

STUDIES ON DEVELOPMENT OF MOTOR CONTROL LEARNING SYSTEM AS A WEB APPLICATION

KOZO HORIUCHI¹, TAKANORI MATSUZAKI² AND HIROSHI SHIRATSUCHI²

¹Gururi Co. Ltd.

MATSUNAGA bldg. 5F MIKAGE1881, 2-1-7 Uomachi, Kokurakita, Kitakyusyu
Fukuoka 802-0006, Japan
kozo.horiuchi@gururi.co.jp

²Graduate School of Humanity-Oriented Science and Engineering
Kindai University

11-6 Kayanomori, Iizuka, Fukuoka 820-8555, Japan
{takanori; sira}@fuk.kindai.ac.jp

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ABSTRACT. *In our previous research, transient responses can be observed from actual motor by updating various programs and creating a user interface in addition to downsizing conventional experiment system for portability and safety. In this present paper, command line operations for the proposed system are replaced by a Web application which can be operated by graphical interface. In addition, experimental result references, simple operator, and graph drawing functions are newly developed as interpreted languages. Integrating these into the proposed Web application, it is possible to respond to advanced tasks.*

Keywords: Engineering education, Web application, PHP, JavaScript, Interpreted language

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 actual motor control systems include delay elements which are power amplifiers and nonlinear controllers in addition to 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 this equipment [1]. In the control theory of 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” provided at our department has three contents; i.e., (i) the static characteristics of DC (Direct Current) 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. 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 equivalent circuit and simulation. It is also important to motivate the control theory from the actual motor control experience [4].

In our previous research, a motor control learning system was developed as an ICT (Information and Communication Technology) teaching material to observe various phenomena occurring in the actual motor control [5]. Through personal computer connected to this system, phenomena observation of nonlinear elements such as motor behavior and output saturation of amplifier becomes possible. After verification experiment by students of the proposed system, results of the questionnaire based on the sensitivity evaluation were performed on statistical analysis viewpoint of usefulness and learning achievement [6,7]. As a result, visual and auditory information is overlapped with actual motor behavior, thus, improvement of learning effect of control theory can be expected. On the other hand, since the motor control learning system is connected to PC (Personal Computer) with a serial interface, there are problems which the command inputs necessary for the experiments are complicated and graph drawing require the process of cut and paste between the several software [8,9].

The purpose of this research is to improve the problem of motor control learning system by software method. That is, command line operations for the proposed system are replaced by a Web application which can be operated by graphical interface. Specifically, PHP language having built-in server capable of stand-alone operation with an experimental PC is adopted. System functions such as serial communication, control command input, experiment parameters, control response recording, graph drawing are implemented. These input/output data can be confirmed in real time through the Web user interface. In addition, experimental result references, simple operator, and graph drawing functions are newly developed as interpreted languages. Integrating these into the proposed Web application, it is possible to respond to advanced tasks.

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. A control board equipped with SH-2 board (64F7145F50V) manufactured by Renesas Electronics Corporation is connected to a motor and an amplifier. The control board outputs the command voltage (PWM (Pulse Width Modulation) 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 rotational speed is observed by an encoder. The control board calculates errors between command values and observed

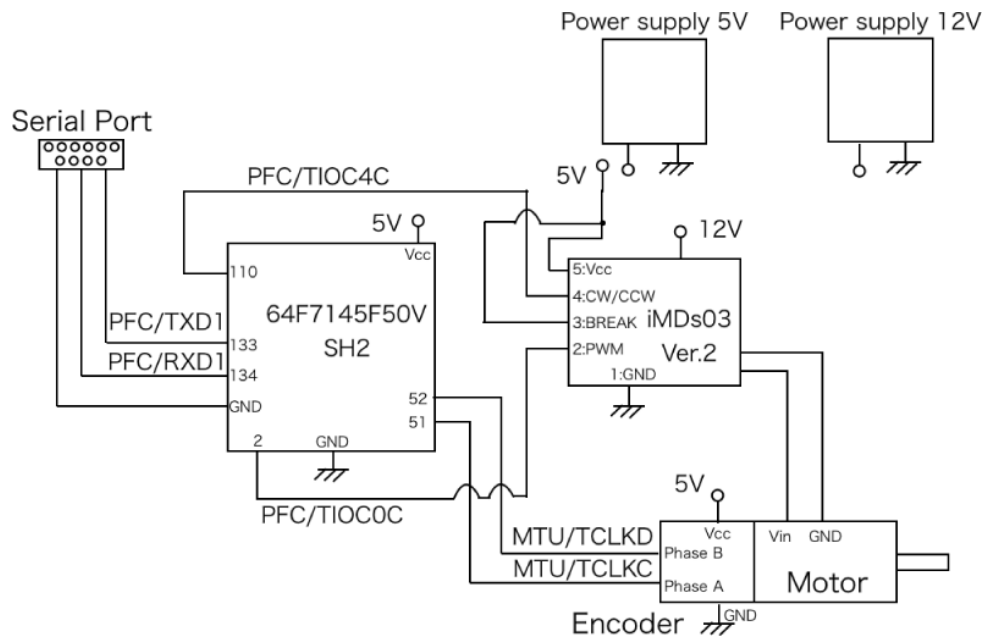


FIGURE 1. Block diagram of motor control learning system

values. Since it is possible to actually observe behavior of the motor, visual information can be obtained compared with observation of the pseudo response characteristic by the equivalent circuit and MATLAB, 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 student's experiment, various improvements such as software expansion and user interface are considered.

3. System Improvement and Experiment Procedure. In order to introduce the motor control learning system to the experiment, we consider portability, operability, and safety of the system. First, a 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 wiring complicated and the maintenance difficult. Next, in the motor control, communication with the SH-2 board is necessary, and the SH-2 board is operated from the console terminal. This operation is difficult for students accustomed to GUI (Graphical User Interface) operation. Furthermore, since SH-2 boards, motor and amplifier are wired directly, it is necessary to secure safety in experiments. Therefore, following improvements are made to the motor control learning system, so that students can select a compact and inexpensive motor, adopt a small switching power supply and make 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 student's own hand. Furthermore, it is possible to ensure portability and safety by packaging constituent equipment inside the case. And students will describe the experimental procedure using the motor control learning system.

3.1. Packaging in consideration of portability and safety. Along with the miniaturization of motor and amplifier, power supply of SH-2 board 5 [V] and power amplifier 12 [V] has been changed from direct current stabilized power supply to switching power supply unit for personal computer (PPA-0250-01 [manufactured by AVANCE TECHNOLOGIES]). In this research, the 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 SH-2 board, the power amplifier, the switching power supply, and a cooling fan were installed in the 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 2 shows the external view of the packaged motor control learning system.

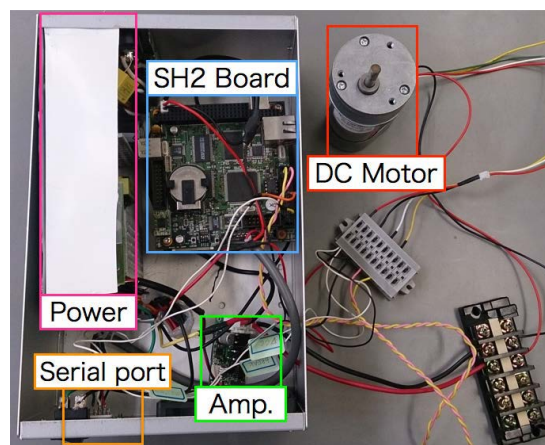
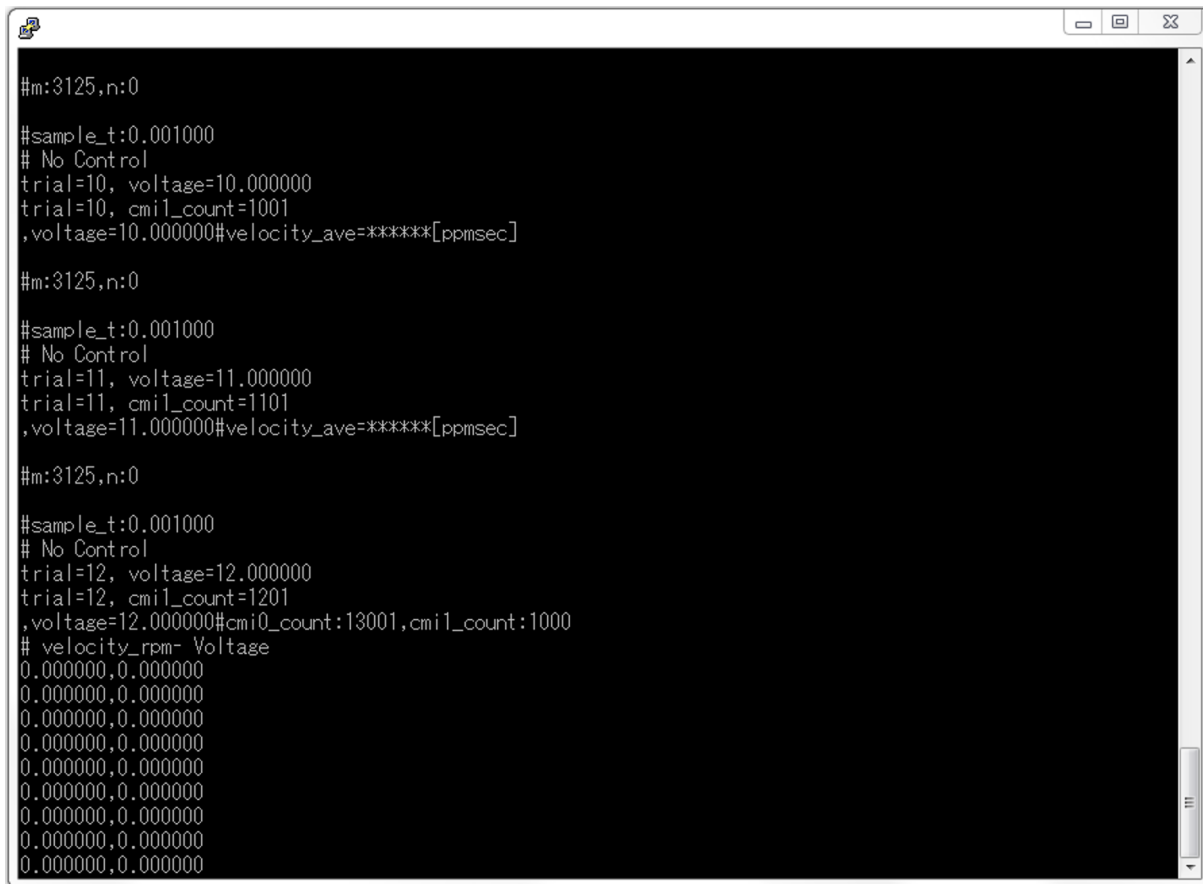


FIGURE 2. Exterior photo of the motor control learning system

3.2. Simplify operability and experiment procedure. It is necessary for students to carry out the proposed experiment in the same environment as the conventional experiment. In order to enable students to experiment independently without relying on experimental assistants, we prepared an experimental text and an operation procedure manual. In the manual, the operating procedures using screenshots of the PC screen are described. By using these text and manual, students can easily carry out the proposed experiment under the same environment as the conventional experiment.

3.3. Experiment procedure using the motor control learning system. The system is connected to the SH-2 board via a serial cable and controlled by a terminal application on PC. Figure 3 shows input commands and results in a terminal window. The system is controlled by the program which is downloaded from the PC. The system executes the program and waits for students input voltage and measurement time in each experiment, and then the system drives the motor and displays experiments results. After these experiments, students copy from a terminal window and save these results as CSV (Comma Separated Values) files and draw result graphs using spreadsheet software. However, this approach is hard for students accustomed to GUI because they use terminal applications. In addition, it is inefficient to copy and save a result of hundred to thousand lines for each measurement. Thirdly, we paste the measurement result from the terminal application to the memo pad application and save it as CSV format. Finally, as shown in Figure 4, we draw a graph from the saved CSV file using spreadsheet software. Each experiment is carried out by the above procedure. However, since console operation is complicated command input, many students will feel that it is difficult to use. Also, it is inefficient to properly select a large amount of time series data displayed on the terminal after measurement and paste it into the memo pad application.



```

#m:3125,n:0
#sample_t:0.001000
# No Control
trial=10, voltage=10.000000
trial=10, cmi1_count=1001
,voltage=10.000000#velocity_ave=*****[ppmsec]

#m:3125,n:0
#sample_t:0.001000
# No Control
trial=11, voltage=11.000000
trial=11, cmi1_count=1101
,voltage=11.000000#velocity_ave=*****[ppmsec]

#m:3125,n:0
#sample_t:0.001000
# No Control
trial=12, voltage=12.000000
trial=12, cmi1_count=1201
,voltage=12.000000#cmi0_count:13001,cmi1_count:1000
# velocity_rpm- Voltage
0.000000,0.000000
0.000000,0.000000
0.000000,0.000000
0.000000,0.000000
0.000000,0.000000
0.000000,0.000000
0.000000,0.000000
0.000000,0.000000
0.000000,0.000000
0.000000,0.000000

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FIGURE 3. The terminal application

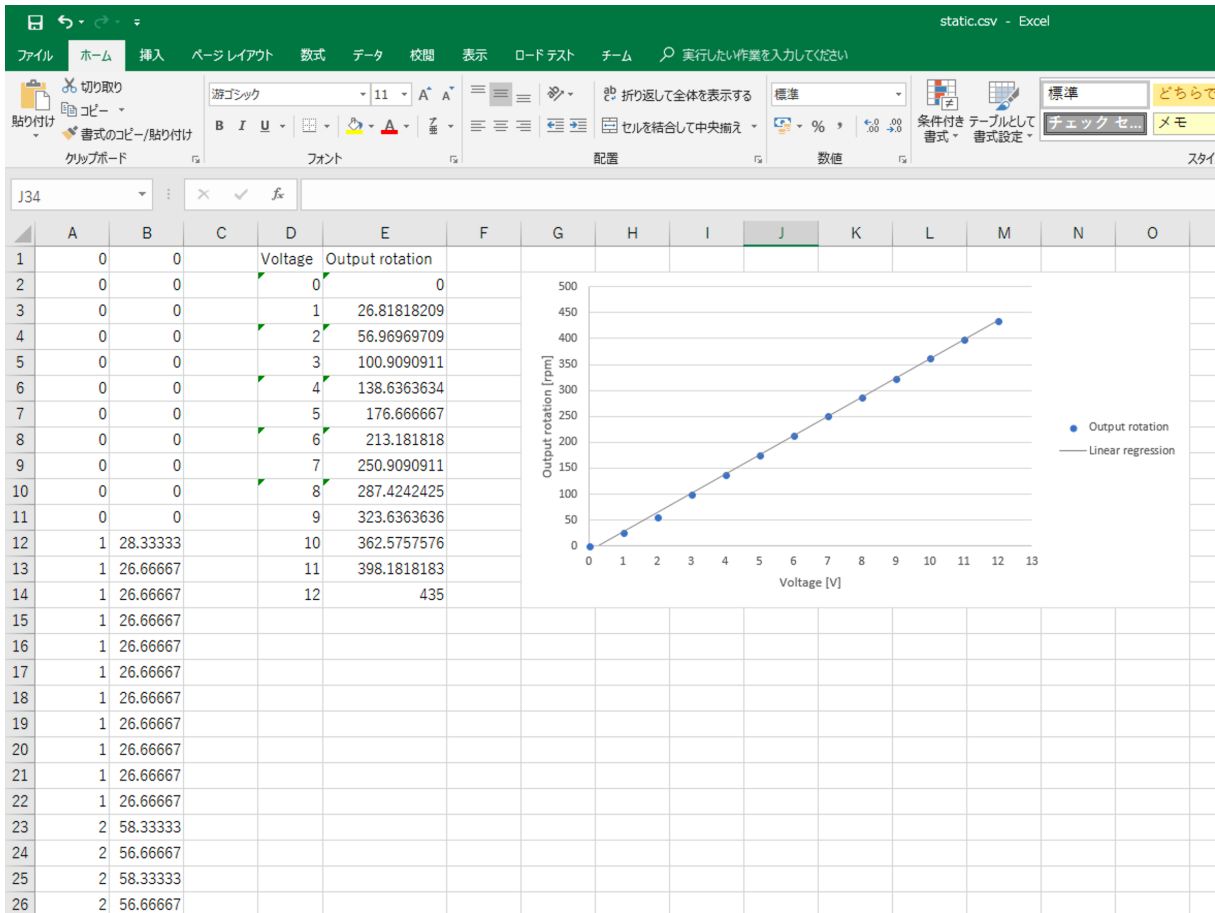


FIGURE 4. Aggregation and graph drawing

4. **Implementing the Web User Interface.** As mentioned in the previous section, the motor control learning system has to input the complex commands on the terminal and is necessary to use some software to generate a graph. Therefore, implementation of the system with the integrated interface from experiment execution to graph generation is considered. That is, the control inputs in experiments, the gatherings of measurement results and drawing graph are implemented on a unified interface. Since the motor control learning system has to be directly connected to the PC, it is necessary to operate the integrated interface on a standalone PC. The integrated interface is developed as a Web application due to flexible window design and software maintainability. In order to implement as a Web application, a server capable of HTTP (Hypertext Transfer Protocol) communication is required. However, it is difficult to prepare a web server environment for each PC. Therefore, in this system, PHP which has a built-in web server was adopted. The built-in web server used in the experiment is started with the following command.

```
$ php -S localhost:8080
```

The built-in web server waits for connection by “http://localhost:8080/”. In addition, the Web application uses Gorilla as a library for serial communication to the SH-2 board, and D3.js as a library for displaying graphs.

This implementation uses a loose coupling because to detach View and Model after implementing to smartphone application in the future version. In addition, using asynchronous communication to increase usability makes it possible to unify the communication with the server to the Web API (Application Programming Interface) format, so environment dependence becomes low. This system uses HTML (Hyper Text Markup

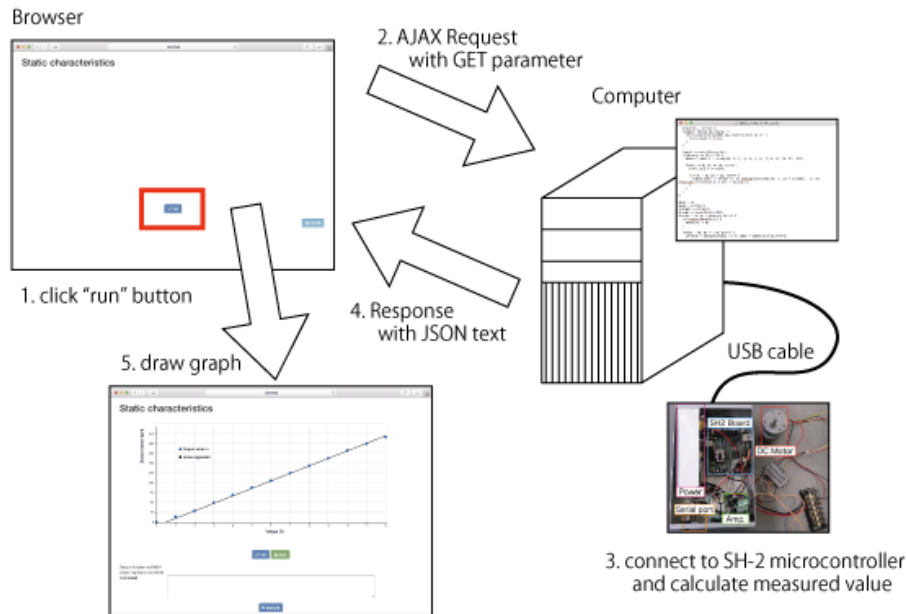


FIGURE 5. Processing of browser and the SH-2 board

```

{
  label : [ 0 : integer, ... ],
  data : [ 0 : [ 0 : [ 0 : { x : integer, y : decimal },
... ], ... ], ... ],
  p : [ 0 : integer, ... ],
  max : decimal,
  min : decimal,
}

```

FIGURE 6. JSON data format

Language) and JavaScript and performs asynchronous communication with AJAX (Asynchronous JavaScript + XML (eXtensible Markup Language)). This system also uses JSON (JavaScript Object Notation) format, which is more compatible with JavaScript and PHP objects than XML format. Figure 5 shows the flowchart of processing for communication and graph drawing. 1) Click the “run” button displayed on the browser. 2) After clicking the button, the browser performs AJAX communication to the server. 3) The server receives the GET parameters from the browser and connects to the SH-2 board. The SH-2 board returns the measurement result as text data as shown in Figure 3. and the server performs text analysis and holds it as internal data. In the static characteristic experiment, it is necessary to draw an approximate straight line using least squares method as shown in Figure 4 from the measurement result. Least squares method is an approximation method for obtaining a straight-line (Equation (2)) that minimizes the sum of squared residuals of data pairs (Equation (1)). The coefficients a and b are derived from Equation (3) and Equation (4). 4) The server returns the measurement result in the JSON format to the browser. Figure 6 shows the format of JSON data. The graph area is initialized to “label”, “min” and “max” in the JSON data, and the line or dot is drawn using “data” in the JSON data. 5) The browser draws a graph using the received JSON data. The response data is already formatted, the browser draws it directly using the D3.js library. The system supports image saving because the drawn graph is necessary for students to create a report, and the system saves an image by clicking the “save”

button.

$$(x_1, y_1), (x_2, y_2), (x_3, y_3), \dots, (x_n, y_n) \tag{1}$$

$$y = ax + b \tag{2}$$

$$a = \frac{n \sum_{n=1}^n x_i y_i - \sum_{n=1}^n x_i \sum_{n=1}^n y_i}{n \sum_{n=1}^n x_i^2 - \left(\sum_{n=1}^n x_i \right)^2} \tag{3}$$

$$b = \frac{\sum_{n=1}^n x_i^2 \sum_{n=1}^n y_i - \sum_{n=1}^n x_i y_i \sum_{n=1}^n x_i}{n \sum_{n=1}^n x_i^2 - \left(\sum_{n=1}^n x_i \right)^2} \tag{4}$$

5. Manipulation of Measurement Results by Students. The system supports unified operation methods as a new interface by improving the experimental teaching material software with the Web application. From the viewpoint of education, the semiautomated systems with simplified operations can affect the students' proficiency improvement. Therefore, the Web application does not support processing the measurement result data by the motor control learning system, and students have to generate graphs and calculate data statistics using a simple interpreted program. An interpreted language which enables students to generate graphs and calculate statistics of data with a simple program is studied to implement instead of processing the measurement result data by the motor control learning system in the Web application. For example, in a static characteristic experiment, first, students obtain a regression line from measurement value data and draw a graph together with theoretical value (Figure 7), thereby confirming that there is a bias voltage element in the measured value. From this, by using this system it expects that students understand the actual motor has internal friction and inertia by the bias component. Therefore, it is necessary for an interpreted language to implement commands to calculate the principal arithmetic operations, average, and total value in addition to the measurement result reference and graph drawing.

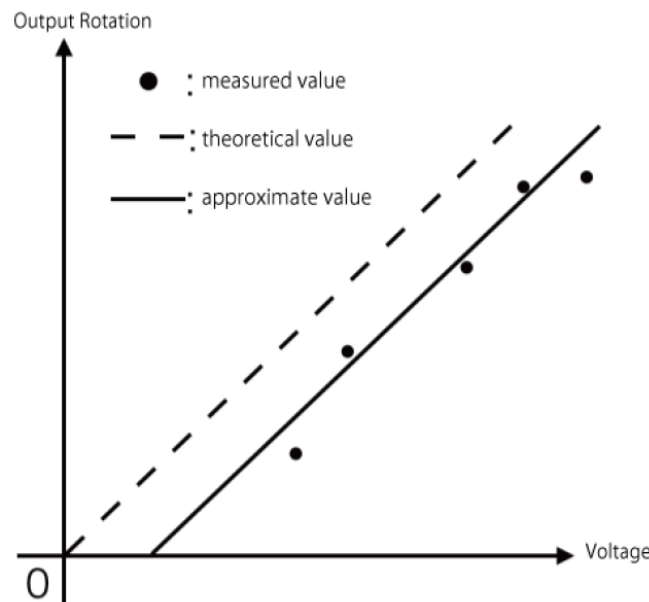


FIGURE 7. Linear approximation in static characteristic

6. Design of Interpreted Language. In the experiment, students have to compare measured values according to various parameters. In data processing languages, measured values need to be converted to arrays or vectors, and the students will feel difficult to create programs. For this reason, the integrated language is developed as a syntax based on the notation of LISP language [10] in order to implement as simple syntax as possible. For example, in the case, “(1 2 3 4)” is stored in variable var1 and “(5 6 7 8)” is stored in variable var2, the expression “ADD var1 var2 var3” represents add operation of elements of var1 and var2 in the list and stores result in var3. Accordingly, this operation processing means “(1 + 5 2 + 6 3 + 7 4 + 8)”, and as a result var3 is “(6 8 10 12)”.

Therefore, as an interpreted language specification to be developed, one line in which words are separated by spaces is regarded as one expression, and the first word is treated as “command” and the remaining words are treated as “data”. In addition, the experiment result data is preliminarily assigned as a reservation variable.

6.1. How to use the implemented interpreted language. In a static characteristic experiment, “Output rotation” of each voltage is provided from the PHP program. The interpreted language assigns the obtained value to the variable. “Output rotation” is named “DATA1”.

The following four instructions are implemented in the system.

1. DRAW arg1 arg2 ...
Draw variables given by arguments in the graph area
arg1 is an array variable containing the measured value, arg2 is displayed format (DOT, LINE)
2. ADD arg1 arg2 arg3
Add arg2 and arg3, and store in arg1
3. SUB arg1 arg2 arg3
Subtract arg3 from arg2, and store in arg1
4. AVE arg1 arg2
Calculate an average from arg2, and store in arg1

If variable already exists, it is overwritten and it can be used in DRAW.

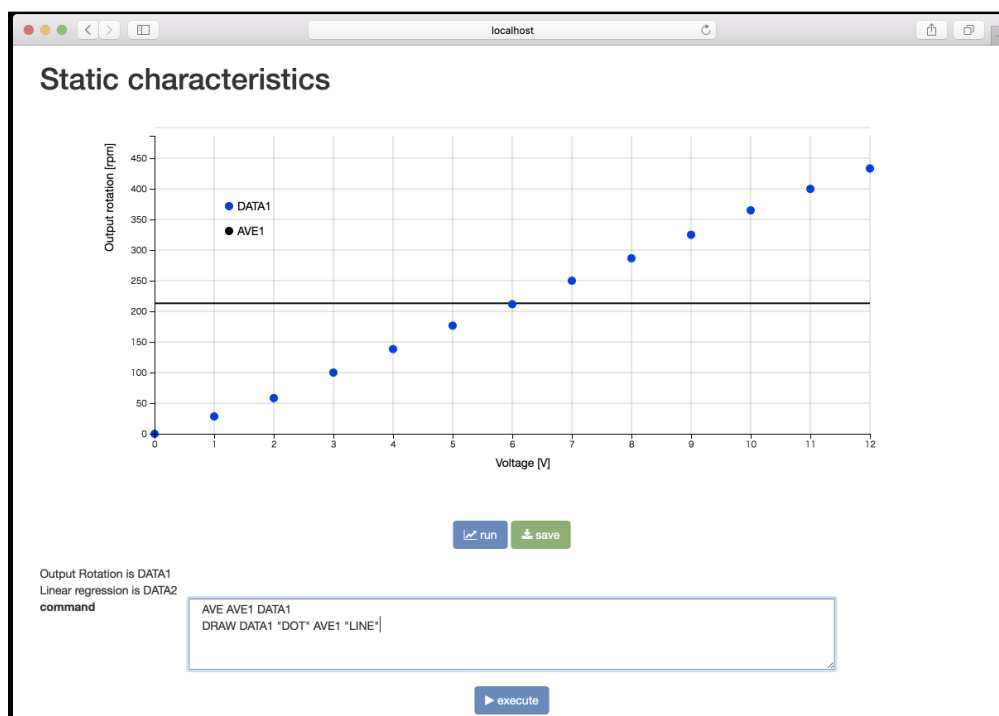


FIGURE 8. Example of interpreter execution

When students click “execute” button, the instructions described in the text area are executed. Figure 8 is an example of drawing an average of the output rotation and the output rotations on the graph area. In this sample program instruction, “AVE AVE1 DATA1” calculates the average of the output rotation and stores it in AVE1. Next “DRAW DATA1 ‘DOT’ AVE1 ‘LINE’” draws DATA1 with dots and AVE1 with a line. The graph can be saved as image data by clicking “save” button.

7. Conclusions. In our research, problems on the operability of the experimental equipment and the process of collecting measurement results are improved through the motor control learning system is reconfigured as the Web application. Since the proposed interface can handle various tasks by clicking on PC screen, loads of beginner students and troubles in repetition of experiments by changing the parameters can be reduced. In addition, the interpreted language which can display the graph using the results of calculating the measured data was implemented.

In our future research, though the proposed user interface will be performed on the actual student experiments, improvements in convenience and learning achievement will be planning to confirm. Furthermore, it is planned to update a system using a JavaScript environment called Node.js which even installing PHP is unnecessary.

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