Development of learning materials for automatic control course

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Abstract

In the new global economy, automation technologies play an important role in the industry, agriculture, transportation and daily life in the 4.0 era. Generally, studying the theory of automatic control involves the design of the dynamic control system. Students have to understand the system and be able to create mathematical models or models of control systems, both open-loop control systems and closed-loop control systems, based on the knowledge of physics, mathematics, and differential equations. They have to use all knowledge to design a control system that provides the desired results by simulating the system with computer software, which is difficult to understand and practice their skills for real implementation. By using the teaching materials that emphasize hands-on practice along with theoretical studies, is very important in creating practical experience and skills. This research has developed learning materials in designing a basic automatic control system by systematically designing and building a controller with the appropriate actuators and sensors. The designing steps are clear and easy to understand include of application of control laws, programming the controller via microcontrollers, and using a Graphic User Interface (GUI) to display the response of the system. The learning materials can compare the results from the different control systems by adjusting the parameters of the dynamics system. Students can experiment with adjusting the parameters of the controller, which makes them understand the automatic control system through actual hands-on operations with the low cost and easy to produce teaching materials.

Keywords: Automatic control, Learning material, Microcontroller, GUI

1. Introduction

In the history of development economics, automatic control technology has been thought of as a key factor in today's industry, agriculture, transportation, as well as daily life in the 4.0 era. Generally, studying the theory of automatic control involves the design of the dynamic control system. Students have to understand the system and be able to create mathematical models or models of control systems, both open-loop control systems and closed-loop control systems, based on the knowledge of physics, mathematics, and differential equations. They have to use all knowledge to design a control system that
provides the desired results by simulating the system with computer software, which is difficult to understand and practice their skills for real implementation. The teaching materials that emphasize a hands-on practice along with theoretical studies is fundamental to create practical experience and skills. [1], [2]

In this research, we have developed the learning materials that the students can design and tune the simple automatic control system. [3] They can practice in designing both open-loop and closed-loop control system. [4] The learning materials consist of the hardware system that they can set up parameters and the software GUI for interface computer with the hardware sets and also display the signal outputs on-screen.

2. Background and Theory
There are several types of automatic control system in common use. The simple system that can act as On-Off to the complicated system includes P, PI, PID, and fuzzy. The basic system that is suitable for basic learning is a closed-loop control system and it is associated with the use of a control mechanism such as P, PI, PID. The PID control system considers the output error relative compare with the setpoint (desired output) by using the three relevant terms P, I, and D, which in the control system P, PI, PID will consider the error from the related term differently. [5]

The P-Term shows only the error that the output is different from the setpoint only, according to Equation 1. The P-Control system will result in the remaining steady-state error (SSE). The system output cannot touch the set point. If the P-Term is increased, the SSE value may be reduced, and it results in an unstable system and output oscillation.

\[ P\text{-Term} = K_p \cdot e(t) \]  

When compared with a PI Control system that has I-Term terms in the system, the system will sum all output error of the system. The value of this term will result in the system to compensate for the error that occurred and achieve the desired output. Consequently, the high magnitude overshoot may occur, and it can also affect the system.

\[ I\text{-Term} = \int_0^T K_i \cdot e(t)dt \]  

Regarding the PID Control system, there is also a D-Term. It indicates the rate of change of the error value (see Equation 3). This can benefit the system, and it has less overshoot than the PI-Control system, or it may not happen.

\[ D\text{-Term} = K_d \cdot \frac{de(t)}{dt} \]  

The D-Term indicates a rapid change in output. Whilst it can cause the noise to the output and can easily lead to instability of the system. That system is formed by the values of all three terms, P, I, and D-Term, as set out in Equation 4. The system model can be seen in Figure 1.

\[ output = K_p \cdot e(t) + \int_0^T K_i \cdot e(t)dt + K_d \cdot \frac{de(t)}{dt} \]
In designing a feedback control system, we can use Equation 4 directly in both P, PI, and PID control systems. Also, we can set appropriate Kp, Ki, and Kd values, or set unnecessary parameters to zero. [7]

3. Design and component
In this project, the learning material was developed from a simple device and interfacing software to work together. The Arduino microcontroller is the key to make all components work properly. Arduino firmware includes all functions required, such as output control, sensor reading, Software interfacing, and control law calculation. The Interfacing Software was used to select the weather of open-loop and closed-loop. It allows users to set up directly.

The developed material was also associated with the use of acrylic as the main component. It accepts the installation of other equipment in the form of tipping arms. It is equipped with a force-generating device at various positions on the arm with a height of 100 mm. The arm length from the pivot point to the motor is 120 mm. The weight position is at 60, 80, and 100 mm on the opposite side. Users can install mass or setup a DC Motor for an adaptive load. With a more complex design, learning material can be set up as a simple feedback control system, or install spring and damper at those positions. The simple method is to put weights at different distances to create a vertical force on arm. Users can also change the setup by installing a motor to be able to vary the force as needed. at the other end, a DC motor is installed to generate a lifting force to keep the system in equilibrium. With complex systems or applied to mechanical vibration systems, additional springs or dampers have installed in the system.

Figure 1. PID Control System model. [6]

Figure 2. The learning material.
About the electronic parts, the system has been designed by using an Arduino Uno microcontroller. Likewise, it can connect to the DC motor unit to generate lift force using the L298N driver. The microcontroller sends the PWM signal to control motor direction and speed through the analog. Then, it can write a function from the Arduino platform. There is an accelerometer for measuring the tilt angle. The MPU6050 sensor is installed to read the angle of inclination calculating from the z-axis acceleration.
force. It is also connected to the microcontroller via the I2C bus. The measurement of the value is ranged between -2 to +2g. The resolution depends on the range of maximum acceleration setting. Regarding programming in Arduino, it is not necessary to convert to acceleration value, except the direct use of the raw sensor data in the calculation. [8]

Figure 6. Electronic parts connection.

Figure 7. PWM Signal from microcontroller can vary DC Motor speed by varying duty cycle.

Figure 8. Calculating tilting angle by sum all force in vertical direction. [8]

Another important part of the learning material is user interface software. The software will be used for parameter setup, function control, and display parameter and output value in both value and graph display. [9] The system is connected with MegunoLink software which is an interface development tool for Arduino. The interface display consists of the setting parameter sections on the left. Users can set PID parameters, Start-Stop control, setup the output angle which is usually at 0, but it can be set to others if necessary. In the case that incorporates with another DC motor as vary load, user can setup percent of load output, and change on-the-fly. On the right side, there is the graph area which can be set to display
output or set point as well as the PWM level signal output. To integrate MegunoLink with Arduino, MegunoLink has a set of built-in functions prepared to communicate between PC Software and Arduino. By pressing a button on the Interface screen, it will activate a sub-function in the Arduino to configure various parameters or control the microcontroller according to the specified parameters. On the other side, Arduino sends plotting data via MegunoLink proprietary protocol to display in the graphing area.

![User interface created by MegunoLink.](image)

The control system uses Arduino as a controller. Arduino process the value received from the MPU6050 sensor and send the signal to control motor speed according to the result of the control law which can be the P, PI, or PID control through the setting of the coefficients Kp, Ki, and Kd.

4. Results of the study
Concerning learning material, the system can accept control from the user. Users can set up parameters for the learning material and monitor the result of the system. Users can compare the result from settings by export data to other software or can compare graphs or display in various plot styles. The rising time, overshoot, settling time and steady-state error can be easily noticed from the graph. Users can configure the parameters Ki, Kp, and Kd for the experiment, which affects the output of the system. If there is an improper configuration, the system will show different behaviors, such as oscillation, divergence. When the system is convergence with different control system parameters, the user can notice the changes from the graph that is displayed.
Regarding microcontroller parts, the user can select the sampling rate for error calculation. System response has changed when the sampling rate is changed. There are some more steady-state errors and oscillation. Since the size of the learning material is small in both structure and motor power, the result error and disturbance to the system is quite noticeable compared to the control signal. The slight increase in external force from the internal friction of the device or the wind from the air conditioner affects the experimental set at the observed level.

5. Conclusion
The investigation of the use of learning material in the course has shown that users have to use all knowledge to design a control system. In the current study, the results showed a significant increase by simulating the system with computer software, which is difficult to understand and practice their skills.
The most obvious finding to emerge from the analysis is that creating practical experience and skills using the teaching materials emphasize hands-on practice along with theoretical studies.

With the low cost and easy to produce teaching materials, students can do the experiment by adjusting the parameters of the controller, which makes them understand the automatic control system through actual hands-on operations. This finding has important implications for developing learning materials for the preliminary mechanical vibration system.

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