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Research Article

Proposal for a Robotics Class using 3D Printer and Development of a Robotics Arm for Education of Design, Manufacturing and Control

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ABSTRACT

In the field of robotics education, understanding the design, manufacturing, and control of robots is an important aspect of understanding the development of robots. Therefore, various university-level robotics education courses have been created to cover these topics. However, students typically learn about design, manufacturing, and control in different classes. This can potentially lower their understanding of robotics development. There are various reasons why these topics are taught in different classes, but the main reason is the difficulty of manufacturing. Manufacturing education parts often requires a machine such as a CNC, and in the case of a class for many students, it takes a lot of time to manufacture objects designed by students. Recently, low-cost 3D printers have become available, which are considered a solution for reducing manufacturing time. In this paper, I propose a year-round robotics class that covers design, manufacturing, and control. Then I introduce the developed 5-axis robotic arm for education, which can be manufactured using 3D a printer, as a result of the proposed class. The evaluation of the developed arm showed that the maximum payload (with a safety factor of 2.5) was 2.2 [kg], and the maximum repeatability was ± 0.201 [mm].

1. Introduction

As the size of the global smart robot industry grows every year[1],[2], the importance of robotics education is increasing. In response, many universities around the world have prepared robotics education courses that include design, manufacturing, and control. However, students typically learn about design, manufacturing, and control in different classes, which can lead to a lack of understanding of the overall flow of robot development. There are various reasons why design, manufacturing, and control are taught in different classes, but the main reason is the difficulty of manufacturing education. In the manufacturing education for robotics, a lot of robot parts designed by students or supervisors are made of metal or plastic. In this case, if the class is for a large number of students, there are various problems with time and cost. This is because expensive machines such as CNCs are required for the manufacture of various shaped robot parts. It is not easy to prepare a large number of CNCs for manufacturing education, so it is difficult to manufacture various robot parts within a fixed class time. Recently, low-cost 3D printers, which are cheaper compared to CNCs, have been introduced into the education field[3],[4],[5], and manufacturing education using low-cost 3D printers is attracting attention as a solution to these time and cost problems.

In this paper, I propose a year-round robotics class that covers design, manufacturing, and control. I also introduce the developed 5-axis robotic arm, which can be

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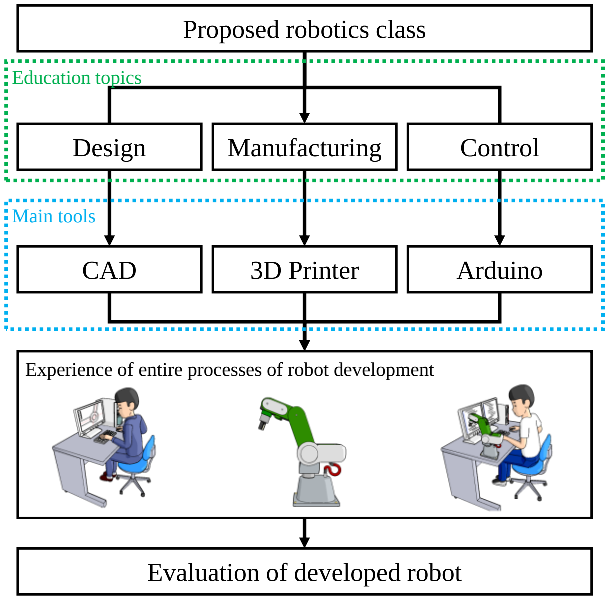

Fig. 1. Overview of the proposed robotics class

manufactured using a 3D printer, as a result of the proposed class.

2. Robotics Education using Robotics Arm

The proposal for a robotics class that covers design, manufacturing, and control is presented in Fig.1.

In the proposed robotics class, students can experience the entire process of robot development, including design, manufacturing, and control, as presented in Fig.1. In the design education portion of the class, the supervisor will teach students how to design robotic arm parts using CAD software. In the manufacturing education portion, students will learn about the basic mechanisms of 3D printers and how to use them. In the control education portion of the class, the supervisor will teach students about the basic mechanisms of motors and motor drivers, and how to use an Arduino board for motor control. Following the design and manufacturing education, students will then build and evaluate their own robotic arms, including measuring the maximum payload and position repeatability. The proposed class plan is shown in Fig. 2.

The plan of proposed robotics class is composed with 28 lectures as shown in Fig.2. The supervisor explains the class content and the basic concepts of the tools in the first lecture. In lectures 2 and 3, students learn basic CAD, and then design the parts of the robotic arm in lectures 4 through 9. In lectures 10 and 11, students learn about basic 3D printing, and then manufacture the designed parts using 3D printers in lectures 12 through 19. After the hardware for the robotic arm is completed, students learn motor control programming using an Arduino board in lectures 20 through 24, and then evaluate the developed robotic arm in lectures 25 through 27. In the final lecture, students present their developed robotic arm.

2.1. *Development of the Robotics Arm*

A designed robotics arm, which will be assembled using manufactured parts produced by a low-cost 3D printer, is illustrated in Fig.3.

As illustrated in Fig.3, the designed robotics arm has 5 actuators. The arm was designed based on general articulated robots[6],[7],[8],[9]. he first actuator is used for yaw-axis rotation, while the second and third

Lecture number	1	2	3	4	5	6	7
Contents of class	Guidance	Basic CAD		Design robotics arm			
Lecture number	8	9	10	11	12	13	14
Contents of class	Design robotics arm		Basic 3D printer		Manufacturing of designed robotics parts		
Lecture number	15	16	17	18	19	20	21
Contents of class	Manufacturing of designed robotics parts					Basic Arduino	
Lecture number	22	23	24	25	26	27	28
Contents of class	Control robotics arm			Evaluation of robotics Arm			Presentation

Fig. 2. Plan of the proposed robotics class

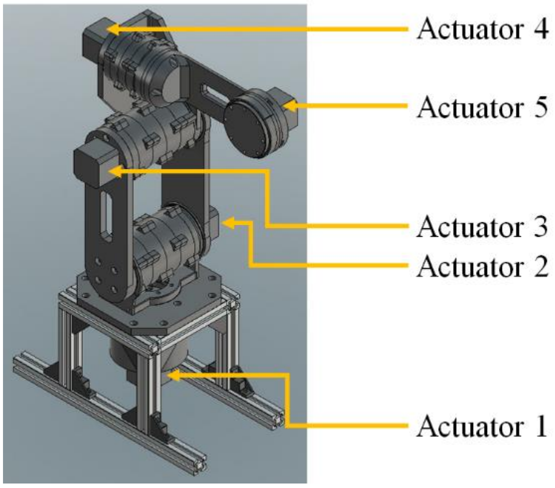

Fig. 3. Overview of the designed robotics arm

Table 1. Details of selected stepper motor

Detail	Values
Operating voltage	9 [V] ~ 40 [V]
Maximum ampere	4 [A]
Maximum torque	0.4 [Nm]
Step angle	1.8 [deg.]
Weight	0.28 [kg]
Cost	About 20.00 dollar (Include motor driver)

actuators are used for pitch-axis rotation. The fourth actuator is used for roll-axis rotation, and the fifth actuator is used for pitch-axis rotation. Each actuator for axis rotation is a stepper motor, which was chosen because it can output high torque and can be easily commanded to move and hold by an Arduino and motor driver without the need for position sensors.

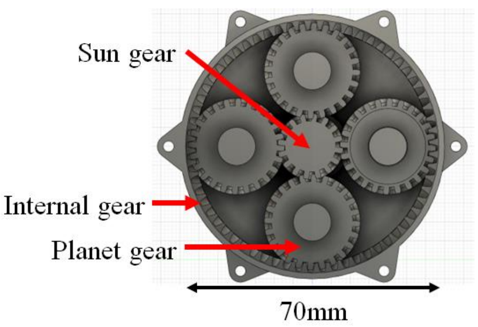

Fig. 4. Overview of the designed reduction drive

The details of selected stepper motor are shown in Table 1.

As shown in Table 1, the selected stepper motor can output a maximum torque of 0.4[Nm]. However, the output of 0.4[Nm] is not sufficient to rotate the link of robotics the arm. Therefore, reduction drives are required to rotate the link of robotics arm. The design of the reduction drive is also included in the design education of the robotics arm. The designed reduction drive is illustrated in Fig.4.

As illustrated in Fig.4, the reduction drive is designed with a planetary gear mechanism because it is compact and provide high power density compared to standard parallel axis gear trains[10]. The reduction ratio of designed reduction drive can be defined as follows:

$$i = \left(\frac{z_a}{z_a + z_c} \cdot \eta_i\right)^2 \qquad (1)$$

where z_a is the number of teeth of the sun gear, z_c is the number of internal gear teeth, and η_i is the efficiency of reduction drive.

In the designed reduction drive, z_a was 16, z_c was 64 and η_i was 0.7. Therefore, the reduction ratio i was 3.5. The

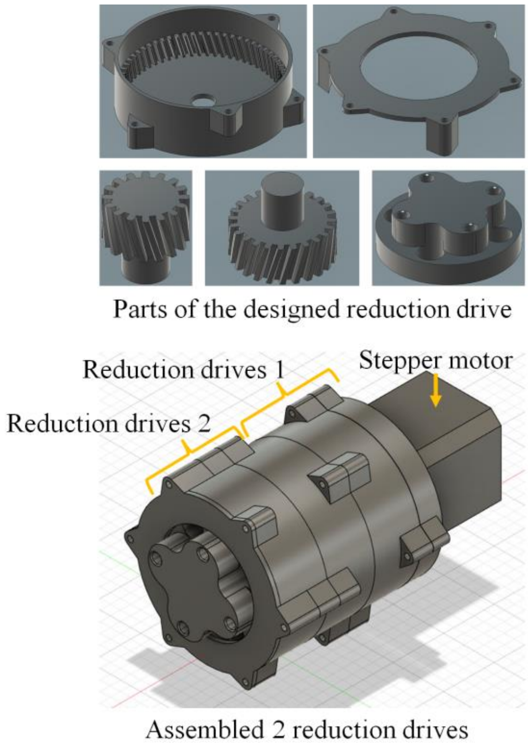

Fig. 5. Parts of reduction drive and assembled 2 reduction drive

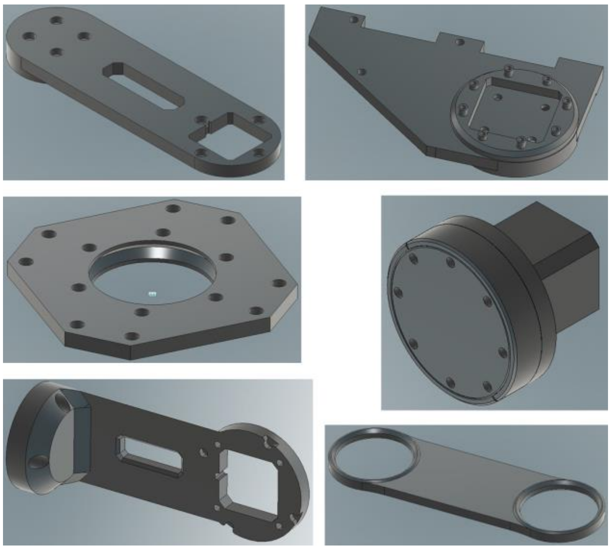

Fig. 6. Designed parts of robotics arm

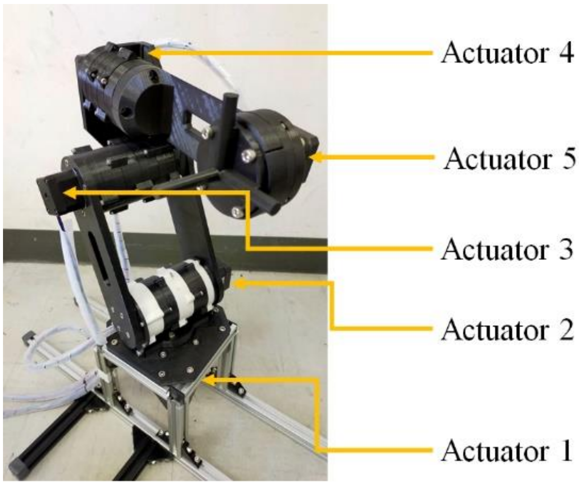

Fig. 7. Overview of the manufactured robotics arm using 3D printer

designed reduction drive can assemble same reduction drives as shown in Fig. 5.

The designed reduction drive can be assembled with multiple copies of itself to increase the output torque, as shown in Fig.5.

The other parts of the designed robotic arm are presented in Fig.6.

These parts, as presented in Fig.6, are also designed using CAD to be manufacture by the low-cost 3D printer and linked together.

The manufactured robotics arm using a low-cost 3D printer is shown in Fig.7.

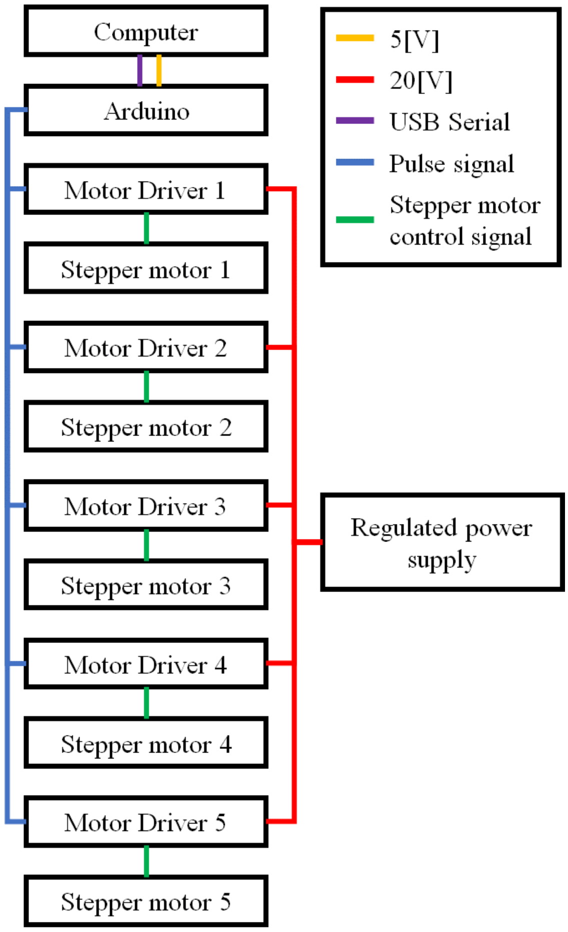

Fig. 8. Overview of power and communication system diagram for manufactured robotics arm

As shown in Fig.7, the manufactured robotics arm was assembled in the same shape as Fig.3.

2.2. *Control Programming of Robotics Arm*

The Arduino[11] board and Arduino IDE are employed to control the manufactured robotics arm. The Arduino board has the Input/Output pins for sensors and actuators, and a programable processor unit for Arduino IDE. The power and communication system diagram to control the manufactured robotics arm is shown in Fig. 8.

As shown in Fig.8, the Arduino is connected to a computer via USB serial, which has the Arduino IDE installed. Students in the class use pulse signals to control the stepper motors that are equipped at each joint of the robotics arm through the motor drivers using the Arduino. They also control the voltage of the regulated power supply to increase motor torque. The controlled movement of each joint of the robotics arm can be viewed

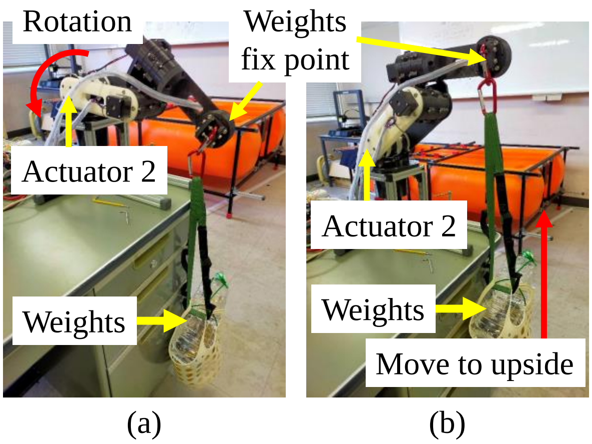

Fig. 9. Scene of the measurement of the maximum payload
(a): Scene of fix weight on the robotic arm
(b): Scene of the actuator 2 rotation

on YouTube at the following URL (https://www.youtube.com/watch?v=Mf9ZWRFVhq0).

3. Evaluation of the robotics arm

In the lecture 24~27 (Fig.2), the students evaluate the performance of the developed robotics arm in terms of maximum payload and position repeatability. The maximum payload is measured using a weight. The scene of maximum payload measurement is shown in Fig. 9.

To measure the maximum payload, a student in the class fixes a weight on the developed robot, rotates the actuator,

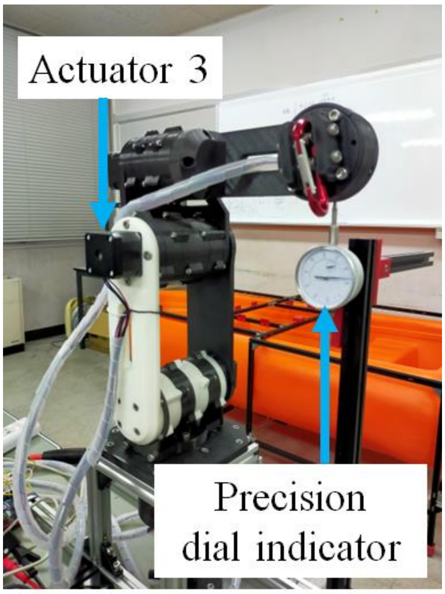

Fig. 10. Scene of the position repeatability measurement of robotics arm

Table 2 Results of position repeatability measurement

Joint No.	1	2	3	4	5
Average of position difference [mm]	0.008	0.005	0.402	0.253	0.216

and increases the weight if the rotation is successful. As a result of the measurement, the measured maximum payload (with a safety factor of 2.5) was 2.2 [kg]. The scene of the position repeatability measurement is shown in Fig. 10.

In Figure 10, the position repeatability is measured using a precision dial indicator, and the position repeatability of each joint is measured 20 times. The results of measurement are shown in Table 2.

As shown in Table 2, minimum average of position difference was 0.005[mm] and maximum average of position difference was 0.402[mm].

4. Conclusion

In this paper, I proposed a year-round robotics class that covers design, manufacturing, and control, and introduce the developed 5-axis robotic arm for education. The participating student completed all the lecture shown in Fig.2. As an evaluation of the developed robotics arm, the maximum payload (with a safety factor 2.5) was 2.2[kg] the maximum repeatability was ± 0.201[mm].

Since this class was conducted on a trial basis, it was attended by only one motivated student. Therefore, the student was able to participate diligently and complete all the content. However, the university has a diverse student population with varying levels of motivation.

As future work, I plan to offer the proposed robotics class to a wider student population and quantitatively evaluate and report on any problems that arise during the class.

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Authors Introduction

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He is an Assistant Professor in the Department of Intelligent Mechanical Engineering at the Hiroshima Institute of Technology in Japan. He graduated with a degree in underwater robotics from the Kyushu Institute of Technology in 2017. His research interests include robotics education, marine robotics systems, intelligent sensing, and underwater communication systems.