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Parametric virtual laboratory development: A hydropower case study with student perspectives

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ABSTRACT

In order to take advantage of trends such as genetic-design students need to be familiar, and comfortable, with the concept of parametric computer models and how their parameters relate to physical-forms. Virtual learning software can aid in creating that understanding and help support studies at all undergraduate levels in engineering design disciplines. As an example, hydropower rotors are complex and largely rely on computational analysis of geometries for single rotor types. That problem can be significantly overcome using a parametric algorithm capable of creating an almost-infinite variety of computer models. Therefore, this paper investigates the shared parametric properties of common crossflow hydropower rotor geometries, resulting in a generic model that is then used to illustrate application in real-time interactive virtual learning software capable of producing accurate stereoscopic images and stereolithography files for 3D printing, as well as linking to constructive solid geometry software for slower, but more detailed, analysis. A pilot survey of student attitudes to the virtual learning prototype and resulting geometries is then discussed, illustrating the potential for 3D graphics as an effective addition to virtual learning of parametric design methods, and giving initial direction for future work.

1. Introduction

1.1. Background

Computers have significant potential in supporting environmental sustainability. For instance, problems with energy security and climate change dictate a need to move from reliance on fossil fuels to adoption of increasing amounts of clean and reliable energy [20]. Marine and river currents are a major energy resource that can be exploited over the long term. For example, the UK is estimated to have tidal stream resources as significant as 36 TWh/year, although this has been underutilized at approximately 2% of that figure [7]. Extraction of electricity from marine currents on a commercial scale is therefore an important developing sector, it being reported in 2002 as an 'emerging market' [9], the world's first tidal stream power station having come online only as recently as 2008 [8].

However, the designers of the future, who will make the largest inroads into sustainable electricity generation, are the students of today. In order to develop skills suitable for efficient three-dimensional design, and trends such as genetic-algorithms for design optimization, those future designers will require a good understanding of parametric design (e.g. using measurements and rules to define geometries) and how it relates to subsequent physical-models. In terms of hydropower design, a good example is the rotor, as this is the element responsible for conversion of kinetic energy into rotational mechanical energy to drive generators. Rotor design using traditional Computer-Aided Design (CAD) techniques is complex and time-consuming, limiting the number of designs that can be created and analysed. However, parametric computer models could provide a very wide range of virtual-rotors for use in visualization and analysis.

Therefore, design of commonly used hydropower rotors has been taken as an example of parametric model construction suitable for development of virtual laboratories with real-time interactive geometry creation, and modification 'on-the-fly', by engineering students. That software is based on a parametric study of crossflow hydropower rotors, in order that the virtual laboratory be able to demonstrate to students both commonly used versions and a plethora of hybrid types. As described in Section 3, the software allows immediate feedback on adjustment of key parameters, as well as allowing integration with constructive solid geometry and computer aided design packages. It also includes use of the digital model to create stereolithography files for rapid prototyping on 3D printers, for subsequent physical testing and analysis.

Following from an introduction to virtual/distance learning and hydropower rotors, this paper includes the in-depth study of rotor

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parametric features required for development of the software prototypes, in Section 2. The parametric study was central in allowing for creation of teaching material that fully illustrates the nature of the parameters being visualized, which will be especially important for distance learning. Then, testing of the resulting parametric model is briefly demonstrated in constructive solid geometry, using the Adaptive-Modeling Language (AML) used by many engineering students at Birmingham City University, in Section 3. Section 4 then describes Java-based code designed to provide real-time interaction between students and rotor parametric-models, including discussing its integration with AML, production of stereoscopic outputs and rapid prototyping through 3D printing. Finally, in Section 5, student perspectives on the prototype virtual learning system will be demonstrated though a pilot survey of first year undergraduate students at Birmingham City University. The student perspectives then allow for future work on virtual laboratory software that respects their needs and design-requirements. Therefore, the paper can be considered to provide a route-map of the complete process undertaken in developing prototype virtual learning software for use in undergraduate study, on and off campus.

1.2. Aims, objectives and rationale

The aim of this research was to explore student perspectives on the potential for use of parametric graphics, in virtual learning software being developed for undergraduate engineering students. It therefore had a number of objectives, as detailed in Table 1, the basis behind which being detailed in Section 1.3. These objectives did not seek to replace existing teaching methods, but rather extend on them to provide new resources (i.e. virtual laboratories) that can be used by teachers and students alike, and that integrate with CAD software widely used by engineering students (including Constructive Solid Geometry – CSG – systems). That allows for reinforcement of learning following lectures and, crucially, allows for additional practical learning off-campus. In developing the objectives it was also speculated that modern students may have a preference toward virtual learning systems, although not necessarily in complete-substitution for traditional teaching. The intended concept can therefore be illustrated by Fig. 1, where the lower part represents traditional learning, and the upper part illustrates extension to include virtual laboratory use.

Hydropower rotor design provided a good opportunity to investigate the aim and objectives because it combines design techniques familiar to engineering students, 3D geometry creation and can be approached from a parametric perspective. Also, no study has been found by the authors showing parametric relationships between a wide range of rotor types: most studies show geometries for one main type and so ignore variations resulting in hybrid rotors that could be useful to, for example, genetic algorithm applications in design. Therefore, it allows students to learn to abstract from standard geometries, and then understand how the root of many geometries can be related, thereby encouraging creative thinking. This adds significantly to the potential for creativity and exploration on the part of students, as it is not easy to get bored after learning a handful of standard designs. It also allows them to learn that very different geometries can be mathematically related, reducing the potential for their design-mindsets to become compartmentalized.

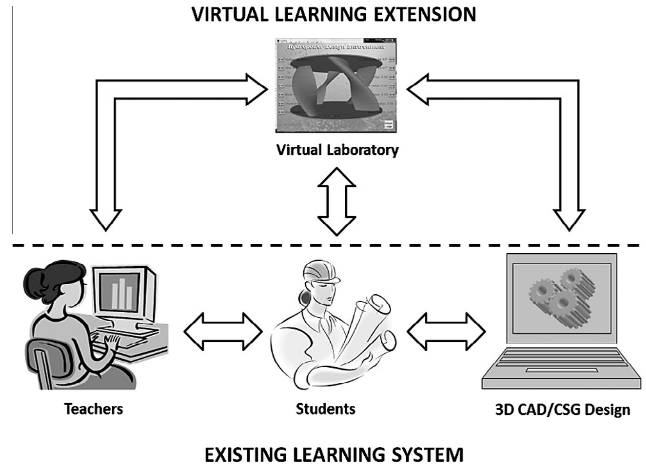

Fig. 1. Context of the virtual laboratory in teaching.

1.3. Virtual and distance learning

Virtual laboratories are becoming familiar components of many higher education courses, as well as being an important aspect of many distance learning courses. The visual thinking they allow has been described as '*crucial to the future of learning*' in science and engineering [25] and the 3D visualizations they can employ allow for much improved student-comprehension, particularly for complicated objects [37]. It has also been shown that virtual learning in engineering can be just as effective as learning in a physical setting [14], including in the work of Okutsu et al. [27] who found close correlation in performance between students engaging in virtual and real-world learning, and considered virtual reality an '*untapped potential*' in early-undergraduate and distance learning. Virtual laboratories are now widely used in computer science teaching, such as the work of Petropoulakis and Stephen [30], who developed web-enabled MatLab for collaborative use. Similarly, Pan et al. [29] provided electronic tutorials on 2D and 3D computer graphics programming. They aimed to provide learning of computer algorithms in a network-enabled collaborative environment. However, in reporting their work on a virtual mechatronics and robotics laboratory, Potkonjak et al. [31] describe distance- and e-learning in technical disciplines as far behind the state-of-play for other areas of implementation. Also, in a ten year review of educational virtual environments, Mikropoulos and Natsis [26] concluded that little information is available on knowledge-retention in those environments and recommended longitudinal studies and further research.

However, there are notable instances of application of virtual learning in physical-engineering subjects. For instance, Budhu [4] developed a virtual laboratory for geotechnical testing, highlighting that it could allow students to develop practical skills while aiding retention of learning knowledge, as well as facilitating exploration of '*what-if situations*' without needing access to a

Table 1
Objectives of the research.

Objective	Description
1	To explore the extent to which early-year undergraduate students had previously been exposed to virtual laboratory systems
2	To explore student perspectives on the use of 3D parametric graphics in virtual laboratory systems
3	To explore student perspectives on the need to integrate physical models (e.g. 3D printed parts) into 3D graphics based virtual laboratories