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A Multi-criteria Method for Improving the Assessment of Students' Laboratory Work Using Online Laboratory*

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Online laboratories have changed the way of assessing students' laboratory work (lab work). Traditionally, students' lab work is mainly assessed by their reports after the experiments, with their attendance considered as well. However, whether the students are actually engaged in experiments and how they perform their assignments are difficult to be traced individually, especially for the case of a large number of students. In this paper, a multi-criteria method for assessing students' lab work based on online laboratory is proposed. Different from the hands-on labs, the online labs are able to trace and store more students' activities automatically. Apart from the quality of the lab reports, the experimental data collected from the database of the online laboratory as well as the snapshots of experimental steps are also considered. Therefore, judging criteria of lab work assessment can be extended to a higher standard, improving the assessment of student learning with much more objectivity based on lab work related information rather than lab reports only. The paper takes Wuhan University (WHU) as a case study, where students in engineering are using Networked Control System Laboratory (NCSLab) as a tool to conduct experiments for their laboratory sessions. Generalized from the practical teaching, the new assessment method is proved to be useful to judge students' performance during the online experimentation.

Keywords: engagement; engineering education; lab work assessment; online laboratory

1. Introduction

Laboratory work (lab work) [1] is essential for offering opportunities to learners who try to put theoretical ideas into practice, especially in engineering education. It is superior to lectures and tutorials in enhancing manual skills, introducing the equipment and its applications, as well as developing inquiry skills [2, 3]. In addition, lab work can help consolidate knowledge while stimulating interest and enjoyment of learning.

Traditional laboratory benefits students by enhancing their laboratory skills and techniques, during which they are able to acquire a deeper understanding of their conceptual and theoretical knowledge from teachers and textbooks. However, conducting experiments in traditional physical laboratories are apparently impossible for the learners who are not in the lab. Moreover, 24/7 accessible physical laboratories are considerable luxury as space and equipment are costly and experimental staff out of hours is in short.

Thus, online laboratory [4] is widely welcomed since it was proposed for its great advantages such as 24/7 remotely accessibility, low-cost and space-saving quality, compared with traditional laboratory. As a new means of experimentation, online laboratory which contributes to the launching of experimental courses gradually finds its way in two different forms as remote laboratory [5, 6] and virtual laboratory [7, 8] with rapid development in the last two decades. From a pedagogical perspective, both of them provide opportunities for those who lack laboratory equipment and apparatus. At the same time, it allows them to repeat the experiments just as the way they like, without any pressure of laboratory reservation and time limitation.

Recent study has shown that online laboratory is becoming a great complement of traditional physical and hands-on laboratories without loss of any level of knowledge [9]. Thus, a number of experimental platforms are set up all over the world, which benefits the engineering fields such as power system [10], control engineering [6, 11], mechanical engineering [12] and industrial electronics applications [13].

2. Lab work assessment methods

The assessment of lab work has been carried out for decades. It is important for both students and teachers. For the students, it helps them to improve their laboratory skills, and for the teachers, the laboratory sessions could be improved according to the assessment. Research in [14] reviewed the three most widely used models for assessing lab

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work in electrical engineering education, including reports written during the lab in the notebook, reports written after the lab and reports after the lab with a practical exam. However, these models have limitations as they only provide inadequate assessment of the students who can copy the lab report with no laboratory activities involved at all. Later, the three-domain model, regarding cognitive, affective and psychomotor, is proposed in [14]. However, the application of this model requires that students carry out experiments under the supervision of the teacher. Lab work assessment in [15] focused on analysing the lab sheet in terms of its effectiveness, while students' engagement cannot be assured.

Besides, several other styles of assessing student lab skills including checklists, rating scales or the laboratory practical examination were reviewed in [16], requiring the teacher to observe and monitor students to carry out experiments in traditional labs. Other assessment methods of lab work such as a twofold model of effectiveness [17], a set of criteria including pre-lab, performance, lab report and final exam [18], and summative and formative assessment [19], were applied in lab work study. However, none of the studies is related to lab work with respect to online laboratory. Traditional lab work assessment practices seem inherently deficient and subjective, with possibilities of bias and unfairness [20].

Although a large number of online laboratories exist, most of them mainly focus on technical issues such as remotely accessibility or virtual experiments they can provide, while less attention has been paid to how online laboratory can help teachers to assess students' lab work, which could be another advantage for online laboratory.

In [20], a Bayesian network-based assessment tool was proposed, but it is limited in a virtual electronic laboratory environment with behavioral data collected and recorded. The virtual CVD laboratory [21] integrated assessment tools into the system to enable the instructor to view the students' experimental information, but it lacks the mechanism to guarantee that the experimenter is the corresponding student.

In this paper, a multi-criteria assessment method of students' lab work with respect to online laboratory is proposed. The proposed assessment method focuses on the lab work itself, which is the essence of the lab work. In contrast to traditional assessing methods, judging criteria of lab work in the proposed method is extended with more information brought in, making it easy for the teacher to distinguish whether the students have conducted the experiments or not and get his judgement with much more objectivity based on lab work related information.

Students in engineering major in Wuhan University (WHU) used the Networked Control System Laboratory (NCSLab), which is an online laboratory to fulfill their lab work assignment in the 2014–2015 academic year. NCSLab has been developed for over 10 years since 2006, both remote [22] and virtual [23, 24] experiments can be provided even if the experimental equipments are located in geographically diverse locations. The assessment method takes advantage of online laboratory with minimum subjectivity, different from traditional hands-on labs.

3. Experimental framework and preparations

The assessment of lab work is to benefit the students by motivating students to master laboratory skills and helping the teacher to keep improving the laboratory sessions. To acquire laboratory skills, engagement is the priority. In traditional physical laboratory, students finish their lab work mainly on site. Teachers would record their attendance either on a piece of paper or in a computer document, which is only effective with limited number of students. However, for the case of a large number of students, some students can just play truant or let others sign in for the absence. What's more, the lab report, which is the final proof of lab work, can also be copied from others.

All of these flaws occurred by the traditional laboratory cannot guarantee a good student engagement into their lab work, especially for the situation that limited teachers must cope with a large number of students, which is common in developing countries. In other words, without a proper assessment, the students cannot be fully motivated to the lab work.

Online laboratory is able to trace and store a large number of students' activities in the server database. This valuable information can be used to judge and verify whether students are actually engaged in experiments and how they perform their assignments, which are also important criteria for assessing students' lab work. Thus, the assessment of students' lab work can be carried out with a platform for online experimentation as well as a relevant experimental course.

3.1 Experimental platform-NCSLab

NCSLab is an online laboratory which provides both virtual and remote experiments. The architecture is illustrated in Fig. 1, which is a multi-tier architecture consisting of web browsers, central web server, regional experiment servers, device control units, and experimental devices. Test rigs integrated into the system are remotely accessible through web

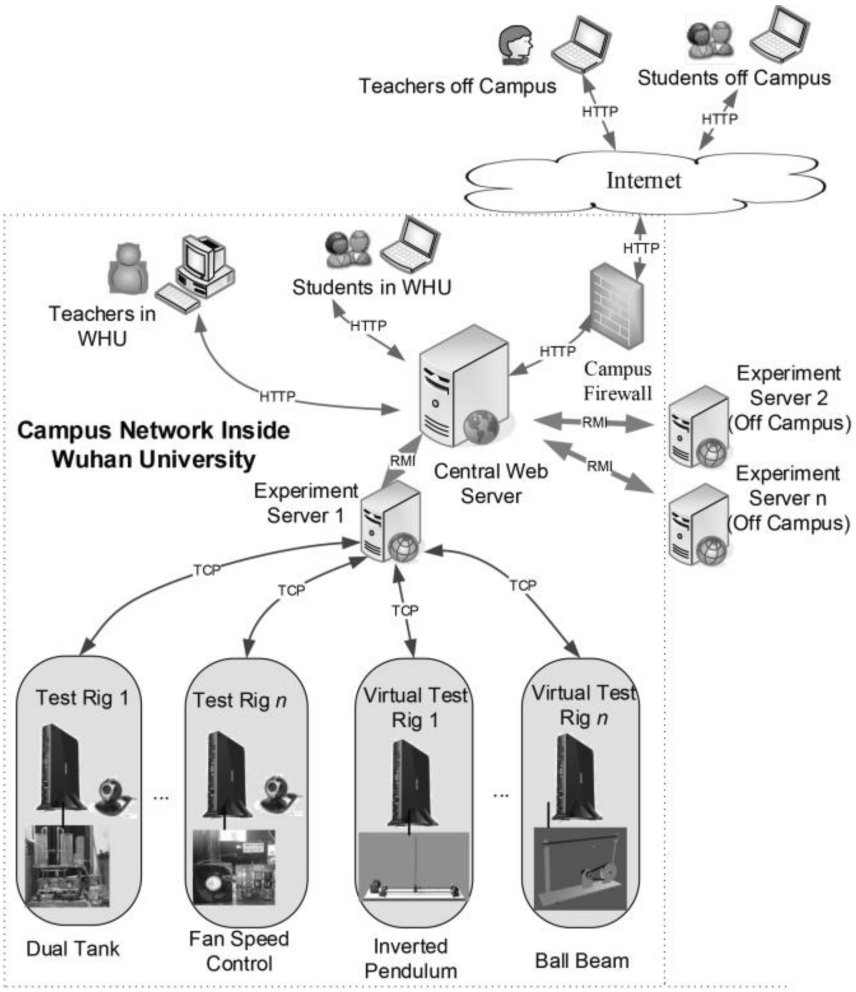

Fig. 1. Architecture of NCSLab deployment in Wuhan University.

browsers without any plug-ins due to the adoption of latest HTML5 [25, 26].

All the control algorithms in NCSLab are designed with the help of MATLAB/Simulink. The simulink block diagrams can be automatically converted into executable codes for control units. The students are encouraged to customize their own control algorithms. A web interface is reserved for them as they can upload their algorithms to NCSLab and also share them with others.

NCSLab also gives users the freedom to customize their own monitoring interface, in which they can decide which parameters to be tuned and which signals to be observed during the experiments by using various 2D widgets as well as 3D widget.

For now, NCSLab is aimed at control engineering. Difficult concepts in traditional teaching method can now be easily understood with the use of NCSLab. For example, conventionally, while learning Proportional—Integral—Derivative (PID) control, students are taught that integration is for reducing and eliminating the static errors. For some students, it is difficult to grasp the actual physical meanings behind the mathematical description. Nevertheless, with online laboratory integrated into the class, students are able to comprehend the functionality of integration through an existing test rig. Fig. 2 illustrates the PI control conducted on a fan speed control system. Once the integration is switched off, it can be seen that there is a big static error as the set point is changed from 10 to 50. However, when the parameter for the integration is set to 0.1, the static error is quickly eliminated by the control algorithm.

3.2 Course description and participants

In WHU, lab work is integrated in the curriculum to prepare students for practical experience. In this paper, 96 undergraduate students in the second year in the Department of Power Engineering and 77 students in the third year from the Department of Automation are required to finish the experimental courses of different subjects using the NCSLab platform in place of MATLAB simulation in the

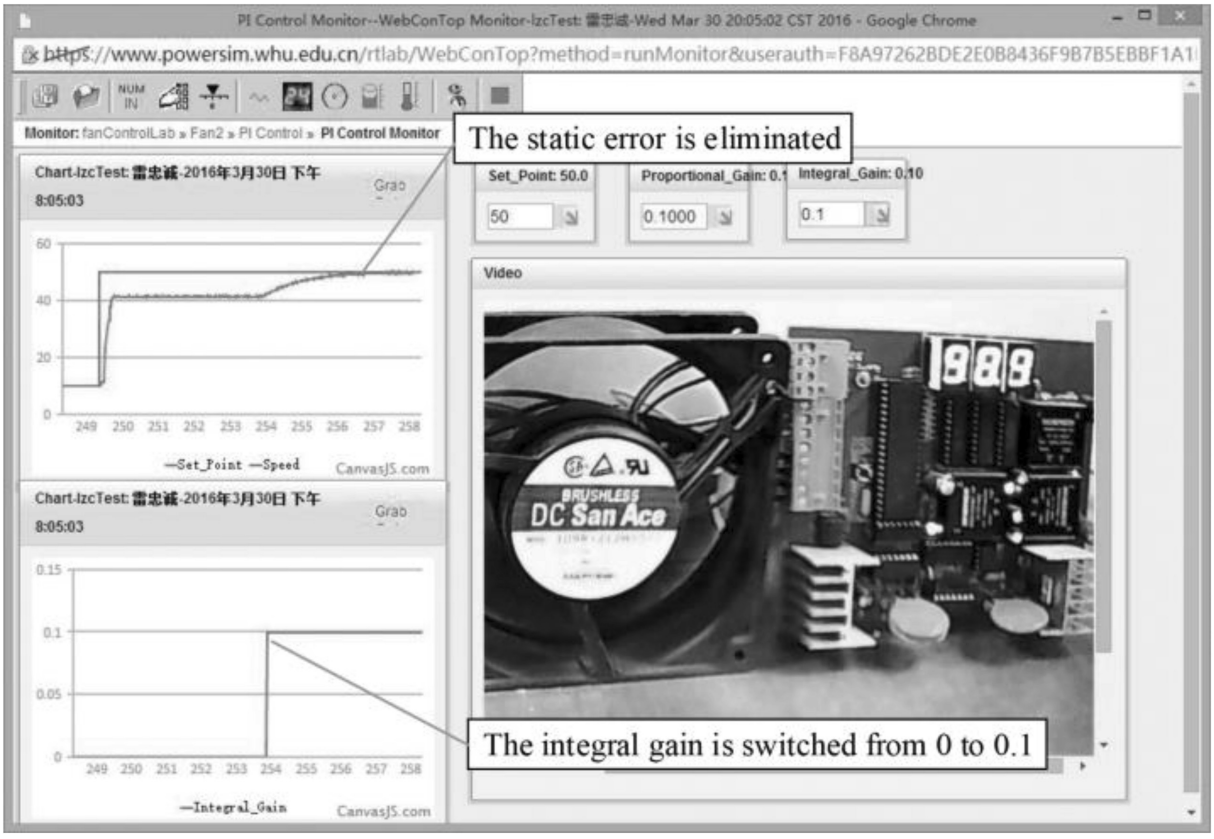

Fig. 2. Online demonstration on a Fan Speed Control System when teaching the effect of integration for PI Control.

2014–2015 Spring semester. *Control System Simulation and Computer Aided Design* is an optional course for students in automation major, and *Classic Control Theory* is a general course taken by different disciplines either as a compulsory or optional course in School of Power and Mechanical Engineering, Wuhan University.

Students in the second year carried out two remote experiments about fan speed control system, which is mainly related to parameter tuning of PID control, referred as Experiment 1 and 2 in Table 1. Students in the third year take the course of *Control System Simulation and Computer Aided Design* as a consecutive course for automation major of *Classic Control Theory* which is a compulsory course in their second year. They are required to perform another three more complicated experiments which include control algorithm design using simulink block diagrams, MATLAB S-function and C MEX S-function, referred as Experiments 1–5 in Table 1.

3.3 Preparations for the online experimentation

To get students ready for the online experiments, some preparations are supposed to be done by the teachers. Students are invited to register in the NCSLab system at http://www.powersim.whu.edu.cn/ncslab. They are required to complete the experimental tasks before a deadline and then submit a lab report containing snapshots of their experimental steps and results.

To make the students familiar with the system as well as the experiment itself, especially for the beginners, normally the teachers who are physically present at the classroom perform a class demonstration before the experimental tasks are assigned to students. Besides, an online discussion group for each class is created using Tencent QQ which is one

Table 1. Assignments of experiment

Experiment	Content
1	Learn to use the remote experimental platform to conduct experiments on classic control theory
2	Closed loop control experimentation on fan speed control system
3	Use PI algorithms to conduct experiments on fan speed control system
4	Write s-function of PI control algorithms with anti-windup protection
5	Write c-mex s-function to remotely control the fan speed control system

Table 2. The assessment method of students' lab work

Criterion	Description	Purpose	Weight
Registration records	Register or not	Fail if not satisfied	N/A
Login time	When students login and carry out experiments	Whether the students miss the deadline	5%
Experiment time	How much time students spend to finish the tasks	Proficiency	10%
Snapshot information	Whether the major steps are right	Engagement	20%
Image capture of the experimenter	Whether the experimenter is the corresponding student	Fail if not satisfied	N/A
Configuration	What configuration students make	Experimental skill level	15%
Lab report	Whether lab reports are handed in and how are the lab reports	Attitude and achievement	50%

of the most popular instant messaging software in China. Students are allowed to feel free to contact the teacher either by email or message whenever they have problems for the experiments. Also, a research student related to NCSLab project is also in the discussion group as a teaching assistant and is available to answer questions and address possible issues raised by the students.

What's more, the experimental instructions are handed out in a soft copy via the online discussion group. No matter tough and fresh as the assignment might be for students, all of efforts mentioned above are aimed to offer scaffolds [27] trying to make it easier for them regarding online experimentation.

4. Methodology

4.1 Assessment method

Conventionally, only lab work resulting in a lab report was assessed. A better scenario appears when the attendance of students is considered. Issues such as the engagement of the students in the laboratory activities and their performance are supposed to be addressed by the teacher.

NCSLab is able to provide more information for assessing students' lab work. It can be seen from Table 2 that seven criteria are chosen to assess students' lab work to the full extend. Thus, their final scores are determined not only by participation but also by their performance.

The information corresponding to each adopted criterion is either traceable in the server database or in the reports handed in by the students. The login time indicates that whether a student performs the experiment before the deadline or not, and the experiment time reflects the proficiency level of students. If more than half of students spend longer time than that of the teacher supposed, the teacher can interact with the students to offer support, which is aimed at improving student learning.

Table 3 lists the collected information in the web page, including experiment time, user name and image capture of the experimenter at Web side camera. All of the information is in the snapshot of the monitoring interface and is used for the comparison with a specific target which uniquely corresponds to each student. Generally, these efforts are made to motivate students to be engaged in experimental activities.

Table 3. Web page information

Info	Target
Experiment time	Recording time in database
User name	Name on the lab report
Web side camera	Submitted photo

Figure 3 shows an example of a well-configured monitoring interface with several 2D widgets including numeric inputs for tuning parameters, LED boards for displays signals, cylinder gauge, real-time video of the test rig and the experimenter, real-time curve chart and 3D model of the test rig. Besides the experimental results, user name and experiment time are shown in the head of the real-time chart. The image of the experimenter can be captured if the webcam is permitted by the student in the web browser.

Students' experimental configuration can be diverse as NCSLab offers the flexibility for them to customize their own monitoring interface. A proper configuration is supposed to include at least the basic widgets such as parameter tuning input boxes for proportion, signal displaying chart for the results, allowing the teacher to judge whether the results obtained by students are correct. For instance, in Fig. 2, a suitable interface should consist of parameter tuning widgets for set point, proportion and integration, and the real-time chart for the speed and its set point (two signals in one chart) as well as the video for the remote fan speed control system. While the chart in the lower left corner of Fig. 2 which depicts the change for integration, visually showing the time for the switch correspond-

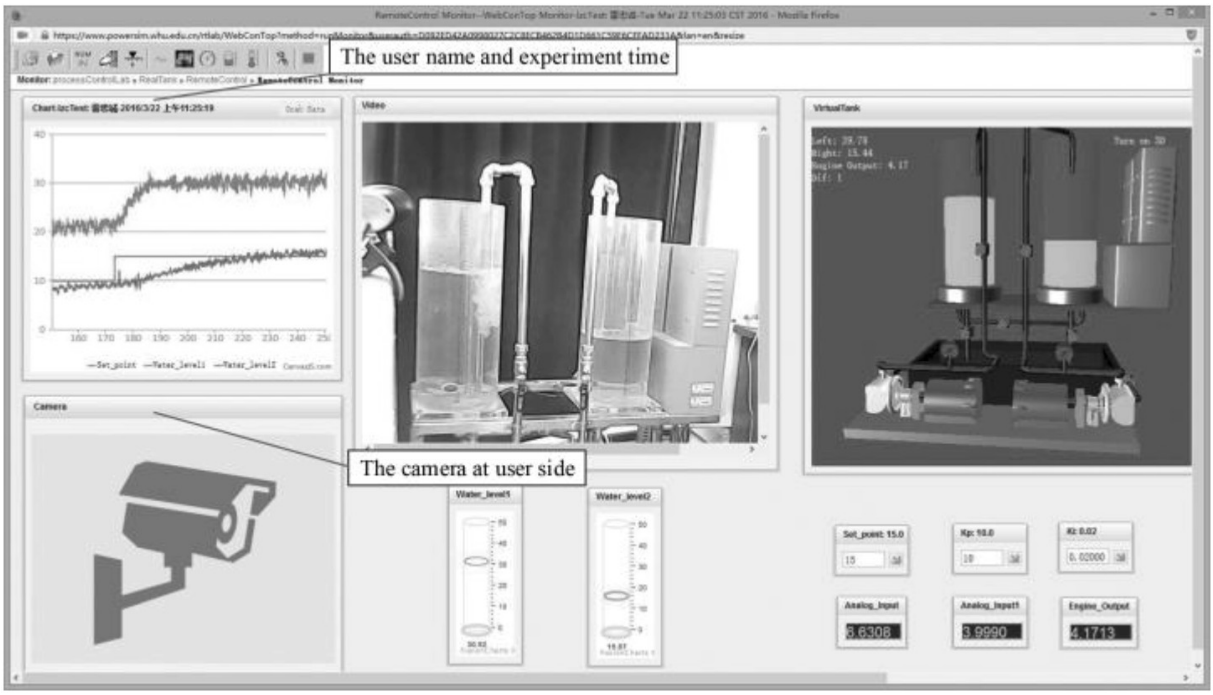

Fig. 3. Monitoring interface of dual tank system in NCSLab.

ing to the upper chart. If a student adds this chart widget for integration in his configuration, it can be interpreted that he knows well of the effect. Hereby, the assessment of student learning is improved using configuration as a criterion.

A list of the items and their weight in the final scores is given in Table 2, which shows the description of every assessment criterion in details in the second column and also the purpose from the perspective of experiment learning in the third column. The final scores are calculated by totaling all percentage earned. Students with less than 60 points fail and must retake the course in the next academic year. Particularly, the student would fail the exam if no registration record is found or if the image of the experimenter does not match the specific student. Fig. 4 depicts the complete process of the lab work assessment regarding online experimentation.

After checking through all the lab work, the teacher is able to find out flaws on the existing laboratory sessions design. Accordingly, efforts could be made to modify the laboratory sessions such as improving the experimental instructions, carrying out more demonstrations before assigning experimental tasks.

4.2 Deterrent for plagiarism

Traditional inadequate assessment of the students' lab work, which is actually the assessment of lab report, overemphasizes written materials. Even worse, students can copy the results, while the teacher cannot easily identify which are the original ones, which could impact the laboratory session and the student learning. Nevertheless, with the use of online laboratory, various criteria can be adopted as deterrents for plagiarism [28, 29].

Registration records and image capture of the experimenter are two effective criteria of deterrent in NCSLab. [30] explores the influence of facial verification software on student academic performance in online learning environments, which is intended to achieve the same effect as the image capture of the experimenter in this paper. For the students, as they know that the teacher is able to find out who is registered or not in an easy way with the database and it is also possible for the teacher to figure out whether the image capture of the experimenter matches the holder of the report, plagiarism activities are potentially prevented.

Efforts are under way to develop a program for automatic anti-plagiarism. A new assessment criterion with respect to carrying out experiments with algorithms individually customized by students is going to be established for further assessment. By running a duplicate checking program in the server database, it becomes easy to know the information of the algorithms such as their similarity and uploading time. Thus, the teacher can judge whether an algorithm is genuinely designed by the student himself or not, deterring the students' attempts to submit a copied work.

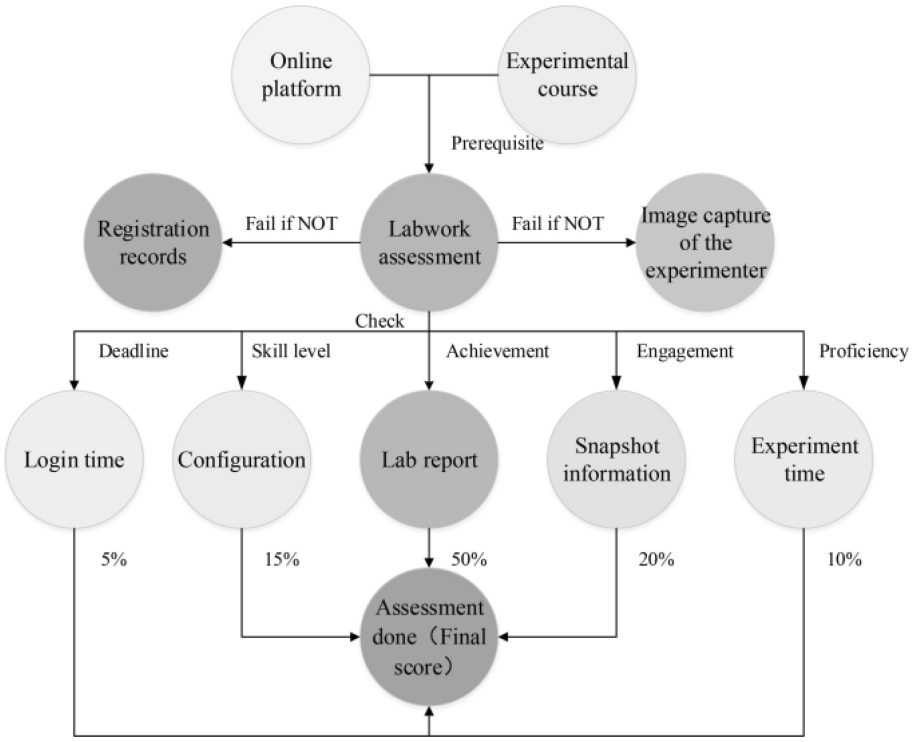

Fig. 4. The process of lab work assessment regarding online experimentation.

5. Online experimentation in Wuhan University

With the development of NCSLab, the online experimentation has become an essential part of the course and is of great importance for students to obtain practical skills in School of Power and Mechanical Engineering, Wuhan University.

The assessment of students' lab work in WHU is carried out in accordance with the method proposed. As shown in Table 2, the proposed assessment method mainly takes seven types of information into consideration. Thus, final scores of lab work would be more reasonable and objective.

Three assessment criteria are chosen to illustrate how the proposed method is actually applied in lab work assessment regarding NCSLab.

5.1 Login time

The login time can be traced from the server database. According to the database, 96 students in Department of Power Engineering and 77 in Department of Automation registered and carried out the experiments in different period of time during the given time, which is consistent with the number of students mentioned in Section III. B.

The given time is divided into several periods of time to explore how students tackle the assigned experimental tasks. The analysis result shows that few students carried out the experiment immediately as it was assigned, even during the first half of the given time, which is the same as students in the second year. One fifth of them even missed the deadline. The surprising but explainable phenomenon that half of the students performed the experiments close to deadline is known as procrastination, which is common for people to put off impending tasks to a later time, especially among the students. This kind of behavior led to a long line of waiting as most students did not perform experiments until deadline, though the teacher had noticed them even before the experiments started.

The login time accounts for 5 percent of the final score as shown in Table 2. The aim of this assessment criterion is to urge students to schedule their time and complete their laboratory assignments on time according to the curriculum as well as summarizing their results and findings in time to enhance their conceptual knowledge learning. From the assessment of the lab reports, it appears that students who login the system after the deadline performed worse as they had bad attitudes to get the credit without laboratory activities involved in at all. Therefore, those who login the system after the deadline (result in late lab report) were taken off five points as addressed before assigning the experimental tasks.

5.2 Image capture of the experimenter

The image capture is implemented by using the camera API of HTML5 in the web browser. This functionality is integrated into the toolbar of the

monitoring interface as a widget for the user side, allowing students who use the mainstream web browsers that support HTML5 to capture the images of themselves. Students are requested to add this widget into their monitoring interface for the teacher to check.

From Fig. 3, it can be seen that the camera at the user side is added to the monitoring interface. With this assessment method, students' engagement can be better guaranteed, which is confirmed by the lab report assessment. The teacher identified those copied reports easily as the students who did not perform the experiment had no image capture to attach. As the students understood they could get caught, fewer similar lab reports were found.

5.3 Lab report assessment

The lab report is a presentation of a student's understanding of experimentation and experimental results, which is the most important part that reflects the final achievement of the lab work. Thus, the assessment of lab report is vital and occupies 50 percent of the final score. Mainly four aspects are considered as follows.

1. The basic structure contains the steps of performing the experiment in detail. Generally, principles, aims, procedures and cautions should be considered.
2. The snapshot information, as shown in Section IV, includes the experiment time, the user name and the image capture of the experimenter. Snapshots of every step bring the reports to a full integration for the teacher to judge whether the experiment was conducted in a right way. The snapshot information shows the attitude and detailed understanding of the students. In the online lab, students have plenty of chances to repeat every detail of the experiments in order to get the perfect snapshot they think.
3. The questions and discussions are concerned with the experiment that students are supposed to figure out.
4. Experimental results are supposed to be completed in figures as well as corresponding explanations, as required by the teachers.

When assessing the lab reports, students who stated their assignments with a clear and comprehensive manner can get higher points. If students used PS tools to modify other students' username to match their name, it would result in a visible recognition by the teacher with the adoption of the proposed assessment method.

6. Discussion

The emergence of online laboratory goes beyond the limitation of traditional hands-on laboratories and provide more opportunities and experiment time for students. It also benefits the teachers for the assessment of lab work as more information about the students' performance can be traced and recorded by the online system. It helps teachers to make more objective judgement and take more aspects into account compared with the conventional assessment methods. What's more, given the fact that abundant online laboratories are set up all over the world, the proposed assessment method can be potentially applied to other online laboratory platform to offer a better lab work assessment as they are informative and helpful to the teacher when the lab work is discrete and easy to observe, benefiting both the students for better laboratory skill and the teacher for better laboratory sessions.

One possible issue remains to be discussed is how much additional work needs to be done by the teachers. The workload could be heavier as more aspects have to be taken into account to assess lab work, thus, more efforts are supposed to be devoted to the procedure. However, this is solvable with the application of new technologies. As most of the current time-consuming work is on the searching of the database, once the judging criteria are finalized, the automatic-processing computer program could be designed to generalize all the need information in a piece of paper for later assessment. In addition, the anti-plagiarism program is able to detect copied control algorithms uploaded by the students.

There is still work to do, to guarantee a better student engagement of lab work in the future. Firstly, from the perspective of online laboratory developers and teachers, the experiment interface and the experiment itself can be made more interesting to attract and motivate students. Secondly, more experimental courses and participants are expected to be explored. What's more, questionnaires about the online laboratory and also the design of the experiment can be handed out so that first-hand data can be collected and used for the improvement of lab work.

7. Conclusion

In this paper, a multi-criteria assessment method of lab work based on online laboratory is proposed. The experimental framework and methodology are presented. Students participated in online experimentation supported by NCSLab are assessed from full aspects with much more objectivity. From the assessment, it can be concluded that the experiment time is longer, and the overall score has been improved. Phenomenon of copying, for instance, monitoring configuration processed with image

processing software to match their own information, has been recognized. And students had to pay more attention to the lab work compared with before.

Students' engagement and performance of the experimentation are verified and well judged as the teacher is able to watch the process of students' experiments with the application of the proposed assessment method. Accordingly, the teacher can improve the laboratory sessions from the assessment of the lab work. Thus, the assessment of students' lab work is improved. It explores an extension of online laboratory functionality from providing online experiments to lab work assessment, which would enhance the laboratory teaching and motivate students to develop their experimental skills.

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