A STUDY ON APPLICATION METHOD OF MOTOR CONTROL LEARNING SYSTEM TO IMPROVE LEARNING EFFECT

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ABSTRACT. *This paper aims to deepen the understanding of actual motor control by improving the motor control learning system developed in our previous research. In the system, the actual motor is used only for the static characteristic, but several characteristics including the transient and frequency response are obtained in a pseudo manner using the equivalent circuit or the numerical simulation. In the present paper, therefore, the transient responses can be observed from the actual motor by updating various programs and creating a user interface in addition to downsizing the conventional experiment system for portability and safety. As the results, in the newly developed experiment, the undergraduate students can visually and specifically learn the true behavior of actual motor control.*
Keywords: Motor control learning system, Student experiment, Sensitivity evaluation

1. **Introduction.** Motor control systems are used in various fields such as manufacturing and industrial use. The basic principle is well explained under linearity assumption in the elementary control theory course lectured at universities. However, since the actual motor control systems include delay and nonlinear elements in power amplifiers and controllers in addition to the computer processing time in multiple stages, it is difficult to obtain the control characteristics precisely. Furthermore, because there are restrictions due to nonlinear factors such as input and output limits of component devices and friction inside the motor, the motor operates according to theory as long as the linearity is guaranteed for these equipment [1].

In the control theory in the university education, after learning Laplace transform and block diagram, the controlled object is given as a transfer function and then its stability and the feedback control are discussed [2, 3]. "Robot control experiment" in "Electrical and Electronic Information Engineering Experiment II" provided at our department has three contents, i.e., (i) the static characteristics of DC servomotor, (ii) the transient characteristics and (iii) the frequency response. However, the actual motor is used only for the static characteristic experiment, and for the other experiments, the characteristics are obtained in a pseudo manner using the equivalent circuit or the numerical simulation by MATLAB. The handling of the motor control system is difficult due to manual measurement using a tachometer. Thus, it is hard to read the time change of the measured value, to observe the frequency response and the transient response. This is the reason for no choice but to rely on the equivalent circuit and simulation. It is also important to motivate the control theory from the actual motor control experience [4].

In this paper, it is aimed at improving the skill of control theory by realizing student experiment using the motor control learning system. In other words, to operate the motor control learning system developed in our previous research is studied from the following three perspectives. First of all, in order to realize downsizing of the system, it is necessary to select a small motor capable of high precision encoder measurement and to change from DC power supply to PC switching power supply. In addition, the control program codes are improved so that it can be adopted to various motors. Then, preparing the operating procedure manual is important because almost all students feel difficult to operate the command line on the console terminal. All circuits and power supply devices must be built in the aluminum case to avoid the electric shock and the equipment damage at the time of experiment. In the proposed motor control learning system, not only the contents including conventional experiments but also proportional control and PID control can be newly realized. These experiments and questionnaire of sensitivity evaluation are performed for students. From the results of questionnaire, it evaluates the effectiveness of understanding for the motor control theory. Specifically, Section 2 describes the structure of the motor control system for teaching materials, and introduce the current student experiments in Section 3. Section 4 proposes experiments using the motor control system for teaching materials, and Section 5 describes the improvement of the necessary system. Section 6 describes the effectiveness of the proposed system based on verification experiments and questionnaire evaluation. Section 7 summarizes the paper.

2. **Composition of the Motor Control Learning System.** Figure 1 shows the external view of the motor control learning system developed in our previous research [5]. A control board equipped with SH2 microcomputer (64F7145F50V) manufactured by Renesas Electronics Corporation is connected to a motor and an amplifier. The control board outputs the command voltage (PWM signal) to the amplifier as speed and position command value information. In the amplifier, the amplified voltage according to the PWM signal is applied to the motor, and the rotational speed is observed by the encoder. The error between the command value and the observed value is calculated in the control board.

Since it is possible to actually observe the behavior of the motor, visual information can be obtained compared with observation of the pseudo response characteristic by the
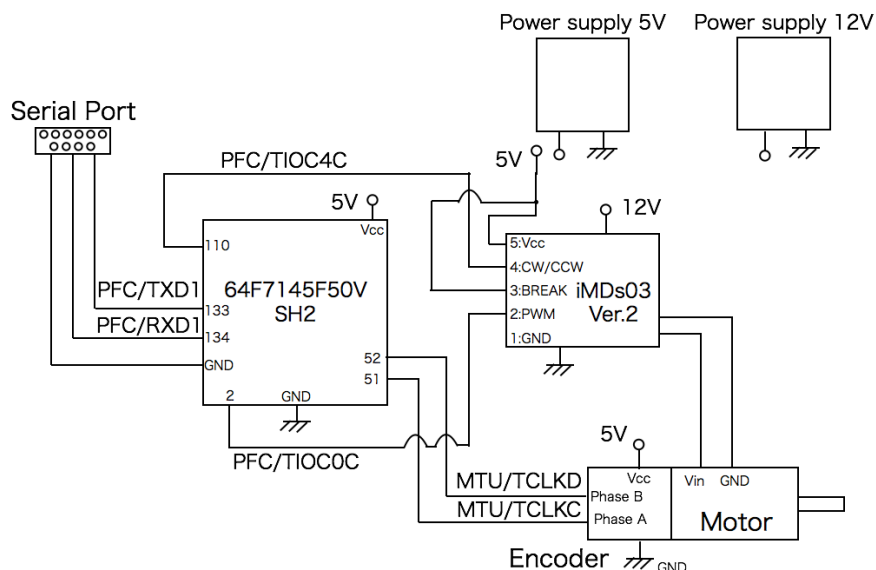

FIGURE 1. Block diagram of motor control system for teaching material

equivalent circuit and MATLAB, and the relation between the output waveform and the actual behavior becomes clear. In consequence, it is expected to improve the learning effect. Therefore, in order to implement this system to the students experiment, various improvements such as software expansion and user interface are considered.

3. **Outline of Current Student Experiment.** "Robot control experiment" in "Electrical and Electronic Information Engineering Experiment II" offered for the third year in our department aims to understand the basic theory of servomotor and its control method. In other words, it aims at understanding of the physical meaning of servomotor behavior usually expressed in an equation of motion. In the experiment, various characteristics of the DC servo motor are investigated: (i) static characteristics of DC servomotor, (ii) response characteristics in transient state, (iii) frequency response and graph plot of control system.

However, it is difficult to measure the rotation speed using PC and encoder. For this reason, manual measurement by a tachometer, numerical simulation using software such as MATLAB or Simulink, an RC equivalent circuit ignoring the armature inductance of the servo motor and the like are currently in place. However, these methods cannot be measured according to time change, so there is a problem that it is difficult to observe the transient state and the frequency response. Also, in actual motor control, it is known that the time constant varies depending on the target value due to the non-linearity of the motor and amplifier used, but a motor driver for driving a commercially available motor is used. Since the driver absorbs the non-linearity of the motor and the amplifier, the observation value has linearity. For this reason, it is necessary to refer to the internal information of the motor driver in order to know the essential characteristics of the motor. Although the encoder information of the motor driver is generally unknown, it is impossible to know the behavior before compensation.

4. **Proposal of Experiment by Motor Control Learning System.** In this section, it is proposed of a method to utilize the motor control learning system in order to solve the problems of the conventional experiment. It is conceivable that observation of response characteristics using actual motors becomes possible and it is easy to observe the behavior of the motor visually. Therefore, it is expected to improve the skill level with respect to the control theory. To this end, a proportional control experiment is newly added to the conventional experiment.

The experiment items proposed in this paper are described below. Firstly, for observation of the static characteristics and dynamic characteristics of the motor, we consider the addition of measurement points and automatic measurement in addition to the previous experiments. Then proportional control which is the basis of feedback control is newly introduced as a control experiment. Proportional control is a theory to learn in elementary control engineering, and the learners can master the basic items of control theory such as deviation and control parameters.

From the above points, the experimental items in the proposed experiment are as follows: (i) static characteristics of DC servomotor, (ii) response characteristics in transient state, (iii) frequency response and graph drawing of control system, (iv) response characteristics by proportional control. Observing these phenomena aims at improving understanding of control theory.

4.1. **Static characteristics of DC servomotor.** In the motor drive, the relationship between the applied voltage and the output rotational speed in the steady state can be expressed as static characteristics as shown in Figure 2(a). As shown in the figure, it is observed that the applied voltage and the rotational speed have linearity property. Then, it is also observed that the actual output rotational speed and the approximate straight line represented by the solid line are lower than the theoretical value of the output

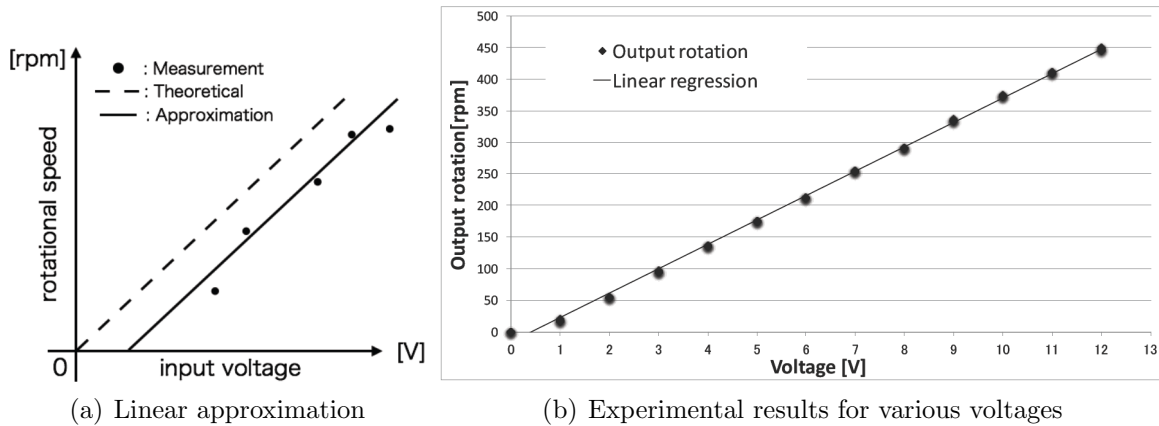(a) Linear approximation   (b) Experimental results for various voltages

FIGURE 2. Linear approximation and experimental result in Static characteristic

rotational speed represented by the broken line. In the static characteristic experiment, since it is necessary to measure the motor rotation speed in the steady state, it is set as the step signal input. Since the rated voltage of the general-purpose motor is 12 [V], the applied voltage is set in increments of 1 [V] from 0 to 12 [V]. For drawing static characteristics charts, it is necessary to measure the number of revolutions in the steady state at each applied voltage. These measurements are automated by a newly developed program. In the automated program, utilizing the result of the time constant $T_{cm} = 0.171$ [sec], the mean value of the measured values from the time 0.99 to 1.00 [sec] in the steady state is displayed on the console terminal.

A static characteristic map can be drawn by importing the displayed data into Microsoft Excel, creating a scatter diagram with the applied voltage [V] on the horizontal axis and the output revolution [rpm] on the vertical axis. From Figure 2(b), it is clear that the measurement points have linearity. As described above, by adopting the automatic measurement using the encoder in the proposed experiment, it is possible to acquire an accurate rotation number at many measurement points. Moreover, it is also confirmed from graph using Microsoft Excel that there are linearities in the applied voltage and the motor rotation speed.

4.2. **Response characteristics in transient state.** In order to investigate the response characteristics in the transient state, observation is made focusing on the time constant derived from the transfer function. That is, in the classical control theory assuming linearity, the time constant is a value that can be derived from the specification of the motor and is unchanged. In the elementary control theory, the time constant is defined as the time until the output reaches 63.2[%] of the target value as shown in Figure 3(a). However, since the actual motor and control system include nonlinear elements, it is known that the time constant changes with the magnitude of the input value. To see this change, the time constant is estimated from the waveform of the transient state for each applied voltage and observing the change. In the proportional control, the control quality depends on the time constant estimation. Therefore, the average and standard deviation are also calculated.

In the response characteristic experiment in the transient state, the sampling time is 1 [msec], the motor driving time is 0.3 second, and the applied voltage is 3 [V] interval from 3 [V] to 12 [V]. Then, the transient responses of the motor are observed by plotting the measurement result on the horizontal axis for time [sec] and the vertical axis for the number of revolutions [rpm]. The kind of responses was simulationally created by using MATLAB in conventional experiment. Furthermore, as shown in Figure 3(b), it is
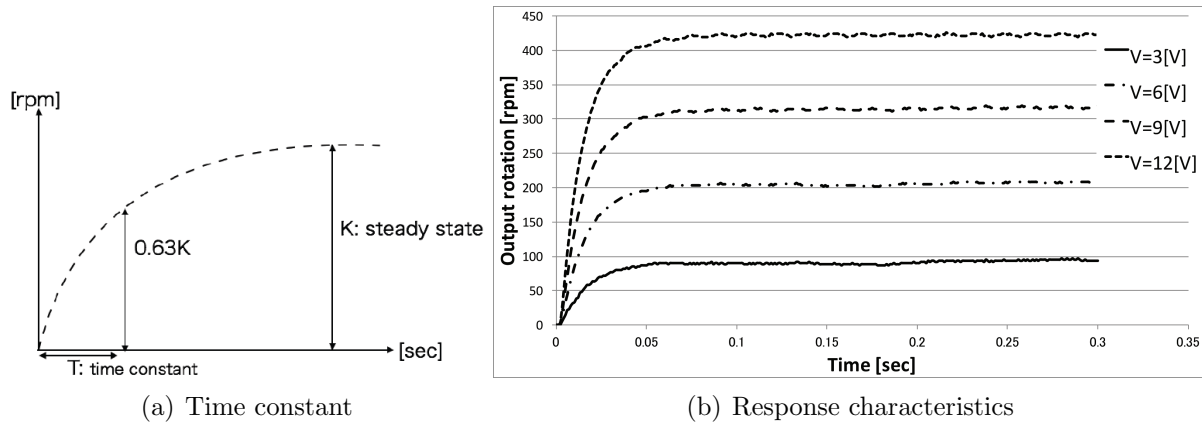
(a) Time constant   (b) Response characteristics

FIGURE 3. Time constant and response characteristics in transient state

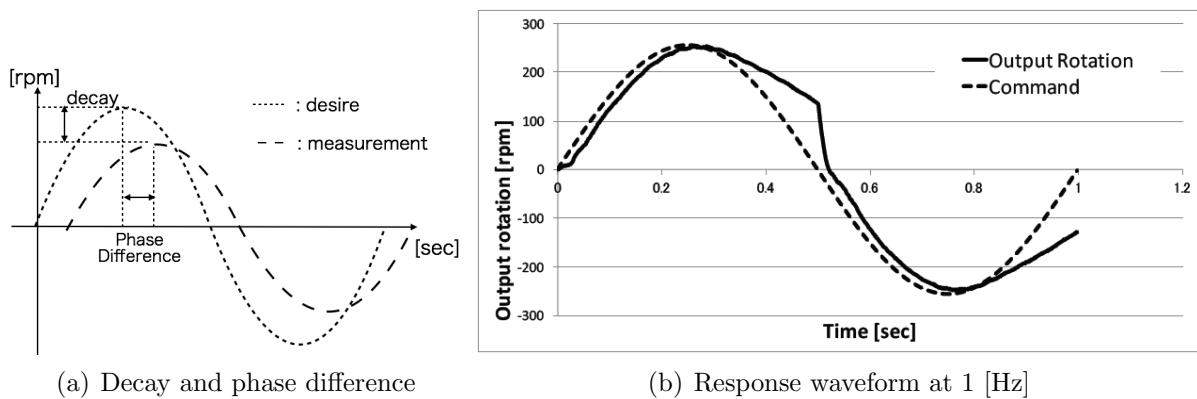(a) Decay and phase difference   (b) Response waveform at 1 [Hz]

FIGURE 4. Decay, phase and response waveform for sinusoidal input

possible to visually observe how the time constant changes by setting the output RPM for each applied voltage.

4.3. **Frequency response characteristic of control system.** In order to learn the frequency response characteristics of the control system as shown in Figure 4(a), the effect of frequency change of the input signal on the amplitude and phase of the output signal is confirmed through experiments. It is also learned through visual observation of motor behavior how the attenuation of the gain and the phase delay affect the actual motor behavior.

In the response characteristic experiment of the control system according to the frequency change of the sine wave input, the sampling time is 1 [msec], the motor driving time is 1 second, and the applied voltage is 7 [V]. Also, the frequency of the sine wave input signal is 1, 5, 10, 25, 50, 100 [Hz]. For each frequency, the actual motor revolution number with respect to the command revolution speed is plotted. From the comparison of input and output waveforms, it is clarified that attenuation of amplitude and phase delay occur when frequency increases. An actual experiment result is shown in Figure 4(b).

4.4. **Response improvement by proportional control.** Proportional control is an example of feedback control, and controls the input value according to the deviation between the output value and the target value. Since the proportional control multiplies the deviation by the proportional gain, the deviation also becomes 0 when the proportional gain $K_p = 0$. Thus, the motor is not proportionally controlled.

When the proportional gain is changed, the actual motor output becomes active to observe behaviors such as overshoot and oscillation. However, in general motor drivers, it is difficult to observe these phenomena, because the control parameters are set in advance to prevent overshoot and oscillation. For this reason, in the motor control learning system, compensation mechanism is selective so that the inherent characteristics of the motor can be observed.

In the proportional control experiment, the sampling time is 1 [msec], the motor driving time is 1 second, and the applied voltage is 7 [V]. As input signals, there are two types of inputs: step input and sinusoidal input, the proportional gain is $K_p = 0$, 1, 5, 10, 20, and frequency of sinusoidal input is $f = 1$, 5, 10, 15, 25, 50 [Hz]. The results in the proportional control experiment are shown in Figure 5. First, in the proportional control experiment of the step input (Figure 5(a)), when the proportional gain is set to an appropriate value ($K_p = 5$), the response is improved. However, if the proportional gain is set to a large value ($K_p = 20$), overshoot and oscillation are found to occur.

On the other hand, when the frequency is low ($f < 10$ [Hz]) with the sinusoidal wave input (Figure 5(b)), it is observed that gain attenuation and phase lag are improved when the proportional gain is increased, and the followability of the target value is improved without overshooting. However, when the frequency was high ($f > 25$ [Hz]), it was confirmed that overshoot could be observed although it was slight.
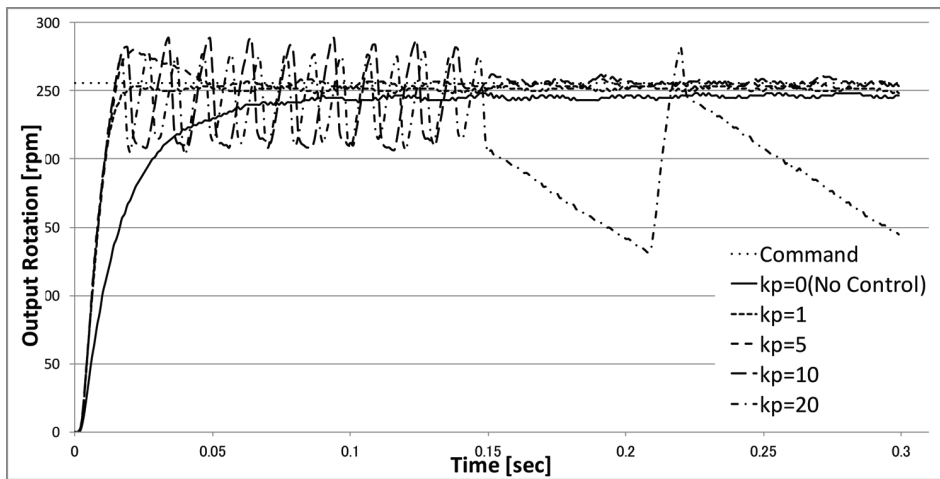
(a) Step signal input
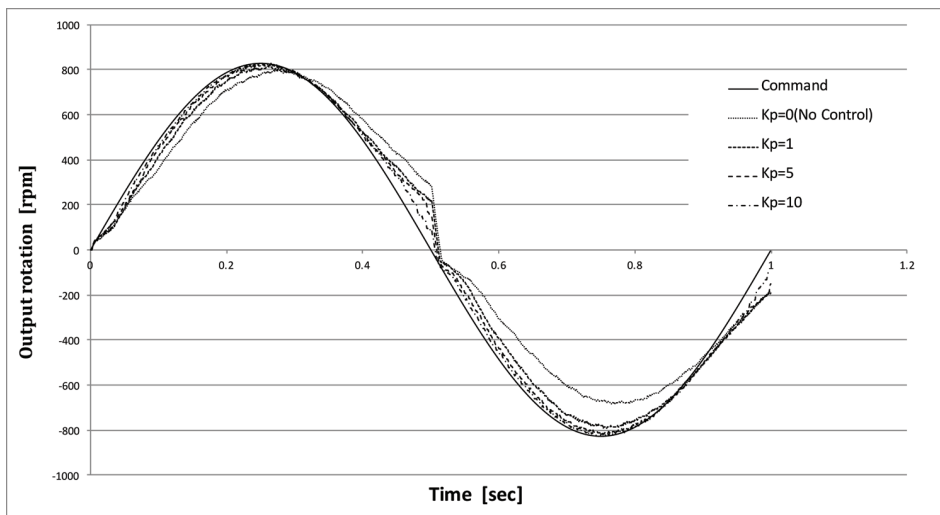
(b) Sine wave signal input

FIGURE 5. Output result in the proportional control

5. **Improvement of Motor Control Learning System for Experiment Introduction.** In order to introduce the teaching material motor control system to the experiment, we consider the portability, operability and safety of the system. First, the conventional motor control learning system adopting a large-sized servo motor for industrial use is no portable and requires large power source capacity. This causes the wiring complicated and the maintenance difficult. Next, in motor control, communication with the SH2 board is necessary, and is operated from the console terminal. This operation is difficult for students accustomed to GUI operation. Furthermore, since SH2 boards, motors and amplifier are wired directly, it is necessary to secure safety in experiments.

Therefore, the following improvements are made to the teaching material motor control system, so that the students can select a compact and inexpensive motor, adopt a small switching power supply and make the maintenance easier. With respect to the operation at the console terminal, a detailed procedure manual is newly created and it is possible to experiment with the student's own hand. Furthermore, it is possible to ensure portability and safety by packaging the constituent equipment inside the case.

5.1. **Internal representation of command value in control program.** Since the motor used in the previous study was too large as the experiment teaching material, a small general purpose motor (RD0-29B50G9A manufactured by Japan Robotech) is selected and its control programs are revised for the student experiment. In addition, the way to set the target value is changed from the plus command (pulse/msec) in the conventional system to the applied voltage command (V) so that the students can easily understand. First, as a result of enabling measurement of the voltage and the PWM on the rotation speed of a general-purpose small motor (RD0-29B50G9A; manufactured by Japan Robotech), their relational expression was obtained as $Rotation = 38.9 * Voltage - 18.85$. Because of this linear relationship between the voltage and the rotational speed, the applied voltage and the rotational speed can be easily converted inside the program.

The power amplifier required for driving the motor was also downsized by using iMDs 03 Ver. 2 (manufactured by iXs Research). Since this amplifier outputs the motor applied voltage corresponding to the PWM signal, another relational expression was derived by preliminary experiments as $PWM = 0.1009 * Rotation + 53.339$. As a result, it is now possible to select one of the motor control commands and the internal calculation of the system, in addition to the rotation speed and the rotation speed. Furthermore, it can be applied to various kinds of motors by changing the proportional coefficient and the slope value in the relational expressions.

5.2. **Packaging in consideration of portability and safety.** Along with the miniaturization of motors and amplifiers, power supply of SH2 board 5 [V] and power amplifier 12 [V] have been changed from direct current stabilized power supply to switching power supply unit for personal computer (PPA-0250-01 [manufactured by AVANCE TECH-NOLOGIES]). In this section, a motor control learning system including a power supply is installed in an aluminum case, and various input/output terminals are arranged on the side of the case to package. The SH2 board, the power amplifier, the switching power supply and a cooling fan were installed in an aluminum case. Then, a serial communication port, a power switch, and a 100 V outlet terminal were attached to the side of the case. The supply of power to the motor and the wiring of the encoder are put out to make it easy to replace the motor. Figure 6(a) shows the external view of packaged teaching material motor control system. This makes it easy to carry the system and allows experiments without restrictions on places.

5.3. **Simplifying operability and simulation procedure.** It is necessary for the student to carry out the proposed experiment in the same environment as the conventional experiment. In order to enable the students to experiment independently without relying
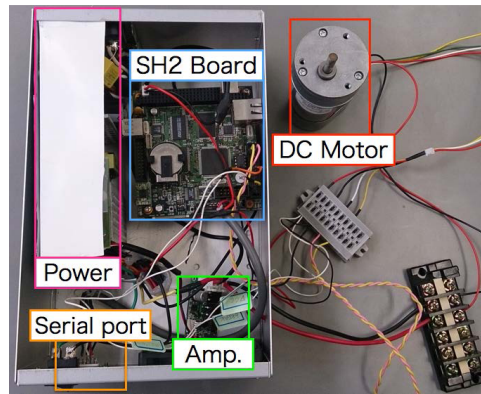
(a) Exterior photo of proposed system
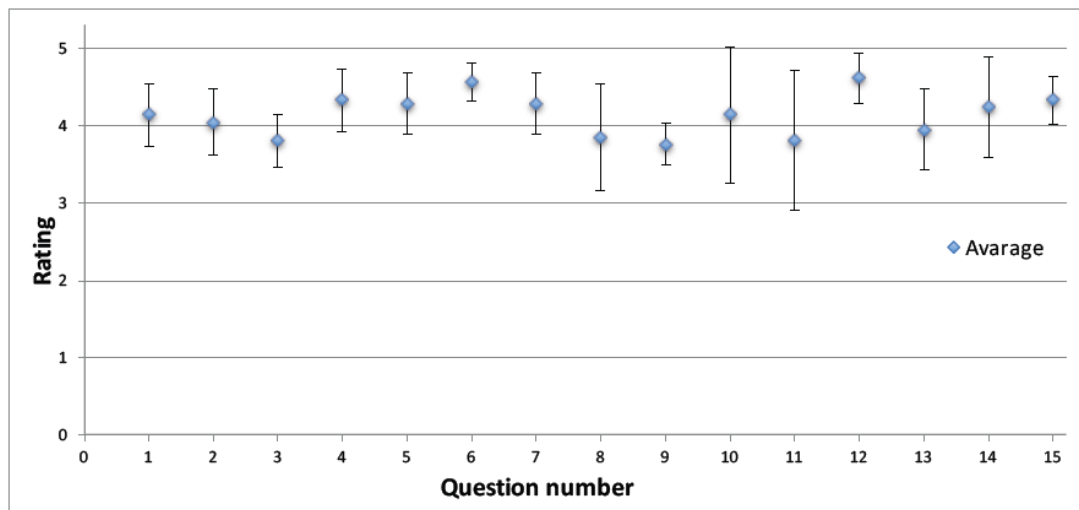
(b) Average values and standard deviations

FIGURE 6. Overview of proposed system and results of questionnaire

on experimental assistants, we prepared an experimental text and an operation procedure manual. In the manual, the operating procedure using the screen shot of the PC screen is described. By using these text and manual, the students can easily carry out the proposed experiment under the same conditions as the conventional experiment.

6. **Implementation of Questionnaires Based on Sensitivity Evaluation.** In this section, the influence of the proposed experiment for the learning of the control theory is considered on the basis of the questionnaire of sensitivity evaluation. In the questionnaire, fifteen items are questioned on three factors: "learning effect", "convenience of teaching materials", and "comparison with the conventional experiments". The learning effect is evaluated from the viewpoint of understanding of control theory and interest in motivation for experiment. The convenience of the teaching materials is also evaluated from the feeling of use of the teaching materials, working time and efficiency. Furthermore, it is investigated whether observing actual motor behavior helps understanding of control theory in comparison with conventional experiments. The questionnaire items created from these views are described below.

  1) Was the experimental time appropriate?
  2) Did you understand the contents of the lecture well?
  3) Did you understand the change in time constant?
  4) Did you understand the difference in output waveform due to input signal?
  5) Did you understand the relationship between motor behavior and output waveform?

6) Could you visually learn the theory compared with the previous one?

7) Did you deepen your understanding of each experiment compared with the previous one?

8) Did you understand what the data acquired by automatic measurement represents?

9) Did you understand the relationship between the behavior of the motor and the theory?

10) Please evaluate the ease of use of experimental equipments.

11) Was the experiment software easy to use?

12) Was it easy to follow the procedure to convert the data to Excel?

13) Did the experiment proceed without confusion?

14) Did you think the teaching material system was safe?

15) Please evaluate the safety of the teaching material system.

16) Please evaluate this lecture comprehensively.

Here, questions 2) to 5) are related to the learning effects, questions 1), 10) to 14) are related to the convenience of teaching materials, and questions 6) to 9) are related to the comparison with the conventional experiments. In order to evaluate the questionnaire results quantitatively, each question is answered in 5 stages [6]. Furthermore, for questions 6) and 11) a free entry field is set up to investigate opinions of the students.

6.1. **Evaluation experiment and questionnaire.** The evaluation experiment and the questionnaire survey of the proposed experiment are carried out. Subjects are 21 third year students in our department who have already experienced the conventional experiments. Experiment is performed according to the experiment procedure manual prepared beforehand. After completing the experiment, the questionnaire survey is concluded. Also, record the required time for each theme in the evaluation experiment.

6.2. **Analysis of questionnaire results.** Figure 6(b) shows the average value and standard deviation for each question in the questionnaire survey results in the proposed experiment. In the figure, the horizontal axis denotes the question number, the vertical axis denotes the evaluation value, and the average value is represented by point and the standard deviation is indicated by the error bar. From this result, it can be seen that the average value is high in all questions. Especially, for questions 6) and 12), the averaged evaluation values are 4.57 or more and their standard deviations are about 0.51. This result shows that the learning system using the actual motor is effective for improving understanding of the control theory. This fact suggests that students can easily operate the motor control learning system by reviewing the program and preparing the procedure manual.

For questions 5) and 7), it can be also seen that the average value is 4.28, the standard deviation is about 0.62 and high ratings are obtained. In addition, in the free description column on question number 6), there were responses such as "It was good to perceive the change in motor rotation speed directly by eyes and ears" and "It was good to compare the actual behavior and the Excels graph easily". However, the average values for questions 8) and 9) are as low as about 3.8, and the standard deviation for question 8) is as high as 0.85. In other words, there is an insufficient part about the essential understanding of measurement data and theory.

For questions 10), 11), and 13) related to question 12), the average values are about 4.0, but the standard deviations are as large as 0.96, 0.98, 0.74, respectively. These large deviations are probably because the control program could not be entered correctly from the console terminal according to the procedure manual. It is a future task to describe in detail how to deal with a mistake in the procedure.

From the above, it is confirmed that the proposed experiment is able to experience the control theory more visually and audibly through the behavior of the motor than

the conventional experiment, and that the motor control learning system is useful for understanding the actual motor control.

7. **Conclusions.** In the present paper, we have studied from various viewpoints to realize motor control experiment for undergraduate students using motor control learning system. First, various programs have been updated so that the command value can be also given by the applied voltage in the motor control learning system, prepared the user interface, and prepared the experiment procedure manual. Also, by integrating the experiment system into a compact size including the power supply, the system has been portable and the students have been able to perform the experiment more safely.

Next, the educational effect of the motor control learning system has been quantitatively evaluated by analyzing the questionnaire results based on the sensitivity evaluation. As a result, we have made it possible to observe the behavior of motor control visually compared with the conventional experiment, so that the understanding degree of the student is improved. As a result it has been clear that the students' comprehension of the actual motor control is improved much more in the proposed experiment than in the conventional experiment since in the former the motor control behaviors can be perceived visually.

Currently, the proposed system operates from the terminal. In order to make it easier to use, various user interfaces will be developed and implemented so that the control operation can be done from Web screens.

REFERENCES

[1] G. Rockis and G. A. Mazur, *Electrical Motor Controls for Integrated Systems*, Amer Technical Pub, 2013.
[2] H. Tanaka, Development of motor control systems for education, *The 57th Japan Joint Automatic Control Conference*, pp.588-593, 2014.
[3] T. Asai, M. Ishikawa, K. Osuka, M. Inoue and Y. Sugimoto, Introductory control experiments to understand control system design objectives and control equipments, *Trans. of the Institute of Systems, Control and Information*, vol.28, no.8, pp.366-375, 2015.
[4] T. Asai, K. Osuka, M. Ishikawa and M. Inoue, A motivational lecture using an experimental control system to get personal experience and its effectiveness, *Trans. of SICE*, vol.48, no.10, pp.622-631, 2012.
[5] S. Kishiyama, H. Shiratsuchi and N. Kyura, Development of educational servo motor control system using embedded computer, *AXIES Annual Convention*, pp.136-139, 2011.
[6] H. Yamaji, *Handbook of Student Evaluation of Teaching*, Tamagawa University Press, 2007.