FIELD VALIDATION OF A REMOTE AND VIRTUAL LAB FOR LASER CLADDING: A DEVELOPMENT JOURNEY

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Abstract

This paper describes the results of the development and field tests of a *Virtual and Remote Laboratory for Laser Cladding Technology* funded by the National Science Foundation under NSF Award Number 0703123. Internet-based and database-supported interactive simulations were developed in a multidimensional approach to multimedia applications in addition to real-time remote access of live laser cladding processes via Internet communications, which combines the development of procedural, technical, scientific, and social-economic skills with critical and creative thinking. Descriptive and inferential statistics from field tests using pre- and post tests with control and test groups indicated significant cost and pedagogical advantages of the developed virtual laboratory.

The Need

Laser cladding makes it possible to join dissimilar materials in remanufacturing critical components of expensive machinery to boost anti-corrosion qualities[7]. This is of great value to the marine, and oil field equipment industry. It provides better bonding compared to arc or plasma spraying, produces lower thermal distortion, is suitable for a wider range of materials, and results in a flaw-free coating via a process repeatable with robotic accuracy. It is considered to be the only acceptable process for many high value precision components for these reasons. Because of the emerging commercialization of the laser cladding process, the process technicians who work in the research laboratories often hold advanced graduate degrees, and their operational skills must transfer and migrate to the technicians in the factory who normally hold associate degrees. The primary goal of work described in this paper is to develop and field test Internet-based, multimedia -interfaced, and database-supported laser cladding training materials, simulation modules, and a supporting remote laboratory for laser cladding technology to train in-service process technicians who will gain transferable skills in the refurbishment industry.

The Development

Five interactive and collaborative modules have been developed for the virtual and remote laboratory at ***http://virtuallabs.niu.edu/nsf/lasercladding/lc_main.html*** Audio-guided navigation of the entire website is now being installed and readers are encouraged to visit the virtual and remote laboratory to explore the interactions.

Module 1 - The Fundamentals of Laser Cladding

This module illustrates differences between laser cladding, alloying, and glazing; different methods of laser cladding; clad dimensional characteristics; important parameters in laser cladding by powder and wire injection; combined parameters; and comparison between laser cladding and other metallic coating techniques. This module also compares laser cladding and other prototyping techniques in terms of bonding strength, dilution, coating materials, coating thickness, repeatability, heat affected zone, controllability, and cost. Figure 1 is snapshot of compute interface for Module 1.

Figure 1 - Snapshot of Compute Interface for Module 1:

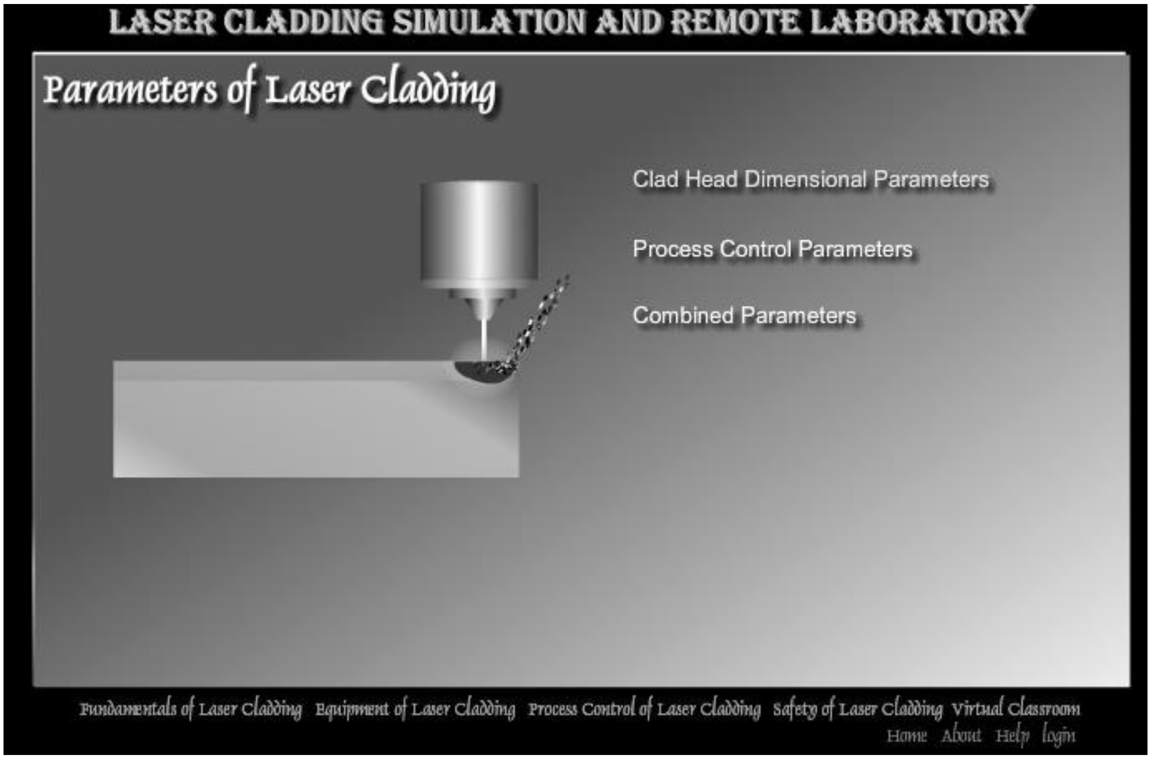
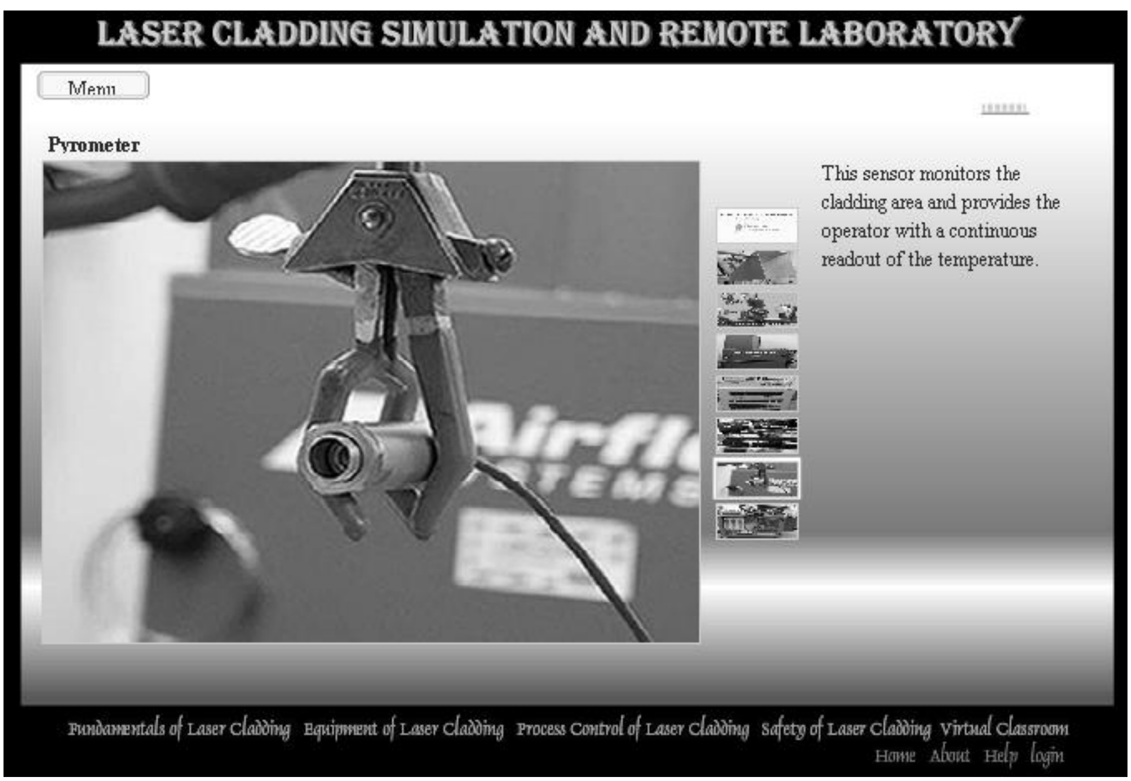


Figure 2 - Snapshot of Compute Interface for Module 2:



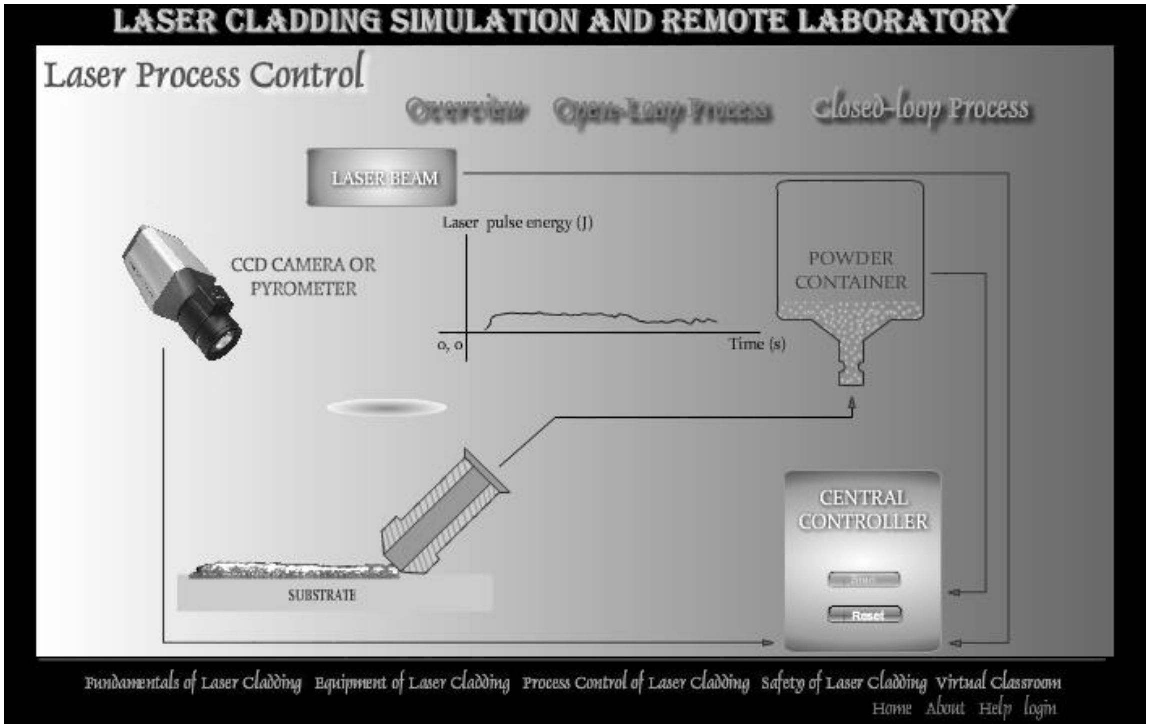


Figure 3 - Snapshot of Compute Interface for Module 3:

Module 2 - The Equipment of Laser Cladding

This module demonstrates the hardware configurations and mechanisms of laser generators, powder and wire feeders, powder delivery nozzles, protective covering gas nozzles, molten metal pool imaging, temperature sensing, part positioning devices, as well as the more general applications of the equipment in laser cleaning, heat treatment, material removing, and welding. Figure 2 is snapshot of compute interface for Module 2.

Module 3 - The Process Control of Laser Cladding

This module introduces the control of intrinsic parameters that relate to the substrate and coating layer properties including absorptivity, thermal conductivity, heat capacity, thermal diffusivity, and work piece geometry. The module also describes the extrinsic parameters that relate to the hardware used in the process such as laser type and power, powder feeder, and positioning system, and laser control parameters such as laser average power, laser focal point distance, powder feeder mass flow, nozzle position and orientation, and relative position and velocity of the laser beam relative to the work piece[8]. This module further illustrates the sensors for both temperature and dimensional measurements, including radiation thermometers, optical pyrometers, thermocouples, as well as vision systems including the use of special visible light radiation filtering techniques that eliminate excess radiation from the 1064 nm beam[4]. Figure 3 is snapshot of compute interface for Module 3.

Module 4 - The Safety of Laser Cladding

This module covers laser hazards, including eye hazards, radiation effects on skin, and collateral radiation such as ionizing radiation, UV and visible, and plasma emission; chemical, fire, explosion, and powder hazards; as well as laser classifications and their implications to laser cladding safety. Guidelines suggested by the Laser Institute of America are incorporated and information on how to determine if individual states have their own licensing or certification requirements is developed. The process of developing a Laser Safety Officer is also included.

Module 5 - The Remote Laboratory of Laser Cladding

All laser cladding training modules are supported by a remote laboratory. The lab contains an operable laser cladding cell consisting of a high-power direct diode laser, a six-axis robot, two rotating positioners, a universal fixture, filler feeding systems, fume exhaust system, operator control room, vision control system, and laser power measurement and calorimetric system. This facility is currently available for use in producing media for the training modules, and for technology demonstrations via webcam[13] to remote sites.

Each module consists of an analytical mode illustrating the scientific interdisciplinary nature of laser cladding, and a synthesized mode simulating the hands-on experience for various case studies. Each module is stand-alone as an individual curriculum entity, including on-line help and quizzes, and can be used in either sequential or random order. A glossary of terms is included in each of the five modules. Three different formats of one set of multiple choice questions were developed for each module that have been used in the pre- and post-tests for both ongoing and confirmative field tests. Each module is designed for an average student to complete the instructional material at a pace of 8 hours per module, not including the exercises, simulation, and test materials.

Throughout the modules, realistic video and graphic images of laser cladding equipment and processes are juxtaposed with schematic illustrations of the system being studied, which reveals the scientific nature of the laser cladding processes, epitomizing the ideal of using virtual reality to enhance reality. Interwoven with the revealing technical and procedural knowledge will be the psychological impetus toward interactive learning, practice, and discovery.

Curriculum effectiveness and efficiency are essential to the pedagogical and cost effectiveness of an instructional simulation system. Such effectiveness and efficiency of the curriculum for the proposed laser cladding simulation and remote laboratory system are three fold.

(1) Learners can customize the curriculum during the one-to-one interactive learning process, because contents in a variety of formats can be accessed in any sequence, at any pace. Following the dual coding learning theory, instructional content is presented in text-image and video or animation-subtitle formats, or both. The learners will have the freedom to choose the preferred presentation style for individualized maximum learning efficiency. Multi-path access to the motivational, theoretical, procedural, and experimental/simulation sections in each module allow technicians to learn each section in any sequence that will optimally match their individual learning and thinking habits.

(2) The curricular modules of the system are fully adaptive to equipment and process changes in future laser cladding training practices, since they can be electronically updated as frequently as needed at minimal cost, either within or beyond the funding period. The cost advantage of the proposed laser cladding simulation and remote laboratory system during updating, within or beyond the funding period of the proposed project, is significant. With only the nominal archiving and server maintenance and updating cost, the simulation software systems and the remote laboratory hardware will have full salvage value when updated. In contrast, actual laser cladding training equipment usually has negligible salvage value when upgrading is necessary.

(3) A confluence of the human and natural environmental issues underlies the significance of the proposed project. Some hazardous laboratory materials and processes are currently used in laser cladding training. The simulation and remote laboratory system can reduce the use of such materials and thereby reduce pollution. Most cost, safety, and environmental concerns are directly linked to laboratory processes to which trainer and trainees are exposed. The proposed simulation and remote laboratory

system will prepare the trainees for, and minimize their exposure to, hazardous processes and possible damages to expensive equipment during laboratory sessions.

The Field Test

Thirty-two community college students were randomly assigned to either the experimental or the control group. The experimental group used the laser cladding website modules and webcam to learn the material. The control group, during the same time period but in a different room, received classroom instruction consisting of lectures and a videotapes.

Each group completed two pre-tests, received the same duration of instruction, and completed two post-tests. The content knowledge test of 25-questions had been piloted three months previously with a comparable group of students. The reliability coefficient for the pilot was 0.67 (Cronbach's alpha). The second assessment was a 7-question attitudinal instrument based on question stems used in previous projects by the investigators with an established reliability of 0.79 (Cronbach's alpha).

Content Knowledge

As shown in the Figure 4, the groups did not differ significantly on the pre-test; however, the repeated measures analysis of variance indicated that the experimental group scored significantly higher on the post-test than did the control group (F=4.735(1), p =.038).

Attitudinal Assessment

The 7-question instrument asked students to rate their opinions on a Likert scale from Strongly Disagree (1) to Strongly Agree (5). One question was reversed scored. The total score for the 7 items are presented in the Figure 5. The two groups did not differ significantly on the pre-test or the post-test. However, both groups increased significantly from the pre-test to the post-test, thus improving their attitudes towards learning laser cladding (experimental: t= 10.706, df 15, p<.000: control: t=8.015, df 15, p<.000).

Figure 4. Differences in Pre-test and Post-test Content Knowledge Scores.

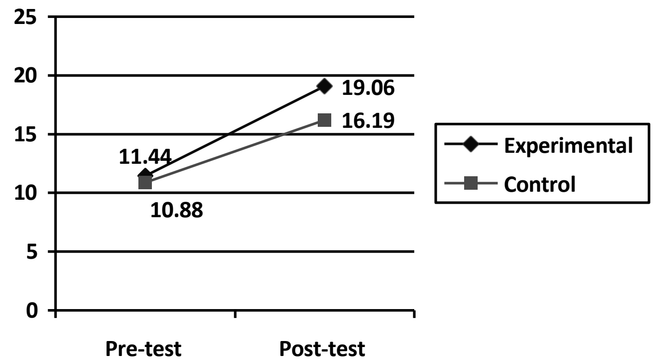
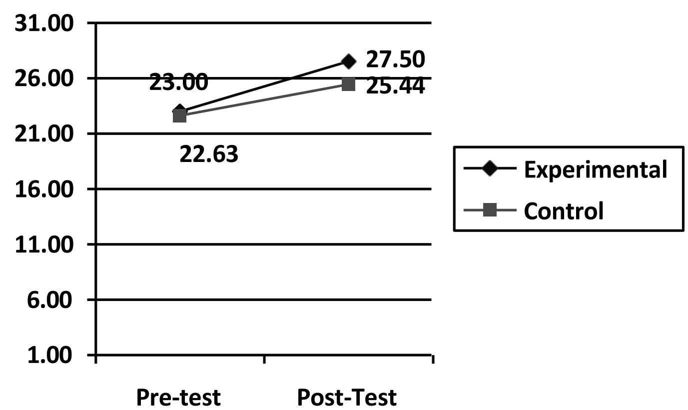


Figure 5. Comparison on Total Score on Attitudinal Assessment.



The On-going Dissemination Efforts

Curriculum integration and customization of the developed and tested virtual and remote laboratory will be the focus of two multi-year and diverse-location faculty workshops. The first workshop will be a pilot trial application workshop with 30 two-year college engineering technology instructors recruited from the northern Illinois, southern Wisconsin, eastern Iowa, and northern Indiana regions to participate in June 2010. In this two-day workshop, the participants will learn, test, and evaluate the alpha versions of the modules, and their suggestions will be incorporated into the final release.

The second two-day workshop will be the dissemination workshop conducted at NIU in DeKalb, Illinois in August 2010 immediately after the field tests with the same 30 faculty participants who will have participated in the first faculty workshop. Beyond mere use of the modules, participants will brainstorm ideas on using the multimedia simulation approach in advanced technological education areas other than, but similar to, the modules as proposed. Participants will also be introduced to basic multimedia program/production techniques needed to create modules similar to the project's modules. This "recursive education"[9] approach, in which faculty members and students are treated not only as users or consumers but also as developers or producers of educational software products, aims to foster positive attitudes toward curricular innovations and computer applications, and to enhance the information reproduction and dissemination rate in engineering technology education.

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Biographical Information

Xueshu Song is a professor of engineering technology at Northern Illinois University (NIU) and the managing co-principal investigator of the NSF-funded laser cladding project. He has been the lead proposal writer and PI or Co-PI of eight successful NSF-funded projects, each of which develops, tests, and disseminates innovative educational software systems previously on CD-ROMs and recently on the Internet.

Richard Johnson is the Director of Engineering Outreach for Research and Development at NIU and the principal investigator of the NSF-funded laser cladding project. He created and obtained funding for programs to develop highly automated laser cladding cell for the U.S. Navy, and served as director of Alion Science and Technology – DuPage Manufacturing Research Center in St. Charles, Illinois. His laser cladding project won an *R&D 100* award in 2004 as one of 2004's most innovative new products.

Phil Pilcher is a co-principal investigator and worked as the field test coordinator, chief critique, and multimedia expert for the NSF-funded laser cladding project.

Charles L. Billman is a co-principal investigator and responsible for the field test and faculty workshops as well as the curriculum integration for the NSF-funded laser cladding project.

Promod Vohra is Dean of College of Engineering and Engineering Technology at NIU. He is a co-principal investigator and responsible for institutional support for the NSF-funded laser cladding project.

Ping Wang served at NIU's eLearning Services and worked as the software architect and developer for six of the eight NSF-funded projects for which the lead author has been the principal or co-principal investigator including the current NSF-funded laser cladding project. She holds degrees of a Master of Science in Operations Management and Information Systems, a Master of Accounting Science, and a Bachelor of Engineering.

Penny Billman is the evaluator and field test specialist of the NSF funded laser cladding project. She received a Ph. D. in Educational Psychology and Research from Purdue University, and currently works as a Research Assistant Professor at the College of Medicine, University of Illinois.