Development of Agent-based Tutor & Simulator System and Assessment of Instructional Modules Implemented in areas of Quality Control, Metrology and Prototyping

Dr. Irina Nicoleta Ciobanescu Husanu, Drexel University (Tech.)

Dr. Ciobanescu –Husanu received her PhD degree in mechanical engineering from Drexel University in 2005 and also hold a MS degree in aeronautical engineering from Polytechnic University of Bucharest. Her dissertation was on numerical investigation of fuel droplet interactions at near zero Reynolds numbers. Other research projects involved computational evaluation of Icing Scaling Methods and development of an ice accretion model for airfoils using a LEWICE code. Currently is appointed as assistant professor at Department of Engineering Technology with College of Engineering, Drexel University and her research interest is in thermal and fluid sciences with applications in micro-combustion, fuel cells and research of alternative and green fuels as well as expanding her research work towards new areas regarding plasma assisted combustion. Dr. Ciobanescu-Husanu has prior industrial experience in aerospace engineering areas, that encompasses both theoretical analysis and experimental investigations such as designing and testing of propulsion systems including design and development of pilot testing facility, mechanical instrumentation of the tested prototype, and developing industrial applications of aircraft engines. Also, in the past 9 years she gained experience in teaching Mechanical Engineering courses with emphasis on thermal-fluid and energy conversion areas from various levels of instruction and addressed to a broad spectrum of students, varying from freshmen to seniors, from high school graduates to adult learners.

Dr. Yalcin Ertekin, Drexel University (Tech.)

Yalcin Ertekin received his Ph.D. degree in mechanical Engineering from Missouri University of Science and Technology (formerly The University of Missouri-Rolla). He is a Certified Quality Engineer (CQE) and Certified Manufacturing Engineer (CMfgE). His teaching responsibilities include Computer Numerical Control, manufacturing processes, applied quality control, mechanical design, and applied mechanics, manufacturing information management systems, introduction to technology and graphical communication as well as senior design courses. He developed two online graduate courses: rapid prototyping and product design and lean manufacturing principles for MSET program. Dr. Ertekin has over six years of industrial experience related to quality and design engineering mostly in automotive industry. He worked for Toyota Motor Corporation as a quality assurance engineer for two years and lived in Toyota City, Japan. His area of expertise is in CAD/CAM, manufacturing processes, machine design with CAE methods, rapid prototyping, CNC machining and quality control. His research interest includes sensor based condition monitoring of machining processes, machine tool accuracy characterization and enhancement, non-invasive surgical tool design and bio-materials applications. During his career, Dr. Ertekin published papers in referred journals and in conference proceedings in his area of research interest. He has also been PI for various NSF research projects including NSF-TUES and MRI programs. Dr. Ertekin is an active member in the Society of Manufacturing Engineers (SME), and currently serves as a chair of Philadelphia SME Chapter-15.

Dr. Radian G Belu, Drexel University (Tech.)

Dr. Radian Belu is Assistant Professor within the Engineering Technology (ET) program - Drexel University, Philadelphia, USA. He is holding a PHD in power engineering and the other in physics. Before joining to the Drexel University Dr. Belu hold faculty and research positions at universities and research institutes in Romania, Canada and United States. He also worked for several years in industry as project manager, senior engineer and consultant. He has taught and developed undergraduate and graduate courses in power electronics, power systems, renewable energy technologies, smart grids, control theory, electric machines, instrumentation, radar and remote sensing, numerical methods and data analysis, space and atmosphere physics, and applied physics. His research interests included power system stability, control and protection, renewable energy system analysis, assessment and design, smart micro-grids, power electronics and electric machines for wind energy conversion, radar and remote sensing, wave and turbulence simulation, measurement and modeling, numerical modeling, electromagnetic compatibility and engineering education. During his career Dr. Belu published eight book chapters, several papers in referred journals and in conference proceedings in his areas of the research interests. He has also been PI or Co-PI for various research projects United States and abroad in power systems analysis and protection, load and energy demand forecasting and analysis, renewable energy, microgrids, turbulence and wave propagation, radar and remote sensing, instrumentation, atmosphere physics, electromagnetic compatibility, and engineering education.

Development of Agent-based Tutor & Simulator System and Assessment of Instructional Modules Implemented in areas of Quality Control, Metrology and Prototyping (Year II of the Project)

Abstract

One of the main goals of our project is to enhance the cognitive learning of our online laboratory activities. In this paper we briefly discuss the new learning modules developed during the second year of the project (virtual 3-D laboratory activities) as well as the status of development of our Advance Knowledge of How Cognitive Learning Develops in Tele-presence System, our Development of an Agent-based Tutor & Simulator System (ATSS) and our assessment and evaluation process.

Introduction

The fundamental challenging problems in manufacturing education are related to improving the student–instructional technologies interface to incorporate the required learning tools, and improving teaching and learning effectiveness in online course and training. The major objectives of our project are to design and use CNC machine control simulator systems to enhance the cognitive learning of online laboratories and design and use of simulator interfaces for metrology and quality control systems to enhance the cognitive learning of online labs. We briefly discuss the development of virtual 3-D laboratory activities (learning modules and tutorials) that provide students with a realistic interaction with CNC machine in the area of prototyping, metrology, quality control and quality assurance, both at undergraduate and graduate level, already implemented in our Engineering Technology curricula (during first year of the project). Also we present the experiential framework (hardware and laboratory modules) and the industrial training modules covering prototyping, precision metrology, offline/online quality control/ assurance, remote monitoring of machining and prototyping, and robotic assembly processes.

The aims of this project presented in this paper are to advance, develop and implement a state-of-the-art offline and online learning environment to support and enhance students' learning and training as they use simulated systems to design and conduct virtual and real-time machining experiments and calibration of precision machine tools. During the project's second year we are in progress of developing, implementing and testing the some of the following:

(1) Advance Knowledge of How Cognitive Learning Develops in Tele-presence System, investigating how students perceive, process, and learn while working with the developed learning systems (tutorials, learning modules and lab activities).

(2) Development of an Agent-based Tutor & Simulator System (ATSS), with an embedded-intelligence and knowledge base to guide and support students in remote operations within the safety and functional boundaries of the equipment. Its main function is to aid remote users in lieu of the teacher's absence through the graphical projection of process plan and process knowledge in machining and robotics operations.

(3) A comprehensive assessment and evaluation plan will be presented, contemplating several quantitative and qualitative measurements used as feeders for necessary calibration and adjustment of the different components of the project. Evaluation of this

project is guided by five foundational evaluation questions, designed to focus data collection and analysis on a) the project's stated objectives and outcomes, b) broader issues such as dissemination of project information and activities, and c) sustainability of project components beyond the life of the grant.

(4) A web page for the re-developed courses carrying the course modules and lectures in a PDF format and Lecture PowerPoint presentations for students and other users to browse and download from any location using remote desktop and virtual lab server. The interactive components, simulations and laboratory experiments are available for other universities and Drexel-affiliated colleges. Online learning will be a channel for use of the developed materials and also their dissemination.

Course Improvement and Re-development: Tutorials

A derived, but nonetheless important objective is to improve and re-develop seven current industrial training modules covering prototyping, machine tool calibration, precision metrology, offline and online quality control, remote monitoring and supervision of machining and robotic assembly processes, and quality assurance. This activity is currently undergoing, its progress being highlighted in the sections below. We will develop industry-supplied and coordinated projects, as well as capstone projects for collaborative student teams. The newly-equipped laboratories will be networked for cross-institutional use between Drexel University and affiliated community colleges. The heart of this project is the hardware and software described in the following sections of the report. The tutorials presented below are designed to enhance and support our re-developed courses as they were presented in our previous published papers[1, 2].

Renishaw XL-80 Laser Interferometer System: Angular Pitch Measurement Tutorial

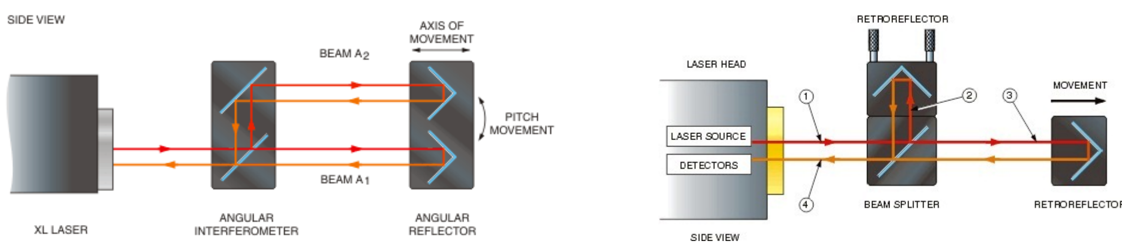


Figure 1 Renishaw XL laser system

The set-up for this experiment will necessitate to turn on the CNC mill and to calibrate the axis XYZ for the start position. Once this is performed, the machine is prepared for the optic set-up. Then start Renishaw Laser XL Angular Measurement (Figure 1, Figure 2). Students are required to prepare and assembly the system for measurements:

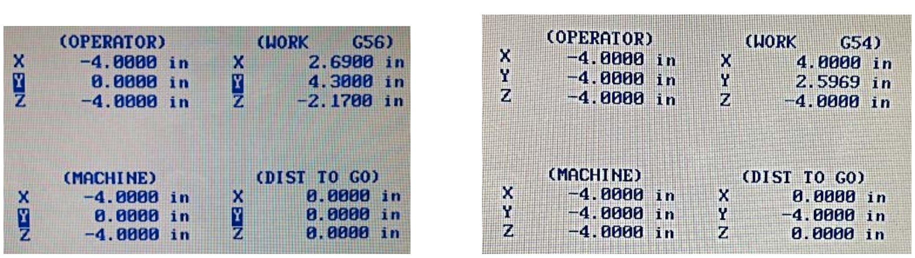


Figure 2 Set-up of the CNC milling machine

1. Secure the three screws to attach XL-80 Laser to tripod stage.
2. Attach baseplate with XL-80 Laser to tripod (black lever releases).
3. Attach power cord to XL-80 Laser and to the power source, and then turn on XL Laser on to preheat for about 6 minutes.
4. Connect the XL-80 Laser to the PC via a USB cable. Plug one end of the cable into the USB socket on the rear of the XL laser and the other end into the PC.
5. Add clamp blocks to angular interferometer and angular reflector
6. Attach angular interferometer to a mounting pillar on magnet base. Do similarly with the angular reflector.
7. Inside the machine, attach the supported angular interferometer to the spinal and the supported angular reflector to the back of machine table. (Figure 3)

Figure 3 Renishaw Laser XL Angular Measurement System mounted

Another step is calibration:

1) Place one alignment target on the angular interferometer and another on the moving angular reflector with the white spot at the top.

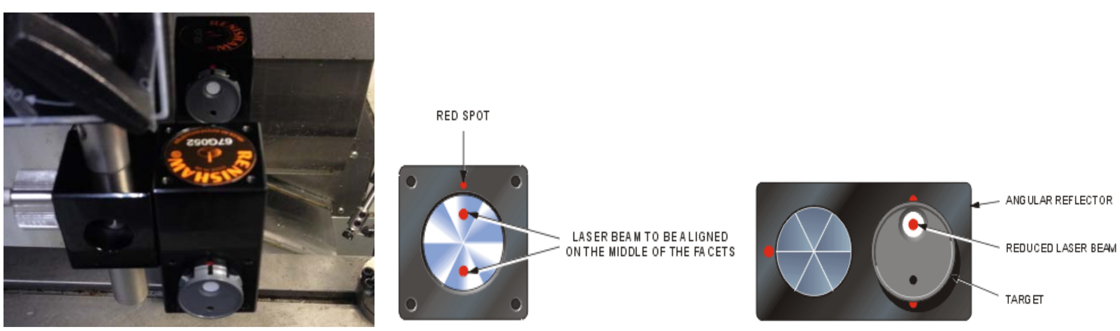


Figure 4 Calibration procedure: aligning the laser beams

*Each reflector should be mounted so that the laser beam hits the middle of one of these facets and not one of the 'lines' which join them.

2) Turn the XL laser shutter to the first alignment position.
3) Using the tripod and laser head adjusters, align the laser beam by eye to be parallel to the

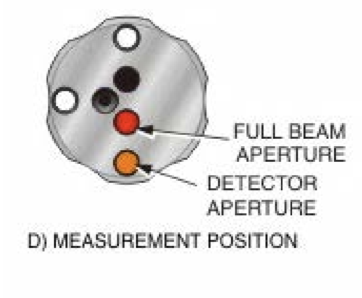
axis of the machine and directed onto the white spot of the angular interferometer target.

* Aim the beam using the knobs in the stage (shown), XL Laser (fine vertical), and the crank on the tripod (vertical).

4) Position the angular reflector close to the angular interferometer using the hand jog and remove the target from the angular interferometer.

* To the best of your ability make sure the optics is parallel to the machine axis, at the same height, and that the sides that face each other are parallel.

5) Align the laser so that the return beam hits the white spot on the shutter. Move the reflector up/down and left/right until the beam hits the white spot on the target in the reflector.
6) Remove the target from the reflector and readjust its position until the return beam from it is a single beam on the white spot of the shutter return port.
7) Using the hand jog, move the machine surface with the reflector to the extent of the negative Y-axis. Realign the laser beam keeping the return on the shutter return port. Then, Drive the machine surface and the reflector back to the interferometer.
8) Move the shutter to the measurement position and check beam strength.



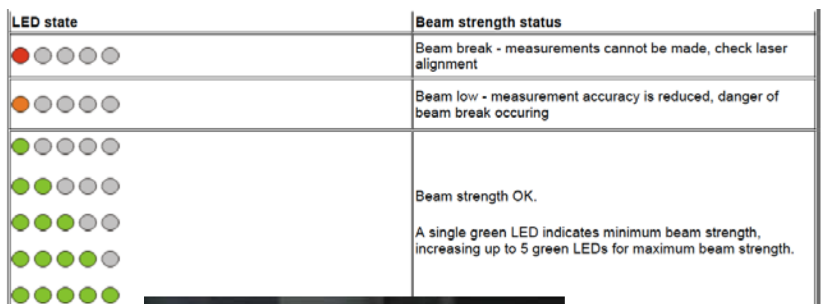


Figure 5 Calibration of the measurement system

<u>Measuring:</u>

Data capture is carried out by moving the machine to a number of different positions (or targets) along the axis under test and measuring the machine's error. You can write a part program to drive the machine from one target position to the next, pausing for a few seconds at each target position. Measurements are taken during each pause (Figure 6 Data capturing and measurement analysis software).

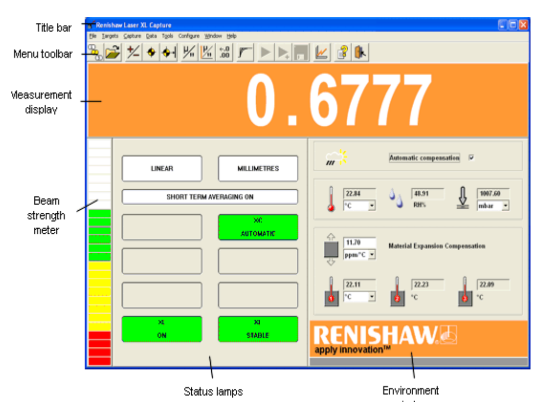
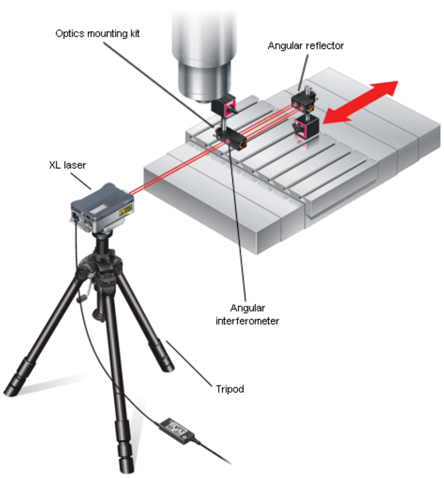


Figure 6 Data capturing and measurement analysis software

Renishaw XL-80 Laser Interferometer System: Angular Yaw Measurement Tutorial



The initial set-up is the same as for the angular measurement. To perform yaw measurement instead of pitch measurement simply change the orientation of the optics from perpendicular to the machine table to parallel to the machine table.

Figure 7 Renishaw XL-80 Laser Interferometer System: Angular Yaw Measurement

Renishaw XL-80 Laser Interferometer System: Linear Measurement Tutorial

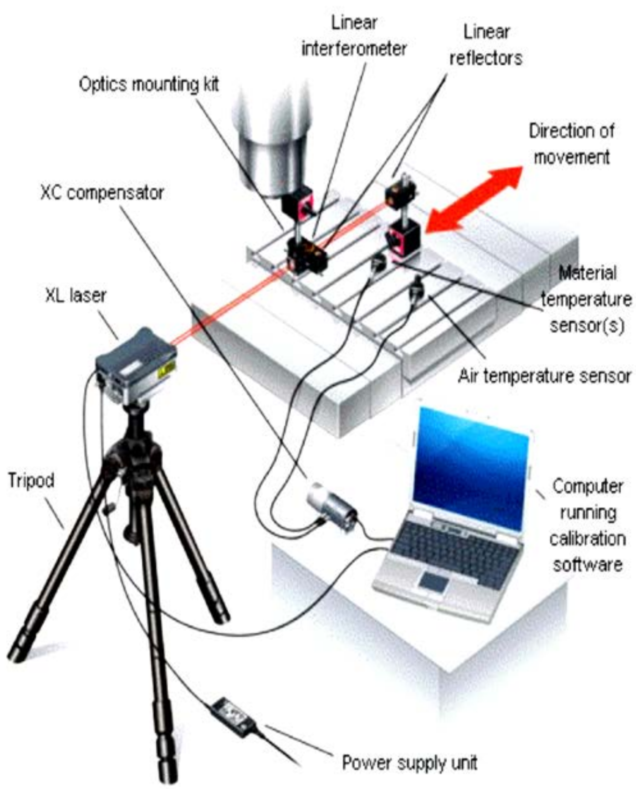


Figure 8 Renishaw XL-80 Laser Interferometer System: Linear Measurement

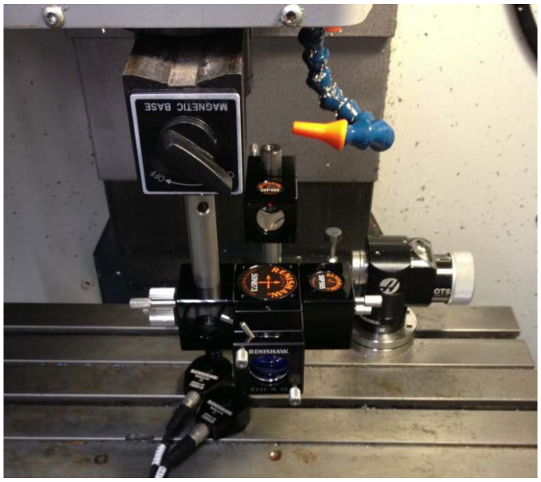


Figure 9 Connecting temperature sensors and the linear interferometer

The system is connected similarly as the previous ones. However, some differences are noted such as connecting the XC compensator, attaching the air temperature and material temperature monitors to XC Environmental Compensation Unit, and the air and material temperature sensors. (Figure 9)

Magnetically attach sensors in a suitable center position on machine table. Attach a clamp block to the linear reflector. Combine beam-splitter and linear refractor using the screws on the linear refractor to form linear interferometer. Then, add a clamp bock to the bottom of the linear interferometer.

Then, attach the laser steerer to the input side of the linear interferometer. Inside the machine, attach the supported linear interferometer to the spinal and the supported linear reflector to the back of the machine table. Calibration procedure is also described in the tutorial. Data measurement and analysis will use the same procedure and software as previous tutorials.

Coordinate Measuring Machine Tutorial

The CMM tutorial has been implemented in the Measurement and Instrumentation course starting with AY 2012-2013. It uses a prototyped block that has faulty dimensions. Students are trained on using the instruments and also on how to calibrate and align the CMM.

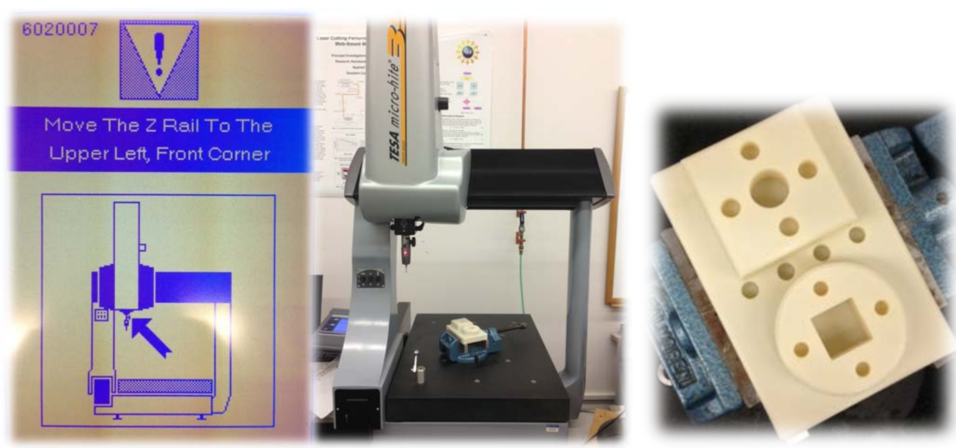


Figure 10 CMM tutorial representation

Agent-based Tutor & Simulator System.

During the second year of our project, we focused our efforts toward developing the Agent-based Tutor and Simulator System (ATSS). The ATSS is still under the development, these tutorials being an integrant part of it. The purpose of this system with an embedded-intelligence and knowledge base is to guide and support students in remote operations within the safety and functional boundaries of the equipment. Its main function is to aid remote users in lieu of the teacher's absence through the graphical projection of process plan and process knowledge in machining and robotics operations. Please see Figure 11 for screen view of online tutorial system that is being developed using Emco campus modules for machining applications.

The first key element for the ATSS is a knowledge base design. ATSS for the online/offline lab allows the students to "learn by doing." It assumes that students have a basic familiarity with important concepts and procedures in the domain before using the tutor/simulator. Specific feedback is given for each skill step, and task difficulty is increased as progress is made. A traditional rule-based approach can be employed to implement the ATSS. However, the most tedious and costly part of building the rule base is the acquisition and hand coding of expert knowledge into rules. Symbolic models are the result of a complex and time-consuming process of knowledge acquisition and knowledge engineering (KA/KE). The artifacts of the KA/KE process are not yet developed, this being our future endeavor that we will report at a later date. A hybrid approach that combines instructors' domain knowledge and automated learned knowledge by an intelligent agent is proposed to build the ATSS. The ATSS will have an Internet-based framework, consisting of three components: (1) a data input receiver; (2) a reasoner/inference mechanism; and (3) a state change effector. The receiver will acquire data from robots and sensors; the reasoner will decide on a course of action, monitor the students' operation and compare the results of the two; the effector is going to provide feedback on the students' operation, such as safety warning in the case of wrong operation. Once this has been completed, the ATSS will learn from the operation and update the knowledge base accordingly. The second key element is the interface design. We are in progress of developing a flexible interface by (1) allowing the instructor to design the machine/process interface freely, while (2) adding the list of basic skills students need to learn in order to reduce the negative effects of poor design. The interface will have two Internet-based windows. One window shows the robot/CNC machine operation manual/instruction with a prerecorded plug-in video showing the movement of the robot/CNC machine step by step. The plug-in videos will be developed by the PIs in line with the planned online experiments. The second window allows students to input the operation command and questions as their tasks progress. The tutor's functionality will be mainly embedded in the second window.

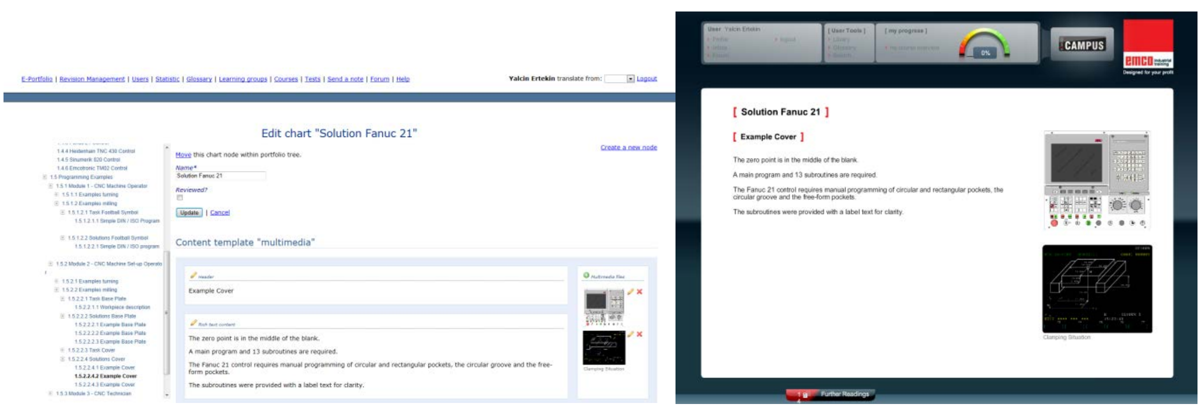


Figure 11 Example online tutorial system developed in cooperation with EMCO Company.

Advance Knowledge of How Cognitive Learning Develops in Tele-presence System

We are investigating how students perceive, process, and learn while working with the proposed 3D tele-presence system. It is hypothesized that the affordances associated with the 3D tele-presence system—including the combined effects of visual and auditory feedback, the viewing angles, the number of multiple views, the field of view, and the format of auditory augmentation—will foster learning. The key is to render the remote systems as realistic as possible; hence, the 3D cameras will need to be carefully calibrated to provide users with proper depth perception and to reduce the amount of distortion. This particular task of our project is still not fully developed and we will report on it at a later date.

Courses impacted during our second year of project development

MHT 226 incorporates additional sensors and measurement techniques that are used to monitor machining processes. Variety of sensors including vibration, acoustic emission, cutting dynamometers (existing equipment) are used for remote process monitoring and control. Data acquisition and processing for tool breakage and quality control of machined parts has been added to the course curriculum. MET316 reflect the competitive trend in the evolution of manufacturing towards increased flexibility, high speed machining, remote quality control, sensors, and Internet-based information and communication technologies using CNC systems and simulators. Students will be able to study parametric programming techniques to run in-process gauging and tool setting probes. The students will convert a CNC machine tool into a coordinate measuring machine, which will eliminate post-process part inspection. This technology is becoming a common practice in discrete part manufacturing industries. Students will measure the effects of the thermal status of the machine tool on the machining accuracy of the machine tool. Student teams conduct experiments to check calibration of the machine tools using Ballbar & LaserXL80 calibration equipment purchased through the NSF grant. Web-based interactive instructional modules and tutors are developed for each sensor and equipment used for course. MET204 & ET635 (graduate level). Quality Control topics at graduate and undergraduate level focus on the information technology aspect of the proposed project. Students will use design of experiments to investigate the effects of the cutting conditions on part quality. Regression analysis and other statistical techniques will be used to develop statistical models for the machining process to predict part quality including control charts and machine/process capability analysis and Failure Mode and Effect Analysis in a real-like industrial setting. These studies will determine the capability of a machine tool to hold specified tolerances in a production setting. Results of the study will be used to match production part specifications to specific machine tools. Laboratory activities focus on conducting the experiment using appropriate statistical sampling methods and analysis techniques. Student teams will conduct experiments to check calibration of the machine tools using ballbar and laser calibration equipment.

Assessment for Online/Offline Laboratory Learning

A comprehensive assessment and evaluation plan is incorporated throughout the entire project. Such a plan contemplates several quantitative and qualitative measurements used as feeders for necessary calibration and adjustment of the different components of the project. The results of the assessment and evaluation may also, ultimately provide important baseline data to be used in investigating curricular reforms by identifying the strengths and weaknesses of those students enrolling in the ET courses. The assessment and evaluation plan is an iterative process to assure continuous quality improvement for ultimately accomplishing the project's goals. We are at our initial investigative phase of our assessment. To assess project's performance, the evaluation first provides a detailed description of the program followed by a focus on three key areas: Implementation, Outcomes Achievement, and Lessons Learned. There are many details in developing the specific assessment instruments, their types, and structure, some of which can be developed only during the course of the project itself, depending upon intermediate outcomes. Therefore, the specifics of the various assessment tools and processes are provided in Table 2. Formative assessment has been performed through tests and questionnaires by systematically collecting feedback from students. Improving learning through formative assessment depends basically on three key factors: (1) effective feedback to students; (2) active involvement of students in their own learning; and (3) adjusting teaching to take into account the results of assessment.

Cognitive assessment is made through the exams, projects and developmental portfolio. In exams for all course offerings, an entering cognitive knowledge test will measure what students are expected to know prior to taking the course, while the final exam will reflect content objectives and expected student knowledge acquisition from the course. The pre-test will include the most missed items on the previous final exams, and the final exams will assess the content objectives and expected student knowledge acquisition from the courses. The predetermined assessment criteria will be communicated to students at the beginning of the instructional period. A student's developmental portfolio for each of the four courses serve as formative evaluation, and will culminate in a best evidence portfolio (summative evaluation), which will be completed at the end of the course offering. The attitude assessment will be conducted through program pre-tests and post-tests on how students perceive themselves as online/offline learners. A Likert type scale questionnaire measured how students feel about aspects of the project

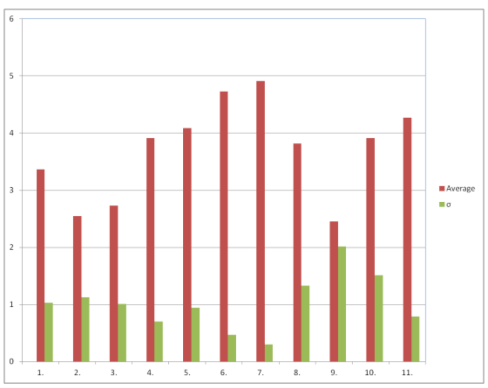


Figure 12 Student survey results (tutorials)

A sample questionnaire is presented below:

1. How much did this course contribute to your understanding of how precision and accuracy of machine tools are assessed?
2. How much did this course contribute to your understanding of how Renishaw Ballbar system works?
3. How much did this course contribute to your understanding of how Renishaw Laser system works?
4. How much did this project contribute to your understanding of CAD/CAM systems (FeatureCAM, VeriCUT)?
5. How much did the term project contribute to your ability to work in teams?
6. How much did you enjoy term project part of the course?
7. I want more hands on use of Haas CNC machine in this course
8. I want more hands on use of CNC machine calibration tools (Renishaw Ballbar and Laser systems) in this course
9. I recommend programming and use of EMCO CNC Turning Center included in this course

10. I recommend programming and use of EMCO CNC Turning Center included in a second (continuation) course
11. I want more use of CAD/CAM tools (FeatureCAM, VeriCUT) in this course

Web-Page Improvements

A web page already under construction for the re-developed courses (as specified in the previous sections) will also carry the course modules and lectures in a PDF format and lecture PowerPoint presentations for students and other users to browse and download from other locations. The interactive components, simulations and laboratory experiments will be made available for other universities and Drexel-affiliated colleges to examine, download, execute and use. Online learning will be a channel for use of the developed materials and also their dissemination.

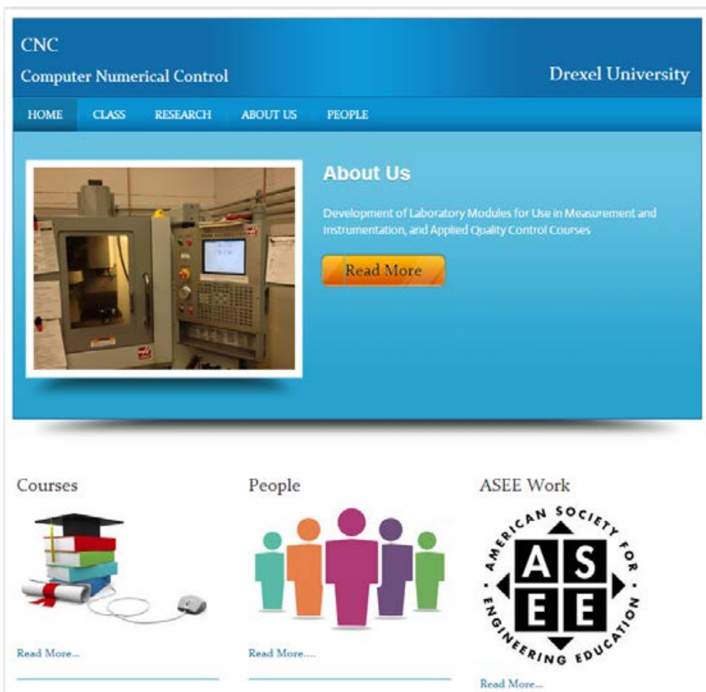


Figure 13 Webpage screenshot

The webpage (Figure 13) does provide the users with a comprehensive view of the project, including but not limited to: faculty profiles and their research fields and interests, the published work of the authors, and the course modules with laboratory tutorials and knowledge base built in.

Acknowledgement

The authors would like to thank the National Science Foundation (Grant No. NSF-DUE-1141087) for its financial support of the project.

References

1. Y. Ertekin, R.G. Belu and I. Husanu - Virtual 3-D Laboratory for CNC Machining and Automation Curriculum, 2013 ASEE Annual Conference and Exposition, Atlanta, USA, June 23-26, 2013
2. I. Husanu , Y. Ertekin, R.G. Belu and J. Zhou- Development of Laboratory Modules for Use in Measurement and Instrumentation, and Applied Quality Control Courses, 2013 ASEE Annual Conference and Exposition, Atlanta, USA, June 23-26, 2013
3. Y. Ertekin, R. Chiou, “Development of a Web-Based Rapid Prototyping and Product Design Course “, ASEE Annual Conference, San Antonio, TX, June 10-13, 2012.
4. Y. Ertekin, R., Chiou, “Interdisciplinary Senior Design Project to Develop a Teaching Tool: Desktop CNC Mill“, 2013 ASEE Annual Conference and Exposition, Atlanta, USA, June 23-26, 2013.
5. "Hands-on, Simulated and Remote Laboratories: A Comparative Literature Review", Jing Ma, Jeffrey V. Nickerson, Stevens Institute of Technology, 2006.
6. EMCO Maier Concept Turn 250, CT-250 EN1250-1 Beschr A, Machine Installation and Operation Manual.
7. Renishaw XL laser System, Portable Laser Measurement and Calibration Manual.
8. Renishaw QC20-W (Wireless) Ballbar System, Performance Measurement and Calibration Manual.
9. H-2000-6222-00-B Haas Insp-Renishaw Probe & OTS Manual
10. Trian Georgeou and Scott Danielson, “CNC Machining: A Value-Added Component of Engineering Technology Education,” ASEE Annual Conference & Exposition, June 22 - 25 - Pittsburgh, PA, 2008.
11. Fei Qiao, Heiko Schlange, Horst Meier, Wolfgang Massberg, “Internet-based Remote Access for a Manufacturing-oriented Teleservice,” Int J Adv Manuf Technol, Vol. 31, pp. 825–832, 2007.
12. Tufan Koc & Erhan Bozdag, “An empirical research for CNC technology implementation in manufacturing SMEs,” International journal of advanced manufacturing technology, Vol. 34, Nº. 11-12, 2007, pp. 1144-1152.
13. M.A.A. Hasin, P. Natavudh, M.A. Sharif, “A Web-based quality management system and its implementation in a computer assembly industry,” International Journal of Computer Applications in Technology, Vol. 17, No. 4, pp. 202 – 212, 2003.
14. CNC Programming- Principles and Applications, 2nd Edition, by Michael Mattson, Publisher Delmar-Cengage Learning.
15. Rapid prototyping and engineering applications, a tool box for prototype development by Frank Liou, Publisher CRC Press, 2007.
16. Rapid Prototyping: Principles and Applications by C. K. Chua, K. F. Leong , C. S. Lim, World Scientific Publishing Company, 2010.
17. Carliner, S., An overview of online learning, Minneapolis, MN: Lakewood Publications/HRD Press, 1999.
18. Connick, G. P., 1997, “Issues and trends to take us into the twenty-first century,” In T. E. Cyrs (Ed.) Teaching and Learning at a Distance: What it Takes to Effectively Design, Deliver and Evaluate Programs: No. 71. New Directions for Teaching and Learning, San Francisco: Jossey-Bass, pp. 7-12.
19. Herring, S., 2002, “Computer-mediated communication on the Internet,” Annual Review of Information Science and Technology (ARIST), Vol. 36, pp. 109-168.
20. Abe, K., Tateoka, T., Suzuki, M., Maeda, Y., Kono, K. & Watanabe, T., 2004, “An integrated laboratory for processor organization, compiler design, and computer networking,” IEEE Transactions on Education, Vol. 47, Issue 3, pp. 311-320.
21. Hoyer, H., Jochheim, A., Rohrig, C. & Bischoff, A., 2004, “A multiuser virtual-reality environment for a tele-operated laboratory,” IEEE Transactions on Education, Vol. 47, Issue 1, pp. 121-126.
22. Kikuchi, T., Fukuda, S., Fukuzaki, A., Nagaoka, K., Tanaka, K., Kenjo, T. & Harris, D.A., 2004, “DVTS-based remote laboratory across the Pacific over the gigabit network,” IEEE Transactions on Education, Vol. 47, Issue 1, pp. 26-32.
23. Koku, A.B. & Kaynak, O., 2001, “An Internet-assisted experimental environment suitable for the reinforcement of undergraduate teaching of advanced control techniques,” IEEE Transactions on Education, Vol. 44, Issue 1, pp. 24-28.

24. Sebastian, J.M., Garcia, D. & Sanchez, F.M., 2003, “Remote-access education based on image acquisition and processing through the Internet,” IEEE Transactions on Education, Vol. 46, Issue 1, pp. 142-148.
25. Orsak, G.C. & Etter, D.M., 1996, “Connecting the engineer to the 21st century through virtual teaming,” IEEE Transactions on Education, Vol. 39, Issue 2, pp. 165-172.
26. Uskov, V., 2003, “Innovative Web-lecturing technology: towards open learning environments,” Proceedings of the International Conference on Information Technology: Coding and Computing, 28-30 April, pp. 32-36.
27. Ertekin, Y. M., Okafor, A. C., “Derivation of Machine Tool Error Models and Error Compensation Procedure for 3 axes Vertical Machining Center Using Rigid Body Kinematics”, International Journal of Machine Tools & Manufacture, v.40(8), pp. 1199-1213, 2000
28. C. Arlett, F. Lamb, R. Dales, L. Willis, E. Hurdle Meeting the needs of industry: the drivers for change in engineering education, 2, Engineering Education, 2010, Vol. 5.
29. M. Borrego, E.P. Douglas, and C.T. Amelink “Quantitative, qualitative, and mixed research methods in engineering education” J. Engineering Education, 2009, pp. 53-66.
30. R. Thorn, N.H. Hancock, P.H. Sydenham The importance of Measurement in engineering curriculum, London: Institution of Electrical Engineers, 1996.
31. Bretz, E. A., Test & Measurement. IEEE, 2000, Vol. Technology 2000, pp. 75-80.