Proceedings of the World Congress on Engineering 2013 Vol II,
WCE 2013, July 3 - 5, 2013, London, U.K.

Development and Evaluation of a Desktop VR System for Electrical Services Engineers

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Abstract **—This paper presents a prototype desktop virtual reality model, developed to enhance electrical safety and design in the built environment. The model presented has the potential to be used as an educational tool for third level students, an industry design tool or as a virtual electrical safety manual for the general public. A description of the development of the virtual reality model is presented along with the applications that were developed within the model. Subsequently, a case study is carried out to evaluate the users' attitudes toward VR learning environments and also the usability of the prototype model developed. Based on the development of this prototype model, it appears from the completed case study that the users perceive the prototype to be a useful tool and were receptive to using VR as a learning and design tool.**

Index Terms **— desktop virtual reality, electrical safety, training and education, touch voltage**

I. Introduction

For electrical safety to continuously progress, it is incumbent on those within the industry to consistently strive for enhanced regulation, improved systems of work and enhanced methods to allay these risks. Such efforts will not just benefit those working and training to work in this industry, but all of society.

Initially this paper sets out an electrical safety model based on the findings of [1] [2] [3] and then continues to present the design process of a desktop VR prototype, "Virtual Electrical Services" (VES), which is developed to address the safety model and demonstrate how VR technology can be applied to the electrical services industry to enhance electrical safety and design in the built environment. Following this, an evaluation of the model is presented which investigates the usability of the system developed and also evaluates the users' attitudes toward VR learning environments.

Users within the system can navigate through a domestic home using a mouse and keyboard, interact with electrical appliances, carry a touch voltage study and sensitivity analysis, determine the most dangerous location of electrical accidents within the home and receive safety and maintenance advice for various electrical appliances. The system also outlines how VR can be utilized for the dissemination of Electrical Regulations and standards to the electrical services industry to allow for greater understanding and rapid transfer of knowledge.

Manuscript submitted on 2nd March, 2012.
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Virtual reality (VR) can be described as a technology that allows users to explore and manipulate computer-generated, three dimensional, interactive environments in real time [4]. Historically, these systems were generally limited to the minority and not widely accessible. However, in more recent times this trend has diminished, mainly due to the culmination of significant price reductions, rapid advancements in computer processing power in addition to the proliferation of broadband connections. Consequently the use of desktop VR for research and development has escalated and become widely accessible as VR systems can now operate on relatively cheap systems such as the ubiquitous PC. Furthermore, with the development and maturity of commercial VR packages such as Quest3D [5] and Virtools [6], it is now possible to create professional VR applications in a relative short time span that have the flexibility to support the development of an online training and design environment.

II. Electrical Safety Concept

Electrical safety in the built environment can be defined as the process of eliminating the risk of incident or injury from electrical installations. To achieve this, an approach must be taken that encompasses all of the elements that influence the outcome. Three predominant factors related to preventing electrical accidents in the built environment are identified in Figure 1.

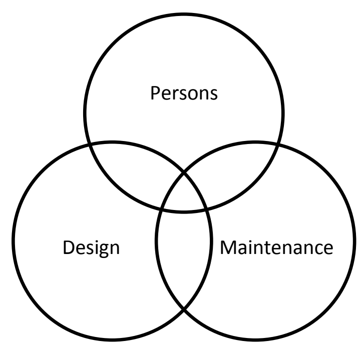

Fig. 1, Electrical Safety Model

These are *design, maintenance* and *persons.* Using the concept of three overlapping circles an electrical safety model is proposed which forms the foundation on which to develop the VR model. The section common to design and persons highlights the potential danger to a person where the design is poor or the person is careless. The section common to maintenance and persons highlights the potential danger to a person where there is poor maintenance or the person is careless, while the section common to maintenance and design highlights the potential danger to a person where there is poor maintenance or where the design is poor. The section common to all three circles yields the greatest risk of danger. The sections which are not common to any part of the circle can be viewed as good design, good maintenance and a safe person. The person can be an ordinary person, skilled or instructed person.

One potential method of addressing each of these elements outlined is to use virtual reality. Through the virtual environment designers can investigate the impact of their designs, persons can become more aware of the dangers of electricity by virtue of the collected accident scenarios [2], while a skilled person can become more informed or virtually instructed before carrying out maintenance. By providing a format to develop and address each of these elements will only serve to heighten awareness and encourage people to use safe electrical practices. Utilised in this manner, VR can add value to the electrical services sector and become an integral part of training for third level students, electricians, design engineers and a valuable electrical safety tool for educating the general public.

III. VR Development Tools

The VR application presented in this paper utilises the authoring tool Quest3D developed by ACT-3D B.V. Quest3D does not generate pictures or 3D models; instead the developer creates a repository of pictures, 3D meshes and sounds in a separate program and imports them into Quest3D. The basic building blocks in Quest3D are the so-called 'channels'. In brief, a channel is a reusable component that contains a piece of application logic. This component is able to interact with the Quest3D interface engine and other channels.

By creating a hierarchical logical framework of linked channels an interactive application can be developed. Quest3D contains many default channels, allowing for the development of a wide range of applications. If more functionality or interactivity is required, the C-based Lua scripting language can be used to create new channels. Quest3D also affords realtime feedback with no need to compile code. The ability to create successive iterations of your application with instant visual feedback is a beneficial feature and it shortens debugging time. Quest3D use a DirectX 9 game engine and hence is supported by all DirectX 9 compliant graphic cards and operating systems. The hardware requirements to run the VES application are Intel Pentium III or Higher or AMD Athlon processor, 512MBytes RAM, Hardware accelerated DirectX compatible graphics card and 1024x768 display resolution [5]. Quest3D supports delivery of the developed application via the web and also through an executable file.

IV. Prototype Model 'VES'

The fundamental objective of VES is to enhance electrical services design and safety in the built environment using a desktop VR system. The system allows full navigation of a virtual electrical installation environment and interaction with many of the electrical elements. In order to provide the user with the highest degree of realism the following were set as the benchmarks for the VES application; 1) visual representation of an electrical installation in the built environment, 2) simulation and representation of the functionality of the installation, 3) strict adherence to the appropriate electrical rules governing the installation under investigation. In addition, the VES application had to ensure the provision of interactivity in an intuitive manner and provide accessibility to the application across the widest range of platforms and interested parties.

The application of VR technologies for engineering design, training and education has generated much interest across many sectors of the engineering community. This is not surprising as using VR technology to build virtual training systems has the advantages of being safe, economical, controllable and repeatable [21]. Virtual Reality also offers the ability to expeditiously attain proficiency and knowledge which is a critical factor for the profitability and sustainability of companies, governments and training organisations. Additionally, in an era where regulatory practices are amended on an ongoing basis there is a requirement on the part of industry and higher education institutes to provide training methods that will allow trainees to quickly and cost effectively up-skill and attain knowledge to adapt to the new and rapidly emerging practices and associated technologies.

The following sections describe the creation of the virtual environment and the applications developed within VES.

A. Touch Voltage Simulator

One of the principle objectives of VES is to allow users enter a virtual electrical installation and investigate the touch voltage that could develop under different design parameters for various earthing conditions.

To make the touch voltage simulator as intuitive as possible the user is presented with two check boxes which can be activated and de-activated on the graphical user interface (GUI). One of the check boxes allows the user to view a single line diagram of the electrical installation. The second check box allows all interactive appliances to flash.

Within the simulator the user can walk around the virtual electrical installation and interact with or simulate an earth fault on any of the interactive appliances, such as the main distribution board, cooker circuit, shower circuit, socket circuit etc. If the user wishes, it is possible to vary the major design parameters that govern the value of the touch voltage. By varying any of these parameters the touch voltage automatically updates and the user can immediately view the impact of any design decisions. It is also possible to view the transfer touch voltage that could develop under fault conditions. A visual example of the GUI and the interactive cooker appliance can be seen in Figure 4.

Familiarity with the virtual environment can allow users to quickly become absorbed in touch voltage design. In this way the user can easily identify if a potentially dangerous touch voltage will develop and the possibility of designing a circuit to have a transfer touch voltage not exceeding 12V to provide protection against electric shock for a person with very low body resistance in a special location (e.g. bathroom) and 50V for all other dry locations.

B. Electrical Safety and Accidents

Statistically it has been shown that domestic properties are one of the leading locations for electrical injury and death [7]. A further investigation into electrical accidents by the author

[2] also singled out domestic properties as one of the prime locations for electrical accidents to occur.

VR provides an opportunity to deepen society's understanding of these issues, raise awareness of potential dangers, train the user how to interact safely with equipment and instruct owners how to carry out maintenance safely. The prototype VES application addresses these concerns and emphasizes the potential benefits of using VR for this purpose.

As the user navigates through the virtual home, electrical safety guidance associated with the user location can be obtained via the GUI. The unique information provided for the user in each location is broken into three sections. The first presents a database of accident scenarios associated with that location based on information obtained from [2]. The ability to select from a range of electrical accidents in the database enables the user to see how accidents occur and the measures required to prevent such accidents. The second section provides general safety advice related to the users' location and the third section provides safety guidance and maintenance advice for the electrical appliances installed in that location

Fig. 2, View of kitchen and GUI in 'VES' (from colour original)

C. Electrical Rules and Standards

Electrical rules and standards are the fundamental guidelines for all electrical installations to ensure a safe environment in which to live and work. The use of a virtual reality training tool to educate students, contractors and engineers on these regulations is an exciting and novel prospect.

Wiring regulations such as ET 101 [8] and BS 7671 [9] in their current format are well documented and each section is clearly defined. However, the language used in these documents is technical and often complex and the precise interpretation of the rules on the part of the reader requires experience and a strong technical knowledge. It is this author's opinion that a virtual representation of the rules and standards will enhance the method by which knowledge is currently transferred and help students and practising engineers develop a greater appreciation of the rules and standards.

Furthermore, as standards evolve from one version to the next it is incumbent on governing authorities to disseminate information pertaining to the updates often in the form of multi-location seminars. The time and cost involved in this process could perhaps be reduced if Web based VR applications such as 'VES' are utilised as a companion training tool by the relevant governing bodies. The fact that desktop VR applications are reusable, convenient to update, can potentially reduce training budgets and can be distributed via the web presents a very attractive option for the industry.

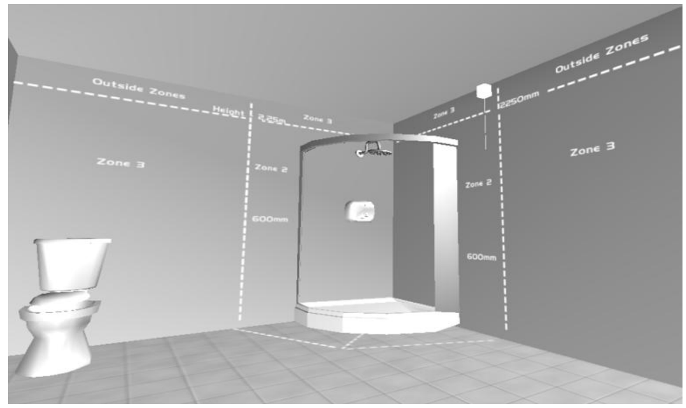

Fig. 3, View of Zones in bathroom in 'VES' (from colour original)

To demonstrate the potential of this novel approach a number of the current rules in ET 101 are demonstrated in the VES prototype. Examples of these include: protection against impact required for wiring systems installed in solid and hollow walls; in the area of switchgear and accessories, the mounting heights of light switches, control devices, socket outlets and distribution boards are demonstrated; in relation to bathrooms in residential dwellings, the zones and the equipment permissible in each zone for these *special installations* are clearly identified (see Figure 3).

V. CASE STUDY

A. 'VES' Model Evaluation

A questionnaire following a usability evaluation period is the primary technique utilized to acquire the user's findings. Within the survey users were afforded the opportunity to express their thoughts on the model and to highlight any perceived areas of strength or weakness. Post evaluation discussion groups were also held with class groups to provide additional feedback. Furthermore, a set of problems which are coded into the VR system are taken by all participants prior to entering the virtual environment receiving only basic tutor instruction on the material. Subsequently using the interactive environment of the 'VES' model where learners can actively participate, the user's are posed the same problems in what is effectively a problem based learning exercise.

The questionnaire was developed in order to primarily answer two research questions (1) evaluate the usability of the prototype model and (2) to assess the users' attitudes toward Desktop VR as a learning environment. Users are assessed over 11 measurement items as shown in Table 1. Items 1-5 set out to primarily evaluate the usability of the system, closely monitoring the unique VR characteristics as they are often cited as being intrinsic in establishing the usability of the system while items 6-8 will provide feedback on the psychological factors that affect the learning experience which in conjunction with items 9-11 should provide a platform to establish user attitudes towards VR as a learning environment.

ISBN: 978-988-19252-8-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

The questionnaire was drafted by referencing survey questions used in published literature.

Table I, Questionnaire Measurement Items and Sources

Measurement Items	References
1. Immersion	Huang et al (2010)
2. Representational Fidelity	Dalgarno et al(2002), Lee et al (2010)
3. Immediacy of Control	Dalgarno et al(2002), Lee et al (2010)
4. Perceived Usefulness	Davis (1989), Lee et al (2010)
5. Perceived Ease of Use	Davis (1989),
6. Presence	Lee et al (2010)
7. Motivation	McAuley et al. (1989)
8. Cognitive benefits	Antonietti et al. (2000)
9. Intention to use system	Huang et al (2010)
10. Perceived Learning Effectiveness	Lee et al (2010)
11. Satisfaction	Chou and Liu (2005)

B. Participants and Procedures

Participants consisted of final year undergraduate students studying Electrical Services Engineering and Energy Management from the School of Electrical Engineering Systems in Dublin Institute of Technology. A total of 101 students were given a brief demonstration on how to use the VR system. Students were then allowed to access the system via the web or as a downloadable executable file. Subsequently an on line questionnaire was distributed to the participants. 87 completed responses were returned for analysis. Males made up 100% of the subjects surveyed. The questionnaire had 41 questions[1] that were evaluated using a 7-point Likert scale ranging from 1 which means ‘‘strongly disagree’’ to 7 which means ‘‘strongly agree’’. After completing the experiment, group discussions were used to provide additional qualitative feedback during debriefing sessions.

VI. Data Analysis and Results

The internal consistency reliability for the measurement items was assessed by computing Cronbach’s αs. The alpha reliability was considered acceptable with values ranging between 0.7 and 0.86. The mean coefficient associated with each measurement item and the standard deviation is outlined in Table 2. Additionally a Spearman correlation was carried out between each measurement item and the results are presented in Table 3. PASW Statistics 18 software package was used for the analysis of the results.

A. Interaction Experience

Analysing the usability of the model, measurement items 1-5 are primarily analysed. Items 4 and 5 which measure the perceived usefulness and perceived ease of use provide feedback on the interaction experience while items 1-3 will provide feedback on the VR characteristics of ‘VES’ and their influence on the usability of the system. Perceived usefulness which can be used to indicate whether the technology can enhance the users performance of a task attained a slightly higher mean score (5.84) than perceived ease of use (5.5). There was a strong, positive correlation between perceived usefulness and all three VR features which is statistically significant as shown in Table 3. Perceived ease of use which can be used to indicate the accessibility of the system and the expectation that a technology requires minimum effort showed a small to medium correlation effect with the VR features. Examining the correlation effect between the perceived usefulness and the user’s intention to use the system and satisfaction with the system shows a strong correlation, which is statistically significant. A medium to strong correlation also exists between perceived ease of use and satisfaction.

In agreement with Lee [10] and Salzman [11] findings, the VR features in this study can be considered to play a significant role and indicate a positive influence in terms of the usability of the system. VR features that were measured by immersion, representational fidelity and immediacy of control which refers to the user’s ability to interact and control the virtual objects collectively impact on the interaction experience of the participants. One could indicate from these findings that with enhanced control components and realism, users will be offered an enhanced interaction experience.

Using the VR measurement outcomes as outlined in Table 2 as a benchmark to evaluate the impact usability has on the system clearly demonstrates that the satisfaction of the user group with the ‘VES’ model is strongly correlated to the usability of the VR system, while more specifically the perceived usefulness of the system can be seen as very influential in determining one’s motivation and intention to use the VR system

A. Learning Experience

In determining the user groups attitude towards VR as a learning environment, items 6-8 were used to assess the psychological factors that affect the learning experience while items 9-11 were used to benchmark the user groups perceived effectiveness and satisfaction with the ‘VES’ prototype model as a learning environment.

Motivation as defined by [12], is an internal state or condition that activates, guides, and maintains or directs behaviour. Sutcliffe [13] suggests that motivation is a major factor that influences learning and thus better-motivated users can learn more effectively. In this study motivation was found to be an influential psychological factor that is positively related to the VR measurement outcomes. This is consistent with previous related studies [10] [14] thereby demonstrating the plausible effect motivation can have on learning effectiveness. VR features were also found to be significant in influencing user motivation, this is in keeping with the findings of Huang [14]. Additionally, usability and in particular perceived usefulness was found to be significant in terms of user motivation indicating that a useful, easy to use system will enhance user motivation.

Cognitive benefits were found to have a strong positive correlation with the perceived learning effectiveness of the VR model, satisfaction and also the intention of the participant to use the system. This is consistent with the findings of lee [10] and Antonetti [15] suggesting that users see VR as advantageous in terms of understanding and memorisation.

The significant influence perceived usefulness has on the cognitive benefits in contrast to the VR features may also indicate that it is the usefulness of the task set within the model more so than representational fidelity which perhaps will heighten user conceptual understanding. This emphasises

[1] Questionnaire measurement items and results can be accessed at http://dl.dropbox.com/u/53879409/VR/VR%20Questionnaire.docx

Table II, Questionnaire Measurement Item

Measurement Items		α	Mean	S.D
1. Immersion	VR Features	0.7	5.3	0.9
2. Representational Fidelity		0.78	5.2	0.99
3. Immediacy of Control		0.76	5.96	0.82
4. Perceived Usefulness	Usability	0.71	5.84	0.81
5. Perceived Ease of Use		0.85	5.5	1.1
6. Presence	Learning Experience	n/a	5.05	1.37
7. Motivation		0.86	5.5	0.97
8. Cognitive Benefits		0.81	5.61	0.8
9. Intention to use system	VR model Measurement outcomes	0.77	5.51	1.04
10. Perceived learning effectiveness		0.85	5.42	0.84
11. Satisfaction		0.82	5.41	0.77

Table III, Spearman correlation between the measurement items *Denotes where ($P > 0.05$)

Measurement Items	1	2	3	4	5	6	7	8	9	10	11
1. Immersion	1										
2. Representational Fidelity	.568	1									
3. Immediacy of Control	.412	.292	1								
4. Perceived Usefulness	.571	.543	.519	1							
5. Perceived Ease of Use	.264	.243	.187*	.174*	1						
6. Presence	.495	.471	.173*	.431	.370	1					
7. Motivation	.461	.493	.329	.611	.229	.437	1				
8. Cognitive Benefits	.423	.379	.401	.665	.199*	.374	.576	1			
9. Intention to use system	.54	.498	.434	.628	.059*	.242	.649	.686	1		
10.Perceived Learning Effectiveness	.51	.501	.485	.649	.304	.342	.606	.724	.671	1	
11.Satisfaction	.506	.363	.416	.571	.413	.348	.511	.648	.598	.636	1

the critical nature of the role instructional content plays in fully capturing the cognitive benefits VR can offer.

Analysing the VR model measurement outcomes in Table 2 highlights that perceived learning effectiveness attained a relatively high mean score (5.42). This finding can be substantiated by the results of the problem based learning exercise developed for the participants, where it was found that by using the VR model users scores increased on average by 31%. This emphasises further and provides evidence for the assertion made by Dalgarno [16] that in order to facilitate conceptual understanding a well designed set of learning tasks is crucial. From the evidence of this research it would appear that the learning activities contained in a VR model have a significant influence on the cognitive benefits which in turn strongly influence the perceived learning effectiveness.

In general, the overall attitude toward VR as a learning environment was found to be positive. The evidence to support this claim can be ascertained by reviewing the mean scores received for the measurement items ‘Satisfaction’ and ‘Intention to use the system’ which can justifiably be argued as indicative benchmarks. The qualitative feedback received from the questionnaire and also the debriefing sessions also support this claim where the majority of users observed the usefulness of the model in addition to the perceived positive influence that VR could have on their learning.

VII. Discussion

The prototype model outlined constitutes a first attempt at attaching a new dimension to the training of electrical services engineers. Undoubtedly the capacity to replicate electrical installations in a virtual environment which affords the user the same functionality is a very interesting option.

In addressing the main research questions posed the evaluation carried out would appear to indicate the developed prototype has the potential to increase understanding of issues related to electrical safety and hence could potentially help to cut down on accidents and fatalities related to electrical shock and electrocution. It would also appear that users were receptive to using VR as a learning and design tool and the prototype model offered an acceptable interaction experience.

Additionally, from the findings of this research and previous studies, there appears to be general agreement that VR can have a strong motivational impact on users. This research suggests that this leads to a greater learning effect that evolves into a potentially greater understanding of the concept or task in hand. One could conclude from this that through the use of a well designed VR model, users will be more competent in the area under study and the net effect in this instance will be to enhance electrical safety in the built environment. However it must be noted that if the usability of the system is poor and the instructional content and tasks are flawed the ability of the system to achieve its objective will be significantly diminished. Therefore, in order to widely deploy VR for electrical safety and design, developers need to appreciate the challenges of utilising VR technology for instruction rather than relying on the novelty of the technology.

To enhance the prototype to a point where it could be successfully commercialised or integrated seamlessly into an educational module in a third level programme will require further development taking account of the feedback received via the questionnaire and debriefing sessions. To this end a number of the issues highlighted will be addressed.

A number of the user’s encountered problems navigating through the system. There were a couple of explanations to account for this. Firstly, difficulties were noted in terms of adjusting to using the arrow keys and mouse for navigation. In general this appeared to be a short lived effect and that after using the system for a period of time users overcame this control issue. However it is noted that this could add to user frustration and weaken the interaction experience. Using a control pad is a viable alternative. Secondly, some users encountered an unsmooth jumpy display navigating the scene. When this issue was discussed with the relevant users, it became apparent that they were using older machines with a reduced processing power in contrast to more modern PC's. In future versions it may be worth highlighting a minimum requirement specification, above which this problem would not be encountered as an issue.

Although many users noted their satisfaction with the representational fidelity of the system, some users did comment on how the graphics of the system should be enhanced. In making this comment, most users reflected on the contrast between this system and current video games that are on the market. It is evident from these comments that users who are familiar with these video games consider this level of detail as the perceived benchmark and the level of expected quality. To bring 'VES' to this standard would require a dedicated development team. However, it does highlight the level of detail that would be expected from the current generation and improvements in this area would undoubtedly increase the fidelity, usability and satisfaction with the system.

It must be acknowledged that desktop VR does not utilise the full 3D potential recognised in other more immersive virtual environments. However, it does offer a very useful tool for enhancing safety and training that can be widely distributed and easily accessed via a personal computer. Desktop VR also offers a proficient substitute for situations that are either impossible or too expensive to set up in a commercial company or training facility. Modern computers have added impetus as VR scenarios that previously required large and expensive equipment are now possible and graphical programming environments provide for an efficient method to develop an application. Hence the ingredients required, to make desktop VR commercially viable such as swift scene creation, platform reliability and flexibility are arguably here.

VIII. CONCLUSION

Virtual reality is identified as a rapidly developing computer based technology that is widely used for a diverse range of applications. Over the past decade, computer systems have rapidly evolved and significantly improved the quality and accessibility of virtual reality systems and also reduced the cost associated with such systems. The net effect has prepared the way for virtual reality technology to be considered in a variety of engineering areas.

The intent of electrical safety is to eliminate as far as reasonably possible the potential of electrical accidents occurring. One potential method of addressing this issue is to use virtual reality. Through a virtual environment designers can view and investigate the impact of their designs, persons can become more aware of the dangers of electricity, while a skilled person can become more informed or virtually instructed before carrying out maintenance. By providing a format to develop and address each of these elements will only serve to heighten awareness and encourage people to use safe electrical practices. It is hoped through the development of this novel prototype, that the potential of virtual reality will be exploited by the industry and the overall research findings will aid in enhancing electrical safety in the built environment which can benefit all of society.

ACKNOWLEDGMENTS

M. Barrett is supported by Dublin Institute of Technology. J. M. Blackledge is supported by the Science Foundation Ireland Stokes Professorship Programme.

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