ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 2, August 2013

Development of Small-Sized Industrial Dual-Arm Robot with Convenient Interface

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Abstract*—Human rights issues that arise due to poor working conditions are becoming a significant problem in modern manufacturing systems. Industrial dual-arm robots are being developed to eliminate the effects of these social issues. A dual-arm robot can work in place of human workers. In this paper, a new dual-arm robot for manufacturing mobile phones and television sets is introduced. It has advantages such as a single controller for both arms and human-sized body and arms. A software platform for the industrial dual-arm robot is also being developed, which is more convenient as compared to conventional robot software platforms. The software platform for the industrial dual-arm robot features real-time control capability, precise motion command, and a user-friendly interface. In this paper, the development of the dual-arm robot is introduced.

***Index Terms*— Dual-Arm Robot, Assembly with Robot, Dual-Arm Robot Controller.**

I. INTRODUCTION

Company put more efforts to get the fast product line-up change system to meet the market needs. Cell production assembly systems, where each employee is responsible for producing the finished product from the beginning till the end, have become the new trend in manufacturing. Manufacturing popular products like cellular phones, automobiles, food, and clothes is possible with cell production. The manufacturing system for the small quantity and batch production is significantly difficult with the automation equipment. Currently, cell production lines consist of human workers and some apparatus. In addition, cell production lines with human laborers often face social issues, in other words, human rights issues at the production sites. Human workers are susceptible to depression if they engage in repetitive processes every day. Those who handle heavy weights suffer from musculoskeletal diseases. Demands for settling human workers' problems have been increasing, and demands for a more flexible, adaptable, and changeable production system have increased to meet the market needs. Life cycle of the end production is getting more speedy. [1] created a production cell called the Raven Super Cell, which consists of a horseshoe-shaped fixed table and a round movable worktable. To reduce the operator's physical burden and improve the assembly's precision, [2] employed a manipulator (arm) to grasp the components during the assembly process. These advancements improved the assembly cell only from the perspective of physical support.

[3] proposed the Attentive Work-Bench to provide informational and physical support to human operators. In this system, a projector is employed to provide assembly information to the operator, and self-moving trays are used to deliver parts. These devices are, however, only experimental and cannot be applied to practical manufacturing processes. Nevertheless, it is seen that the system still depends largely on human factors.

[4] introduced the examples of human-machine cooperation for assembly lines. However, there are no concreteness methods in it.

[5] introduced a new cell production assembly system with human-robot cooperation.

Industrial robot systems have been widely used for manufacturing processes such as laser welding, transfer, and many repetitive processes. They can operate all day without any pause or error. Conventional industrial robots such as the serial robot have only one arm. In case of the serial robot, a motion with 6 degrees of freedom (DOF) is commonly used to precisely position the end-effector with the exact orientation. However, they cannot replace human workers in cell production lines because their low DOF and one-arm structure serve as limitations. The human body can perform motions with multiple DOFs, and has redundant joints that allow a worker to be flexible for complex work. Dual arms allow handling of more complex and peculiar objects.

Recently, industrial robot systems with dual arms, such as Motoman [6], Frida [7], and Baxter [8], have been gaining popularity for use in cell line manufacturing systems. Skilled robotic systems are key components in fully automated assembly processes and contribute to highly efficient production. They have almost same the DOFs as humans. They can have 6 or 7 DOFs in one arm depending on shoulder motion. They can meet the demands for increased flexibility and adaptability to changing the end-product.

However, conventional dual-arm industrial robots have some shortcomings. First, all of them lack teaching convenience. Dual-arm industrial robots have a more complicated kinematic structure. In conventional robots, users can program each (right and left) arm to command them to pick up an object. In these cases, users must consider the synchronization between the two arms. Second, all the robots need more power to size ratio. Motoman has a high power of more than 10 kg for each arm. However, its size is double that of a human adult. Actually, Frida and Baxter are limited to light object handling processes due to their low payload.

To overcome all these shortcomings, we have developed a human-sized, dual-arm, easy-to-use industrial robot with high payload. In this paper, we aim to introduce the development of our robot and its applications.

II. APPLICATION PROCESS

Fig. 1 Application process - cellular phone packaging

We aim to apply the developed dual-arm robot to the cell line for IT product manufacturing, which is designed like that in Fig. 1. Currently, products such as mobile phones and television sets are made by humans, who work in the standing position all day at the designated area. Their work is repetitive. Robots, specifically, dual-arm robots, which have functions like a human can serve as optimum substitutes for such tedious and repetitive work. In our scenario, two or three robots cooperate to pack and assemble a mobile phone. Because the dual-arm robots have two arms like humans, then can manage objects like human, without the need for additional large and expensive tools for automation.

III. HARDWARE DESIGN

The developed robot is intended to be the replacement for a human worker, and sometimes it may need to cooperate with human workers. We referred to the research of [9], where we can find the average adult male workers upper body size, for the body sizes of male workers. The robot's dynamic parameters such as velocity are determined from the experiments, in which the subject (robot) attached many markers on the important links packed the cellular phone. The robot's kinematic and dynamic parameters are listed in Tables 1–2.

Table 1 Kinematics parameters of the developed dual-arm robot

Shoulder length	416mm
Arm length	847mm
Humerus(Axis 2-4)	315mm
Radius(Axis 4-6)	295mm
Hand(Axis 6-7) with tool	237mm

Table 2 Dynamics parameters of the dual-arm robot

Joint	Max. Torque (Nm)	Rated Torque (Nm)	Max. Velocity (degree/s)	Motion Range (degree)
1	120	60	150	+180 ~ -180
2	120	60	150	+135 ~ -60
3	70	30	150	+180 ~ -180
4	70	30	150	+144 ~ -55
5	35	15	240	+180 ~ -180
6	35	15	240	+90 ~ -90
7	25	10	240	+90 ~ -90

In addition, the developed robot has 7 DOF (degree of freedom) for each arm. The DOF of the whole body is displayed below:

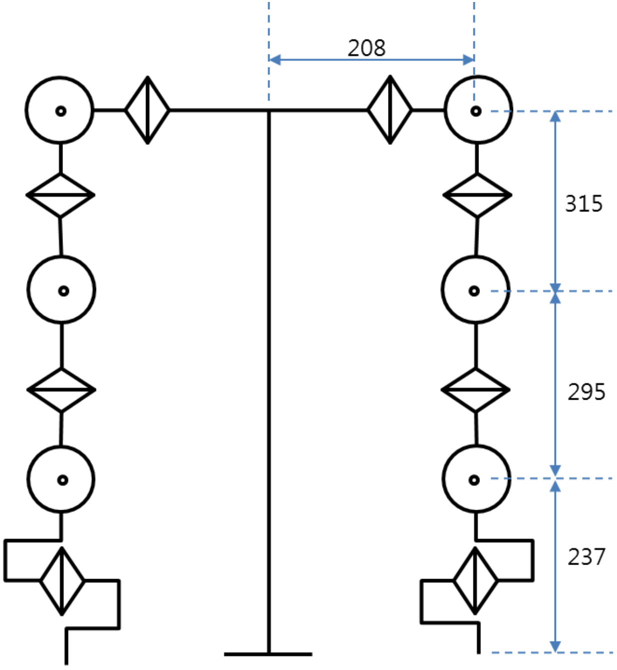


Fig. 2 Whole body joint structure

Currently, the waist is being developed with 2 DOF. With the waist, the workspace of the robot can be extended. Actuator modules have been developed to reduce the size of the robot. Details of the modules are described in [10]. Briefly, the robot has strength despite its compact size thanks to a modular structure; the robot also has high power. The developed dual-arm robot can lift an object of more than 5 kg. The payload to weight ratio will be at least 1/2.

Table 3 Actuator module parameters

Joint #	Diameter (mm)	Max. Torque (Nm)	Rated Torque (Nm)	Max. Velocity (degree/s)	Gear Ratio	Weight (kg)
1	106	120	60	150	160:1	2.3
2	106	120	60	150	160:1	2.3
3	90	70	30	150	160:1	1.6
4	90	70	30	150	160:1	1.6
5	90	35	15	240	100:1	1.5

6	90	35	15	240	100:1	1.5
7	85	25	10	240	100:1	1.3

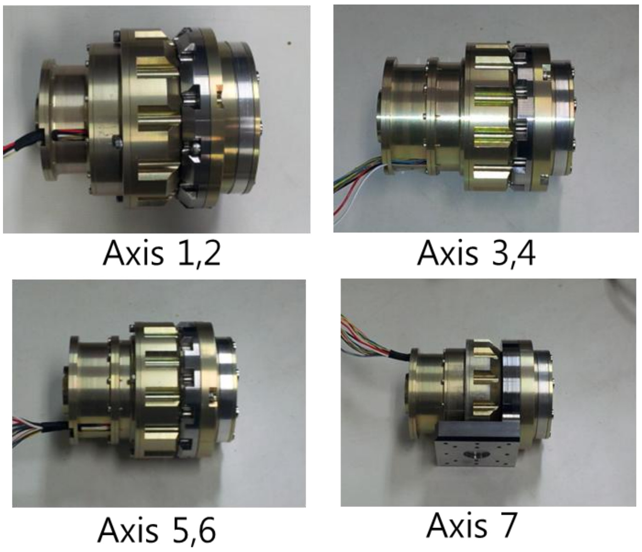

Axis 1,2
Axis 3,4
Axis 5,6
Axis 7

Fig. 3 Developed actuator module

Finally, the fully developed dual-arm robot is shown in Fig. 3. The one on the left has been photographed without clothes. The one on the right is with clothes. Some wires have not been embedded inside the hollow of the module to make robot installation convenient. For example, an air hose can be used or not depending on the nature of work. All actuators and force torque sensors communicate via the EtherCAT protocol of [11] and [12]. EtherCAT is a communication standard introduced by Beckhoff Inc. It uses the conventional local area network (LAN) physical layer and hardware, so users do not need to add any special equipment. It also uses the daisy chain topology for connection. In our robot, hollow axis actuators and sensors are used and all signals pass through the hole. Therefore, serial connection using Ether CAT is very useful in this study. Actually, there are many serial connection methods. However, only Ether CAT guarantees real-time communication without the need for additional expensive special hardware.

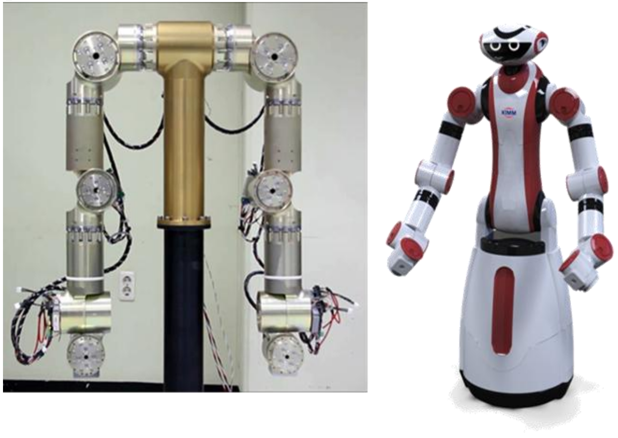


Fig. 4 Developed actuator module

IV. CONTROL SOFTWARE ARCHITECTURE

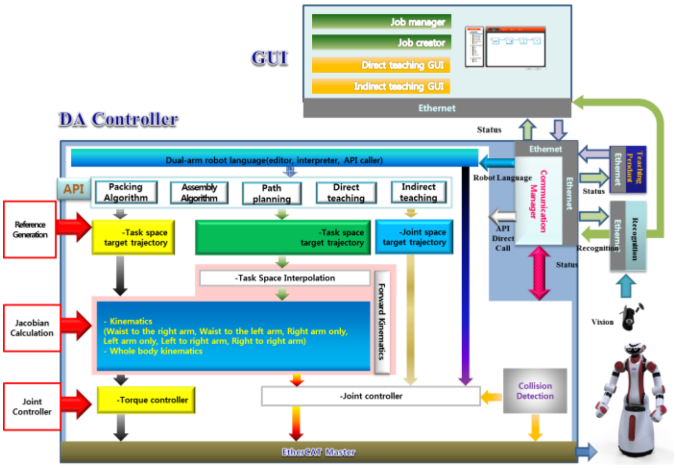


Fig. 5 Control Software Architecture

The dual-arm robot requires real-time control. The performance requirement for speed and precision is higher than that for the conventional robots such as serving, walking, and mobile robots. A control output with strictly regular intervals of more than 1 kHz is usually necessary to guarantee the required performance in industrial applications. Developers prefer Microsoft Windows with visual studio developer tools due to ease of use. However, unfortunately, in this user-friendly operating system, i.e., [13] Windows, it is difficult to schedule regular intervals because of its heavy background processing. The commercial software RTX kernel [14] is used to meet the real-time control requirement. In fact, EtherCAT communication is only possible on a real-time kernel.

Generally, industrial robots must be taught to memorize their repetitive actions. Industrial robot teaching is a tedious and difficult process. Teaching pendant and command console are used to program the robots' tasks. Their operation trajectory must be programed in detail using special robot language [15]. To overcome the conventional tedious teaching process, some intuitive methods like direct teaching [16] were introduced. These teaching methods designed for conventional single manipulators are not suitable for a dual-arm robot because its tasks are complex. Dual-arm robots assemble parts and cooperate with other robots to handle heavy objects like humans. Their work is determined not by trajectory, but by their tasks. To simplify the programming in robots such as humanoid, mobile, and toy robots, novel robot program methods based on flow chart schemes and graphical user interfaces (GUIs) were introduced, such as [13, 17, 18]. They all have a common structure and similar GUI. Users can define the robot's motions via state diagrams or flow charts using a mouse. Each part of the state or flow is described by actions such as "go," "stop," and "do something." The robot moves according to the programmed actions. Of course, each action can be easily reconfigured to create new motion, like in the Object Oriented Program (OOP) method. In this method, it is difficult to define a detailed motion trajectory. Precision of motion is the most important aspect for industrial robots. To overcome the shortcomings of the conventional method, the developed dual-arm robot system facilitates both ways of GUI and command. Some useful commands for dual-arm operation are listed in Table 4.

Table 4 Some examples of the dual-arm command

DA_CAP_JMOV	Simultaneous movement in the joint coordination of the both right and left arms
DA_CAP_JMOV	Simultaneous movement in the cartesian coordination of the both right and left arms
DA_CP_LMOV	Both arm moves with keeping the relative distance between both arms
DA_CP_CMOV	Both arm moves around the goad position making a relative circle motion
LR_SYNC	Define the synchronization of the specific motions

Fig. 5 shows the overall control software structure. The developed software contains a fundamental kinematics and dynamics library, low-level commands such as joint move and end effector move commands, high-level commands such as grip the specific object with the help of camera, assemble the desired object with the help of intelligent algorithm, etc.

V. EXPERIMENTS

We designed a simple process that forms part of the cellphone packaging process. Cellphones contain parts such as batteries, manuals, earphones, USB cables, power adapters, battery chargers, and so on. Four objects (a battery, an earphone, battery charger, and power adapter) are selected and positioned on the worktable. The worktable has special back-lighting. This helps the robot detect the object inside its vinyl cover when the camera detects the position of the target object. It is very difficult to detect the desired object inside a vinyl cover due to excessive noise. The dual-arm robot is equipped with tools that have suction properties. The final goal of the dual-arm robot is to pick up all parts and put them in the cellphone case.

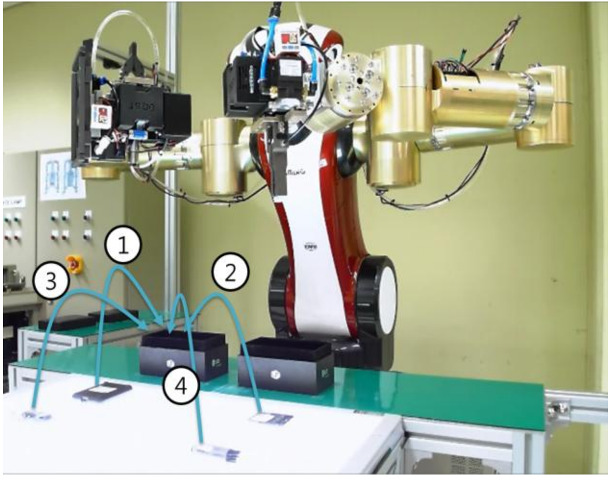
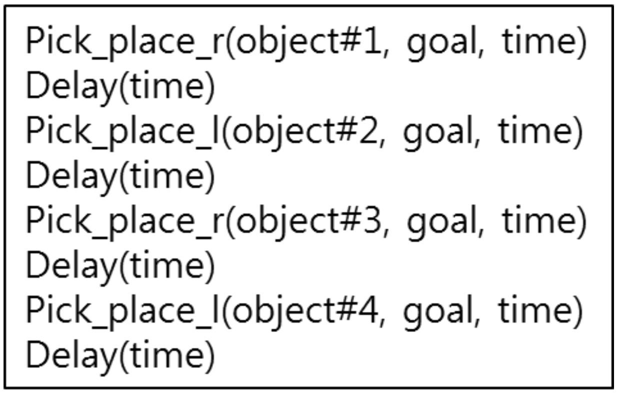


Fig. 6 Pick and place 4 parts into the box

With the special language developed for the dual-arm robot, only eight lines of commands, consisting of three types of commands, are enough to execute the desired mission. The commands used are listed in Table 5.



Pick_place_r(object#1, goal, time)
Delay(time)
Pick_place_l(object#2, goal, time)
Delay(time)
Pick_place_r(object#3, goal, time)
Delay(time)
Pick_place_l(object#4, goal, time)
Delay(time)

Fig. 7 Command list

Table 5 Used command in the experiment

Pick_place_r(object, goal, time)	Pick the 'object' and put it in the 'goal' object using the right arm during 'time'
Pick_place_l(object, goal, time)	Pick the 'object' and put it in the 'goal' object using the left arm during 'time'
Delay(time)	Delay during 'time'

In the experiments, the developed robot executed the desired task without errors as shown in Fig. 8. The motions executed by the robot during the packaging process were similar to that of a human worker.

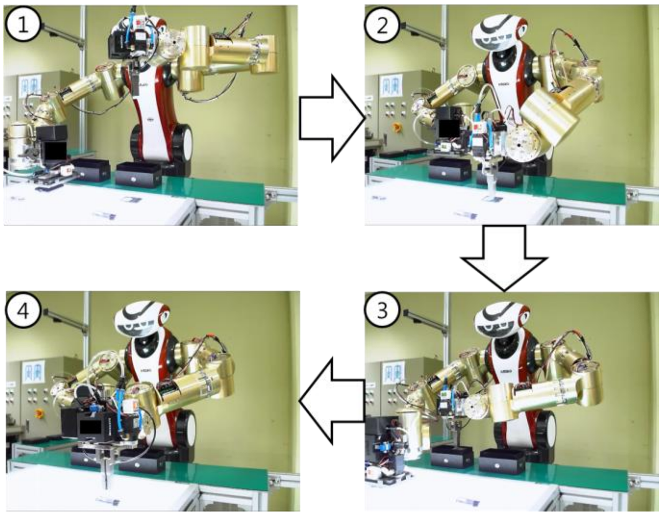


Fig. 8 Cellular phone packaging partial process

VI. CONCLUSION

Currently, there are few dual-arm robots designed for industrial applications. However, all of them have shortcomings related to size, payload, user interface, and so on. In this study, a small-sized dual-arm robot with high torque to handle various objects has been developed. It also features a convenient user-friendly interface. As an experiment, it was applied to a part of the cellphone packaging process. The developed robot showed excellent performance and was easy to program.

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