Assessment of Experiments in a Controls Course

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Abstract

A set of new multimedia materials (videos and images) was developed to elucidate the working of proportional, integral and derivative control techniques covered in a senior-level mechanical engineering controls course. These materials also illustrated the advantages and disadvantages of these controllers. The materials were presented to students in class. Assessment of the student outcomes in learning the materials was conducted in a written exam. The questions in the exam tested the students their conceptual understanding of these controllers. The analytics are presented. The finding is that the student outcome for this topic was met.

Keywords

Tracking control; position control; linear control; microcontroller applications

Introduction

The mechanical engineering controls course, a three-credit hour lecture course, covers the theory and design of linear control techniques applied to the control of machinery. It is appropriate to cover the topic of proportional, integral, and derivative control techniques. A set of new multimedia materials (videos and images) was developed to elucidate the working of these controllers in a feedback control system. The plant of the control system was Feedback Inc.'s Mechanical Unit Model 33-100. A drawing and a photo of the unit are shown in Fig. 1 and 2, respectively.

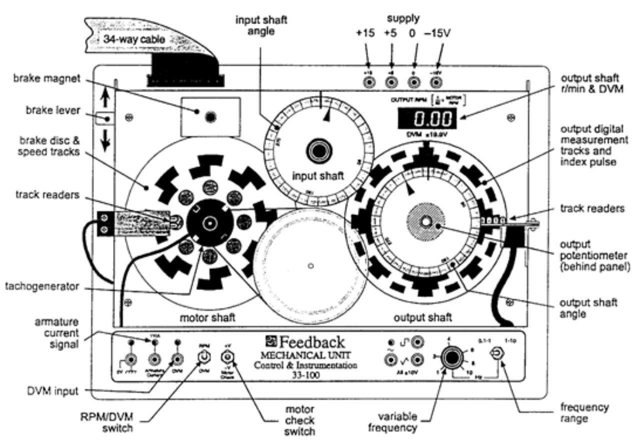

Fig. 1: Feedback Inc.'s Mechanical Unit Model 33-100

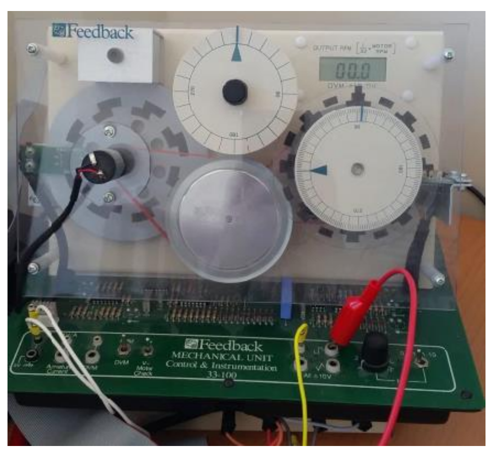

Fig. 2: Photo of the Mechanical Unit

This unit was used for position control. It contains 1) input and output shaft potentiometers for sensing the angular positions of the shafts; 2) Amplifiers and H-bridge for driving the motor with gear train; and 3) Tachometer for sensing angular velocity. A block diagram of the control system is shown in Fig. 3.

The proportional, integral, and derivative controllers were implemented as C programs[1]. The codes were run on a Freescale (now NXP) MC9S12C32 microcontroller. Signal conditioning circuits were built also for interfacing the analog signals of the control systems (range: -10 V to 10 V) to the microcontroller's analog-to-digital converter (range: 0 V to 5 V). A photo of the microcontroller and the signal conditioning circuits is shown in Fig. 4.

To develop the multimedia materials, experiments were performed. These experiments are described in the next section. The results were recorded and were presented to students in the lecture course. The theory of these controllers are readily available in the literature, for example, the textbooks[2-6]. The assessment and the concluding remarks are provided in the two sections following the next one.

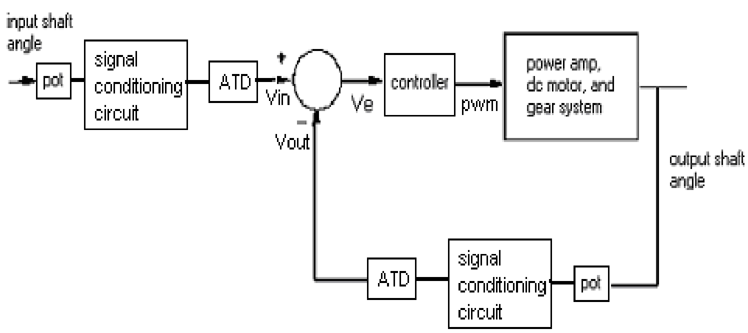

Fig. 3: Block diagram of the control system

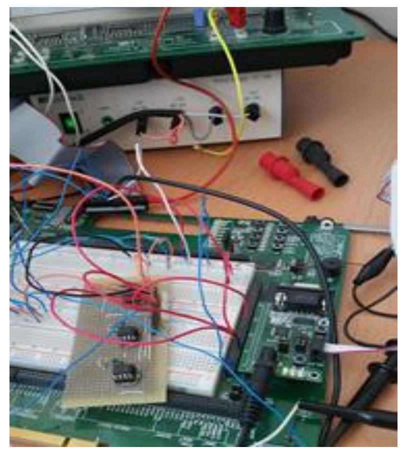

Fig. 4: Microcontroller and signal conditioning circuits

Experiments demonstrated in class

The first position control experiment was to drive the output shaft angle in Fig. 3 to track the input shaft angle. The input shaft angle signal came from the input shaft potentiometer and was a step input. It is the signal in cyan in Fig. 5. The output shaft angle signal came from the output shaft potentiometer, which is identical to that of the input one. The output shaft signal is the one in green in Fig. 5. The controller was a proportional controller with a gain factor K_p, which value is indicated in Fig. 5. The output shaft angle tracked the input shaft angle with almost zero steady state error but with undesirable overshoot and ringing as indicated in the green waveform in Fig. 5. The 2% settling time (1.223 s) is shown in that figure. The rise time (447.6 ms) from 10% to 90% of the output shaft signal is shown in Fig. 6. The waveforms were shown and explained to the students in one of the lectures. The benefits and drawbacks of the proportional controller were also explained. The next experiment showed the students a method to remove the overshoot and ringing.

The derivative of the output shaft angle was used in the feedback path to remove the overshoot and ringing. This derivative signal was obtained as the output of a tachometer connected to the output shaft. This derivative signal was conditioned for the microcontroller’s analog-to-digital converter and a gain factor K_v was used to scale this derivative in the derivative controller C program. The corresponding output shaft signals are shown as the green waveform in Fig. 7 and Fig. 8. The 2% settling time (686.3 ms) is indicated in Fig. 7 and the rise time (456.1 ms) is indicated in Fig. 8. It is observed that the overshoot and ringing were removed. The 2% settling time for derivative control is about 56% of that of proportional control. This is a significant improvement. However, the rise time is slightly increased as compared to the proportional controller.

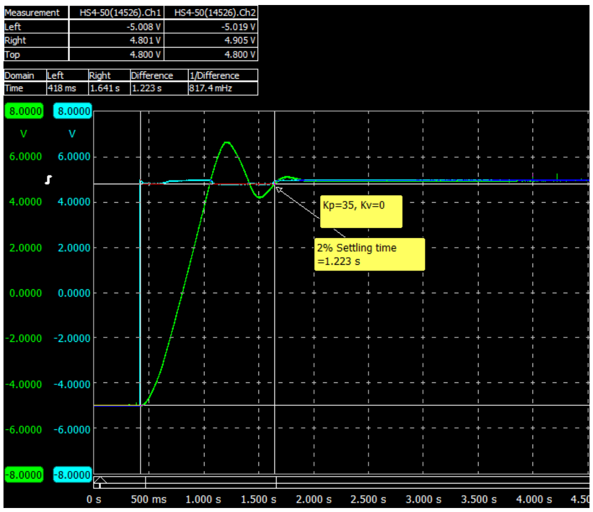

Fig. 5: proportional control (input signal in cyan and output signal in green)

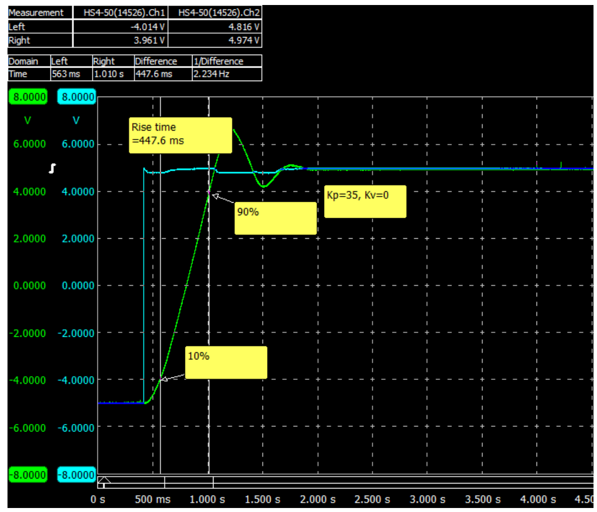

Fig. 6: proportional control, rise time of the output signal

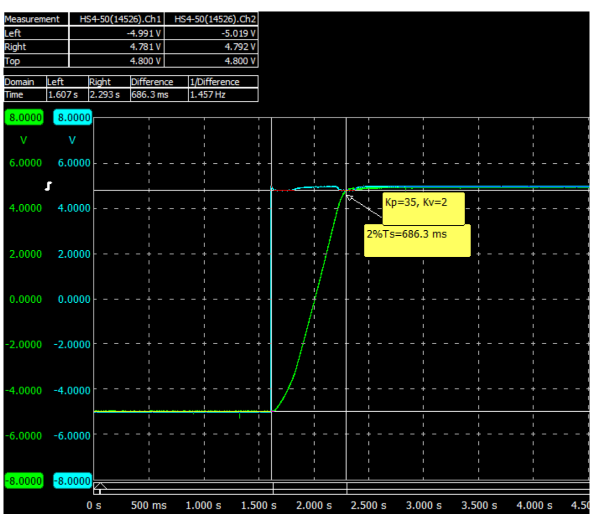

Fig. 7: derivative control, settling time=686.3 ms

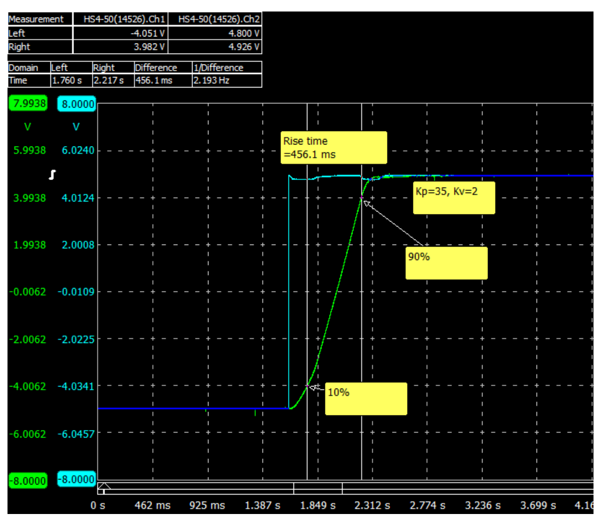

Fig. 8: derivative control, rise time =456.1 ms

The third experiment was to illustrate the effect of integral control. A moving target (triangular signal) was used as the input. In the demonstration, a proportional controller was used alone for tracking the moving target. The advantages and disadvantages of the proportional controller tracking the triangular signal were discussed The students observed that there was steady state tracking error as indicated in Fig. 9. To remove the steady state error, an integral controller was used. It did eliminate the steady state error as shown in Fig. 10 but the response contained much oscillations, which was undesirable. To reduce the oscillations, derivative control was used. The result is shown in Fig. 11.

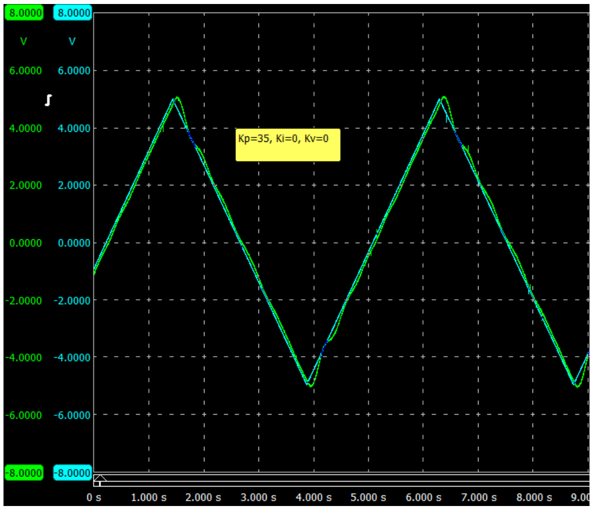

Fig. 9: tracking a triangular signal using a proportional controller

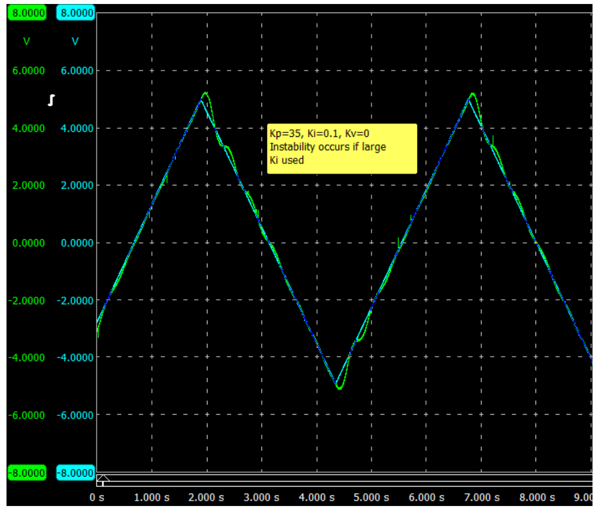

Fig. 10: proportional and integral control

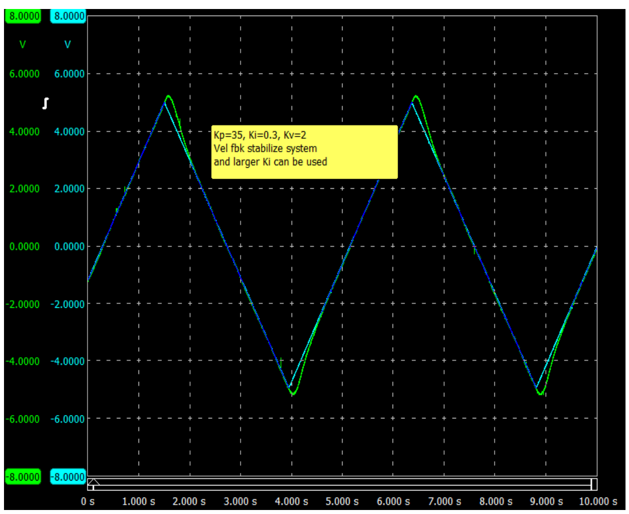

Fig. 11: proportional, integral, and derivative control

Video clips showing the movement of the input and output shafts as controlled by the proportional, integral, and derivative controllers in the experiments above were also presented to the students in class. These videos clarified the working of these control techniques and their advantages and disadvantages.

Assessment

To evaluate the effectiveness of this pedagogical approach, an assessment was conducted after the students observed the working of the controllers in the control system. The assessment focused on the amount of understanding of the applications of proportional, integral, and derivative controllers. It was done as a part of a closed-book exam. One of the problems in the exam consisted of the following conceptual questions.

- What are the transfer functions of the integral and derivative controllers?
- If the gain of the proportional controller is increased, describe two main advantages.
- If the gain of the proportional controller is increased too much, describe two main disadvantages.
- Describe two major benefits of using derivative (velocity feedback) control?
- Suppose you are tracking a moving target, e.g., the ramp input demonstrated in class. What controllers that you would choose to use to help reducing the steady state error?
- Describe one major disadvantage of integral control in the tracking of the ramp input.

The scores for this particular problem are shown in Fig. 12. There were 44 students in the exam. In evaluating the student learning outcome for this topic, the departmental criterion was used. The criterion was that a student learning outcome was considered met if 70% of the students scored above 70% in the exam for that outcome. There were 32 out of 44 students scored above 70% as indicated in Fig. 12, i.e., 72.72% of students scored above 70%. According to the criterion, this student learning outcome was met.

This assessment criterion could be improved. For example, other analytic parameters can also be considered for the assessment as a supplement to the criterion above. These parameters include the average score and the standard deviation. The average and the standard deviation of the data in Fig. 12 are 77% and 16%, respectively. The student scores could be normalized to a z-score (defined as (student score – average score)/(standard deviation)). The number of students with z-scores within +/- 1 were 30, which corresponded to 68% of the population. Note that z-score of +1 indicates 84^{th} percentile and that of -1 16^{th} percentile. A performance criterion could be developed from these statistical parameters.

Also, individual score of each of the questions above can be used to evaluate the corresponding experiment. This analysis will be performed in the future when more data are collected in the next offering of this course.

Concluding remarks

New multimedia materials were developed for and used in the controls course. These materials helped the students in their understanding of the proportional, integral, and derivative controllers. The assessment result was that the student learning outcome for this topic was achieved. Such materials can be re-used again in future offerings of this course.

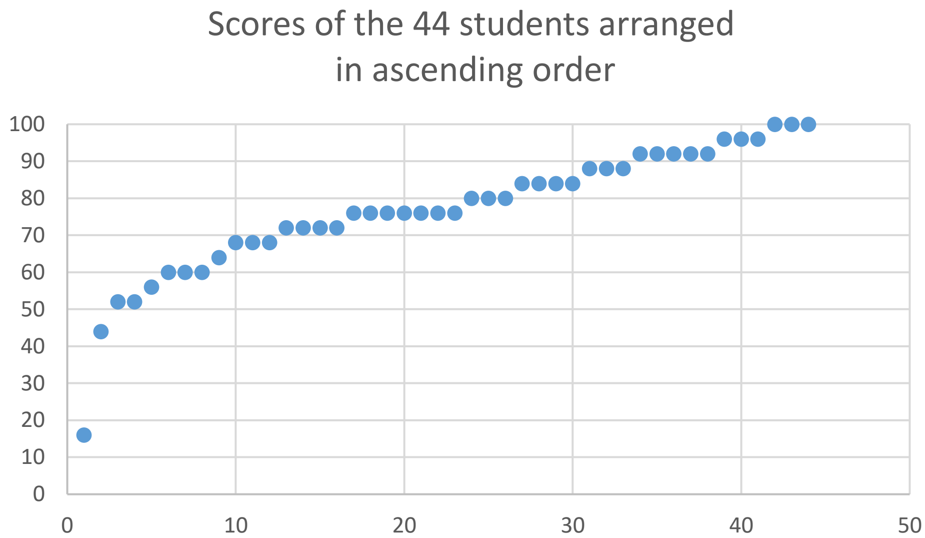

Fig. 12: Score distribution of the evaluation (highest score=100)

References

1. C. Choi, "Comparing Microcontroller and Analog Methods for Tracking Control Experiments," Frontiers in Education Conference, El Paso, TX, 2015, pp. 1-4.
2. K. Ogata, *Modern Control Engineering*, 5th ed., Prentice Hall, 2009
3. R. C. Dorf and R. H. Bishop, *Modern Control Systems*, 12th ed., Prentice Hall, 2010.
4. G. F. Franklin, J. D. Powell, and A. Emami-Naeini, *Feedback Control of Dynamic Systems*, 6th ed., Pearson, 2009.
5. N. S. Nise, *Control Systems Engineering*, 7th ed., John Wiley, 2015.
6. R. T. Stefani, B. Shahian, C. J. Savant, and G. H. Hostetter, *Design of Feedback Control Systems*, 4th ed., Oxford., 2001.

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