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Low production cost virtual modelling and control laboratories for chemical engineering students

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Abstract: This paper gives a brief review of work on virtual and remote laboratories along with a critique of their strengths and weaknesses. This is used as a motivation for a proposed method for producing virtual laboratories which, while relatively crude in comparison with professional alternatives, are much cheaper and faster to produce and thus can be created using the skill set and time of normal academics. Some examples and the coding processes are demonstrated.

Keywords: Virtual laboratories, staff efficiency, student engagement, independent learning.

1. INTRODUCTION

For the sake of brevity, this paper will assume the high value of laboratory activities within a chemical engineering education and move immediately to consideration of how this might be delivered. It is well recognised that the infrastructure costs (space, equipment and technical support) combined with student timetabling challenges (that is ensuring timing close to corresponding lectures) are some of the reasons why, in practice, engineering undergraduates have lower exposure to hardware than would be desirable. As a consequence, Universities (e.g. Abdulwahed 2010, Qiao et al. 2012, Rossiter et al. 2011) have sought to improve student access to authentic activities by introducing pseudo laboratory activities whereby students interact with a realistic simulator or even with real hardware via a web interface. Moreover, a further advantage of software/computer based activities is that they enable students more freedom for independent learning activities.

1.1 Background on remote and virtual laboratories

The focus of this paper will be on so called virtual laboratories, that is laboratories which are based on simulations, perhaps of high fidelity process models, rather than on hardware. The focus on virtual laboratories as opposed to say remote laboratories (RL) (Dormido et al 2012) is for a few simple reasons:

- Remote laboratories are known to be costly and time consuming to produce and maintain and moreover require staff with significant expertise in many areas such as database use and web scripting which are outside their normal knowledge (Chen et al. 2010, Vargas et al. 2011). Most departments do not have the expertise or resource to support this activity effectively.
- Remote laboratories have limited accessibility in practice due to the queueing required by students combined with the possibly slow time constants of chemical processes. This mitigates against the intended benefits of 24/7 accessibility for students, especially with large classes.

Nevertheless, the design of an accessible virtual laboratory (VL) is fraught with equally many challenges and in particular the fact that web accessibility requires significant software skills from the author, in addition of course to understanding and implementing any pedagogical requirements. Some of the examples in the literature such as (Cameron 2009, Goodwin et al 2011) are excellent virtual environments on which to study chemical engineering, but the creation of such artefacts is not achievable for most academics indeed the authors of those environments assumed that departments would pay a substantial annual license fee for students to access their simulators. Even what might be considered an accessible (essentially free) web based system and well used software environment (Easy Java Simulation (EJS)) is non trivial to code accept for elementary scenarios (de la Torre 2013, Fabregas 2011, Perez et al. 2011, Guzman 2006).

1.2 Paper motivation and ethos

It is well accepted that high quality virtual/remote laboratory activities are a significant enhancement to the student learning environment. One obvious and perhaps less well publicised use is for laboratory preparation and post activities (e.g Abdulwahed 2010, Rossiter et al. 2014) which reinforce key learning outcomes because the environment is an effective emulator (Memoli 2011) of the real hardware set up in the laboratory.

- Students can use RL/VL in order to anticipate the activities and concepts they will encounter with the hardware and thus to support preparation of key computations, notes, algorithms and concepts they enable them to make the most effective use of their time on the equipment.
- After the hardware laboratory, students can use the RL/VL to test any hypothesis not completed success-

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fully, forgotten or recognised during the write up and reflection phase.

Consequently, this paper takes the motivation for RL/VL as a given and instead focuses on a different issue. Specifically, this paper takes the following premise:

(1) Most academic staff do not have the time, support or departmental infrastructure to develop robust web accessible remote or virtual laboratories.
(2) Where funding is available and there is a tight synergy with the course learning outcomes, departments may choose to purchase licenses for commercial simulators (indeed the authors department used the Goodwin 2010 resource for a few years).
(3) In practice, the bespoke nature of each departments course/module design and learning outcomes mean that the requirements for laboratory activities are rarely met closely by off the shelf resources and thus there is a need to do some in-house development.

Herein lies a major challenge. Academic staff may wish to develop RL/VL activities to support student engagement and independent learning, but they lack the expertise or support required to produce a high quality and fully web accessible resource. Consequently an alternative solution is required.

The author believes in pragmatic solutions, that is, better a simple solution that can be implemented tomorrow than a perfect solution in 2-3 years (if ever). Moreover, simple and cheap solutions often have the advantages of being equally cheap and easy to modify should the departmental requirements change whereas expensive resources are often equally expensive and difficult to modify. The reality of most student learning, lectures, tutorial classes and indeed real industrial processes are that they are not manicured environments. Rather lecturers often mumble, make mistakes in lectures and correct themselves (or not), write illegibly and so forth, and despite all this students may still comment that the lecture course was well presented, clear, enjoyable, etc. In summary, a VL/RL does not need to be coded and presented to commercial standards in order to be an effective learning tool.

1.3 Proposal for virtual laboratory development

In summary, this paper proposes a pragmatic approach to virtual laboratory development, that is an approach with a typical academic could achieve with relatively little coding expertise and, more importantly, relatively little time. The sacrifice of being able to produce learning resources quickly is a reduction in accessibility, that is the resources may no longer be web accessible. However, this need not be an impediment in that the real requirement for accessibility is that the students can access and use the resources 24/7, that is, as and when they need too; being on the web is rather secondary and could even be an impediment where wireless or broadband is unreliable. The author favours the use of MATLAB software for the development of VLs for 3 major reasons.

(1) Within his University (and indeed many Universities) there is a site license so students can guarantee access to the software and indeed get a version for their own laptops should they prefer.
(2) Students can easily be provided with the MATLAB source code and thus as many students as you like can use the VL simultaneously, asynchronously or indeed however they wish. The only impediment to accessibility is access to a suitable computer and the assumption that the student has downloaded the relevant files.
(3) MATLAB is easy to code and thus one can produce an effective VL using the GUI environment in about half a day with minimal expertise.

This paper will make 2 brief contributions: first it will demonstrate some of the VL the author has produced for chemical engineers to support learning of modelling and control and second it will give an introduction to the coding requirements in the hope that readers will be reassured that this is indeed a skill they could easily and quickly acquire.

2. EXAMPLES OF MATLAB BASED VIRTUAL LABORATORIES

This section will illustrate 4 examples of virtual laboratories that have been produced for chemical engineering students to help them relate their module in modelling and control to real scenarios and also to reinforce key concepts. Currently the author embeds the use of these into a quiz assessment to ensure students make use of them, but a long term plan when hardware becomes available (a new teaching building is nearly complete), is to make a closer link with a real laboratory using a tri-lab design (Abdulwahed 2010).

2.1 Dynamics and GUI for a mixing tank

A simple mixing tank can be modelled by an equation of the following form:

$$\frac{V}{F}\frac{dC_A}{dt} + C_A = C_{A0} \tag{1}$$

where V is the tank volume, F the flow rate through the tank, C_A the concentration coming out of the tank and C_{A0} the concentration of the inflow. A typical set of learning outcomes are for students to understand the impact on behaviours of changes in any of the parameters (V, F) and the input (input flow concentration).

The remainder of this section describes the GUI created by the author for this scenario. A short video demonstrating how to run and use this file is available on this link [http://controleducation.group.shef.ac.uk/matlabguis.html].

A screen dump of the VL (or GUI interface) is shown in figure 1. In this case the student has used 3 different values for input flow from which it is clear that the time constant, but not the gain, depends upon the input flow. It is also clear that asymptotically, the output concentration matches the input concentration.

- The GUI will overlay lines each time the push to update button is selected. Hence students should plan which variants of parameters they wish to overlay before beginning.
- Students can change 4 different values and thus explore how each of these affects the dynamics.