Paper ID #19144

Development of an Educational Wind Turbine Troubleshooting and Safety Simulator

Mr. John Moreland, Purdue University Northwest

John Moreland is Senior Research Scientist at the Center for Innovation through Visualization and Simulation at Purdue University Northwest. He has over 50 technical publications in the areas of simulation and visualization for education and design.

Mr. Michael Edward Hoerter, CIVS
Mr. SHENG WANG, PURDUE UNIVERSITY NORTHWEST CIVS

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Abstract

An NSF-ATE project is being developed building upon two previous projects: 1) “Wind Tech TV”, a 2010 ATE project which created a library of online training videos for wind turbine maintenance, and 2) "Mixed Reality Simulators for Wind Energy Education", a U.S. Department of Education FIPSE project which produced a series of simulators for wind energy education. The current project is integrating a library of real scenarios with existing simulators to allow students to have hands-on experiences that would otherwise be dangerous or impractical. It includes open-ended questions for students to learn critical thinking and problem solving.

An interdisciplinary team including representatives from four community colleges (Kalamazoo Valley, Riverland, Ivy Tech, and Highland), a wind energy company (EDF Renewable), two ATE Centers (CA2VES & AMTEC), and a university research center (CIVS) are collaborating on this project. Some team members have worked together on various projects including the development of a variety of software for wind energy education and technician training. A leadership team consisting of the PIs and representatives from community colleges, industry, and ATE centers is overseeing the development and implementation of the project. Community colleges are leading the curriculum and educational module design and implementation for the simulator. Industry collaborators are advising on the skills needed in industry. CIVS is developing the simulator. Formative assessment throughout the project will enable cyclical improvements. Current status of the development and future plans are discussed.

Introduction

With the expansion of the renewable energy sector, the United States is facing a critical shortage of wind turbine technicians skilled in effective and safe troubleshooting strategies [1]. In 2015, wind energy provided 4% of the nation’s electricity and is expected to increase to 35% by 2050 [2]. In the next 5 years alone, over 15,000 new technicians will be needed. With wind energy employers already struggling to find qualified technicians, new methods of education and training are needed now to meet wind energy demands [3].Troubleshooting is a key skill that many current and prospective wind turbine technicians lack, resulting in significant downtime and lost energy production. Furthermore, the limited ability of students to apply concepts from the classroom to real world scenarios is a serious issue [4], and is compounded by hazardous conditions. Safe practices while troubleshooting are critical to preventing injury and death in the field.

This shortage of well trained technicians is expected to be mitigated largely by advanced technology education. Community colleges are making a great effort to address these issues through application of new technologies. Interactive simulators involving real-world scenarios have been identified as an effective method for preparing technicians to improve safety and enhance troubleshooting strategies to help technicians avoid “groping in the dark”, which is both inefficient and dangerous [5].

The single most important factor in learning to troubleshoot properly is extensive practice using actual or simulated systems [6]. Troubleshooting strategies, such as root cause analysis, allow technicians to fix problems efficiently, but this practice requires physical wind turbine equipment, which few community colleges possess [7,8,9]. Moreover, it is difficult to replicate some troubleshooting and safety scenarios due to safety concerns and limitations of actual systems. Research has shown that more engaging training methods, such as interactive 3D simulators, can reduce accidents and injuries more effectively than passive methods [10,11,12]. Authentic, immersive, emotional experiences within virtual learning environments have been shown to be integral to learning and retention of information, especially for safety training [13].

This project involves the development of an interactive 3D simulator incorporating fault-based troubleshooting and safety scenarios into real world situations and education modules to provide community college students with unlimited opportunities to practice and refine troubleshooting strategies while avoiding bodily endangerment. A team focused on the development of this simulator was created, composed of members from Kalamazoo Valley, Riverland, Ivy Tech, and Highland community colleges, EDF Renewable wind energy company, the committees of operation and maintenance, the American Wind Energy Association (AWEA), the CA2VES and AMTEC Advanced Technological Education (ATE) centers, and the Purdue Northwest Center for Innovation through Visualization and Simulation (CIVS). Some team members have worked together on various projects including the development of a variety of software for wind energy education and technician training [14,15,16,17]. For this project, community colleges will lead the curriculum and educational module design and implementation of the simulator, with assistance from industry collaborators who will advise on the skills needed in industry.

The proposed simulator will build upon two previous projects: “Wind Tech TV”, a previous ATE project (DUE 1003448), which created a library of online training videos for wind turbine maintenance, and "Mixed Reality Simulators for Wind Energy Education" a U.S. Dept. of Education FIPSE project (P116B100322), which produced a series of online simulators for wind energy education. The simulator will allow students to experience hands-on work scenarios that would be dangerous or impractical in traditional lab settings. It will include open-ended questions for students to exercise critical thinking and problem solving skills. The simulator will utilize Universal Design for Learning (UDL), a framework that guides development of flexible learning environments that can accommodate individual learning differences [18]. The project will also include internal and external evaluators to carry out formative assessment throughout the project to enable cyclical improvements, and summative assessment to measure success of the project. Once completed, the project is expected to have direct impact on more than 500 community college students, in addition to being used for K-12 outreach to increase interest in STEM and build the pipeline into wind energy careers.

Goals and Objectives

Goals

- To transform teaching practices in community college wind energy programs through the use of an interactive, web-based, 3D simulator for troubleshooting and safety.
- To improve the quality of the wind energy workforce to meet the critical needs of the industry.

Objectives

- To develop teaching modules for troubleshooting strategies and safety in community colleges through a web-based, interactive 3D troubleshooting and safety simulator based on real scenarios for wind turbine technician education.
- To use the simulator in existing community college courses for specific troubleshooting and safety learning objectives.
- To assess the effectiveness of the troubleshooting and safety simulator and its derivative formats for improving the learning objectives.

Learning objectives for wind turbine technician students have been provided by the community colleges with input from the industry. The simulator is designed to meet these learning objectives with activities to facilitate learning and teach troubleshooting and safety strategies to enable students to solve problems in a safe and timely fashion. A focus on instructional alignment, where the learning objectives, activities and assessments are consistent with one, will ensure that the technology is being integrated effectively to facilitate and enhance student learning. The evaluation plan is thereafter constructed to assess each of the following eight learning objectives.

As a result of participating in a unit of instruction and engaging in hands-on practice in the simulator, students should have effective troubleshooting and safety, critical thinking, and problem-solving skills needed for the wind energy industry. Specifically, students should meet the following eight learning objectives.

- Objective #1: Students will identify safety hazards in the wind turbine environment with these learning actions:
    - Students will examine and assess safety conditions in the virtual wind turbine.
    - Students will select appropriate personal protective equipment.
- Objective #2: Students will apply task-based hazard assessment with this learning action:
    - Students will examine a work plan and assess potential hazards for each task in virtual scenarios.
- Objective #3: Students will create and follow a safety plan and correct safety procedures with this learning action:
    - Students will examine existing safety plans and develop new plans in the virtual scenarios.
- Objective #4: Students will read engineering prints and interpret schematic symbols with this learning action:
    - Students will access and utilize virtual schematics within the virtual scenarios.
- Objective #5: Students will create a causal map with this learning action:

  - Students will examine existing causal maps and develop new causal maps based on the virtual scenarios.
- Objective #6: Students will use critical thinking to systematically troubleshoot issues this learning action:
  - Students will follow causal maps, take measurements, and trace potential problems within the virtual wind turbine.
- Objective #7: Students will use problem solving to demonstrate mastery of troubleshooting wind turbine systems with this learning action:
  - Students will participate in virtual fault-based troubleshooting scenarios covering electric circuits, components, PLC (Programmable Logic Controller), electric motor, mechanical systems, and hydraulic systems
- Objective #8: Students will demonstrate high-level problem solving through open-ended questions with these learning actions:
  - Given open-ended situations, students will determine the likelihood of scenario causes and prioritize actions to be made for troubleshooting
  - Students will determine the root cause of scenarios in an efficient manner.

Significance

This project addresses how to transfer knowledge from the classroom to real world situations using engaging, dynamic content and realistic simulations. The simulator's purpose is to improve troubleshooting and safety education by teaching critical thinking and problem solving for real world problems. The project will contribute to the body of knowledge on the effectiveness, perceptions, and attitudes regarding web-based interactive 3D simulators for technical education and also measure the learning that comes from the different formats (web-based interactive 3D simulators, videos, and text-based materials). An expected outcome of this project is that computer-based simulators will be increasingly used in the future for transferring learned concepts to practical applications. Specifically, a virtual wind turbine simulator can provide numerous realistic scenarios that allow students to engage in hands-on experiences that would be dangerous or impractical in traditional lab settings.

National Significance

Despite large monetary investments in wind energy, modern wind farms and individual wind turbines have lower power output and operational uptime than design forecasts, leading to the suboptimal economics of wind power [19]. The workforce does not yet exist to sufficiently optimize current wind energy systems. There are over 85,000 professionals working in the U.S. wind energy industry [20]. These professionals are responsible for the currently installed 75,000 Megawatts of wind energy capacity in the country [21]. However, as mentioned above, wind energy supplies 4% of the nation's electricity and is expected to grow to 35% by 2050, with increasing needs for skillful technicians. At the same time, the efficiency and reliability of individual wind turbines, wind farms, and related systems must also be increased. There is a need for over 15,000 new technicians over the next 5 years [3]. A significant increase in the number and quality of wind energy professionals is critical to meeting current and future demands.

Intellectual Merit

This proposed project addresses the wide-spread issue of transferring knowledge from the classroom to real world situations using engaging, dynamic content and realistic simulations. The proposed simulator not only aims to improve troubleshooting and safety education, but to also teach critical thinking and problem solving for real world problems. The project will contribute to the body of knowledge on the effectiveness, perceptions, and attitudes regarding web-based interactive 3D simulators for technical education, as well as how much learning comes from different formats (simulator, videos, and text-based materials). It is expected that interactive computer-based simulators will be increasingly used in the future for transferring learned concepts to practical applications.

Innovation

This project is innovative in two aspects. The web-based interactive 3D simulator, which integrates various real world scenarios and education modules, is based on engaging, dynamic and realistic simulations of real wind turbine geometry and behavior. It has the capability to potentially provide unlimited troubleshooting and safety scenarios based on real conditions. The input and feedback from industry will be used to ensure the technical accuracy of the turbine geometry and behavior in both physical and electrical systems. The project also innovates through comprehensive troubleshooting scenarios that include embedded safety activities, remote troubleshooting with Supervisory Control and Data Acquisition (SCADA) systems, logs, weather data, and on-site troubleshooting, using real wind turbine schematics and interactive measurement tools. It provides a platform for fault-based troubleshooting and safety using critical thinking and problem-solving strategies instead of less efficient trial-and-error.

Broader Impacts

The project seeks to provide a crucially needed and better-prepared skilled workforce for the wind energy industry. This will lead to more wind energy production, which will lessen the need for burning fossil fuel and decrease CO_2 and other pollutant emissions. It also focuses on improving technology education in general. Through dissemination efforts, such an innovative approach may be expanded and adopted by other community colleges in wind energy education and other programs. The simulator and associated teaching techniques may be later adapted for other technician fields. Finally, the developers hope to inspire K-12 students into STEM education. Through outreach efforts, K-12 students will be excited and motivated to pursue courses and careers in wind energy and other STEM fields.

Potential Replicability

One of the benefits of making the virtual simulator compatible with virtual reality systems is the ability to scale the interaction and computational display based on the availability of hardware. This enables easy transfer of the project to community colleges and schools with different computing and visualization hardware capabilities. The virtual simulator will typically be accessed online with a PC, but the simulator can also be deployed on mobile devices and virtual reality systems. The use of scripts and parameters frees users from specific configurations and allows usage in a variety of environments, ranging from computer labs, classrooms and offices, to dedicated visualization facilities. All core functionality of the software will be accessible in any configuration, with some additional interface and immersive options becoming available as needed.

Design

The U.S. Wind Energy Industry has a critical need for more wind technicians who are well-trained in troubleshooting strategies and safety. A national skills assessment by the U.S. Department of Energy indicated an expected demand for over 3,000 new wind technicians each year for the next 15 years, but 79% of employers reported difficulty in finding qualified applicants for wind technicians [22]. While troubleshooting is a critical skill needed by wind technicians to diagnose and repair problems, many technicians lack this ability and instead rely on "groping in the dark" (i.e. using trial and error without any systematic approach), which results in significant unnecessary downtime and safety issues. Currently, community college programs lack the ability to provide context for students to practice the skill on real-world problems for teaching troubleshooting strategies. A few colleges possess authentic wind turbines for this purpose, but still cannot allow for students to have unlimited hands-on experiences that would be dangerous or impractical in traditional lab settings. This context is critical for both safety and troubleshooting.

Computer simulations and virtual reality have increasingly been used as educational tools and there is a growing movement to teach and assess broader competencies more rigorously [23]. The United States military has pioneered much of the work for using computer simulation to train technicians, with many of the concepts still applying to today's technology [24]. The NSF funded the Center for Aviation and Automotive Technical Education Using Virtual E-Schools (CA2VES) to provide online learning tools. Virtual simulators have been developed in-industry as well, and have been shown to be important for learning [13,25,26,27,28,29]. While computer simulations have been shown to be effective for many learners, the Universal Design for Learning (UDL) model developed by the Center for Applied Special Technology (CAST) provides a framework that makes learning experiences more equitable and accessible to all learners [30]. This is done by addressing learning variability between individuals and suggesting alternate goals, methodologies, resources, and assessments to meet outcomes. UDL's framework is founded on the following three principles based on neuroscience research: (1) providing multiple means of representation, (2) providing multiple means of expression, and (3) providing multiple means of engagement [31]. To follow the UDL model, the web-based interactive 3D simulator will have two derivative formats (Videos and Text-based material) to provide options for better learning.

Methodology

Overview of Software Design

The task of the first year of the proposed three-year project is to build scenarios into the simulator. Extensive research and industry experience is essential to designing a working wind turbine simulator, no small part of which is the generation of detailed geometry for all of the turbine's larger systems. The primary software used for this purpose is Autodesk 3DStudio

MAX, which is an industry-standard tool for generating high quality 3D models and animations. Autodesk Maya—a program similar to 3D Studio MAX—is also being utilized to a lesser extent. For designing the programming and logic of the simulator, Unity3D is used. With it, developers are creating a virtual wind farm to serve as the environment for the virtual wind turbine that will be maintenanced.

Some of the controls that have already been developed include instructional guides that prompt users to explore the world inside the simulator, a “slider bar” that controls the movement speed of your “character” within the simulation, and a virtualized multimeter for testing current, voltage, and resistance of various electrical systems. Once the simulator reaches a basic level of functionality, it will be distributed to the four community colleges on the development panel to test its impact on learning outcomes. Student knowledge will be surveyed before and after exposure to the simulator, and the results will guide its continued development.

Creation of 3D models

While generating 3D geometric models, great care is taken to adhere to standardized measurements for each element of the turbine so as to ensure the machine fits together properly and is an accurate representation of a real turbine. Extensive documentation has been provided by industry and community college development members, allowing for the creation of detailed and accurate representations of machinery.

Figure 1: Front view (left) and side view (right) of the virtual wind turbine

The majority of the interior machinery is housed inside the nacelle, the “body” of the turbine, to which the fan-hub is connected. . The machinery, some of which is shown in Figure 2, is modeled in detail to ensure accurate representation of the nacelle interior.

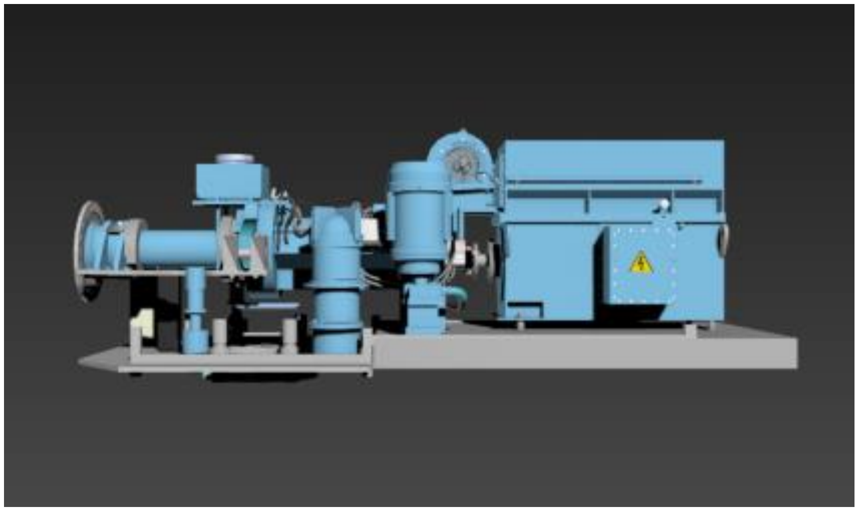

Figure 2: Machinery inside the nacelle

Finished models are then exported from 3DStudio MAX into Unity3D. All models must be assigned a material shader which “paints” the surface geometry with either a solid color or a bitmap image. The material editor is shown in Figure 3. Models that contain complex animation data must have that data exported specially using the .FBX file format, as shown in Figure 4.

Figure 3: Material editor in 3DStudio MAX

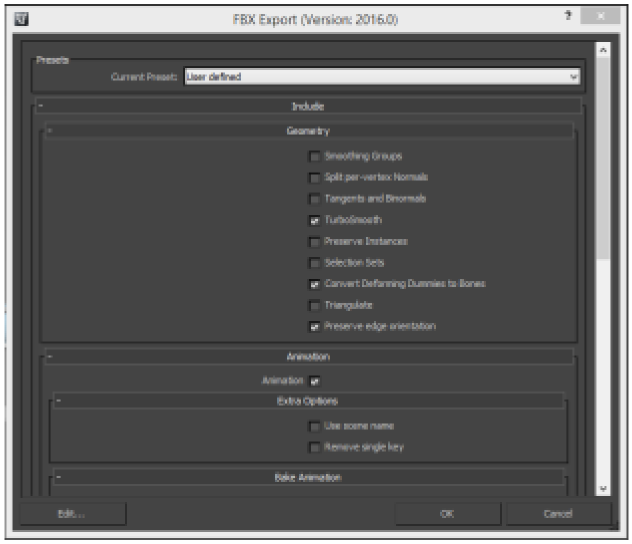

Figure 4: Export window in 3DStudio MAX

Construction of virtual simulator in Unity3D

With the preliminary geometry of the turbine and most internal systems imported into Unity3D, a graphical user interface (GUI) is programmed using the C# language.. The start screen and main menu of the simulator are shown in Figure 5.

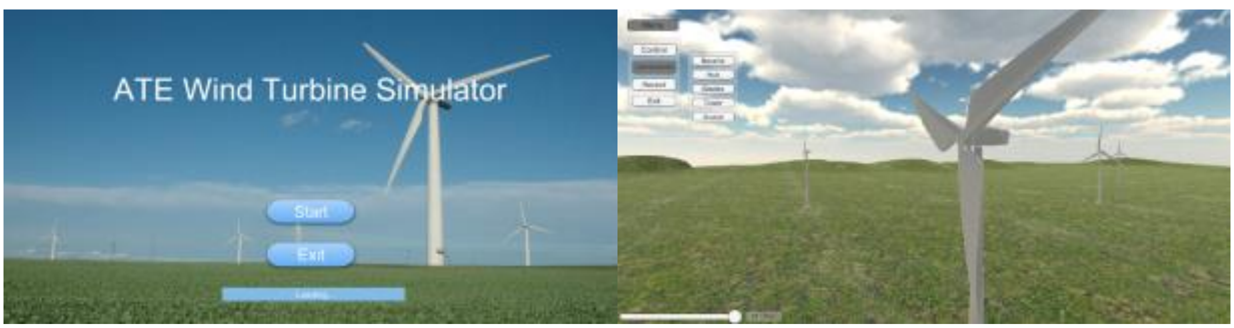

Figure 5: Start screen (left) and main menu (right) of the simulator

As the simulator is developed and new geometry is generated, new geometry can be added by using the transform values of the object, as shown in Figure 6. This allows the developer to import a modified model and ensure that it lines up perfectly with its predecessor, allowing for fast and precise revisions and improvements to be made without disrupting workflow and sacrificing time.

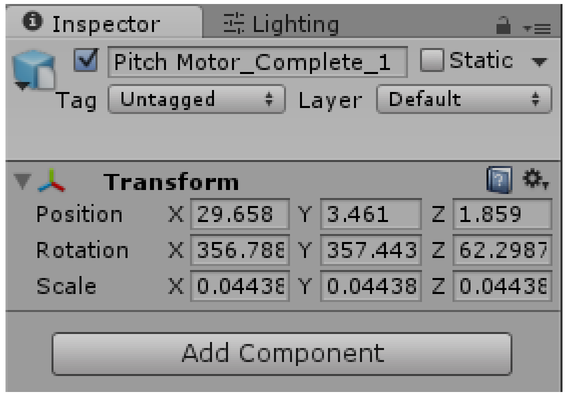

Figure 6: The transform value of a model in the simulator

Conclusion

In this paper, we detailed the dire need of skillfully trained technicians to maintenance the ever-increasing number of wind turbines being erected every year. With the strengths of a Universal Design for Learning framework and simulated training to augment existing technician training, this project aims to help colleges meet this growing need. Comprehensive surveys of student knowledge before and after exposure to the simulator will help validate its effectiveness and drive toward improving subsequent iterations of the software.

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