

Development of an Educational Wind Turbine Troubleshooting and Safety Simulator

Mr. Kyle Alexander Toth, Purdue University Northwest

Associate Research Engineer at the Center for Innovation through Visualization, 5 published papers on topics revolving around game-based training and Virtual Reality (VR) applications. Fields of expertise and study are game development and algorithms, cutting-edge VR hardware and application, and electrical systems. Currently graduated from Purdue University Northwest with a Master's of Science in Electrical and Computer Engineering, with undergraduate focuses in control systems, computer science, and applied mathematics.

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.

Prof. Chenn Q. Zhou, CIVS, Purdue University Northwest

Dr. Chenn Zhou is the founding Director of the Steel Manufacturing Simulation (SMSVC) and Visualization Consortium and the Center for Innovation through Visualization and Simulation (CIVS), Professor of Mechanical Engineering at Purdue University Northwest, and Professor by Courtesy at Purdue University West Lafayette. Dr. Zhou received her B.S. and M.S. degrees in power engineering from Nanjing University of Aeronautics and Astronautics, China, and a Ph.D. in mechanical engineering from Carnegie Mellon University, USA. She joined Purdue University Northwest in 1994 after three years of industrial experience. Dr. Zhou has more than 36 years of experience in the areas of computational fluid dynamics (CFD), combustion, energy, multiphase reacting flows, and air pollution control. She has been developing state-of-the-art CFD models and applied them to aluminum, glass, refinery, steel, and power industries. She is on the cutting edge in the integration of computer simulation and virtual reality visualization for industrial and educational applications. Dr. Zhou has conducted a large number of funded research projects totaling over \$21 million and collaborated with many experts from over 110 organizations including academia, national laboratories, and industries. Dr. Zhou has published more than 350 technical papers, five copyrighted CFD codes, and two patents. She has received numerous awards including the R&D 100 Award in 2004, the Medal Award by the American Iron and Steel Institute in 2005, the J. Keith Brimacombe Memorial Lecture Award by the Association of Iron and Steel Technology (AIST) in 2010, the 2012 Chanute Prize for Team Innovation, and the Gerald I. Lamkin Fellow Award for Innovation & Service 2017-2018, October 2017. She and her co-authors also received the AIST Josef S. Kapitan Award in 2005, 2016, and 2017, the AIST Computer Applications Best Paper award in 2006 and 2017, the 2017 AIST Hunt-Kelly Outstanding Paper Award – First Place, and the 2014 International Thermoelectric Society Outstanding Poster Award. She was named "One of 12 Most Influential over 50" by Northwest Indiana Business Quarterly Magazine in 2014. Dr. Zhou received the awards of Outstanding Faculty in Teaching, Research, and Engagement at Purdue University Northwest. Dr. Zhou has been a Fellow of the American Society of Mechanical Engineers since 2003. Dr. Zhou has been very active in professional societies. She has served as the chair of the Fire and Combustion Committee in the Heat Transfer Division of ASME and the Associate Editor of the Journal of Thermal Engineering and Science. She has chaired international conferences and organized a number of technical sessions for various conferences. She has served as a member of various boards and committees such as the AIST Foundation Board of Trustees.

Mrs. Anusree Balachandran, Center for Innovation through Visualization and Simulation

First year graduate student, studying Computer Science at Purdue University Calumet. Working as Research Student at CIVS(Center for Innovation through Visualization and Simulation), the research department of Purdue University.

Miss Fangzhou Zhang, Purdue University Northwest

Fangzhou Zhang received the degree of master of science in electrical and computer engineering in 2019 from Purdue University Northwest, Indiana. She is currently working for the Center for Innovation through Visualization and Simulation (CIVS).

Mr. John Claude Roudebush, Ivy Tech Community College

Biographical Sketch John Roudebush TITLE: PROGRAM CHAIR ENERGY TECHNOLOGY Ivy Tech Community College Lafayette, IN

A. Professional Preparation: Emergency Medical Technician Greater Lafayette Health Services Certified, 2000 Indiana University, Indianapolis IN Liberal Arts A.A., 2002 Indiana University, Indianapolis IN Labor Studies-H.D. A.S., 2003 Indiana University, Indianapolis IN General Studies B.G.S., 2003 Ivy Tech Community College, Lafayette IN Electrical Science A.A.S., 2008

United States Department of Labor-LEJATC IBEW-5-year Apprenticeship Electrician, 2009 Capital Safety Wind Energy Competent Rescue Certified, 2009

B. Appointments: 2012-present Co-PI Grant 1601707-ATE NSF- Troubleshooting and Safety Simulator for Wind Turbine Technician Education 2012-present Program Chair Energy Technology, Ivy Tech Community College, Lafayette, IN. 2009-2012 Wind Turbine Tower Wiring Foreman, Henkel's and McCoy, Blue Bell, PA. 2007-2009 Industrial Maintenance, Long Electric/Caterpillar Contract, Lafayette, IN. 2005-2007 Electrician, Twin City Electric, Lafayette, IN. 2004-2005 Utility Locator, Reliant Services, Crawfordville, IN

C. Products (0)

D. Synergistic Activities: 1) ATE National Science Foundation 3 year grant award, "Wind Turbine Safety and Troubleshooting Simulator". Duration of Grant: July 2015-present. CO-PI and key consultant on simulator development and academic curriculum. 2) Dept. of Education FIPSE Comprehensive Program. Mixed Reality Simulators for Wind Energy Education. Duration of funding: January 2011-Jun 2015. Role: Volunteer Advisor 3) Craig Porter Energy Center. Directed the construction of Craig Porter Energy Laboratory. Technology in place: Multiple Wind Turbines, Solar systems, Home Automation systems, Geothermal, Solar Thermal, Grid monitoring, Net Metering, Battery Back up, electric vehicle car charging stations, a variety of demonstrators and trainers, etc. Role: Principle Investigator 4) Energy Technology Program Ivy Tech Community College. Creation of new laboratory facilities and development of the following Ivy Tech College level courses: SUST 101: Wind Power, SUST 111: Wind Mechanical I, SUST 211: Wind Mechanical II, SUST 102: Solar, Wind, and Geothermal, SUST 280: Sustainable Energy Internship Program, ENRG 111: Smart Grid Home Integration, ENRG 112: Electrical Power Distribution, ENRG 113: Energy Storage, ENRG 114: Smart Grid Controls Infrastructure and Networking, ENRG 202: Photovoltaic System Installation, INDT 125: Industrial Wiring, INDT 204: Electrical Circuits, IMTC 122: Electrical Wiring Fundamental/NEC Code. INDT 113: Basic Electricity Role: Program Chair 5) Energy Day 2014. Directed the first Energy Day on the Ivy Tech Campus that brought 500 K-12 level students to Ivy Tech. The event also included up to an estimated 1,000 Ivy Tech students and public participants. During that day tours of multiple facilities and renewable energy systems we demonstrated, including but not limited to the Dept. of Education FIPSE Mixed Reality Simulators for Wind Energy Education. Role: Director 6) Henkel's and McCoy Midwest Wind Division. Oversaw all electrical work (Wiring, underground, fiber optics, grounding, sensors, PLCs, controls, lighting, power, generation, troubleshooting, commissioning, etc.) and participated initially in the original construction of a variety of Industrial Sized Wind Turbines and Wind Farms, including, but not limited to Meadow Lake Wind Farm: 47 2.1 MW Suzlon Wind Turbines; 121 Vestas V82 1.65 MW Wind Turbines; 69 General Electric 1.5 MW Wind Turbines. Pioneer Trail Wind Farm: 94 GE 1.6 MW Wind Turbines. Settlers Trail: 94 GE 1.6 MW. Gratiot Wind Farm: 69 GE 1.6 Wind Turbines. Laurel Mountain Wind Farm: 61 GE 1.6 MW Wind Turbines. Bishop Hill Wind Farm: 134 GE 1.85 MW and 1.5 SLE MW Wind Turbines. Role: Wind Turbine Tower Wiring Foreman

Development of an Educational Wind Turbine Troubleshooting and Safety Simulator

Abstract

This project is developing a web-based, interactive 3D simulator for community college wind energy technician training programs. Directly contributing to the current project are two previous wind energy projects: “Wind Tech TV,” a 2010 NSF Advanced Technological Education (ATE) project that compiled a library of online training materials for wind turbine technician training, and “Mixed Reality Simulators for Wind Energy Education,” a U.S. Department of Education Fund for the Improvement of Postsecondary Education (FIPSE) project that produced a series of simulators for wind energy educators and students to provide hands-on experiences and promote critical thinking. The new simulator is designed to teach troubleshooting and safety strategies, promote critical-thinking and problem-solving skills, and enhance the transfer of knowledge from classrooms to real-world situations. Learner immersion in a simulated environment and progression through numerous troubleshooting scenarios is expected to provide a better-prepared and more skilled workforce for the wind energy industry. Multiple community colleges, a wind energy company, two NSF ATE Centers, and a university research center comprise the multi-disciplinary team working on this project. Community colleges are leading the curriculum and educational module design and implementation, industry collaborators are advising on needed skills and recommended activities, and the university research center is developing the software. Data from implementation in one community college so far show a 10% score increase for students using the simulator compared to traditional instruction alone.

Introduction

As renewable energy expands, there is an increased need for trained personnel who can work on the increased number of devices and systems being used in fields like solar, wind, and hydrokinetics effectively and safely [1]. For a sense of scale in the growth of wind in the scheme of US energy production, it can be seen that in 2015, the percentage of energy coming from wind in the US was approximately 4% [2]. As of the end of 2017, the percentage had changed to 6.3% [3]. That means in just two years, we have seen a significant increase in wind energy, which is only projected to increase based on the initiatives from the US Department of Energy [2]. With this rapid expansion, employers that are maintaining this equipment will need to hire increasing amounts of technicians, meaning that the current training and education for those technicians will need to keep up. Tools to help those instructors and educators giving this training become increasingly important. One of the most important things to reinforce during the education process before it becomes a problem are proper troubleshooting techniques. Many problems caused from improper repair and unnecessary downtime come from improper troubleshooting technique, and can be addressed in training. Trying to improve the relation of ideas learned in the classroom to how they are applied is also a problem to be tackled in the classroom [4].

The most important factor that has been identified in learning to troubleshoot probably is using actual scenarios to practice on using actual or simulated systems [5]. However, getting access to

physical wind turbine equipment is usually difficult or impossible at some locations [6], [7], [8]. Also, some situations are hard to replicate due to some limitations on factors like safety concerns for inexperienced technicians, rare occurrence rates, or difficulty to reproduce artificially. Research has shown that interactive simulation software can be a viable way to practice tasks in a safe environment and can improve learning outcomes compared to passive methods [9], [10], [11]. Active learning methods have been shown to provide better experiences and retention of information, particularly in the field of safety [12].

This project is based in the development of an interactive 3D simulator incorporating fault-based troubleshooting and safety topics into real world scenarios and education modules to provide community college students with unlimited opportunities for practice at the convenience of having a computer or laptop with at least some CPU and GPU power. A team composed of members of multiple community colleges like Riverland CC, IvyTech CC, and Kalamazoo CC, as well as other members from Purdue University Northwest, and the CA²VES and AMTEC ATE centers. Some members have worked on previous projects that deal with a variety of software in education and technician training, particularly dealing with wind energy and renewables in general [13], [14], [15], [16]. The community colleges are leading the curriculum and module design and are testing the simulator, while Purdue leads development, and the ATE centers offering advice along the way.

The simulator builds upon two previous projects: “Wind Tech TV” (Figure 1), which was a previous ATE project (DUE 1003448), which made a library of online training videos for wind turbine technicians about different areas of maintenance, and “Mixed Reality Simulators for Wind Energy Education” (Figure 2) a US DoE FIPSE project (P116B100322), which produced a suite of simulators online for wind energy education. It allowed hands-on education scenarios that would be harder to explain using text and visual representation of abstract concepts. The simulator is utilizing Universal Design for Learning (UDL), to accommodate individual learning differences [17]. Internal and external evaluators will carry out formative assessment to enable improvements, and summative assessments to see the success of the simulator over time. Once the project heads to completion, it is expected to have impacts on multiple community college renewable energy programs with wind components, in addition to being used for K-12 outreach to increase interest in STEM fields and renewable energies.



Figure 1: Former WindTech TV Homepage

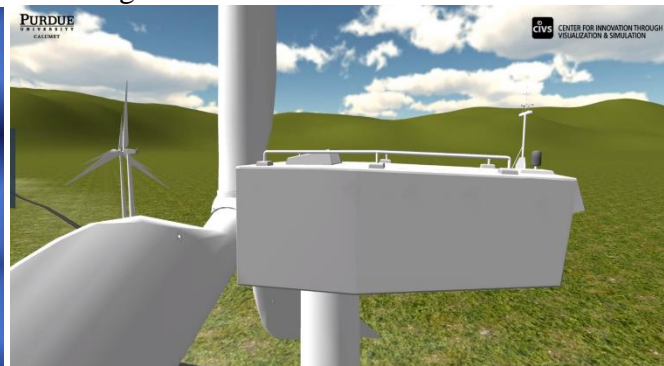


Figure 2: Image from FIPSE Mixed Reality Simulators for Wind Energy Education

Goals and Objectives of the Project

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.

Specific learning objectives targeted in the project were provided by the collaborating community colleges after various discussions. The simulator is being designed to meet these learning objectives with activities to facilitate timely and safe learning. A focus on alignment with existing teaching methods will ensure that the software and any technology is well integrated and enhances existing training.

After discussion between all involved parties, the following learning objectives and associated learning actions were chosen for student educational program development and assessment:

- 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.

Project Significance

This project tries to address ways to take classroom knowledge and apply it to real world scenarios using virtual content that allows students without ready access to physical equipment practice things learned in class on a virtual system either with the instructor or self-paced from their own computer. The project will contribute to the body of knowledge on the effectiveness, perceptions, and attitudes regarding interactive 3D simulators for technical education and also measure the learning that comes from the different formats (interactive 3D simulators, videos, and text-based materials). The expected outcome of this project is that computer-based simulators will be increasingly used to apply classroom concepts to real-world applications. In this case, a virtual wind turbine can provide numerous realistic scenarios that allow students to engage in hands-on experiences that would be dangerous or impractical otherwise.

National Significance

Despite investment in wind energy, modern wind farms and individual wind turbines have lower output and uptimes than planned forecasts, leading to non-optimal return on investment [18]. Improving the workforce will be one avenue to deal with these issues. There are currently over 85,000 people involved in the wind energy industry [19]. They are all tasked with installing and maintaining over 83,000 Megawatts of energy capacity in the current wind energy infrastructure [20]. Reliability and efficiency of individual turbines, wind farms, and related systems becomes more important over time, and the need for even more skilled technicians to tackle this becomes necessary [21].

Intellectual Merits

This project attempts to address the issue of transferring knowledge from classroom learning to real world applications. The use of interactive dynamic, content aims not only to improve troubleshooting and safety awareness, but also help teach critical thinking and problem solving skills. By the end of the project, surveys and classroom testing will hope to contribute to the

body of knowledge in the fields of educational applications of web-based interactive 3D simulators for technicians, as well as the effectiveness of active and interactive learning methods versus passive methods. It is expected that more interactive training methods, while they have started to wear out novelty in the gaming space, still have plenty of potential to grow in both corporate and education sectors for training purposes.

Innovation

There are two avenues of innovation this project explores. The first is making a web-based interactive 3D simulator, which integrates real-world scenarios and education modules. While this on its own may not be a novel idea, the subject matter of wind energy and the potential output platforms lend to make this project relatively new in its field. The second is the creation of virtual troubleshooting in the software using tools like Personal Protection Equipment (PPE) selection and basic safety, virtual multi-meter usage, and use of Supervisory Control and Data Acquisition (SCADA) systems. It provides a platform for troubleshooting and safety training that encourages critical thinking and problem-solving instead of less effective trial-and-error.

Potential Impacts

The improvement in the workforce for the wind energy industry is an important step for renewable energy. It will lead to better, more efficient wind energy, which can decrease the need for fossil fuels as wind picks up more share of the energy consumption in the country. It also focuses on improving technology education in general, by setting an example for potential virtual learning in the future. Dissemination of the project will allow multiple community colleges to use the software or become inspired to do similar works. Finally, the software will give us an outlet to reach out to K-12 students, increasing STEM awareness and interest in renewable energies.

Potential Replicability

One of the benefits to making the simulator in Unity, as will be described in the methodology, is the ability to scale interaction and platform based and the availability of hardware. This enables the easy transfer of the project to platforms like Mac OS, Windows, Mobile Devices, and WebGL. This means that there are plenty of options for deployment in a variety of environments. These could be ranging from someone's personal PC, to their MacBook, to their tablet, to classroom computers, to VR labs. All the core functionality of the software can be accessible in any configuration, as long as the desire and resources are available.

Design Philosophy

Wind energy in the US has a critical need for additional wind technicians properly trained in troubleshooting strategies and safety. A national skills assessment made by the U.S. Department of Energy indicated that there will need to be long term growth, especially as companies growing in wind energy have growing problems finding qualified technicians [22]. While troubleshooting is a critical skill in the field, many technicians tend to lack comprehensive skills and “grope in

the dark” (i.e. using basic trial and error without any cause & effect analysis or logical reasoning), which can easily result in unnecessary downtime and safety issues. Currently, many community college programs lack the ability to give a viable platform to have hands-on experience with the topics learned in the classroom. A few colleges may have access to physical wind turbines or test rigs, but that does not allow for all students to have nearly-unlimited access to all the hands-on experiences and situations that may come up in the workplace. This is the context for the focus on troubleshooting and safety in the simulator.

Computer simulations and virtual reality have seen increased use as educational tools and there is a growth in interest to use these to teach and assess broader competencies more rigorously [23]. The NSF funded ATE center, the Center for Aviation and Automotive Technical Education Using Virtual E-Schools (CA²VES) provides a good example of educational facilities doing similar work. Virtual simulators have also been developed in-industry and have been shown to improve learning outcomes [24], [25], [26], [27], [28]. While computer simulations have proven to be effective in many cases, a Universal Design for Learning (UDL) model has been developed by the Center for Applied Special Technology (CAST), providing a framework that makes learning experiences more accessible to all learners [29]. This is done by addressing the learning variability between individuals and suggests the use of alternate goals, methodologies, resources, and assessment styles to boost learning outcomes. UDL’s framework is founded on three principles based in neuroscience research:

1. Providing Multiple Means of Representation – There are plenty of ways for the user to gather information to draw possible conclusions
2. Providing Multiple Means of Expression – Making the experiences open-ended can allow for multiple paths to the same end result
3. Providing Multiple Means of Engagement – By providing multiple modules, students can use what works best for them

In order to follow this model, the simulator will make use of two primary outlets (Open-ended simulated scenarios and Video/Text reference materials) to provide multiple options for students to learn concepts covered in the simulator.

Methodology

Overview of Design Process

The simulator is being designed in the virtual space using common components to modern day game development, only in this case to create an educational software instead of just a game for pure entertainment. Extensive research and industry experience is needed to guide and design a working simulator, as well as a variety of tools both commercially and personally available. Here is a list of some of the software being used in the production of the simulator, at least in terms of creation:

- **Autodesk 3Ds Max** – a software used for making 3D models of assets used in the virtual environment, as well as provide a platform to map 3D textures and animations, in some cases, frame by frame renders for
- **Adobe Photoshop** – a photo-editing software that is used to make User Interface assets for the simulator and create basic textures for use in the 3D modelling software
- **Substance Painter** – a software used to generate material textures for 3D models that may need things like weathered effects, and can be used like a 3D painting program
- **Unity 3D** – an open-source game engine used to combine assets modeled in 3D Max and provide an outlet to code various interactions, and a publishing software that allows for multiple output platforms
- **MonoDevelop** – an open-source coding platform bundles with Unity that is used to code and compile C# and JavaScript scripts for use as assets in the Unity 3D game engine, and is currently being phased out by Unity in favor of using Microsoft Visual Studio with a Unity-based plugin to import Unity libraries
- **Microsoft Visual Studio** – Microsoft coding platform used in this case to develop script assets for Unity alongside MonoDevelop

Overview of Workflow

The overall workflow for the simulator is very circular. There are many stages that go back to literature and reference sources, and feedback from the collaborators is also a big factor in many stages of development (Figure 3). The stages of the process can be broken down into the following steps/processes:

- **Literature Review/Reference Review** – This stage is pretty self-explanatory, but is probably most important step in the creation process. Part of the literature review was going through the previous work done in the previous two projects mentioned in the introduction and information provided by the collaborators in the form of schematics used in the classroom, physical simulators, reference images, and contacts in the industry. These are referenced constantly at all stages of modelling and scripting, and are updated as the project needs.
- **3D Modelling/Texturing** - This stage involves the development of the development of the CAD models and other assets to be used in the construction of the virtual environment in Unity 3D. This also includes any pre-built assets and models that need to be acquired from the Unity Assets Store through the interface in the game engine interface. Texturing the models also happens at this stage, which in some cases requires the use of not only the 3D modelling software, but third party programs like Adobe Photoshop to do basic photo editing and Substance Painter to do some 3D texture sculpting.
- **Scripting/Interaction Behavior** – This stage involves using C# programming in either MonoDevelop or Microsoft Visual Studio with Unity’s built-in code libraries. Here, all the behaviors and functionality of the simulator are coded to work and can be used in the Unity 3D engine to bring parts of the environment to life or be able to interact with it in a

meaningful way. These will eventually make their way into Unity 3D and be used with the models and assets from the 3D modelling software in the Unity 3D interface.

- **Developing the Virtual Environment** – This stage involves all of the Unity 3D development. It involves taking inputs from both the 3D Modelling software and the built-in Unity Assets Store to piece together a virtual scene, as well as coding and scripts from MonoDevelop and Visual Studio. This can eventually be outputted using the built in compilers to multiple build platforms like WebGL, Windows PC, or MacOS. The majority of the overall software development happens here.
- **Collaborator Feedback** – At most stages of the project, progress and short term goals are presented to a committee made up of instructors from the involved community colleges for immediate feedback and additional guidance.
- **Student Testing** – During stages of the development, when it is appropriate for use based on the curriculum of the community colleges, there may be a prepared version of the software at the current stage of development meant to be classroom tested, and feedback regarding the user experience and user expectations, which then influences new changes for the software.

Current Completion Progress

The current state of the simulator has several implemented features at this stage of development. The components of the software currently developed, pending any changes to accommodate additional information or scenarios, are the following:

1. **Main Menu** – The user can navigate the many options available by navigating through the menu the user is presented with from the very beginning of the software (Figure 4). The user has options to select from many things here, from the troubleshooting scenes, to the reference materials, and the customization features. Over time, these are expected to be changed to accommodate any additional features or modules that are developed for the project.

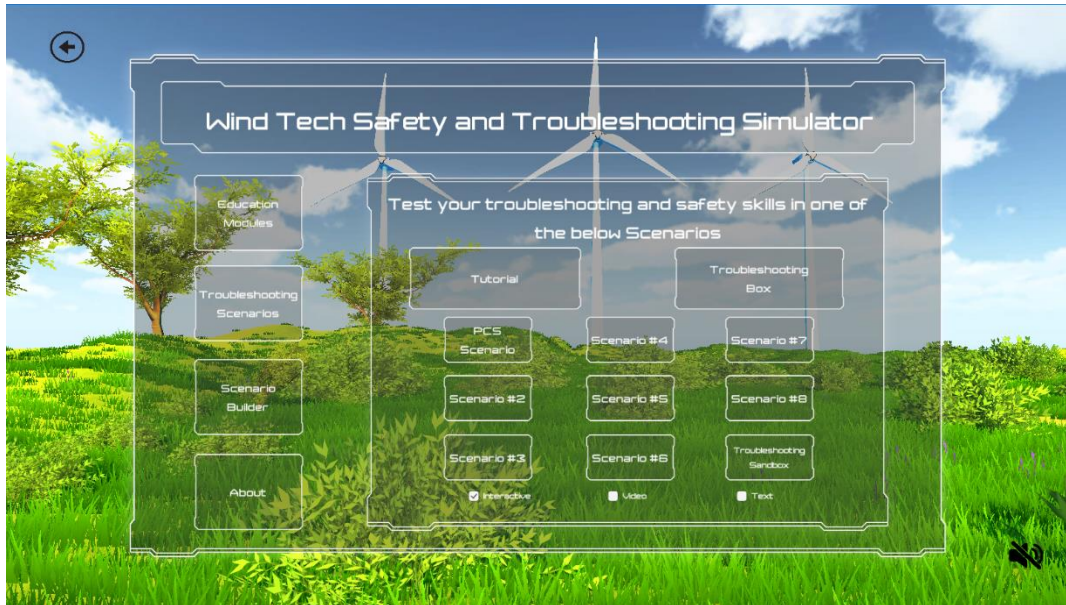


Figure 3: Screenshot from the Main Menu in the Software

2. **Educational Reference Modules** – One of the features that has already been implemented in an early form are the internal reference material. The goal of these is to tackle trying to bridge the gap in some areas of knowledge that the user may not be privy to initially that will be useful while using the troubleshooting simulator. Right now, the currently implemented module covers driving safety topics that is covered in a format much like an online Learning Management System (LMS). The user gets to navigate through a series of slides at their own speed (Figure 4) and eventually take a quiz over the content to gauge their comprehension. This data can then be recorded locally so that the user can keep track of which modules have been individually completed when looking at the module selections.



Figure 4: Image of Driving Safety Module

- Troubleshooting Scenarios** – Another one of the features that is currently implemented in the software are actual troubleshooting scenarios. The development of these is currently being guided by the instructors from the community colleges that are part of the technical committee and implemented by developers at Purdue Northwest. These cover some important systems that are general parts of every wind turbine like Pitch Control Systems (PCS), Power Distribution, Programmable Logic Controllers, and many others. Currently, the implemented scenario in the software is based around components of the PCS and the surrounding systems in the Hub of the wind turbine (Figure 5). The user receives a notification from a central warehouse about a SCADA reported error in the PCS of a turbine and has to go investigate. Through reading of IEC schematics, and use of a virtual multi-meter, the user tries to identify and report the issue and proposed solution. These are then output into report files on the local machine that can then be sent to an instructor for review. Moving forward, as more topics are introduced, functionality will be increased to include more systems.

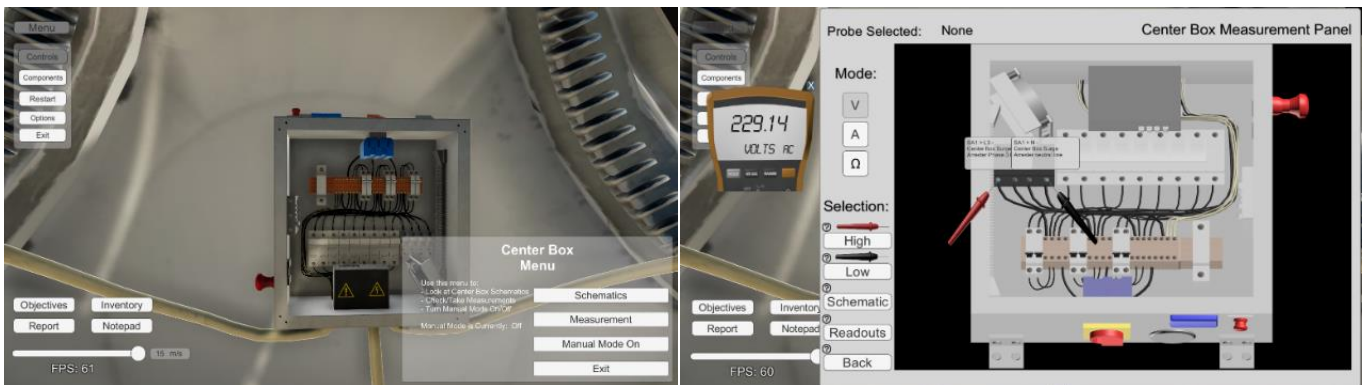


Figure 5: Pictures of the Troubleshooting Scene

- Customizable Scenario Builder** – The last of the large currently implemented features is the ability for customizable scenarios. Very early in the project, it was identified that in order to ensure the longevity and usefulness of the software, making the features that exist customizable to be compatible with multiple curriculums. In this case, we have created the skeleton for a framework that allows the user/instructor to navigate menus to change values for different measurement nodes on different pieces of equipment to emulate different scenarios (Figure 6). The end result is an outputted spreadsheet that can be loaded into the software to reproduce your desired scenario. At the end of the project, this will allow instructors to continue to use the simulator in new ways that were never even considered during the design process.

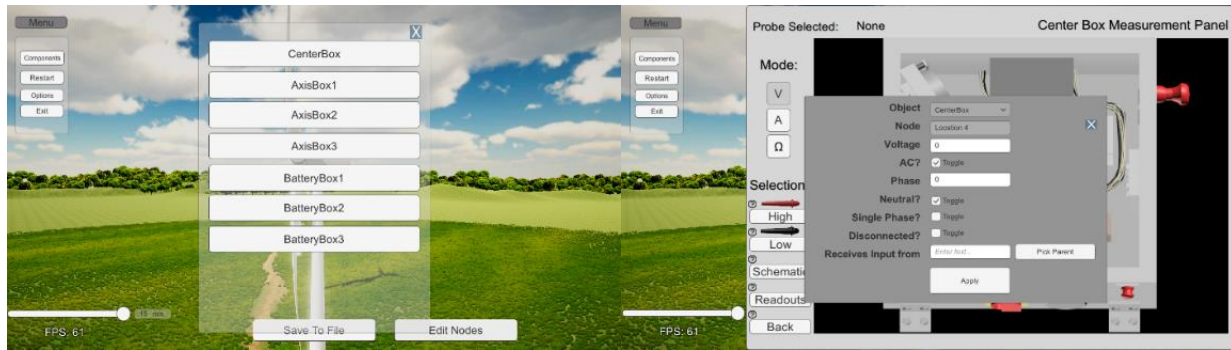


Figure 6: Custom Scenario Builder

Current Development Areas

Right now, there are two aspects that are being looked at for current feature development to enhance the troubleshooting of the simulator. One would be the incorporation of Personal Protection Equipment and more interactive safety topics, and the other would be the inclusion of a virtual SCADA system for the user to interact with in the troubleshooting scenarios. These will be explored in more detail with background information on what they are and why they are important to the project.

Wind Technician Safety

Part of learning about performing maintenance and repairs on wind turbines is learning how to perform the maintenance and repairs safely. Because of the recent development of the wind industry, it seems that increasing workforce sizes are performing increasingly complex tasks, which introduce new safety hazards in increasingly large and complex turbines [30]. Appropriate safety practices save lives, and reinforcing those practices needs to happen at all stages of training is important, and this simulator is no different.

In the simulator, work is being done to approach this from two potential angles. The first system is the previously mentioned educational reference modules to allow the user to get entry level information, the second system that is currently under development is the ability to enact these topics in the actual simulator for practice. The user will select from different PPE choices in the centralized warehouse based on the type of work they will be performing and making sure that once they have arrived at the tower that needs maintenance, using the equipment correctly. The current safety topics that are the focus of current development are arc flash safety and fall protection, which are very serious concerns in the current workforce.

Virtual SCADA System

Supervisory Control and Data Acquisition software (SCADA) is a system of software that allows users in industrial applications to do some of the following:

- Controlling processes locally and/or remotely
- Monitoring, gathering, and processing real-time data
- Directly interface with many devices using IoT devices and human machine interfaces
- Interact with logs and log files

SCADA systems are crucial in many industries since they allow more streamlined decision-making, communication, and downtime mitigations. Modern SCADA systems allow access to real-time information from almost anywhere in the world, making access to data driven decisions much easier and faster than ever before.

In the application of Wind turbines, SCADA systems offer a very large assortment of different data spreads and sensor data to view either locally at each of the individual wind turbines or the whole system from a centralized location. This allows a user to get some information regarding each of the virtual turbines and see what error codes are being read out for any turbines that are in fault. This is a very big part of remote troubleshooting and identifying the type of work and equipment needed for the repairs needed during downtimes. Knowing how to use the SCADA system is a skill for identifying causes for issues that in some cases is overlooked in some training programs, and the simulator wants to address this.

Future Work and Conclusions

As was previously mentioned, most if not all the functionality of the simulator will continue to be developed over time. The direction will continue to be guided by the Community College renewable energy program programs that are involved in the project. The project intends to tackle many learning objectives and address them in a way to positively influence learning outcomes, particularly at colleges that lack the physical resources to reproduce the experiences physically for training. Going into the last phases of the project, testing in classrooms and trying to make the currently included features as polished as possible is becoming priority, and potentially look for other long-term funding to continue long term development is now underway.

References

1. S. Tegen, *Growing a Wind Workforce: The National Wind Energy Skills Assessment Report (Poster)*. No. NREL/PO-5000-61251. National Renewable Energy Laboratory (NREL), Golden, CO., 2014.
2. "Wind Vision: A New Era for Wind Power in the United States," <https://energy.gov/eere/wind/maps/wind-vision>, 2015 (accessed January 2017).
3. "AWEA U.S. 2017 Market Reports" <https://www.awea.org/resources/publications-and-reports/market-reports/2017-u-s-wind-industry-market-reports>, 2017 (accessed December 2018)
4. D. Billing, "Teaching for Transfer of Core/Key Skills in Higher Education: Cognitive Skills," *Higher education* 53.4 (2007): 483-516.
5. E. Lamos, M. Simon, and M. J. Waits, "A Sharper Focus on Technical Workers: How to Educate and Train for the Global Economy," *NGA Center for Best Practices* (2010).
6. N. Morris and W. Rouse. "Review and evaluation of empirical research in troubleshooting," *Human factors* 27.5 (1985): 503-530.
7. T. Milfont and R. Fischer. "Testing Measurement Invariance Across Groups: Applications in Cross-Cultural Research," *International Journal of Psychological Research* 3.1 (2015): 111-130.
8. K. Kapur and M. Pecht. *Reliability Engineering*, John Wiley & Sons, 2014.
9. M. Burke, et al., "Relative Effectiveness of Worker Safety and Health Training Methods." *American Journal of Public Health* 96.2 (2006): 315-324.
10. J. Assfalg, A. Del Bimbo, and E. Vicario. "Using 3D and Ancillary Media to Train Construction Workers." *IEEE MultiMedia* 9.2 (2002): 88-92.
11. M. Filigenzi, T. J. Orr, and T. M. Ruff. "Virtual Reality for Mine Safety Training." *Applied Occupational and Environmental Hygiene* 15.6 (2000): 465-469.
12. T. Reiners, et al. "Authentic, Immersive, and Emotional Experience in Virtual Learning Environments: The Fear of Dying as an Important Learning Experience in a Simulation," 2014.
13. T. Okosun, et al. "Development of a Wake Simulator for Wind Energy Analysis." *Proceedings of the Conference on Summer Computer Simulation*. Society for Computer Simulation International, 2015.
14. J. Moreland, G. Dekker, T. Okosun, X. Wang, C. Zhou, "Virtual Training for Wind Turbine Technicians" AWEA Wind Power Conference, Las Vegas, NV. May 5-8, 2014.

15. J. Wang, J. Moreland, Y. Liu, H. Zhang, H. Pan, Y. Li, G. Zhang, M. Du, C. Zhou, "Virtual Wind Turbine for Augmented Reality Gearbox Inspection". *Proceedings of WorldComp 2015 International Conference on Modeling, Simulation and Visualization Methods (MSV'15)*. Las Vegas, NV, July 27-30, 2015.
16. J. Moreland, et al., "Development and Pilot Implementation of a Virtual Wind Turbine Simulator." *American Wind Energy Association WindPower Conference*. Atlanta, GA. 2012.
17. D. H. Rose and A. Meyer, *Teaching Every Student in the Digital Age: Universal Design for Learning*. Association for Supervision and Curriculum Development, 1703 N. Beauregard St., Alexandria, VA 22311-1714, 2002.
18. A. Kusiak, Z. Haiyang, and S. Zhe, "Models for Monitoring Wind Farm Power." *Renewable Energy* 34.3 (2009): 583-590.
19. "AWEA Wind Energy Facts at a Glance", <http://www.awea.org/Resources/Content.aspx?ItemNumber=5059&navItemNumber=742>, 2010, (accessed January 2017).
20. "U.S. Wind Energy EIA Audit 2017", <https://www.eia.gov/tools/faqs/faq.php?id=427&t=3>, 2018, (accessed January 2018)
21. M. Leventhal, and S. Tegen, "A National Skills Assessment of the US Wind Industry in 2012," *National Renewable Energy Laboratory*, 2013.
22. D. A. Damassa and T. D. Sitko, "Simulation Technologies in Higher Education: Uses, Trends, and Implications." *ECAR Research Bulletin* 3, 2010.
23. A. Lesgold, "SHERLOCK: A Coached Practice Environment for an Electronics Troubleshooting Job," 1988.
24. J. Moreland, S. Dubec, T. Okosun, X. Wang, C. Zhou, "A 3D Wind Turbine Simulator for Aerodynamics Education," *Proceedings of the ASME International Mechanical Engineering Congress & Exposition, IMECE*, San Diego, CA, November, 2013.
25. D. Fu, et al., "Integration of Numerical Simulation Data with Immersive 3D Visualization." *Proceedings of the International Conference on Modeling, Simulation and Visualization Methods (MSV)*. The Steering Committee of The World Congress in Computer Science, Computer Engineering and Applied Computing (WorldComp), 2013.a
26. M. I. Zelaya, et al., "Technology Education E-Learning Model: The South Carolina partnership." *American Society for Engineering Education*. American Society for Engineering Education, 2011.

27. A. Strelzoff, T. Sulbaran, and L. Duckworth, "A Survey of Virtual Crane Simulation." *Seventh LACCEI Latin American and Caribbean Conference for Engineering and Technology*, 2009.
28. D. M. Gaba and D. Raemer, "The tide is turning: organizational structures to embed simulation in the fabric of healthcare," *Simulat Healthcare*, 2007.
29. UDL on Campus, <http://udloncampus.cast.org>, 2014, (accessed January 2017).
30. "Strategies for Safety in the Wind Industry", <https://incident-prevention.com/ip-articles/safety-in-the-wind-industry>, 2018, (accessed January 2018)