Combining MOOL with MOOC to Promote Control Engineering Education: Experience with NCSLab

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Abstract: MOOC and MOOL alter the economics of education and provide an easy-access and cost-efficient way of online learning with unlimited participation and no limitation on time and locations. This paper explores the combination of MOOC and MOOL to promote control engineering education. NCSLab which is a web-based MOOL that has been providing online experimental services for over 12 years has been taken as an example, the MOOC of which has been created and put online on a national MOOC platform in China. The design, content, application example and teaching supports of the MOOC are investigated in details, in which the MOOL has been integrated. Meanwhile, in the MOOL platform, a notice for the MOOC has been published with the web access included for promotion. The MOOC experience with NCSLab can be used as a reference for other researches to promote engineering education.

Keywords: Control engineering education, MOOC, MOOL, Online laboratory, Remote laboratory, Virtual laboratory, Classroom demonstration, After-class experimentation.

1. INTRODUCTION

With the development of Internet technologies and web technologies, distance education and online education has become a trend for learners and also a hot research topic for researchers. As a distinguished approach to promoting online education, a great many of Massive Open Online Course (MOOC) platforms such as *edX* (Breslow et al. (2013)),*Coursera* (Schmidt and McCormick (2013)), and *FutureLearn* (Sunar et al. (2017)) have been established in the last two decades, which benefit numerous users throughout the world. MOOCs have been called Campus 2.0 that are transforming higher education and providing fodder for scientific research (Waldrop (2013)), which enables open accessibility and unlimited participation.

For online learning, MOOCs are sufficient for humanities and social sciences to provide theoretical knowledge. However, as for engineering fields, in addition to theoretical knowledge, experiments are vital not only for helping the comprehension of theoretical knowledge but also enhancing students' practical skills. The emergence of Massive Open Online Laboratory (MOOL) (Lowe (2014)) provides a complement for MOOC to address the issue of sharing equipment in an easy-access and cost-efficient way compared with conventional laboratories. MOOLs are important for scientific inquiry and education as well-established MOOLs can be a good complement of hands-on laboratories without loss of any level of knowledge (de Jong et al. (2013); Hossain et al. (2016)).

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As is the case of MOOCs, MOOLs have also been set up by researchers all over the world. For example, iLab (Harward et al. (2008)) developed a distributed software toolkit and infrastructure for Internet-accessible laboratories which can promote the sharing among universities on a worldwide scale. Go-Lab (de Jong et al. (2014)) offers a portal of remote and virtual laboratories, and virtual instrument systems in reality (VISIR) (Tawfik et al. (2013)) provides wiring on virtual breadboard for education in electrical and electronic engineering.

MOOL has also been largely applied to control engineering field. For example, WebLab-Deusto (Orduña et al. (2016); Garcia-Zubia et al. (2009)) explored robot control and FPGA laboratory with which students can program and submit the binary compiled file for control purposes. UNILabs (Sáenz et al. (2015);de la Torre et al. (2015)) at UNED researched on the following activities that can be performed with the laboratory system: system identification, PID tuning and frequency response analysis. Networked control system laboratory (NCSLab) (Hu et al. (2017); Lei et al. (2018c)) at Wuhan University focused on algorithm implementation, monitoring interface configuration and three-dimensional (3-D) interactions. All of these online laboratories has been applied to control teaching and experiment scenarios for years.

MOOC and MOOL share some common features. Fig. 1 illustrates the contents and features of MOOC and MOOL. Both MOOC and MOOL provide supports for open-access Internet-based online learning with unlimited participation. The combination of MOOC and MOOL has the potential to promote education.

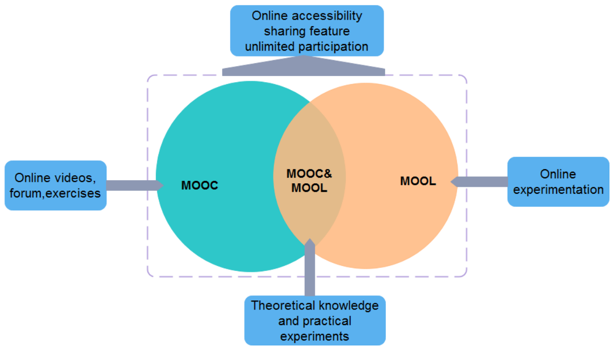

Fig. 1. Illustration of MOOC and MOOL

In Salzmann et al. (2016), a solution to deploy remote laboratories within MOOC infrastructures is provided using *edX* which is open source that allows an institution to install its own instance of *edX*. Using smart devices, a MOOL has been integrated into the MOOC. The results show that the combination of MOOC and MOOL strengthens and enhances the existing advantages.

To achieve towards the same purpose, MOOL and MOOC are combined to promote control engineering education in this paper. However, as a mature online platform that has been providing experimental services for over 12 years, the solution in Salzmann et al. (2016) may not be the best option for NCSLab.

To provide MOOC students with a MOOL for online experimentation, one issue that should be addressed is the accessibility of the MOOL. The more portable the MOOL is, the more students will conduct experiments with it. Thus, web-based laboratories are best options, with which students do not have to install any other software.

The remainder of this paper is organized as follow. Section 2 presents the previous work of the MOOL platform NCSLab, which includes the architecture and experimental services. Section 3 explores the MOOC design and content for the MOOL platform, in which the application and effect as well as teaching supports are also investigated. In Section 4, discussions are provided regarding the lessons learned from the first round of MOOC on a national platform, and the issues that remain to be addressed are also discussed. Finally, Section 5 concludes the paper.

2. PREVIOUS WORK OF THE MOOL PLATFORM NCSLAB

NCSLab is one of those MOOLs that can provide massive open online laboratories for experimentation. Developed as a web-based application, NCSLab enables access with web browsers without installation of software. Moreover, the latest HTML5 implementation (Hu et al. (2017)) allows students to conduct experiments with mainstream browsers without any plug-ins, which avoids crash/update issues caused by Flash. Thus, NCSLab is a perfect candidate for MOOC-MOOL combination. The web-based online laboratory platform NCSLab can be accessed at https://www.powersim.whu.edu.cn/ncslab through any web browser. For better user experience, mainstream web browsers such as Google Chrome, Microsoft Edge and Mozilla Firefox that support HTML5 are recommended.

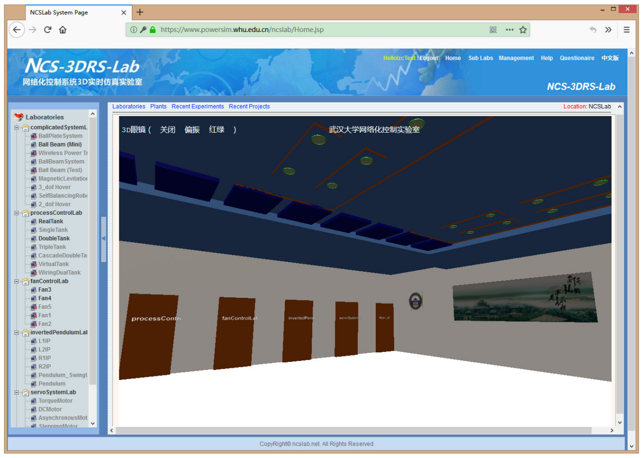

Fig. 2. NCSLab web page

Currently, 26 different test rigs are integrated into the laboratory platform for control engineering education focusing on proportional-integral-derivative (PID) tuning, control algorithm implementation such as PI control and Linear Quadratic Regulator (LQR) control, visual configuring, wiring and measurement. NCSLab has been used for classroom online demonstration and after-class experimentation to enhance student learning (Hu et al. (2017); Lei et al. (2018b)).

2.1 *Architecture*

NCSLab can be simply concluded into a four-tier architecture (Lei et al. (2018c)). The user side tier is a web-based interface where users can log in, configure the monitoring interface and remotely interact with test rigs. The server tier includes a server for communication with the controllers and user-side web interface. In the controller tier, Linux-based ARM embedded systems and Windows-based mini PCs are used as controllers to run control algorithms. Virtual and physical test rigs are in the test rig tier for virtual and remote experiments.

The NCSLab web page is shown in Fig. 2. The left-hand side is a list of sub-laboratories, where test rigs are cataloged according to their functionalities. A 3-D virtual laboratory room which includes different sub-laboratories is in the right-hand side. The user can carry out an experiment either by clicking the test rigs at the left side or by “picking up” a test rig after entering one of the sub-laboratories through the virtual door.

2.2 *Experimental Services*

NCSLab has been providing web-based 3-D experiment services at Wuhan University for over seven years. Since 2015, NCSLab has been applied to classroom online demonstration and after-class experimentation on a large scale, which involves over 200 students per year and three class modules as *Classic Control Theory*, *System Identification (SI)* and *Control System Simulation and Computer Aided Design*. NCSLab can be leveraged for different class modules for students at different levels.

Different experimental services can be delivered by NCSLab. For example, virtual experimental test rigs including a 3-D virtual ball and beam system (Hu et al. (2017)), an inverted pendulum (Hu et al. (2017)) and a DC motor control system (Lei et al. (2018b)) can be used for PID control and LQR control. In this case, 3-D virtual models are constructed and rendering in the web browser to achieve a visualized experimental process in the absence of real video. Remote experiments provided by fan speed control systems (Zhou et al. (2017)), a wireless power transfer system (Lei et al. (2018a)) and a dual tank system (Hu et al. (2017); Lei et al. (2016)) are also integrated where users can watch the experimental process through images from the on-site cameras. To assess student performance of laboratory work using online laboratory NCSLab, a multi-criteria method has been proposed in Zhou et al. (2017) to achieve much more objective evaluation.

3. MOOC FOR NCSLAB

In 2016, a NCSLab related MOOC project named *Remote and Virtual Simulation Experimentation for Classic Control Theory* has been launched by *Prof.* Zhou Hong and *Prof.* Wenshan Hu at Department of Automation, Wuhan University. The MOOC has been created to be combined with the MOOL NCSLab to promote control engineering education. After two-year preparation, the MOOC has been completed and put online on a national MOOC platform *China University MOOC* (China-University-MOOC (2018)) on November 26, 2018.

3.1 Motivation

MOOC and MOOL can drive each other. NCSLab can provide web-based access to experiment test rigs, which shares equipment throughout the world in an easy-access and low-cost approach. However, some theoretical concepts and operation instructions can be better delivered through videos. Considering the advantages of the MOOC, which allows online access and teacher-student interactions, a MOOC for NCSLab has been designed with the purpose of the combination of MOOC and MOOL to promote control engineering education through a national MOOC platform. While MOOL provides support for experimental services, MOOC offers teaching environment of theoretical knowledge and operation instructions, *etc.* To the best of the authors' knowledge, this MOOC is the first MOOC in China that focuses on remote and virtual experimentation using an online experimentation platform, which can provide potential solutions for other fields of engineering for the promotion of education.

3.2 MOOC Design and Content

The general design principle for the MOOC is to proceed from the elementary to the profound which covers both theoretical concepts and practice with the online experimentation platform. For example, an introduction of remote and virtual experiments as well as famous platforms, basic concepts in control engineering such as closed-loop control and PID controller, operation instructions of NCSLab, and also comprehensive experiments are all included. To earn a certificate, students are supposed to watch all the lecture videos, complete the exercises, pass the final exam and finish their experiments in NCSLab.

Fig. 3. NCSLab MOOC homepage

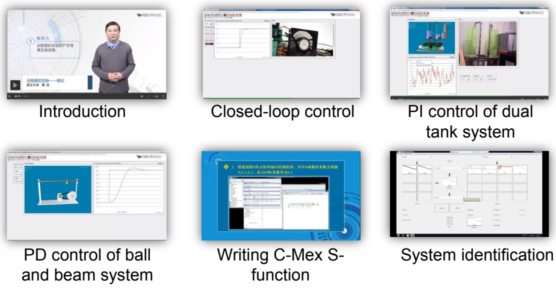

Fig. 4. Course design of the NCSLab MOOC

Fig. 3 shows the homepage of the NCSLab MOOC on *China University MOOC*. The course description and learning objective *etc.* are listed on the homepage. Six teachers are involved in the teaching process. The six lecture videos are concluded into five chapters, the contents of which are summarized in table 1. It can be concluded that for control engineering education, remote experiments with a fan speed control system and a dual tank system for water level control and virtual experiment with a ball and beam system are integrated into the MOOC. Fig. 4 illustrates the course design of NCSLab MOOC, in which the pictures are screenshots from different chapters of the MOOC.

The MOOC aims to provide a foundation for online experimentation with NCSLab. Fig. 5 shows the course content, in which basic concepts of MOOL, the illustration of the 3-D model of ball and beam system, the control algorithm design and implementation, operations of experiments and exercises are all integrated into the MOOC. In addition, after each chapter, students are required to finish corresponding exercises, which accounts for 20 percent of the final score. The chapter exercise examples are listed in table 2. Exercises are in the type of single-answer multiple-choice questions (MCQs), multi-answer MCQs, true/false questions and fill-in-the-blanks questions regarding the platform, PID control and system identification, *etc.* These exercises are intended for the comprehension of concepts as well as the laboratory platform.

Table 1. NCSLab MOOC contents

ID	Chapter Content	Learning Objectives	Topic
1	Introduction to remote and virtual experiments and the use of NCSLab	Getting familiar with remote and virtual experiments and NCSLab	Background of remote and virtual experiments, NCSLab and its operation instructions
2	Remote experimentation on a fan speed control system and a dual tank system	Closed-loop control, Comparison with open-loop control	Remote experiments, PI control, Closed-loop control
3	Virtual experimentation on a ball and beam system	Feature of PD control, PD control with virtual test rig	Virtual experiments, PD control, 3-D model, Control algorithm implementation
4	Writing C-MEX S-function of PI control algorithms with anti-windup protection	Writing C-MEX S-function for PI control with anti-windup protection	Control algorithm implementation, C-Mex S-function, Anti-windup protection
5	Using NCSLab to conduct system identification of fan speed control system	Getting familiar with data acquisition methods using NCSLab and MATLAB SI Toolbox	Control algorithm implementation, Data acquisition using NCSLab, MATLAB SI Toolbox

Table 2. Chapter exercise examples

Chapter ID	Exercise	Type of Question	Topic
1	Which of the following is the website of the corresponding online experimentation platform?	Single-answer MCQ	NCSLab
2	Why remote and virtual experiments are necessary in some cases?	Multi-answer MCQ	Background of remote and virtual laboratories
3	Misconduction in remote experiments would cause damage to the physical equipment.	True/False Question	Background of remote and virtual laboratories
4	Which of the following is the controller that has been used in the control of ball and beam system in the MOOC?	Single-answer MCQ	Theoretical knowledge of control education and MOOC content
5	In the SI experiment, what is the MATLAB command for SI toolbox?	Fill-in-the-blank Question	MOOC content and experiment

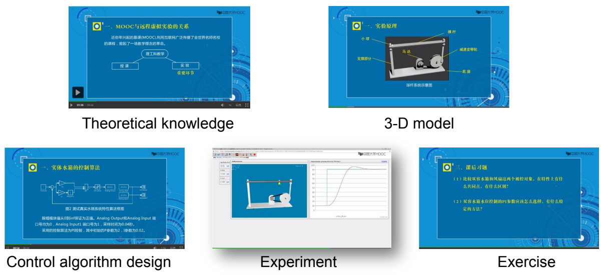

Fig. 5. Course content of the NCSLab MOOC

3.3 Application and Its Effect

The arrangement for NCSLab MOOC is to put online a chapter every Monday on *China University MOOC* until all of them are available online. After being put online for one month, over 500 nationwide students have chosen the MOOC, and the number has been increasing day by day. Fig. 6 shows the statistics of students who have chosen the MOOC during the one-month time slot (Users in a week of a preview release of the MOOC has also been included). It can be seen that quite a lot of students are interested in the remote and virtual experiments related MOOC. According to the recorded data in the NCSLab database, more and more students throughout China have registered and logged in NCSLab for online experimentation, which is a proof that MOOC can promote MOOL, and also MOOL can offer experimental services for the MOOC learning.

The MOOC can be used for student learning before their experimental assignments. The last three-month time slots user data from NCSLab database are analyzed in table 3. The data reveals that quite a lot of MOOC students registered in NCSLab (Note that before the MOOC was formally put online, it is announced a week in advance on the MOOC platform in the second month time slot). From their comments on the platform, the conclusion can also be drawn that NCSLab really attracts them.

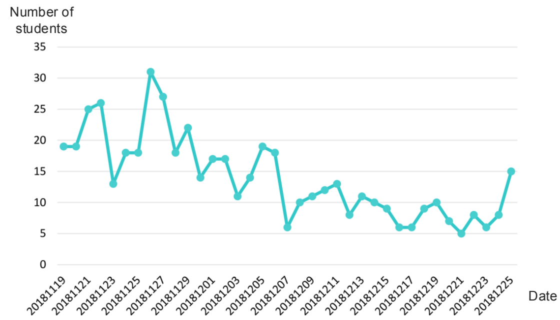

Fig. 6. Statistics of students who have chosen the MOOC during the one-month time slot

Table 3. NCSLab user data in the three-month time slot

Date (2018)	Number of Users	Number of institutions or universities
September 26 – October 25	18	3
October 26 – November 25	20	10
November 26 – December 25	35	19

By combining MOOC and MOOL, the advantages of MOOC and MOOL are incorporated, thus, both theoretical knowledge and equipment are shared through the Internet. Students can learn both theoretical knowledge and practice with experiment equipment online at any time from anywhere as long as they have Internet access.

3.4 Teaching Supports

MOOC provides a forum for *Q&A*, and other technical supports for NCSLab are available in case that students need any help. Through the forum, teacher-student interactions can be achieved.

For students, if they have any questions during their learning process, they can ask questions by leaving messages online, or by sending Emails to the teachers. If they encountered problems while conducting experiments, they can contact the administrator for help.

For teachers, in addition to their teaching videos, they can publish notifications, upload teaching materials, release chapter exercises and get involved in discussions to provide teaching supports. After they update something on the MOOC platform, an Email notification can be an option to reach the students.

Moreover, a dedicated teaching assistant has been assigned to offer support for both MOOC and MOOL, which can shorten the time that students get their help.

4. DISCUSSION

As stated in Waldrop (2013), MOOC alters the economics of education. MOOL also alters the economics of education in the form of classroom online demonstration and after-class experimentation. The combination of MOOC and MOOL will have an impact on education as well.

According to the regulation of *China University MOOC*, MOOCs are put online for different rounds in different semesters. As it is the first time of NCSLab MOOC to be online, thus, it is called the first round, the experience of which can work as a foundation for other rounds to provide better services for the students.

As is the case of MOOC which works as a means to promoting the MOOL NCSLab, MOOC also needs to be promoted, and can be promoted via the MOOL. Currently, NCSLab has published a notice on the NCSLab homepage, which provides information and direct access to the MOOC.

There are still issues remain to be addressed. Previously, privilege control of NCSLab sets a registered user as a normal user by default after their activation by Email, therefore, users can only view the homepage without the control privilege for test rigs. If students would like to conduct an experiment, they need to contact the NCSLab administrator for control. For the case of MOOC, extra workloads and waiting time may discourage students who spare their time for online learning. To address this issue, considering the open access feature, every registered and activated user has been granted to be an advanced user with 30 minutes' time slot for their experiments following a "*First Come First Served*" principle. If they are really interested in the experimentation, they can apply for more experiment time by simply sending an Email, which has been published as a notification on the MOOC platform recently.

Currently, the exercises account for 20 percent of the final score. However, the exercise bank is relatively small. To provide students with more helpful instructions and focusing them on learning, more exercise can be integrated to expand the exercise bank.

5. CONCLUSION

In this paper, a MOOC for the MOOL NCSLab has been designed and applied to promote control engineering education at Wuhan University. The design and detailed content of the MOOC are presented, in which the MOOL has been integrated. The MOOC has been put online on a national MOOC platform in China. Data show that over 500 students have selected the NCSLab MOOC in a one-month time slot. Analysis of the data from NCSLab database shows there is a substantial increase regarding the number of registered users as well as the number of users from different institutions or universities compared with the months without the application of the MOOC. It can be concluded that the combination of MOOC and MOOL has potential for promoting education, which can also provide potential solutions for other fields of engineering.

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