DEVELOPMENT AND FIELD TEST OF A WEB-BASED MULTIMEDIA SIMULATION AND VIRTUAL LABORATORY FOR WIND TURBINE MAINTENANCE TECHNOLOGY

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Abstract

This paper describes the results of the development and field tests of a Virtual Laboratory for wind turbine maintenance technology funded by the National Science Foundation under NSF Award Number 1003448. Internet-based and on-demand streamed digital videos combined with interactive Adobe Flash animations and simulations were developed to form the virtual laboratory. Findings from both descriptive and inferential statistics on the results of a series of field tests using pre- and post- tests with control and test groups revealed significant cost and pedagogical advantages of the development as an example of computer applications in education.

The Need

The second-largest new resource added to the US electrical grid in terms of capacity, wind power ranked only behind natural gas fired plants, but ahead of new coal. Nationwide, soaring demand for wind power spurred the expansion of wind turbine manufacturing and installations [1].

It is projected that by 2030, approximately 180,000 people will be directly employed by the wind industry. More than 500,000 jobs are forecast to be supported by the industry, making wind power a significant part of our national economy [2].

The availability of a quality workforce in the wind turbine field will be crucial, and colleges that offer wind turbine technician training will be instrumental in meeting the demand. Currently, at least 100 renewable energy programs exist nationwide, and wind power technician curricular standards are emerging.

The wind technology field is evolving, and the selection of materials on wind technology is limited. In order to accelerate the output of skilled wind turbine installment and maintenance technicians, curriculum infrastructure needs to be installed and shared among institutions.

This paper describes a virtual laboratory as developed, and the results of its field tests, which aimed to supplement and complement the current wind turbine curriculum with enhanced cost and pedagogical efficiency.

The Development

Six modules of the virtual laboratory have been developed covering the yaw system, high strength bolt maintenance, fiber optics, hydraulics, wind turbine physics, industry report, which are now accessible at ***http://www. windtechtv.org***

The yaw system module included introduction to yaw systems, yaw brake hydraulics, yaw system controls, yaw sensor operation, reduction gearbox operation, and yaw ring installation.

The high-strength bolt maintenance module introduced fastener fundamentals, fastener identification codes, wind turbine bolt preload, wind turbine torque procedure, alternatives to bolt preloading, and the hydraulic wrench use.

The fiber optics module focused on physics of fiber optics, fiber optics fundamentals, and working with plastic optical fiber. The hydraulics module is an online course consisting of on-demand streamed videos.

The wind turbine physics module covered concepts and principles of solid strain and stress, fluid viscosity, heat transfer, gearbox vibrations, blade force and stress analyses, gyroscopic force during yaw movement, and frictional forces in the main shaft and yaw braking.

Lastly, the industry report module covered Borescope inspection, the demonstration of the Everest XLG3 video probe, and wind turbine grounding.

With the on-demand and streamed video series, functional and procedural principles of wind turbine maintenance are demonstrated under normal and malfunction conditions, designed to foster students' comprehension and appreciation, as well as a strong sense of responsibility for human and equipment safety, by demonstrating the disastrous consequences of inadequate maintenance or operations.

Under the wind turbine physics module, animated and interactive Flash movies and simulations show the concepts and principles of fundamental engineering science and their relevance to wind turbine maintenance practices, where realistic multimedia documentations of the wind turbine maintenance procedures are juxtaposed with schematic, and sometimes with microscopic views and simulated scenarios, for the concepts and systems being studied, illustrating the scientific nature of the processes, epitomizing the ideal of using virtual reality to complement and enhance the traditional educational laboratory reality. Interwoven with the revealing technical and procedural knowledge is the socioeconomic and intellectual impetus to self-motivated learning, practice, and discovery.

The development activities have been guided and motivated by the principle and the pursuit of learning efficiency, which includes time efficiency, cost efficiency, intellectual and emotional efficiency of learning, in a multidimensional approach to the development of the procedural, technical, scientific, social-economic, and intellectual skills [3],[4],[5],[6].

The following figures are some of the screen examples of the virtual laboratory. Figure 1 is a video still that shows a typical yaw sensor that functions to provide the positioning data during the yaw movement. Figure 2 is an animation still on the incremental encoders that convert the angular position or motion of the yaw to digital codes. Figure 3 is a screen example in gearbox force and stress analyses under the wind turbine physics module, illustrating the change of stress distribution along the contact area of the engaging teeth of the gears.

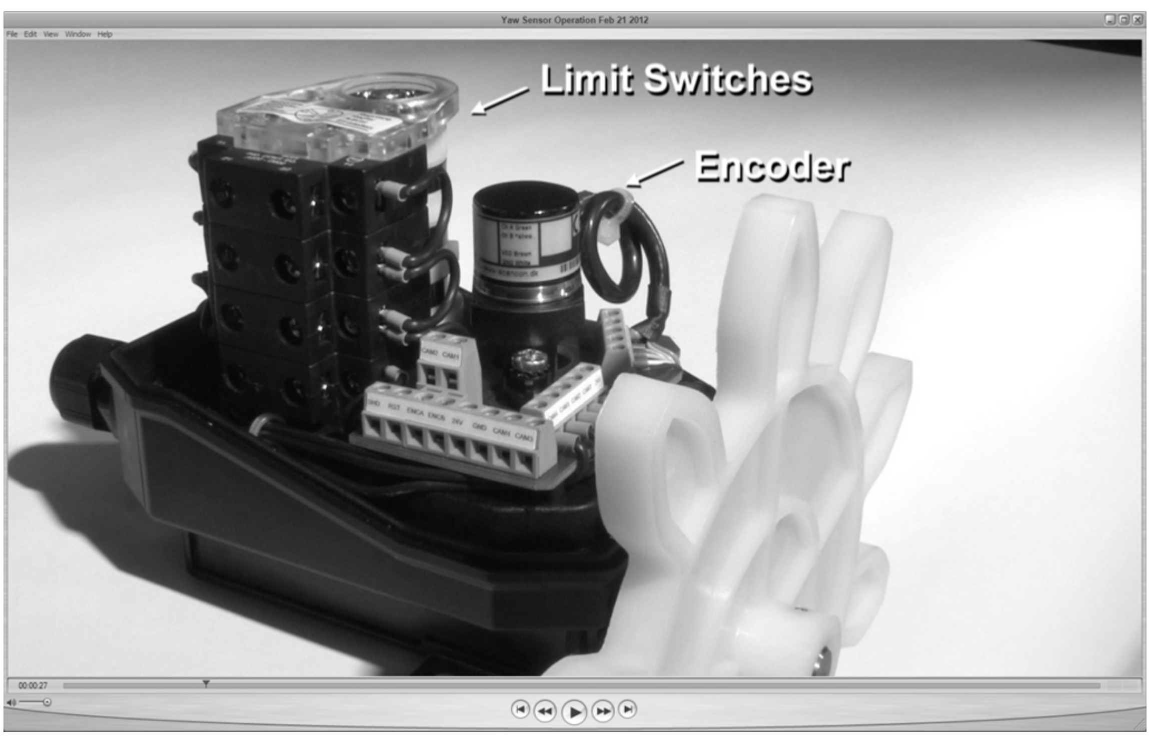

Figure 1 - Wind Turbine Assembly Yaw Sensor.

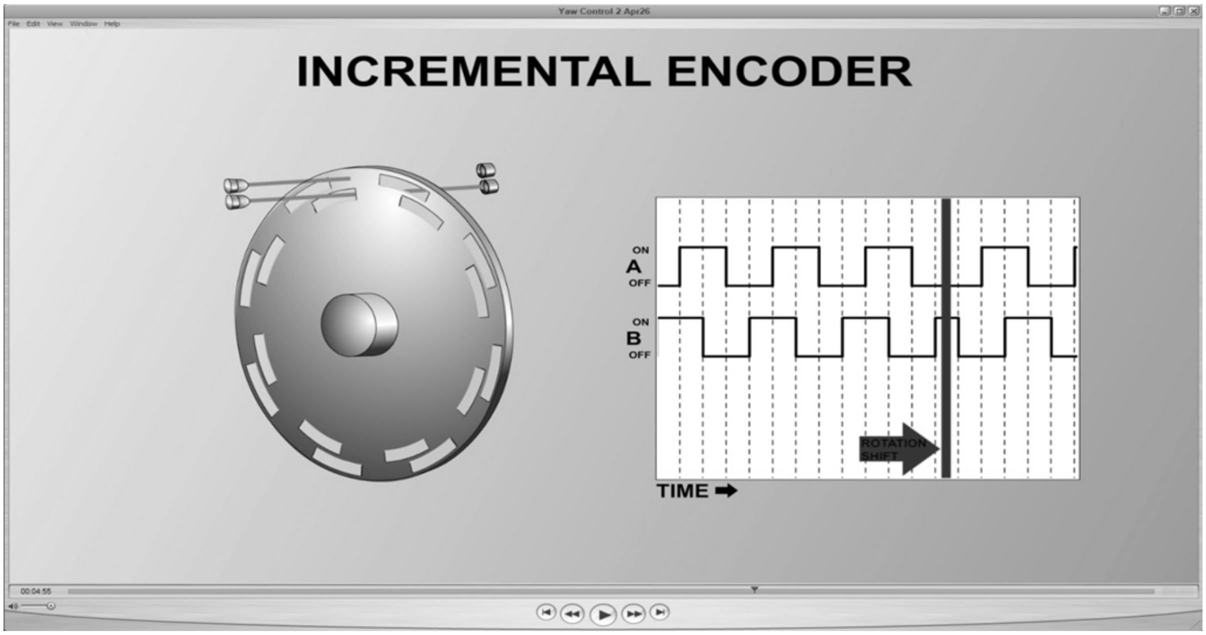

Figure 2 – Encoder.

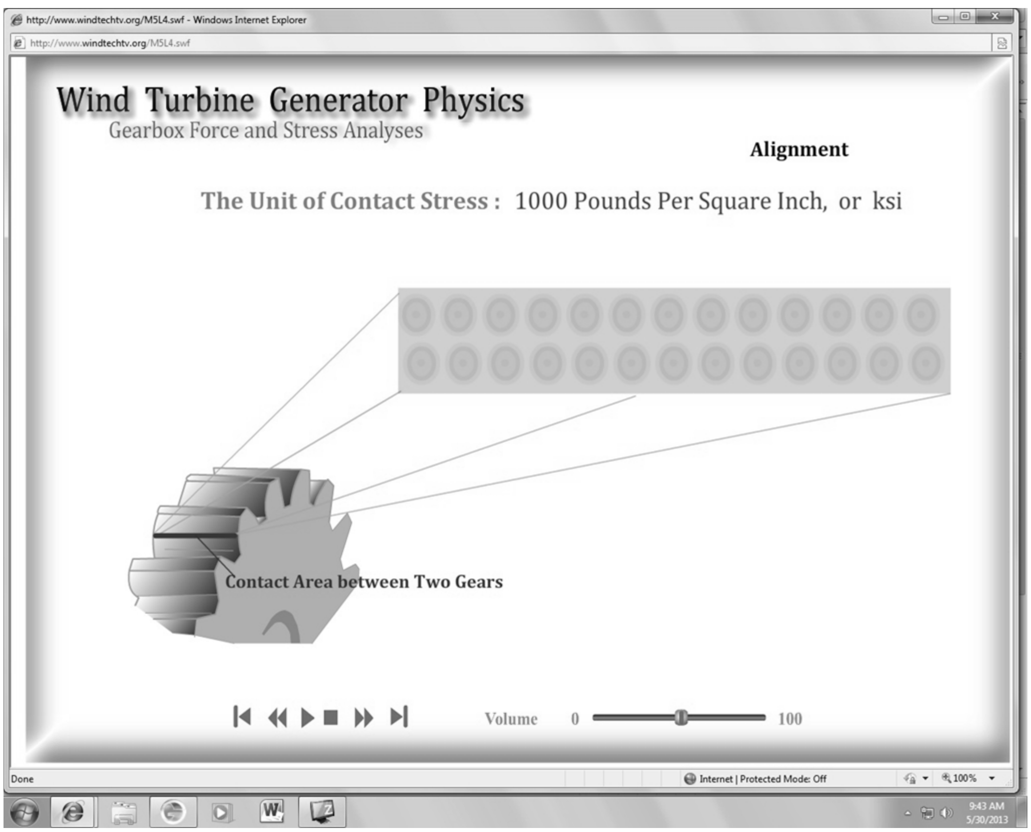

Figure 3 - Gearbox Force and Stress Analyses.

The Field Test

Data were collected during the field tests via pre- and post-tests to measure the knowledge and attitudinal changes due to the use of the virtual laboratory. Because no practical differences in the outcomes were noted between gender or ethnicity groups during three field tests, the data were then aggregated by control and test groups only. A total of 120 students participated in the field tests. The test instruments are currently accessible online as part of the simulation modules and the virtual laboratory.

The analyses of the data consisted of looking at differences between the experimental and the control groups, and within each of the experimental and control groups.

The first analysis used repeated measures of ANOVA tests to determine if the changes in content knowledge differed depending on whether the student learned the material with the use of the developed virtual laboratory or with the use of only the traditional in-class presentations. The p-level was set as 0.05; e.g., any significance of less than or equal to 0.05 would be considered statistically significant. As would be expected, students in all lessons increased their learning significantly between the pre-test and the post-tests.

A repeated measures t-test was used to show that individual students had greater learning gains when using the virtual laboratory modules than when taught using only in-class presentations. Overall, when students were in the virtual laboratory lessons, they increased their test scores by 12.3 points (standard deviation = 6.8). When in only in-class presentations, their test scores increased by only 5.7 points (standard deviation = 5.1). This is statistically significant (repeated t = 8.385, df(68), p < .000). The effect size increase in student learning in the virtual laboratory group was 1.8 compared to the effect size of 1.1 in the group of the only in-class presentations.

An attitudinal scale was given to the students before they completed any lessons and at the end of the lessons. A seven-item scale measured their attitude towards wind turbine maintenance technology. The pre-scale reliability was .838 and the post-scale reliability was .715. The larger the score, the more favorably the student was inclined towards a positive view of wind turbine maintenance technology. The pre-measure had a mean of 17.1 (standard deviation = 5.3), and the post-measure had a mean of 19.8 (standard deviation = 4.1). The repeated t-test indicated a statistically significant increase in their attitude towards wind energy after the field test (repeated t = 7.664, df (60), p < .000), even though the change cannot be attributed to the use of the virtual laboratory alone, because the data from both the control group and the test group of the entire cohort of the field test participants were merged.

The On-going Dissemination Efforts

College academics from eight states participated in webinars on the virtual laboratory. Follow-up online surveys showed that all respondents indicated satisfactory or above with the usefulness, the content accuracy, and the selection of topics of the webinars, as well as with the quality of audio and visual, amount of technical assistance in receiving and connecting and participating, and with the use of webinars in general as a way of disseminating the results and findings of the development and field tests.

Half of the respondents to the surveys have been currently using the virtual laboratory as part of their teaching and 90% of the respondents envisioned expanding the use of the materials. Highland Community College, Illinois Valley Community College, Community Colleges in Minnesota, Columbia Gorge CC in Oregon, and Cloud County CC in Kansas have adopted the materials in their curriculum.

The virtual laboratory materials were distributed at the American Wind Energy Association's Windpower 2013 conference with over 10,000 attendees. All alternative energy programs listed in the National Renewable Energy Laboratory (NREL) have been contacted on the emergence of the virtual laboratory at ***http://www.windtechtv.org***

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Biographical Information

Xueshu Song is a professor emeritus of engineering technology at Northern Illinois University and the co-principal investigator and the lead wind turbine physics developer for the NSF-funded wind turbine maintenance project at Highland Community College. He has been a sole or lead proposal writer and principal investigator or co-principal investigator of nine successful NSF-funded projects, each of which developed, tested, and disseminated innovative educational software systems in the field of engineering and engineering technology education.

Phil Pilcher is the principal investigator and project director for the NSF-funded wind turbine maintenance project at Highland Community College, and served as the writer, director, and producer of the on-demand and streamed videos for the virtual laboratory. He has been a major contributor to many educational research and development projects, and he has served as co-principal investigator for four NSF-funded projects with the lead author.

Penny Billman is the chief scientist at REGS Consulting, LLC, and has worked on the evaluation of this NSF funded wind turbine maintenance project. She received a Ph.D. in Educational Psychology and Research from Purdue University, has been a senior college administrator and university research professor for decades. She is currently a research consultant on numerous significant educational research projects nationwide.

Ping Wang served as a software architect and developer for eight of the nine NSF-funded projects for which the lead author has been the principal or co-principal investigator including the NSF-funded wind turbine maintenance project, and generated the Flash animations and simulations of the wind turbine physics module. She holds degrees of Master of Science in Operations Management and Information Systems, Master of Accounting Science, and Bachelor of Engineering.

Charles L. Billman is the evaluator of the NSF-funded wind turbine maintenance project, and a principal investigator or co-principal investigator of six NSF-funded educational projects over the past twenty years with the lead author. Having been a successful college administrator and professor of aviation maintenance technology for decades, he is now a consultant on many educational research and development projects nationwide.