A Case Study of Off the Job Training Course for Control Engineering

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ABSTRACT

In this paper, a case study of Off the Job Training course for control engineering designed based on the collaboration with authors and an industry is presented. This course is six weeks long and is a blended learning one composed of a face-to-face classroom, e-learning class and experiment based learning using a simple hardware. A case study suggested experiment based learning is effective, however the class schedule should be designed in a careful way.

Keywords: Off the Job Training, Collaboration with Academy and Industry, Experiment Based Learning, Blended Learning

1. INTRODUCTION

In industry, On the Job Training (OJT) is very common for fresh engineers or mid-career engineers to develop their job skill or to get wider engineering and management skill. On the other hand, Off the Job Training (Off-JT) is also enforced mainly for mid-career engineers to enhance their capabilities in the different field or to collaborate with engineers in another section of the company by studying together. In this paper, a case study of Off the Job Training course for control engineering designed based on the collaboration with authors and an industry is presented.

A company, which produces information devices and information systems with more than 1000 employees, planned an Off-JT course for mid-career engineers with authors. The objective of the Off-JT are 1) to study the advanced control technology, 2) to improve problem solving skill in the field of mechatronics by considering the difference between the theoretical response and the real response, 3) to improve collaborate skill with engineers in other section of the company. Most of the professional territory of participants is not control engineering but other field such as mechanics, electronics, chemistry and so on.

Basic control engineering is very essential knowledge for every engineers and covers wide area such as mathematics, physics, chemistry, mechanics, electronics and so on. Figure 1 shows standard learning process of control engineering. Firstly, students learn control theory by instructors in a class using mainly textbook. Secondly, they verify the studied theory by digital simulation using CAD tools and so on. Finally, they verify the actual motion by experiment. Each process and combinational study of these three process are very important. In particular, essential practical details can be lost if learning is reduced only to lectures and digital simulations bypassing physical experiments because of their relatively high costs or time-consuming [1]. Experiment-based teaching or learning is absolutely necessary.

So far, authors have developed several Off-JT control engineering course in collaboration with industries as follows.

1) One Month Intensive Course:
Study topics are learning theory, designing controller, verifying by simulation, implementing digital controller and analyzing the actual motion using a simple robot with group-wise work.

2) One Week Intensive Course:
Study topics are learning theory, designing controller, verifying by simulation and analyzing the actual motion using given controller of a simple robot with group-wise work.

3) Three Days Intensive Course:
Study topics are learning theory, designing controller, verifying by simulation and analyzing the actual motion using given controller of a simple robot without group-wise work.

Fig. 1 Learning process of Control Engineering
One Month Intensive Course was the most effective one for engineers, however it had time-problems for both engineers and industry. One month Off-JT course is too long to be difficult to enroll for mid-career engineers because they have daily routine work. Three Days Intensive Course is good for their time-schedule, however they have no time in the course to try their own control idea or to follow through the theory by simulation and experiment. They only studied lecture’s explanations or follow prepared experimental results. One Week Intensive Course is better than three days one, however they don not have enough time to consider, for example a couple of days, or to try their own control idea and to implement own digital controller.

According to these experience, experiment-based learning is found very effective as shown in [1]. However, for both engineers and company, an intensive course is very difficult due to their daily routine work. A virtual lab system or a remote experience lab system will be one of the learning style instead of real experiment-based learning [2],[3]. On the other hand, e-learning using Internet is getting popular from viewpoint of learning at anytime and anywhere [4],[5].

Authors designed a new course, which includes face to face class lecture, e-learning and experience-based learning according to a company’s request. In this paper, the course design and some results are described.

2. COURSE DESIGN

Most of companies have planned and organized many kinds of On the Job or Off the Job training course for fresh engineers or mid-career engineers to develop their job skill or to get wider engineering and management skill.

This time, the company’s request to Off-JT course for authors is as follows.

1) students:
   About 10 mid-career engineers who belong to different section and have different specialized field each other.

2) class room:
   They can attend a class opened in industry full or half day (four to eight hours) once a week. The course should be one to two months.

3) objective 1:
   They want to learn the principal of a control system from viewpoint of “Monozukuri” (Manufacturing), especially the design approach based on control theory.

4) objective 2:
   They want to study in cooperation with other section’s engineer due to carry out a complicated and big project in industry.

Authors have several classes for control engineering, electric engineering and mechatronics laboratory in each university and have knowledge that a hands-on mechanical system with a microprocessor called Arm-Robot, control design CAD (Scilab®), web-based discussion forum and group-wise work using Arm-Robot are very effective educational materials [6],[7].

The structure of the Arm-Robot is shown in Fig. 2. A small motor (1 Watt) with gears drives a small bar called the arm. The angle of the arm is determined with a hand-made encoder.
The control board with a microcontroller shown in Fig. 3 is a digital controller of the robot and has an interface with a PC. The control program (based on C) of the microcontroller can be easily changed by the PC. Photograph 1 shows the arm robot and the amplifier.

Authors designed a following new course as a result of consulting the company’s supervisors.

1) Course Materials:
   Hardware: Arm-Robot, controller board and PC
   Software: Scilab®, Arduino® IDE and control programs
2) Course Style:
   The course is totally six weeks combined with face to face classroom (once a week) and e-learning class. Each student has one set course materials (an Arm-Robot, controller board and PC).
3) Course Contents:
   Web-based lecture note, web-based simulation tools and Remote-lab system are set up.
4) Course Topics:
   Basic control theory such as transfer function, stability, PID controller design, digital controller implementation, Group-wise Project (system design with three robots)

3. COURSE MATERIALS

3.1 Arm- Robot System

It is a big problem which kind of experiment system is better for students [6]. In this course, we focus on a simple and low-cost hands-on system [7],[8]. This system is basically composed of following three parts as shown in Fig.1 and Photo.1.

1) An Arm-Robot
2) A Control Board with a microcontroller
3) A control program for the Control Board, Scilab and Arduino IDE on Windows system

The Arm-Robot system is so simple that its linear dynamic equation is derived as

\[
J \frac{d^2}{dt^2} y(t) + c \frac{dy}{dt} y(t) = ku(t)
\]  

where, \( J \): moment of inertia, \( c \): coefficient of viscous friction, \( k \): coefficient of motor torque.

A real step response of PID controlled system is usually different from a theoretical one because of its non-linearity as shown in Fig. 4. Recognizing and analyzing this difference is the most important practice for control engineers. The simulation considering its non-linearity is one of good practice for students. This means that Eq.(1) will be modified as

\[
J \frac{d^2}{dt^2} y(t) + c \frac{dy}{dt} y(t) + a(\frac{dy}{dt}) y(t) = \beta(u(t))
\]  

and students are going to find out more precise mathematical model of the target system. On the other hand, as the objective of the control is tracking the reference, tuning PID parameters is the another good practice to achieve the objective as shown in Fig. 5. This shows the advantageous effect of feedback control system that a small model error is reduced by high gain feedback technique.

[2] shows emulation-based virtual laboratories. The above experience can be possible by simulation, however a complicated nonlinear model as Eq.(2) is necessary and its realistic derivation is sometimes very difficult.
The control board uses a microcontroller called Arduino, which shall be easily programmed by C language using Arduino IDE, so students can learn digital control algorithm and will try their own idea. A couple of programs, a control program on PC and a digital control program on Arduino, is prepared for beginners to study and analyze the standard PID feedback control system for the Arm-Robot. Figure 6 shows the snapshot of the control program on PC. At the first experiment, students only need to change controller’s parameters.

Authors have set up and used five kinds of course contents. First one is animated simulation of Arm-Robot motion on the web, which is used as first experience for students. Second one is simulation on the web based on Java script. Students who can not use CAD tool, can easily get step response by setting parameters. Third one is CAD tool “Scilab”, which is installed each student’s PC. After mastering usage of Scilab, they do not have to use the second one. They can make up more complicated control system configuration. Fourth one is Arm-Robot experiment system. All students are given their own experiment system with their own PC (Photo. 1). Last one is Remote-lab system for Arm-Robot (see Photo.2, Fig.7 and Fig.8). When students can not use their Arm-Robot system, they can access this Remote-lab system via the Internet and get the real response.

3.2 Blended Learning

Figure 8 shows the educational setting of this course. Each student has their own PC and hands-on Arm-Robot system, which can be used in a classroom and at their office. We developed 1) Lecture note, 2) Discussion forum, and 3) Remote-lab system on a web serve in our university [7]. Off the Job training consists of a face-to-face classroom during working hours and self-study (e-learning class) after office hours,
both of which are included in their working hours in this training term. The classroom is opened once a week and students can discuss with instructors or other students. At any other time, students can discuss with each other or instructors by using web discussion forum system. It is important that students have come from different section of the company and they seldom have the opportunity to meet during working hours. In this point of view, blended learning as Fig. 8 is necessary and considered effective.

Collaborative learning using web system is very popular these days [3],[5]. There are many type of web system, on which students can discuss each other or lecture can timely advise each student. Authors use a hands-on simple web forum system shown in Fig. 9.

3.3 Group-wise Project
The Arm-Robot system uses a microcontroller board, which can be easily programmed by PC and has several unused I/O ports (Fig. 3). After designing an optimum control system, students can connect each robot by using these ports and can make robot system with collaborative motion. Final group-wise project assignment for student, where one group consists of three members, is such that “Design and make sure a tracking PID control system for the Arm-Robot and build up a cooperative robot system using three Arm-Robot”. This type of group work is intended to summarize or review the course. Authors have fond this work was very effective for university students.

4. A CASE STUDY

4.1 Schedule
Nine engineers who belong different section joined this class in 2009 and 2010 respectively. The class schedule is shown below.

<table>
<thead>
<tr>
<th>WEEK</th>
<th>TIME</th>
<th>TOPICS</th>
<th>ASSIGNMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-week</td>
<td></td>
<td>Individual Preparation</td>
<td>Self-introduction</td>
</tr>
<tr>
<td>1st week (Mon.)</td>
<td>9:00 - 17:00</td>
<td>Course Navigation</td>
<td>PD control system</td>
</tr>
<tr>
<td>2nd week (Thu.)</td>
<td>13:00 - 17:00</td>
<td>Analysis of Control system</td>
<td>Stability and Step Response</td>
</tr>
<tr>
<td>3rd week (Thu.)</td>
<td>13:00 - 17:00</td>
<td>Design of PID control system</td>
<td>Simulation and Experiment</td>
</tr>
<tr>
<td>4th week (Thu.)</td>
<td>13:00 - 17:00</td>
<td>Implementation of digital controller</td>
<td>Group-wise Project</td>
</tr>
<tr>
<td>5th week (Thu.)</td>
<td>13:00 - 17:00</td>
<td>Evaluation method of control system</td>
<td>Group-wise Project</td>
</tr>
<tr>
<td>6th week (Fri.)</td>
<td>13:00 - 17:00</td>
<td>Presentation of project theme</td>
<td>Group-wise Project</td>
</tr>
</tbody>
</table>

4.2 Discussion
The topics and assignments in each week is as follows.

Pre-week: The discussion forum is opened 2 weeks before the class to introduce each other, because students belong to different section and they do not know each other until staring of this course. On the web, students have to pre-study contents such as fundamental mathematical knowledge, basic idea of feedback control system and control trial using virtual animation tool or remote laboratory. As a result, all students posted their self-introduction and instructors answered their submission and both students and instructors could understand each background.

1st week: 1st lecture is called “Course Navigation”, which shows students the outline of the course and how to use software and hardware. It took full day and trial and error controller design was the most important study for students.

2nd week: The main topic is fundamental control theory such as modeling, Laplace transform and stability. Students measure real physical parameters of their robot and verify their validity by simulation and experiment. The assignment is the review of the lecture, however some of students could not keep the due date because of their daily routine work.

3rd week: The main topic is PID controller design. The integrator of PID controller usually works well, however sometimes does not work well because of mechanical static friction. The experiment using Arm-robot explicitly show this phenomenon, which is very difficult to understand by simulation. Through these experiment, students can acquire optimal parameter tuning technique.

4th week: The explanation of group-wise project theme and programming technique of controller are topics. Some students are inexperienced in programming, however they solved assignment in a group setting.

Fig. 9 A snap shot of Discussion Forum (Ex. [5],[6],[7] and [13] are posted ones by a student and [17] is a comment by another student. [22] and [33] are comments by an instructor.)
5th week: After showing the final assignment and frequency analysis technique shortly, students got to work on group project. It was very difficult for students to take time to work together due to their daily work. This was unexpected when authors designed this course.

6th week: Last class is each groups presentation and demonstration of the final assignment (design a controller according to the given specification) and group project. The group project theme is “build up a cooperative robot system using three Arm-Robot”. Supervisors of students took part in the presentation.

4.3 Questionnaire
Students’ questionnaire results are follows.
1) Experiment based learning is very easy to understand. (61%)  
2) I understand the difference between the real response and the simulation response. (44%)  
3) Discussion on the web is good because we can read other’s answers or comments. (44%)  
4) Programming in the project is rather hard work. (11%)  
5) We need more time to review topics and to discuss with other members. (56%)  
6) It is very difficult to collaborate with other members for the final project. (22%)  
7) I want to use Arm-Robot system in pre-week.  
8) I think group presentation every two week is better.  
9) Mathematics is very difficult.  
10) I do not use Remote-lab system, because I could use my own experiment system. (80%)  

These show that Experiment based learning using a simple structured robot is effective, however learning contents are too much or too wider. At the same time, it was difficult for students to arrange study time under their daily routine work.

5. CONCLUSION
In this paper, a case study of Off the Job Training course for control engineering is presented. Six weeks blended learning course which includes once a week face to face class, e-learning class with discussion forum and Remote-lab system and experimental based learning, is designed based on the collaboration with authors and a company. Experiment based learning using a simple structured robot is found effective for mid-career engineers whose professional filed are not control engineering. The blended class is also effective for such a vocational education, however we have to consider the class schedule in a careful way. Authors will try to change study items or use longer class period while discussing with the company’s supervisors.

5. REFERENCES