

Integrating Real Equipment into Virtual Worlds

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BACKGROUND

Remote Laboratories have been shown to provide a number of benefits to engineering educators and students (Abdulwahed, 2009; Aziz, Esche, & Chassapis, 2009; Cooper & Ferreira, 2009). The computer-mediated interface of remote laboratories also presents the opportunity for educators to manipulate the presentation of the laboratory in order to provide additional information and context to students conducting the laboratories. There are a number of learning affordances of virtual worlds that have been identified (Chapman & Stone, 2011; Dalgarno & Lee, 2010; Oloruntegbe & Alam, 2010) that would allow educators to convey this supplemental information to students. Virtual worlds provide the ability to add domain context to a laboratory activity with explicit illustrative examples of how the learning outcomes of the laboratory could be applied in the real world. In order to achieve these enhanced interfaces however, it is essential that the real laboratory equipment can be integrated into the virtual world without compromising students' ability to complete the laboratory or their awareness of the reality of the laboratory equipment they are using (Lindsay, Murray, Liu, Lowe, & Bright, 2009).

PURPOSE

In this paper we consider how well existing different virtual world systems support the representation of, and interactions with, physical equipment and associated contexts. This paper investigates this question in order to understand what the implications are for implementations of remote laboratories in virtual worlds.

DESIGN/METHOD

The investigation was conducted by analysing the literature describing current implementations of real equipment integration into virtual worlds. Additionally two virtual worlds (Second Life and Open Wonderland) were analysed in detail with respect to the extent to which remote laboratory integration is supported. The specific needs of remote laboratories were determined in terms of the representation within the virtual world and the ability to support user interaction with that representation in a way that could maintain a suitable connection with the real physical equipment. The potential and problems associated with integrating real equipment into the currently available virtual world environments was then analysed in terms of the extent to which these specific needs were supported. This included assessing the strengths and weaknesses of the virtual worlds, comparing existing implementations in terms of the identified requirements, and the analysing the factors that affect how easily labs could be developed and integrated into the specific virtual world.

RESULTS

The investigation has identified the potential of integrating real equipment into virtual worlds with the aim of supporting learning in remote laboratories by adding contextual information that is not normally available in a traditional laboratory. Specifically, Open Wonderland and Second Life have been shown in existing applications to have the potential to meet the requirements for integrating with remote laboratory equipment and the limitations and potential of each of these are identified.

CONCLUSIONS

The results show that for the authors' future research aims, Open Wonderland has the potential to provide a cost effective, extendable solution that can be implemented to facilitate the provision of context to students in such a way that the reality of the equipment they are using, or their ability to complete the laboratory, is not likely to be compromised.

KEYWORDS

Virtual worlds, remote laboratories.

Introduction

Remote Laboratories have been shown to provide a number of benefits (both logistical and pedagogic) to engineering educators and students (Abdulwahed, 2009; Aziz et al., 2009; Cooper & Ferreira, 2009). The computer-mediated interface of remote laboratories also presents the opportunity for educators to manipulate the presentation of the laboratory in order to provide additional information and context to students conducting the laboratories that would not be available to them in a traditional laboratory setting.

The context in which a learning activity occurs has been shown to have an effect on learning outcomes (Godden & Baddeley, 1975). It is therefore worthwhile investigating how learning outcomes for laboratories may be improved by enhancing a laboratory activity with suitably designed contextual information. These authors have identified the potential that virtual worlds may provide in this regard: namely, virtual worlds can provide a mechanism whereby rich domain context can be added to remote laboratories so that the effects of contextualising laboratories can be studied (Machet, Lowe, & Gütl, 2012).

A number of learning affordances of virtual worlds have been described in the literature, particularly with respect to allowing educators to convey supplemental information to students (Chapman & Stone, 2011; Dalgarno & Lee, 2010; Oloruntegbe & Alam, 2010). As an example, one could add domain context to a laboratory activity by providing explicit illustrative examples of how the learning outcomes of the laboratory could be applied in the real world. In order to achieve these enhanced interfaces however, it is essential that the real laboratory equipment can be integrated into the virtual world without compromising students' ability to complete the laboratory or their awareness of the reality of the laboratory equipment they are using (Lindsay et al., 2009).

This paper aims to determine the criteria for a system that integrates existing remote laboratories into a virtual world and then analyses some commonly used virtual worlds in order to select one that best meets the needs for this integrated system. This work is intended to be used as a base for future research and development into how the learning outcomes of laboratories can be improved, specifically by adding contextual information through the use of virtual worlds.

To begin the investigation, this paper describes the research into existing implementations which integrate real equipment into virtual worlds and discusses the different approaches that have been explored. The authors then discuss the requirements that need to be met in order to integrate existing remote laboratories into the real world and what factors would affect the design of such a system. Finally the paper investigates two specific virtual worlds (Second Life and Open Wonderland) for their suitability and draws a conclusion about which would best meet requirements.

Real Equipment in Virtual Worlds

There exists a spectrum of interaction that runs from the completely real world to an immersive, purely virtual world. Along this spectrum we encounter "mixed reality" systems that have aspects of the real and virtual combined in some way (Milgram & Colquhoun Jr., 1999). These could be in the form of 'augmented reality' whereby the virtual elements are integrated into a real environment in real time (such as a head mounted display that can superimpose a new proposed building on a streetscape to see how it would look) (Azuma, 1997). Alternatively, mixed reality can take the form of a virtual world in which the world is completely modelled but real data has been included in parts – 'augmented virtuality' (Milgram & Colquhoun Jr., 1999). An example of this might be a meeting room in a virtual world that has live video of meeting attendees superimposed on the chairs.

For the purposes of this investigation, we are interested in how real equipment can be integrated into and represented within virtual worlds, or a type of augmented virtuality. By looking at the existing literature and state of development, we can analyse differing

approaches that have been taken to integration between the real world and the virtual world, how they are technically achieved and what this may mean for our own future research into remote laboratories set within virtual worlds. The literature was searched for references to real equipment integration into virtual worlds, with the primary conferences, journals and centres of research in the field being identified. In selecting what to include in our analysis, preference given to peer reviewed articles which described successful implementations. Much information was contained in project reports and these were analysed in terms of how the conclusions and implementations used could be generalised outside of the specific project scope. We also looked at a number of literature reviews comparing virtual worlds which were analysed in terms of how relevant their assessments were to educational implementations (rather than recreational or gaming).

The Intelligent Systems Research Center at the University of Ulster has done much work in the area of integrating real equipment into a virtual world (“Serious Games and Virtual World Team,” 2012). They have selected the Second Life virtual world and have developed a number of integrated systems that link real hardware to the virtual world and track, in Moodle, the results of any interaction. One such integration is that of a physical washing machine simulator being linked to a virtual replica of the simulator in Second Life (Delacoux & Perrin, 2009). Figure 1 illustrates the virtual world replica of the washing machine simulator (at the top of the figure), and the physical washing machine simulator (at the bottom of the figure).

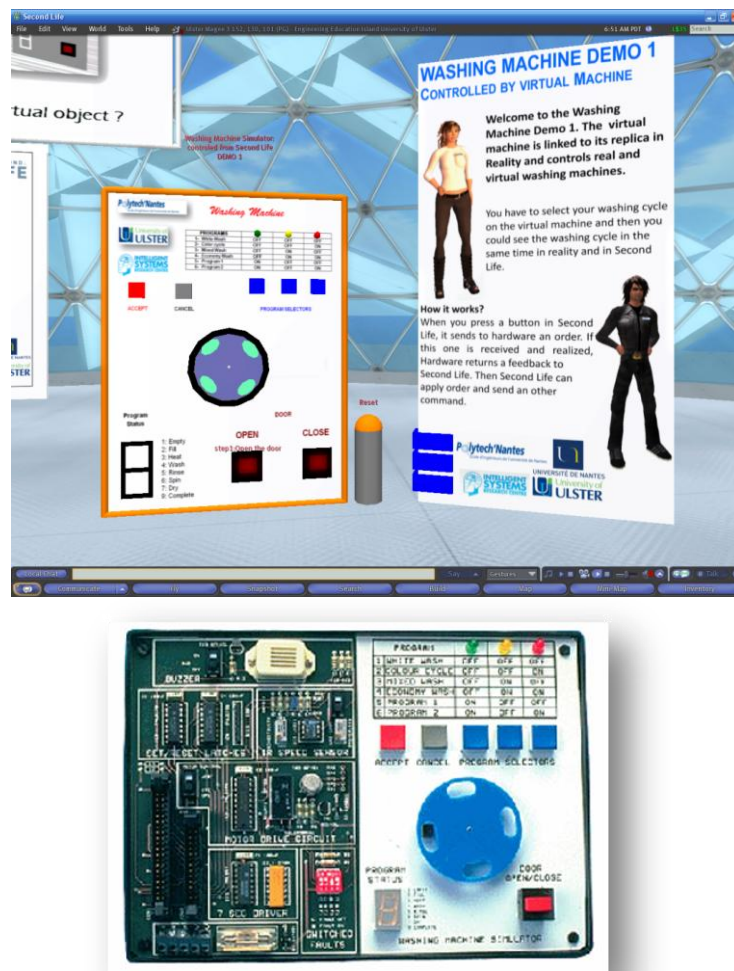


Figure 1: Virtual world replica of the washing machine simulator (TOP) and the physical washing machine simulator (BOTTOM). (From Delacoux & Perrin, 2009)

The real and virtual washing machine simulators are very similar to each other but bear little resemblance to a real washing machine. Any changes to the real (i.e. physical) washing machine simulator must be reflected in the virtual simulator, and any changes made in the virtual world must follow the logic of the real simulator and be communicated to the real washing machine simulator. While there are some limitations to the control from both the real and virtual washing machine simulators, this integration has been shown to work effectively, at least in terms of technical integration.

In order to implement this, the real washing machine simulator and a PC are connected to a microprocessor which handles the logic of the simulator operation taking inputs either from the operation of the real washing machine simulator, or from a serial connection to the PC. In Second Life the commands are received and sent to the hardware as HTTP requests via XML-RPC. The proprietary Second Life scripting language Linden Scripting Language (LSL) can receive XML-RPC requests and direct them to the appropriate Second Life 'primitive'. Responses are sent as HTTP requests written to a database where they can be retrieved by an external program. In the case of the washing machine simulator, this is a C++ program which configures, manages and sends information to the serial port communicating with the real washing machine simulator controller.

There are some limitations to this implementation: the user must manually select whether to control the physical machine simulator directly or via the Second Life emulation. Further, some aspects of the simulator (specifically some LED's) cannot be controlled by Second Life. The implementation here is very specific to the hardware being used but the method of communication between Second Life and real hardware, while it involves the implementation of a number of interfaces, has been shown to work effectively and can be applied to other microprocessor controlled hardware.

The group has done similar work with displaying real temperature sensors in a virtual building, and more complex integration of electrical circuits into a virtual world based game environment. These implementations utilise Second Life and connections to real hardware.

In an alternative implementation, WebLab-Duesto created SecondLab - an integration of one of their existing remote laboratories into Second Life. While successful, a number of problems were found with the choice of Second Life as a virtual world. They concluded that Second Life presented technical limitations due to its limited scripting language, the fact that few user interface components are readily available, there are memory restrictions on the size of each script and there is a lack of high level communication protocols (Garcia-Zubia et al., 2010).

A further example of real equipment integration into a virtual world is the remote "Force on a Dipole" laboratory that has been integrated into Open Wonderland (Scheucher, Bailey, Gütl, & Harward, 2009). The implementation is focussed on preserving the perception students have of real equipment while augmenting the lab with additional virtual information – a simulation of the field lines around the dipole. This lab is presented to students as a control interface which their virtual avatars can manipulate, a video stream showing a camera feed of the real equipment while the experiment is being conducted, and a virtual simulation of the dipole that moves along with the real experiment and is enhanced by field lines. Figure 2 illustrates the avatars in the virtual world with access to the control panel (on the left) and the camera feed from the real equipment (right). In front of the video feed is a simulation showing field lines around the dipole that uses the real data from the lab to illustrate the effect of the dipole moving.



Figure 2: iLabs Remote Lab accessed through virtual world Wonderland (from http://www.youtube.com/watch?v=cBlufoJi_Ro)

The integration between Open Wonderland and the real equipment is once again in both directions. An existing iLabs experiment with a LabView interface was used for this project and the LabView control interface can be manipulated by avatars in the virtual world. The effects of running the lab can be seen in the live video stream, and the output from the real equipment is read into the existing (though customized) TEALSim simulation. In this project, the LabView control panel is available through the use of a VNC viewer tool within Open Wonderland which allows a remote desktop application to be shared in the virtual world. The TEALSim simulation is Java applet that is allowed to run within the virtual world and connect to the experiment to read information. There is no direct communication between the hardware and the virtual world, but Open Wonderland allows the existing remote laboratory control interface and simulation to be embedded within the virtual world.

Further case studies in the literature illustrate that Open Wonderland has been used to integrate different existing remote laboratories into virtual worlds with no substantial additional costs other than the server (Fayolle & Gravier, 2011), as well as interfacing directly with hardware such as the Microsoft Kinect (Schmidt, 2011).

There are further examples of remote laboratories using different virtual world platforms: the GCAR-3DAutoSysLab (Pereira, Paladini, & Schaf, 2012) has been integrated into OpenSimulator (which an open source virtual world similar to Second Life); and the Virtual Factory (a mixed reality chocolate factory) has been trialled on Open Wonderland and OpenSimulator among others (Back, Kimber, Rieffel, & Dunnigan, 2010).

The range of implementations, experiences and research outcomes indicate that there is no one stand out virtual world that is most suitable for meeting the requirements of integrating real hardware in general, or remote laboratories in particular, into a virtual world. While it seems that there are a range of technically feasible solutions, in order to select a suitable virtual world platform, it is important to look at the system requirements for what we are aiming to achieve: a system that can be used to improve learning outcomes for students by adding contextual information to remote laboratories through setting them within context rich virtual worlds.

Requirements for a Remote Lab in a Virtual World

Having investigated a number of examples where real equipment is integrated into virtual worlds, the paper will now look at the requirements for the authors' future research aims.

Our goal is to develop a system that allows students to access a remote laboratory through a virtual world where the student can be presented with relevant contextual information that will support the students' learning. The laboratories being looked at are those for which The Labshare Institute can mediate access. These represent a range of different types of labs that are all accessed through the Sahara lab sharing interface which books, queues and manages laboratory sessions for users ("Labshare - Home," 2012). While this paper will focus on these laboratories, the analysis can be applied to other existing remote laboratories.

1. **The reality of the remote laboratory equipment should be established and maintained while students conduct the lab.** Previous research has shown that students' perception of whether or not they are working on real equipment can significantly affect the learning outcomes they achieve from the laboratory. This tells us that maintaining the realism is of importance when incorporating remote labs into virtual worlds (Fayolle & Gravier, 2011; Lindsay et al., 2009; Scheucher et al., 2009). To this end, neither the virtual world itself nor the implementation of the integration should undermine the perceived reality of the equipment that students would experience were they to conduct the experiment without the virtual world. We envisage that this can be achieved to some extent with the use of a live camera feed from the experiment.
2. **The execution of the laboratory in the virtual world should be similar to that in the real world.** The importance of this depends on how familiar students are with real world interfaces and whether having to learn a new interface would distract from the learning objective. Students should be able to carry out the laboratory experiment as they would for a customary remote lab. For this reason we suggest that the platform should support shared applications and multiple language plug-ins so that familiar remote laboratory controls and components can be used.
3. **There must be the ability for the virtual world to control real equipment as well as read inputs from real equipment.** This is a necessity for integration, though the nature of the connection can be either directly to the hardware or via existing remote lab interfaces (such a LabView control panel). Ideally this interaction should be easy to implement, have been shown to work in other cases, and should not limit the functioning of the experiment in any way.
4. **The virtual world must be able to support the creation of suitable contextual information.** For this, we require that objects in the virtual world can be reasonably easily created and designed to behave like real world objects that will contextualise learning for students. This may include simulating real world phenomenon that cannot normally be visualised (such as the field lines in the force on a dipole experiment) or ensuring that virtual objects can imitate real ones well enough to provide contextual information. Some cases may require the ability for contextual information to interact with the laboratory interface. For example, a virtual car moving across a representation of a real physical beam (to convey that a beam deformation may be representative of what occurs in a real bridge). The effectiveness of the contextualisation may in part depend upon being able to show the car overlaid directly on the beam, and not just in its vicinity.

The platform should ideally provide: a GUI tool that allows the creation of virtual world content, support for object animation, an easy method to import content of different formats and collision detection (preferably with a physics engine).
5. **Open Source preferred.** This has implications for the extensibility and the cost of the installation and future changes.

6. **Client and Server considerations:** A stable platform is required. The client should run cross-platform (Windows, Mac and Linux). Installation of both the client and server should be clear and simple. The server should be able to be hosted behind a firewall for security and access issues within universities.
7. **Future work in the area should be considered.** Following a proof of concept, future work would include expanding this system to allow for a number of different remote laboratories to be integrated into the virtual world. For this there are some additional requirements to be considered:
 - a. An existing or designed standard interface between the virtual world and the real equipment would be valuable. There is some literature that describes an attempt to standardise an interface to virtual worlds - the Virtual World and Real world Interface or VRI (Syamsuddin, Lee, & Kwon, 2009).
 - b. Good documentation and a support community of developers and researchers interested in laboratory teaching in worlds (or the integration of real equipment into virtual worlds) is useful for the project to be taken up and expanded.
 - c. Rapid deployment. The ease of development for integration with new labs and keeping up to changes with existing labs in terms of the costs in time and money of redevelopment, the skills needed to integrate new laboratories and the limitations imposed by the virtual world must be considered.
 - d. Low cost of installation and use. Future research will depend in part on the willingness of universities and students to use and develop the system. Cost in terms of money and time for providers and users will be a factor.
 - e. Collaboration tools. A significant affordance of virtual worlds, and one that may provide an opportunity to improve selected learning outcomes in laboratories, is the ability for students to collaborate while carrying out remote laboratories.
 - f. Virtual learning environment integration. The ability to track and evaluate students while they conduct laboratory experiments (for instance with a virtual learning environment such as Moodle), and potentially adapt their laboratory experience accordingly in real time, is an avenue for future research.
 - g. Security. Uptake of any integrated system by providers of remote laboratories and their users may depend on how secure the system is in terms of being able to restrict access to internal networks and authentication of users.
 - h. Support for a high number of users. Once again, any system that will be useful for universities into the future must be able to support a number of concurrent users.

Given this list of broad requirements this paper now looks at the suitability of two popular virtual worlds for this project: Second Life and Open Wonderland. The virtual worlds are evaluated in terms of the requirements as well as discussions about the platforms in the literature.

Comparing virtual worlds

Based on the information presented from the literature, it can be seen that Second Life and Open Wonderland have the ability to interact with real equipment and support the integration of remote laboratories into the virtual world. The choice of virtual world platform will determine how the system is developed and delivered.

Some literature already exists evaluating and comparing virtual world platforms from differing points of view. Warburton assesses the affordances and barriers of use of Second Life as a teaching tool and classifies relevant barriers include the cost and time taken to develop, test and deploy learning material (Warburton, 2009). Gardener discusses the choice of Open Wonderland over other virtual worlds such as Second Life and OpenSim due to, amongst

other factors, its live application sharing ability, and its open and extensible nature (Gardner, Scott, & Horan, 2008). Others have looked at virtual worlds as collaboration and communication tools of the different platforms (Wynne, 2010; Zutshi, 2009). Other sources both implicitly and explicitly compare virtual world while describing or creating virtual world implementations (Back et al., 2010; Boulos, Hetherington, & Wheeler, 2007).

We can look at the requirements outlined previously and use information from the literature and the virtual world specifications to assess the suitability of the platforms:

1. **The reality of the remote laboratory equipment should be established and maintained while students conduct the lab.** Both Second Life and Open Wonderland allow live video streaming which can be used to establish and maintain the perception of the reality of the equipment. The development of a realistic looking control panel would be supported in Open Wonderland with its support of Java and plug-ins in multiple languages. While arguably technically achievable in Second Life, the need to use LSL and the limited size of scripts would make development much more complex.
2. **The execution of the laboratory in the virtual world should be similar to that in the real world.** Open Wonderland allows shared applications and supports multiple language plug-ins. The VNC viewer tool for example would allow control of a desktop hosting a remote laboratory control interface such as LabView. Second Life does not support this type of sharing, however controls can be rendered and replicated in the virtual world that are similar to the real world at a cost of time and effort.
3. **There must be the ability for the virtual world to control real equipment as well as read inputs from real equipment.** The examples described in this paper illustrate that this is possible for both Open Wonderland and Second Life; however the ability to re-use existing control interfaces for Open Wonderland makes development simpler and quicker.
4. **The virtual world must be able to support the creation of suitable contextual information.** Open Wonderland allows in-world editing and the easy importing of existing content in the form of video, animations and numerous file formats meaning that existing work can be re-used to speed up development. Open Wonderland does not have a sophisticated physics engine, so while it supports collision detection, more complex physical phenomenon would have to be achieved through the use of a physics engine plug in ("Marble Physics," 2009) or developed specifically for the object. Second Life can add contextual information though the formats supported are more limited and in some cases content must be purchased. Second Life uses the Havok physics engine.
5. **Open Source preferred.** Open Wonderland is a completely open source, Java based platform that is extensible and free. Second Life is proprietary software that requires developer to 'buy land' to develop and requires the use of the Linden Scripting Language.
6. **Client and Server considerations.** Both Open Wonderland and Second Life are simple to install and are stable platforms. Open Wonderland continues to develop and incorporate community member code. Both platforms have clients that can run on a variety of platforms. Second Life must be hosted by Linden Lab while an Open Wonderland installation can stand alone behind a firewall. Open Wonderland requires a number of TCP and UDP ports to be open from the server to function correctly (Parsons & Stockdale, 2009).
7. **Future work.** Open wonderland supports application sharing (Java and X11 applications can run inside the virtual world) and allows the easy importation of existing content (drag and drop images, documents, animations etc.) so that there can be low cost, relatively rapid deployment of laboratories where control applications already exist.

Both Second Life and Open Wonderland have good documentation for developers and a community of developers who are accessible and interested in solving the problems of integrating real world equipment and remote laboratories into virtual worlds. Second Life

development is done in the Linden Scripting Language and has limited support for high level protocols to interface to external software (Garcia-Zubia et al., 2010).

Open Wonderland supports a larger variety of collaboration tools than Second Life (notes, document sharing). Second Life is supported by a Moodle module, Sloodle, that merges the virtual world with the virtual learning environment and is very useful for tracking and evaluation of students work within laboratories.

The Open Wonderland server can be installed behind a firewall, and supports LDAP creating a more secure environment.

Having looked at Second Life and Open Wonderland in more detail in terms of our requirements, the authors suggest that while both virtual worlds provide feasible technical solutions for a system to support future research, Open Wonderland is most suitable for our project because of its open source nature, and the ability to more rapidly develop and expand a system for existing remote laboratories.

Conclusions

This paper has looked at existing virtual worlds in order to determine which would be most suitable for a system that integrates remote laboratories into a context rich virtual world, with the aim of improving learning outcomes by presenting users with the relevant contextual information that would not normally be available.

The authors have reviewed existing instances of the integration of real world equipment into virtual worlds, and analysed some of the examples in detail. It was found that it is technically feasible to interface from a number of virtual worlds to real equipment and that this has been done in the context of remote laboratories for both Second Life and Open Wonderland. Having established the feasibility, the authors looked at the requirements we have for our mixed reality system.

Based on the assessment of Second Life and Open Wonderland against these requirements, the authors suggest that Open Wonderland be used for the system. Using Open Wonderland would allow a cost effective solution that can be rapidly deployed given that we are looking to integrate remote labs with existing control interfaces. The ability to use a commonly used programming language (Java) and existing graphics and animations to add context to our virtual world will also allow for more rapid development.

This investigation is the basis for future work into the mixed reality laboratory. Future work includes using this information to build and test a prototype of a Sahara accessed remote laboratory within Open Wonderland that has relevant contextual information added.

The research has also highlighted the fact that no standard interface is being used for interaction between the real and virtual worlds. Future research should investigate the feasibility of using a recently defined VRI interface (Syamsuddin et al., 2009) in any system implementation.

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