A Short-Term Experimental Class for Robotics Education
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ABSTRACT
Robots have been attracting students' interest recently. Therefore, they are a good way to motivate to study related subjects. However, there are difficulties in teaching general students because a wide background is required to understand the fundamentals of robotics. In order to teach robotics fundamentals to beginners in a short period, an effective experimental class, including several phased experiments, is proposed in this paper. A portable two-DOF robot arm system with servo motors was developed for experiments, and the operation method based on kinematics was introduced for its operation. The effectiveness of the class was investigated by using a questionnaire after carrying it out in a university class for junior students.

Keywords: Robotics education, Experimental class, Robot arm, Robot programming

I. Introduction
Recently, many programs in robotics education have been developed and carried out, not only as a regular class in universities, but also as special courses in industry and even in high schools and middle schools. This means that the educational needs of the young students and society, including industry, are very great.

The recent educational courses in robotics have been carried out in the following forms. Typical lectures or classes have been carried out in higher educational institutes, including universities and high schools [1,2]. Additionally, special programs for robot engineers have been held by some companies related to essential robotic products, such as microcomputers, sensors, actuators, and so on. Moreover, robot contests, such as ‘the Micro-mouse Competition,’ ‘the Line Tracer Competition,’ ‘the Humanoid Robot Competition,’ ‘Robot Soccer,’ and ‘ROBOCON,’ are very active [3].

Robotics is interesting enough to attract students’ interest. This fact indicates that it can increase their motivation to learn. However, as shown in Fig. 1, robotics is an interdisciplinary field that relates to wide variety of areas, such as mechanical engineering with kinematics and dynamics, computer science, control engineering with electronics, information technology, and so on. Therefore, in general, robotics lectures at the university level are prepared as advanced subjects taking up a semester or one year for seniors or graduate students. That is due to the fact that wide knowledge and background are required to begin studying robotics. Thus, it is difficult to learn robotics for some students that have a great interest, but could not complete the required courses. General students do not know how to start learning or enjoying robotics by themselves. Unfortunately, a typical robotics class has been conducted as a form of theoretical lecture in a university classroom with little understanding of real systems. This negatively influences to student’s motivation, even though robotics is actually a very interesting subject. Therefore, we propose a short-term class with several phased experiments both to introduce the fundamentals of robotics and to provide realistic experience in this paper.
The proposed class is effective in teaching basic robotics knowledge to general students without a great deal of preliminary knowledge. It has been designed for the university students who have high school level mathematics knowledge. It can also give experiential knowledge related to practical robot engineering. After a short introduction to the robot system and programming basic, the students carry out the phased experiments for about four hours. Through the proposed class, the students can understand the robotics basics and operate a simple robot arm. The merit of the program is that the students can learn the fundamentals of robot operation without passing over the core theory.

II. Proposed Program

1. Objective

This experimental class aims to teach the fundamentals of robotics to general students with high school level mathematics. Therefore, it is expected that the students can understand the basic principles of robot operation and move a robot arm using the PTP (point to point) method through the proposed class. Therefore, the class mainly consists of understanding a simple robot system and operating method with simple programming. However, it is not restricted to learning how to play with a robot or only how to program it, but covers understanding the structure of the robot to operational technique with programming for control based on the kinematics of the system.

2. Educational Contents

The class consists of the following knowledge and techniques, which are required for the operation of a two-DOF robot arm with a microcomputer and its program.

- **General configuration of robot system**: components to compose the robot system and the functional relationship between them.
- **Interrelationship between theoretical model and real system**: how the theoretical model, i.e., kinematics, is related to robot structure and motion.
- **Forward kinematics**: how to find out the position of end effector with the given values of the joint angle.
- **Inverse kinematics**: how to compute the values of the joint angle from the given position of end effector.
- **Programming basics**: how to make a program for robot operation, which includes variables, computation, control, and printing out the results to the screen.
- **Micro controller**: how to utilize micro controllers with program language for robot motion.
- **Servo motor with embedded controller**: how to utilize servo motors, including an embedded controller.
- **PTP movement**: how to move the endpoint of the robot from the current to a goal position.

3. Experimental System

The configuration of the experimental system developed for the class is shown in Fig. 2. Fig. 3 shows a picture of the experimental system[4]. It consists of a two-DOF robot arm with two servo motors at each joint, a main controller, a computer, and a DC power adaptor. In order
to operate the robot, after making a program to control the robot, students download it into the main controller and execute it. For editing and compiling a control program, the software called as ‘GCC Developer Lite,’ which is installed in the computer, is used. Its source code is made using ‘C’ language. The executable file compiled from the source code is downloaded to the main controller by using terminal software named by ‘Simple-Term.’ This software is also utilized as a terminal device to print out the results while the program executes.

In general, the capability to control each joint is the precondition for easy robot operation, although it is not so simple a problem for general students without abundant knowledge of controls. A stepping motor is usually used as an actuator at the robot’s joint because its control method is easier than others. However, it has some weak points, such as the fact that the output torque is so small and sometimes shows abnormal motion due to the stepping out phenomenon. Additionally, a DC motor is also a typical type of actuator for robot systems and has good performance. Thus, it is a better method than previous one, but its control is not easy and requires real-time software and special hardware for sensing and driving.

Recently, a new servo motor that has embedded control hardware and software has been developed, which was employed in the experimental system as a solution for the abovementioned problems. Fig. 4 shows its internal structure, and Fig. 5 shows how to connect multiple servo motors to the host controller. It works according to commands transferred through a communication line from the host controller and replies regarding its status, such as angular position. The host controller can access each motor independently by using its ID number. Therefore, users can move the robot by sending commands to the motors installed at the joints. We could reduce the burden of time for education related to motor control by using the servo motor and program library.

4. Two-DOF Robot Arm and its Kinematics

The structure of the robot arm is displayed in Fig. 6, and its kinematic model is shown in Fig. 7, respectively. It was designed in a compact and portable form to be easily carried. Thus, it can be installed in general desks in a general lecture room. Its total length is about 20cm. The forward kinematic solution of the system is the basic theory of the general robotics class and can be achieved in well-known texts as follows [5].
The solution of the inverse kinematics, which is driven by the above two equations, is given as follows. The angle of the second joint is computed by

$$\theta_2 = \arctan2(\sin \theta_2, \cos \theta_2)$$

(3)

where,

$$\cos \theta_2 = \frac{x_p^2 + y_p^2 - L_1^2 - L_2^2}{2L_1L_2}$$

(4)

and

$$\sin \theta_2 = \sqrt{1 - (\cos \theta_2)^2}$$

(5)

The angle of the first joint is achieved by

$$\theta_1 = \arctan2(\sin \theta_1, \cos \theta_1)$$

(6)

where,

$$\sin \theta_1 = \frac{y_p(L_1 + L_2\cos \theta_2) - x_p(L_2\sin \theta_2)}{(L_1 + L_2\cos \theta_2) + (L_2\sin \theta_2)}$$

(7)

and

$$\cos \theta_1 = \frac{x_p(L_1 + L_2\cos \theta_2) - y_p(L_2\sin \theta_2)}{(L_1 + L_2\cos \theta_2) + (L_2\sin \theta_2)}$$

(8)

5. Procedure of the Class

The class is carried out according to the procedure presented in Table 1. After the introduction to the outline of the class, an explanation about kinematics theory as related to the robot is given. Next, students check the simple motion with the given sample program to rotate the first joint according to the keyboard input. While operating the sample program step-by-step, they can learn how to compile it, download it, and operate the robot naturally.

Additional explanations about programming basics are given with simple examples. Some examples of programming errors are also examined. After that, students perform three tasks that can be completed by modifying the first sample program and applying the knowledge of kinematics. Finally, students write up their reports as homework, which include the summary of the experiment, the derivation of the inverse kinematics, a flowchart and source code of all programs, their considerations and so on.

Table 1 Procedure of the program

| No.  | Contents/Activity                          | Time (min.) |
|------|------------------------------------------|-------------|
| 1    | Introduction                              | 5           |
| 2    | Forward/inverse kinematics                | 30          |
| 3    | Check robot motion with a sample program (one-DOF) | 25          |
| 4    | Programming basic                         | 30          |
| 5    | Task 1: Simple two-DOF motion             | 20          |
| 6    | Task 2: Simple motion with forward kinematics | 30          |
| 7    | Task 3: Simple motion with inverse kinematics | 60          |
| 8    | Task 4: Multiple points movement         | 40          |
| 9    | Report                                    | Homework    |

III. Questionnaire and Considerations

1. Execution of the Class

The proposed class was carried out for junior students who major in mechanical engineering. It was one theme of the omnibus subject 'Mechanical Engineering Laboratory,'
Fig. 8 Scene of the experiments using the robot system

Fig. 9 An example of a final task

which consisted of eleven small themes related to mechanical engineering. The task was carried out as teamwork by two students, and about ten students, i.e., five or six pairs, participated in one class.

Fig. 8 shows a scene of the class being carried out by two students. Fig. 9 shows an example of a final task: that the robot moves via five points successively. About 31% of participants could achieve the final goal of multi-point movement, and the others could reach the third task: to move the robot by using the inverse kinematic solution.

2. Questionnaire Survey

In order to investigate the educational effectiveness of the class, questionnaires were distributed, as shown in Fig. 10.

They consisted of seven questions about the difficulty of the class and tasks, the effectiveness of the explanations, the effectiveness of the class for understanding robotics fundamentals, and the group work. On the whole, students reported that the proposed class is a little difficult. This is coincident with the fact that only one third of all participants could complete the final goal. The main reason for this was that they are not familiar with computer programming. The detailed reasons for their difficulties
stem from the difference between computer code and mathematical equations, misunderstanding of the coordinate system, carelessness in transforming angle units, i.e., radians and degrees, etc. Though the difficulty due to computer programming is considered an important obstacle of the class, this indicates that the class is a good opportunity for experiencing the realistic core of robot operations. Additionally, it could be a realistic review of preparation for programming technology. In spite of these difficulties, their satisfaction in understanding basic robotics and experiencing a real robot system was high.

IV. Conclusion

In this paper, an experimental class to teach robotics basics to general university students in a short time was proposed. A phased experimental program utilizing an experimental system with a two-DOF robot arm was developed for the class. The objective of the class was to make students not just be familiar to robots, but gain an overall view of and knowledge about robotics through task-oriented experimentation. From the results of questionnaire, after conducting the program, it was found that the program is effective for educating students regarding robotics fundamentals and principles of robot operation. The level of overall difficulty needs to be improved by adjusting experimental tasks according to the preparation and the backgrounds of students.

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