fields for supporting the human being.

The developed manipulators have 7 degrees of freedom and are controlled for handling the dishes and the trays of the dishwasher. A manipulator is used for setting the dishes to the tray of the dishwasher, and inserts the tray with dishes to the dishwasher. It is also used for handling the empty tray to the original position in order to set the next stacked dishes on the table. The other manipulator is used for handling the dishes washed by the dishwasher. First, it pulls the tray with dishes out of the dishwasher and clears away them into the basket.

B. Grasping System with Hook Structure

Many researchers have proposed the multi-fingered hands [1]-[4]. However, most of multi-fingered hands developed so far have not been used for real applications. The multi-fingered hands have been designed mainly based on the shape of a human hand. To design a practical multi-fingered hand, we need to consider how we use our fingers for grasping an object. We need to observe the grasping motion of a human hand and apprehend the human grasping patterns according to the grasped object for achieving robust grasping by a robot hand.

Many classification methods for grasping patterns have been proposed so far. One of the most well-known classifications is the one proposed by Napier [5], in which the grasping patterns are classified into the power grasp and the precision grasp. This classification, however, does not include grasping patterns, which can be observed frequently in our daily life, such as the pattern with which we grasp a pencil. Kamakura et al. [6] proposed a classification of grasping patterns taking grasping patterns in our daily life into account. According to the classification by Kamakura et al., our grasping patterns are classified into four major classes: 1) Power grasp, 2) Lateral grasp, 3) Precision grasp and 4) Adduction grasp. In this paper, we focus on the lateral grasp and propose a novel robot hand for achieving lateral grasp for handling flat-shaped objects.

The lateral grasp is more effective for grasping flat-shaped objects firmly and robustly than the power grasp or the precision grasp, but most of robot hands have been developed mainly for achieving the power grasp or the precision grasp. This might be one of the reasons why multi-fingered hands could not be used in practical applications in our daily life, for which grasping of flat-shaped objects are also important. In this paper, we consider a grasping mechanism for flat shaped objects and a task to grasp a dish as a practical example of grasping.

We developed a grasping system with hook structure to handle the several kinds of dishes. Similar to the manipulators, the light weight grasping system is also required, because this grasping system have to be attached to the tip of the

manipulators. The hook-structured hand is designed to realize lateral grasp [7], which is an effective grasping method for flat-shaped objects. The hook-structured robot hand consists of active fingers and passive hook part, and its structure is shown in Fig.2. The hook part is used for constraining object by mechanical contacts, and fingers are used to apply force to the grasped object in order to increase the robustness of the grasping.

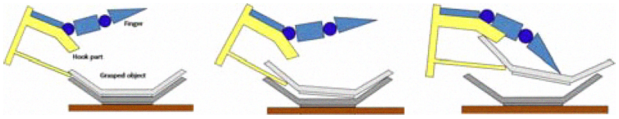
Large finger force is not required for grasping a flat-shaped object by the proposed hook-structured mechanism compared to other types of multi-fingered hands or grippers, since the grasping is mainly realized by mechanical contacts with the passive hook structure. The grasping mechanism and the evaluation of robustness are explained in detail in [7].

C. Vision Based Sensing System

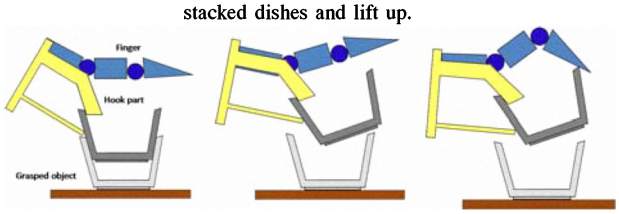
Sensing system consists of 0.3Mpixel IEEE1394 camera for recognition of dish type and 2Mpixel IEEE1394 camera and laser scanner for measurement of dish position [8]. By using the sensing system, the shape of the dishes and its positional data are gotten and are sent to the controller of the manipulator and the grasping system. The controller of the system stores with the manipulation skill of the several kinds of dishes and the robot system is controlled based on the data from the sensing system and the manipulation skill database.

D. Integration Controller

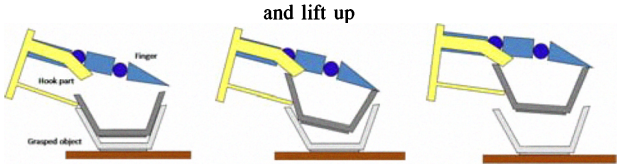
Integration controller controls the motion and the start timing at each system, the handling of dishes by manipulation system, the measurement of dish position by vision system and open/close of dishwasher. Fig.3(a) shows the interface of integration controller with two manipulation systems and vision sensing systems, and Fig.3(b) indicates the interface of integration controller with the motion of open/close of dishwasher.



(a) Grasp method I : insert the tip of hook into the space between stacked dishes and lift up.



(b) Grasp method II : hook a part of dish jut out and lift up



(c) Grasp method III : tilt a dish by finger to hook and lift up

Fig. 5. Grasp method for stacked dishes

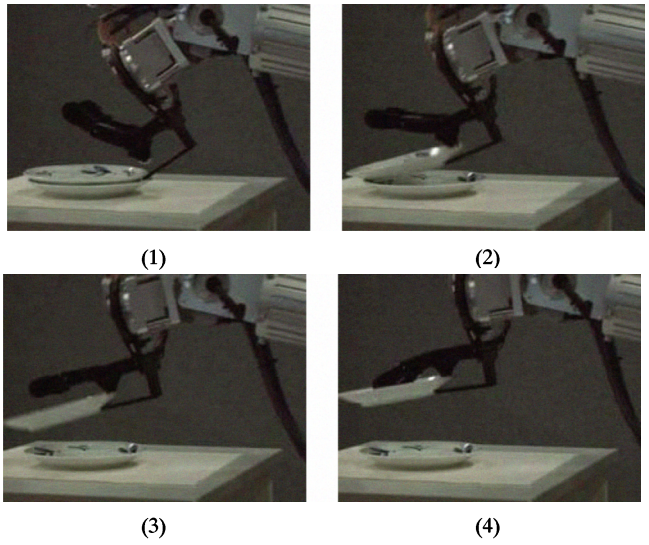


Fig. 6. Grasping based on grasp method I

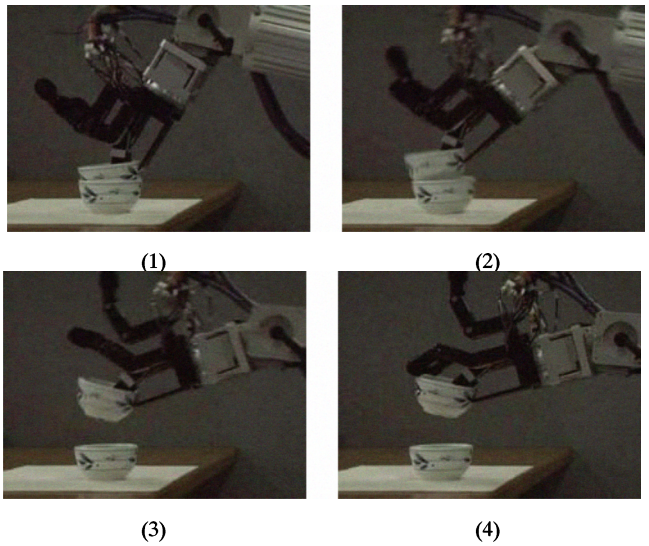


Fig. 7. Grasping based on grasp method II

III. Experiments

In this section, we conduct several experiments for illustrating the validity of the required tasks for realizing the automatic dishwashing robot system. For the experiment, six types of dishes in different shapes and sizes are selected which are generally used in hotels, hospitals, etc.

A. Entry Side

In the entry side of dishwasher, we performed four experiments for handling dishes.

1) Grasping Dishes Robustly: Fig.4 shows that the grasping by the hook-structured hand is maintained even with disturbance force generated by shaking the dish with $0.2 \sim 0.9$[kg] up and down. When shaking the object, the grasping system should hold the object against force arising from accelerating the object as well as the gravity. We confirmed the same results in all the selected dishes. Through the experiment, you can see

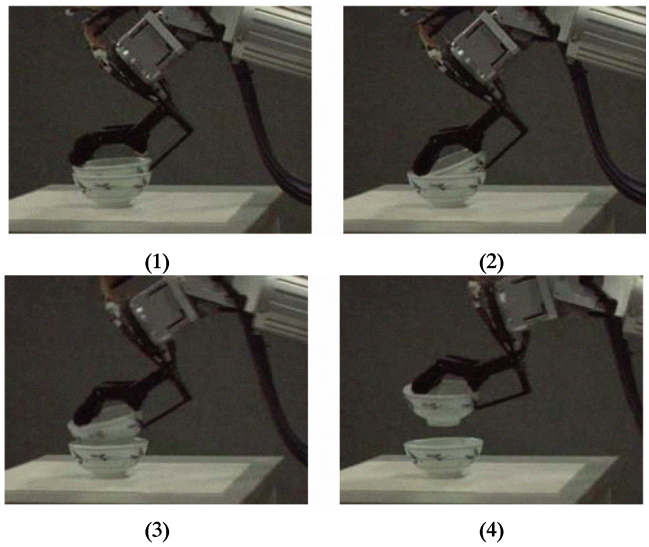


Fig. 8. Grasping based on grasp method III

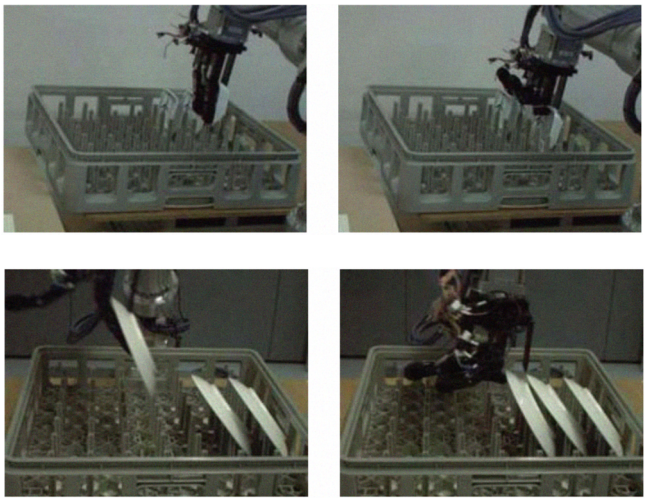


Fig. 9. Arrangement of dishes by hook-structured hand

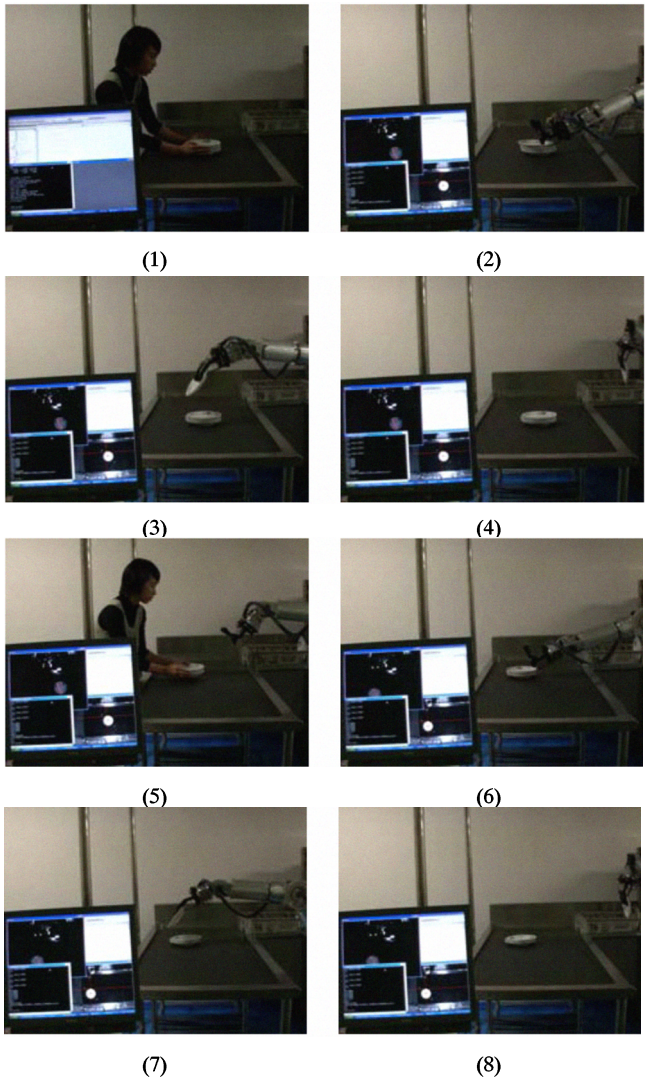


Fig. 10. Grasping of dishes based on vision sensing at entry side

that the grasping by the proposed robot hand has very high robustness.

2) Grasp of Stacked Dishes: It is difficult to grasp stacked multiple flat-shaped objects by existing robot hands, in spite of the essential task in many applications, because there is very small space between stacked flat-shaped objects. We consider three grasping methods according to dish shapes in order to realize the grasping of stacked dishes as shown in Fig.5. Fig.6-Fig.8 also show the sequence of grasping stacked dishes based on appropriate grasping method according to its shape respectively. Through this experiment, it is confirmed to be able to grasp the stacked dishes robustly for all the selected dishes. The experimental results indicate that the realization of grasping of the stacked dishes, which cannot be realized by existing robot hands so far, is enabled by the simplicity of the hook-structured hand.

3) Arrangement of Dishes: Fig.9 shows examples of experimental results to set dishes into the dish tray. The highly positional precision of end effector is required to arrange dishes in a limited space of tray.

4) Grasping of Dishes Based on Vision Sensing: Fig.10 shows that it is possible to grasp dishes put on the table arbitrarily based on vision sensing. The positional data of dish in 3-DOF space is gotten by vision sensing system and sent to the manipulation controller. The manipulation system is handled to grasp dishes based on the positional data sent from vision system.

B. Exit Side

Experiments at the exit side of dishwasher are preformed. Fig.11 shows that a dish grasped by the hook-structured hand is brought out from the tray and the dish is stacked in the basket. After this operation, the stacked dishes are arranged with the use of robot hands in the backward of the basket.

We perform this operation for more dishes. In addition, the vision sensing is utilized for measuring the position of the dishes as shown in Fig.12. The position of dishes are sent to

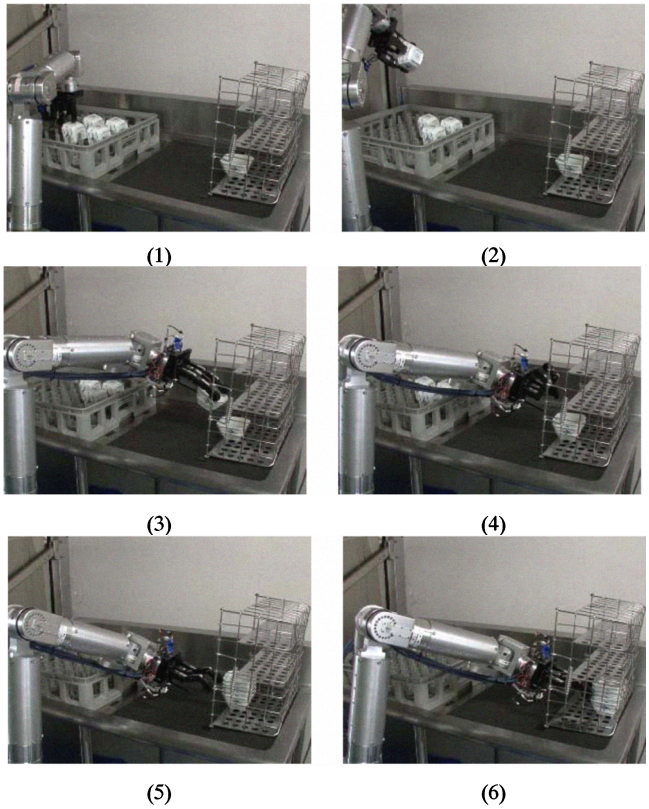


Fig. 11. Arrangement of dishes to basket

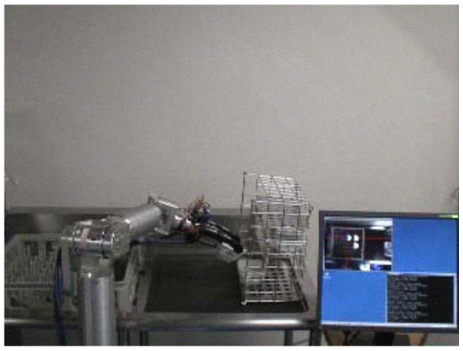


Fig. 12. Grasping of dishes based on vision sensing at exit side

the integration controller for controlling the manipulator of the exit side.

C. Realization of Automatic Dishwashing Robot System

By realizing the tasks of entry side and the exit side of dishwasher mentioned above, we illustrate the validity of the prototype system of the developed automatic dishwashing robot system. The process of the system is indicated as follows:

Step 1 (entry side): The various types of stacked dishes are put on the table arbitrarily. The vision sensing system begins to recognize the type of dish and measure the position of it, when the signal of ready to handle it is sent from the manipulation system.

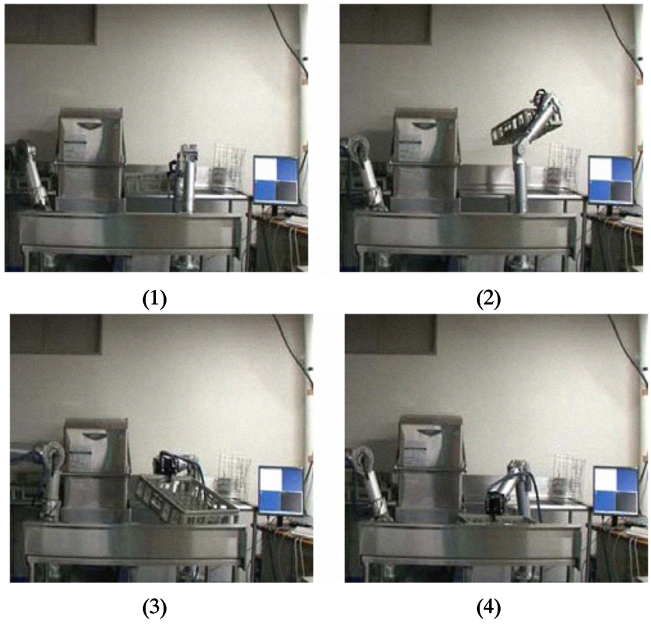


Fig. 13. Handling of tray

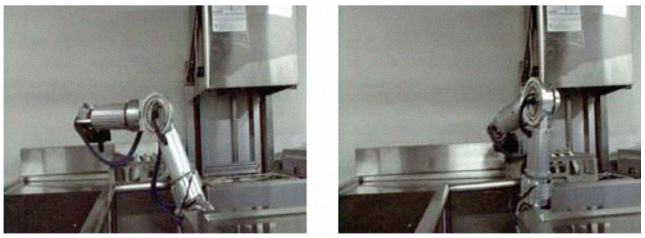


Fig. 14. Inserting of tray into dishwasher

Step 2 (entry side): After getting data of dish from vision system, the manipulator of the entry side of dishwasher grasps the dishes and sets them to tray.

Step 3 (entry side): When the tray is full of dishes, the manipulation system sends signal to integration controller to open the dishwasher and moves the tray into a dishwasher. And then dish washing is started by the dishwasher.

Step 4 (entry side): The manipulator of the entry side handles an empty tray and repeats the process of Step 1 $\sim$ Step 3 until there is no dishes on the table.

Step 5 (exit side): After washing the dishes by using dishwasher, the manipulator of the exit side pulls the tray out of the dishwasher and arranges dishes from tray to the basket based on the information of the vision sensing system.

Step 6 (exit side): When all the dishes in the tray are arranged, the manipulator of the exit side handles the empty tray to a place near the manipulator of the entry side.

Step 7 (exit side): The manipulator of the exit side repeats the process of Step 5$\sim$ Step 6 until all the dishes are arranged to the basket.

The handling of tray as well as dishes is required for realizing the sequential tasks of the dish washing. Fig.13 and Fig.14 show the example of handling tray. The motions

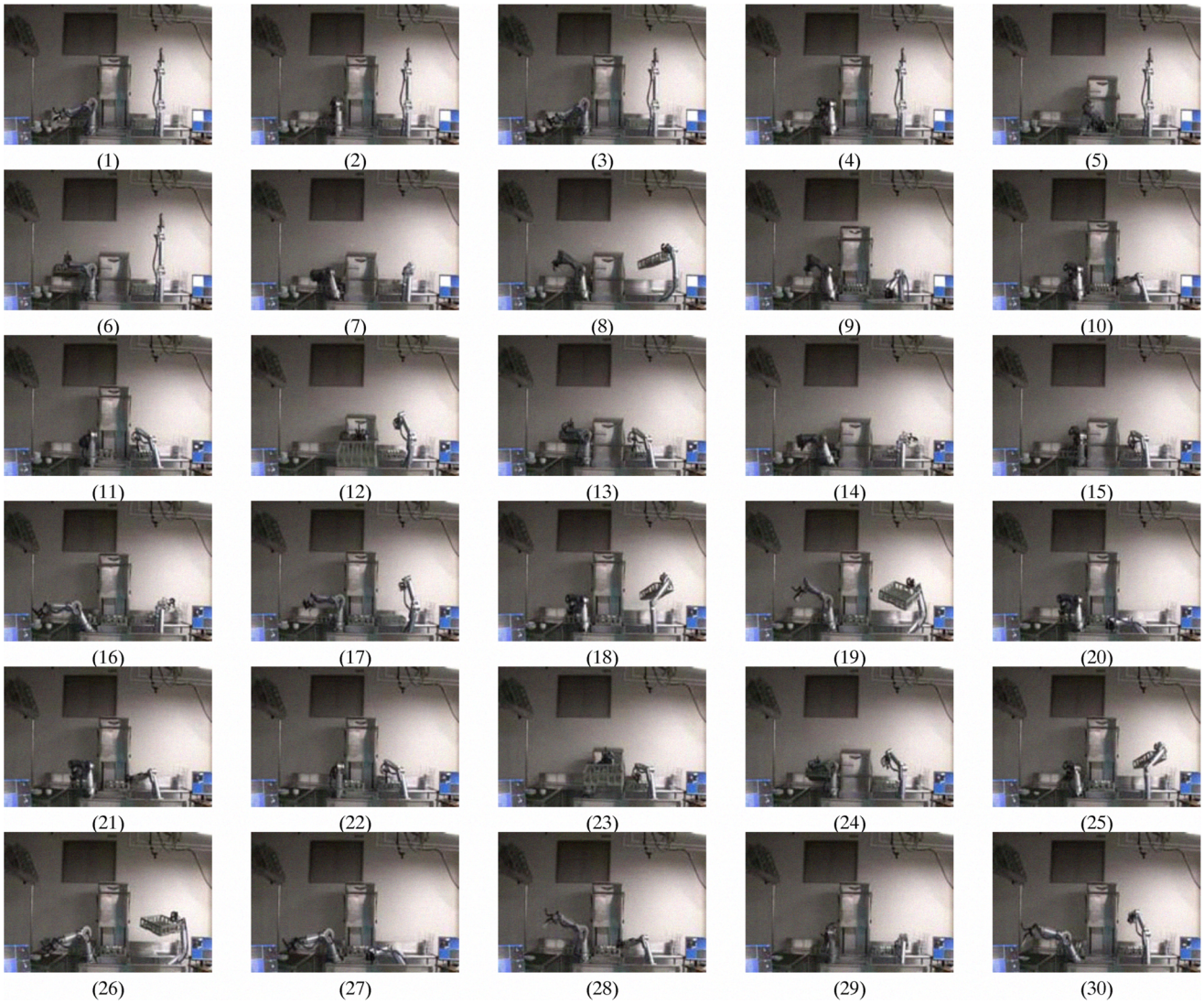


Fig. 15. Sequence of tasks by automatic dishwashing robot system

of two manipulators at the entry side and the exit side are performed at the same time according to the signal from the integration controller. Fig.15 shows an example of total process of dishwashing robot system. The experimental results show the validity of the developed automatic dishwashing robot system.

IV. Conclusion

In this paper, we proposed the automatic dishwashing robot system, which consists of two manipulators, hook-structured grasping system, vision based sensing system, and integration controller. By integrating these components appropriately, we can realize the automatics dishwashing task. The experimental results with the prototype system also illustrated the validity of it. As the future works, we will extend this system to not only the dishwashing system but also the systems for realizing various works.

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