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Virtual 3-D Laboratory for CNC Machining and Automation Curriculum

Dr. Yalcin Ertekin, Drexel University (Engineering Technology)
Dr. Irina Nicoleta Ciobanescu Husanu, Drexel University (Tech.)

Dr. Ciobanescu Husanu is an assistant professor in Mechanical Engineering Technology at Drexel University. She received her Ph.D. in Mechanical Engineering from Drexel University and also a M.S. in Aeronautical Engineering. Her research interest is in thermo-fluid sciences with applications in micro-combustion, fuel cells, green fuels and plasma assisted combustion. Dr. Husanu has prior industrial experience in aerospace engineering 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, and industrial applications of aircraft engines. In the last eight years, Dr. Husanu gained experience in teaching ME and ET courses in both quality control and quality assurance areas. Dr. Husanu has addressed a broad spectrum of students. After instructing various levels of education, she was granted experience in thermal-fluid, energy conversion and mechanical areas. She also has extensive experience in curriculum development.

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

Dr. Radian Belu is an assistant professor within the Engineering Technology program at Drexel University in Philadelphia. He holds the second position as research assistant professor at Desert Research Institute–Renewable Energy Center at Reno, Nev. Before Drexel University, Dr. Belu held faculty and research positions at universities and research institutes in Romania, Canada and the United States. He also worked for several years as a project manager and senior consultant. He has taught and developed undergraduate and graduate courses in electronics, power systems, control and power electronics, electric machines, instrumentation, radar and remote sensing, numerical methods and data analysis, space and atmosphere physics, and physics. His research interests include power system stability, control and protection, renewable energy system analysis, assessment and design, 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 several papers in referred journals and in conference proceedings. He has also been PI or co-PI for various research projects in the United States and abroad in power systems analysis and protection, load and energy demand forecasting and analysis, renewable energy analysis, assessment and design, turbulence and wave propagation, radar and remote sensing, instrumentation, atmosphere physics, electromagnetic compatibility, and engineering education.

Prof. Jack G. Zhou, Drexel University (Eng.)

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Abstract

Global competitions and technological advances are forcing manufacturers, designers and engineers to constantly innovate new product manufacturing strategies in reducing product development cost and time. Contemporary manufacturers have the option of selecting optimum technologies or processes to suit their manufacturing environment. When these technologies are judiciously combined to address a specific manufacturing challenge such as the one presented in the paper, rapid product development for quantity production, will produce suitable results in terms of cost, quality, and time. Equipping engineering students with the skills and knowledge required to be successful global engineers in the 21st century is one of the primary objectives of undergraduate educators. The key to unlocking the full potential of the Computer Numerical Control (CNC) programmers and engineers lies in the ability to use the full range of the productivity tools incorporated into the CNC equipment and software, while providing realistic operation, part programming, and maintenance environment. Using actual CNC equipment or machine tools to deliver the hands-on experience that is vital to acquiring and demonstrating competence might be too expensive, especially when multiple locations are used for training purposes. Software simulators and hardware emulators can mimic the actual lathes, machining centers, and compound applications, while lowering the overall instructional cost, enabling students to acquire the required skills in a safe environment. The fundamental challenging problems in manufacturing education are related to: (a) Improving the student–instructional technologies interface to incorporate the required learning tools; (b) Improving teaching and learning effectiveness in online course and training. Therefore, the 24 hour access to intensive and informative training tool is desired. The paper discusses the development of a virtual 3-D laboratory set of activities consisting of learning modules and tutorials that will provide students with a realistic interaction with CNC machine. The simulators used enable development of complex machine troubleshooting scenarios that are not feasible on real equipment. These simulators provide a realistic operation, part programming and maintenance environment at a fraction of the cost of using a real CNC hardware or a production machine tool, therefore lowering the training costs. These simulation tools are basically means of optimizing part, machining process and tooling design. Hardware and software simulators allow the users to learn how to program and operate the CNC machine in a virtual environment while the goal of the tutor system is to enhance student learning when the instructor is not available. Incorporating 3D animation allows students to visualize the machining processes and provides greater understanding of the challenges and operating characteristics. Machine simulation includes real components like coolant, sound for machining operations and chips generation. Simulation software has over fifty different control models so that not only will our students get familiar with the HAAS CNC milling machine that exist in our laboratory but also other universal control models such as Fanuc (Fanuc USA) or Sinumerik (Siemens).

1. Introduction

One of the key objectives in durable goods-manufacturing is to create faster industrial processes throughput by eliminating the needs for off-line quality control and part inspection. Nowadays, as automation, high performance machining and labor savings are introduced in machining of discrete component designing, prototyping and manufacturing, it is desirable to reduce the time and the manpower for inspection, and have an intelligent and real-time quality control of the products. This is typically performed by using coordinate measuring machines (CMMs) and related inspection tools. Great savings of both time and labor during the inspection process can be realized in the machining of discrete components through gains in automation, information technology and high performance machining. The major goals and objectives of our project is to integrate strategic process optimization concepts and intelligent controls in high speed machining, creative thinking and solutions-based applications, machine tool calibration, on-machine quality control, precision metrology applications into the existing engineering curriculum through the development and implementation of learning modules that will simulate industry approach to product development cycle that is design, analysis, prototyping and improvement into selected required coursework in each engineering discipline.

The major project outcomes are: 1) Facilitate student exposure to potential careers in the CNC and modern manufacturing technology areas of manufacturing, as well as the overcoming precision metrology skills shortages by incorporating current advances in CNC technology and engineering metrology into our undergraduate program with an emphasis placed on the laboratory activities and projects that will simulate innovative design, design analysis and process simulation, prototyping and improvement cycle. 2) Using Project Centered Learning (PCL) pedagogy in the learning modules, students will develop skills to confront ambiguity and uncertainty as expected and integral part of the solving engineering problems.

Through the developed and implemented experimental settings during this project, we are beginning to engage the students in both on-site and online/remote laboratory experiments, although this endeavor is just in its initial phase. The next phase is related to the development and implementation of a computer-based CNC (Computer Numerical Control) control simulators, software applications, as well as exemplary associated learning modules. Virtual, remote or hands-on laboratories by themselves can't guarantee successful student learning outcomes; each has its advantages and disadvantages. However, virtual labs offer cost savings and active learning, but they are not real and present limited opportunities for trial and error. Remote labs provide real experiments with real equipment at lower cost but lack the "feel" of handling real equipment and can be less engaging. Onsite labs offer hands-on experience and problem-solving opportunities but are costly, less flexible and fail to provide access and ease of use for the disabled and distance learners. The literature suggests that a "mixture of elements might be superior to any single technology." A key aspect of our project, therefore, is to use and improve the onsite Engineering Laboratory with the High Speed CNC components, to enhance student lab experiences by allowing them to perform real laboratory experiments and tasks that both reinforce and assess what they've learned in their virtual lab studies in less time and with less risk than would normally be present. Our strategy based on virtual-labs-to-onsite-labs approach is focused on increasing the students' efficiency while performing physical laboratory activities by shifting the center of attention towards the learning objectives of the laboratory rather than on "how to do the laboratory."

A derived, but nonetheless important objective is to improve, re-design and re-develop seven current industrial training modules covering High Speed CNC machining, prototyping, machine tool calibration, precision metrology, offline and online quality control, remote monitoring and supervision of machining and robotic assembly processes, quality assurance and computer aided design/machining (CAD/CAM). This activity is currently undergoing, its progress being highlighted in the following sections. The CNC simulators to be developed and implemented during this project will provide realistic operation, part programming and maintenance environment at a fraction of the current cost. This will be done by using a real CNC hardware, therefore significantly lowering training costs. Industry-supplied and coordinated projects will be used in conjunction with capstone projects using collaborative student teams. The newly-equipped laboratories will be networked for cross-institutional use between Drexel University and affiliated community colleges. Figure 1 shows the overall architecture of the proposed collaborative project involving web-enabled, advanced manufacturing systems over the Internet. The heart of this project is the hardware and software described in the following sections.

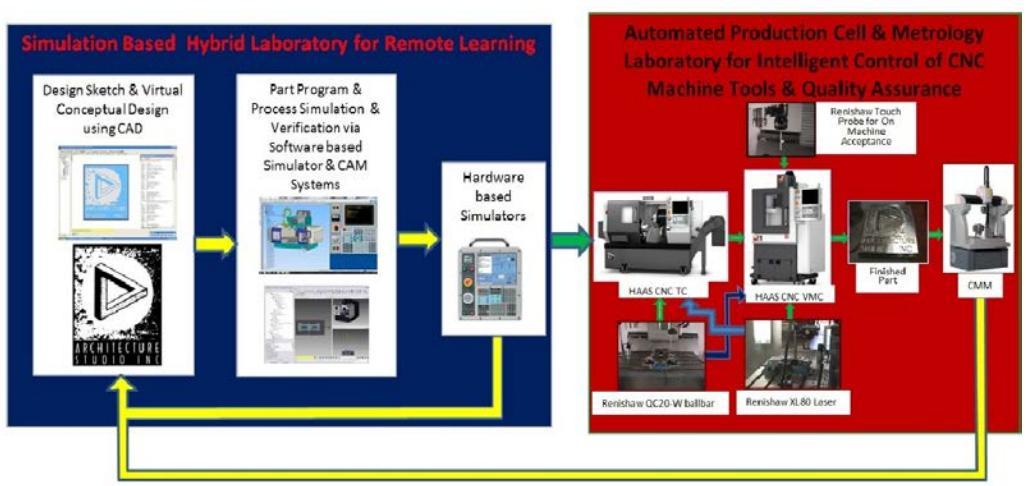
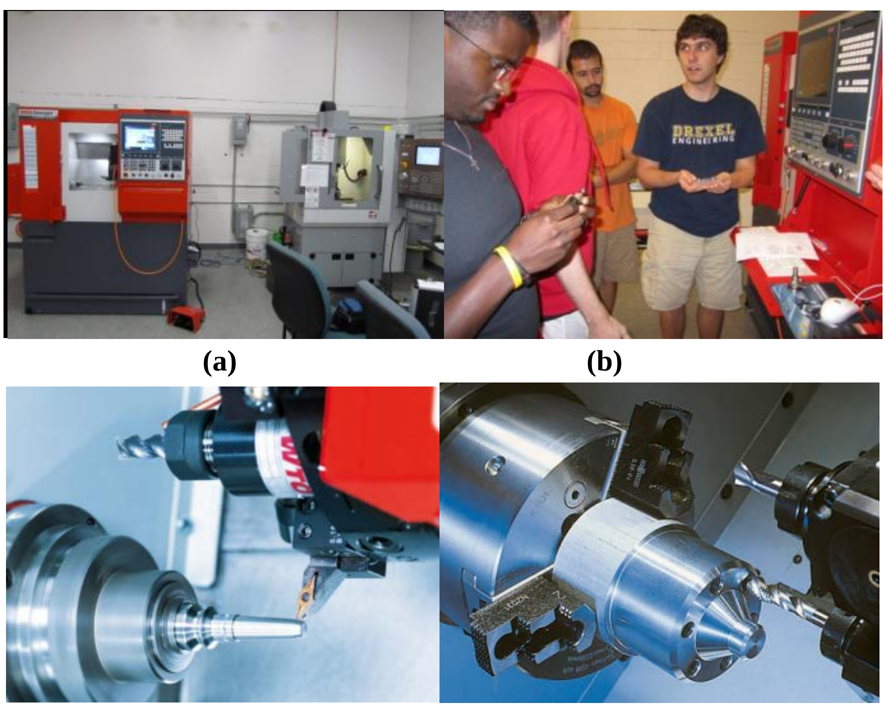


Figure 1. Overall architecture of proposed project.

2. Hardware and Software Experiential Framework

2. 1. EMCO Concept Turn 250 CNC Turning Center (TC)

EMCO has a capability to machine metallic stock material up to 3.346 in diameter with a tail stock support for long and slender work parts. This is very critical to eliminate chatter vibrations during machining low stiffness (high length to diameter ratio) parts. Machine structure is designed with a slant angle of 60° allowing easy chip removal[2]. The machine bed is made of cast iron, extremely resistant to torsions and vibration-damping. The headstock, slide unit and tailstock are mounted on the machine bed. Due to the three-point support of the machine bed a distortion and thus an impairment of the accuracy is avoided. The slides are traversed by AC motors via recirculating ball screw spindles. The amply dimensioned spindles, the rigid spindle nuts and the axial bearings without backlash provide high-positioning and working accuracy. Above features made this machine superior to other vendors and played a critical role during the equipment selection process. This machine is designed for complete machining by turning, drilling and milling of machinable metals and plastics. Figure 2 is showing various aspects of utilization, installation and experimentation of the EMCO system. This equipment is built based on a unique concept -interchangeable control- meaning that EMCO could be equipped with up to five different interchangeable control panels and interfaces. In doing so, the user is trained on all CNC industry controls that are common to the market. Currently Fanuc and Siemens control interfaces are loaded in the Machine Controller so that students can get experience with two different types of controls. Up to eight different control units can be installed and taught on one single machine at present. The result is that CNC technologists and engineers are flexible to work in a variety of settings.



(a) **(b)**

(c)

Figure 2 (a**)** EMCO CNC TC and Haas VMC located at Engineering Technology Mechanical Laboratories **(b)** ETStudents are being trained on EMCO CNC TC with Fanuc control. (c**)** Various test parts machined using EMCO TC.

2.2 Renishaw QC20-W (Wireless) Ballbar System

The Renishaw QC20-W Ballbar (Figure 3) and the software package is used to measure geometric errors present in a CNC machine tool and detect inaccuracies induced by its controller and servo drive systems. Errors are measured by instructing the machine tool to "Perform a Ballbar Test" which will make it scribe a circular arc or circle. Small deviations in the radius of this movement are measured by a transducer and captured by the software. The resultant data is then plotted on the screen or to a printer, to reveal how well the machine performed the test. If the machine had no errors, the plotted data would show a perfect circle. The presence of any errors will distort this circle, for example, by adding peaks along its circumference and possibly making it more elliptical. These deviations from a perfect circle reveal problems and inaccuracies in the numerical control, drive servos and the machine's axes. In theory if we program a CNC machine to trace out a circular path and the positioning performance of the machine was perfect then the actual circle would exactly match the programmed circle. In practice many factors in the machine geometry, control system and wear can cause the radius of the test circle and its shape to deviate from the programmed circle. If we can accurately measure the actual circular path and compare it with the programmed path then we would have a measure of the machine's accuracy. This is the basis of all telescopic ballbar testing and of the Renishaw QC20-W ballbar system. The user has a choice of several report formats according to International standards (e.g. ISO, ASME) and the comprehensive Renishaw diagnostics (including volumetric analysis) with a number of different screens views and links to the help manual[4].

Figure 1 Renishaw QC20-W (Wireless) Ballbar System in its protective carrying case (left) and Ballbar application simulation software (right)

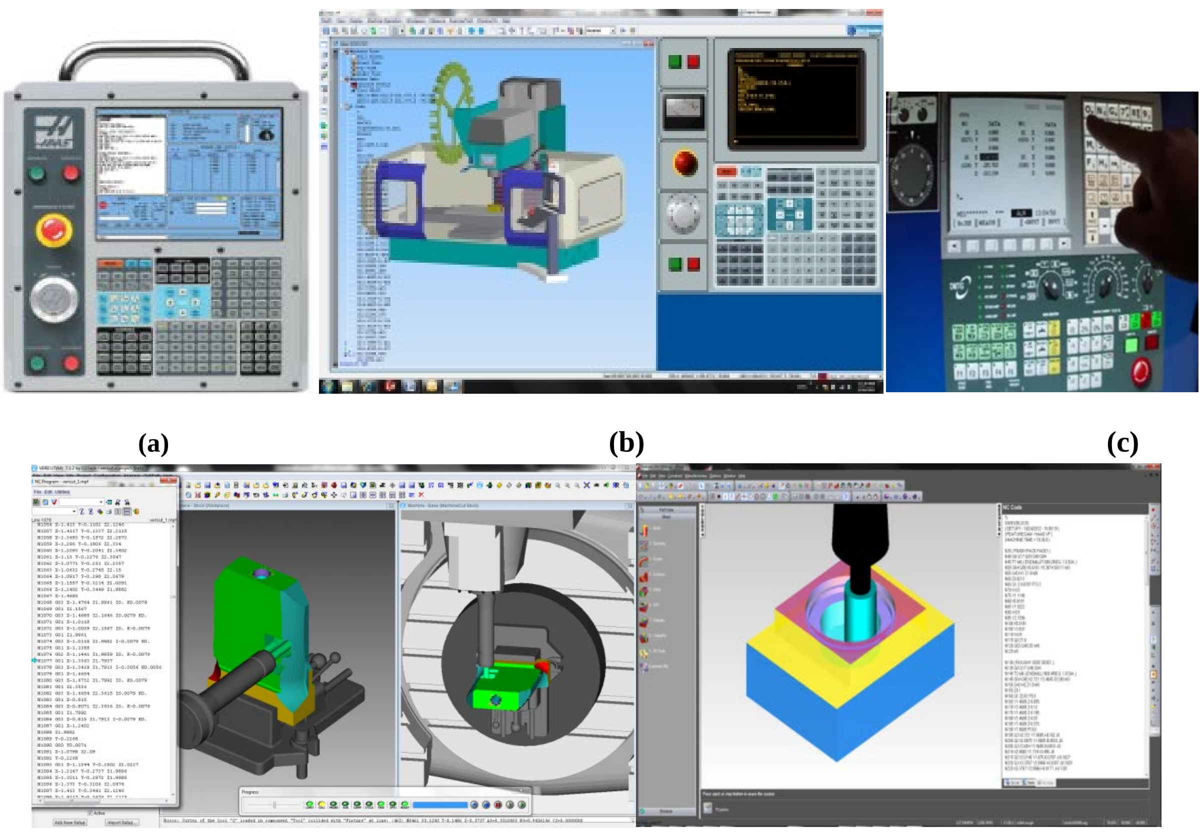
3. Integration of Hardware and Software Based Simulator Systems into Course Curricula

The key to unlocking the full potential of Computer Numerical Control (CNC) to the programmers and engineers lies in ability to train them to use the many productivity tools incorporated into the CNC equipment, providing realistic operation, part programming, and maintenance environment. Software and hardware based simulators can simulate lathes, machining centers, and compound applications. Engineers and programmers can repeatedly practice complex actions and develop Custom Macro B subprograms without risks to people or machine tool assets. Simulators also enable development of complex machine troubleshooting scenarios that are not feasible on real equipment. These simulators provide a realistic operation, part programming and maintenance environment at a fraction of the cost of using a real CNC hardware or a production machine tool, therefore lowering training costs. Using actual CNC equipment or machine tools to deliver the hands-on experience that is vital to acquiring and demonstrating competence might be too expensive when multiple locations are used for training purposes. Multiple display and keyboard configurations can be selected and saved to match each of the CNCs being used in a school laboratory. Software and hardware based simulators can provide:

- Enhanced comprehension and increased speed of development by performing hands-on exercises in a ergonomically-friendly class room environment;
- Increased safety and productivity by allowing students to repeatedly practice complex actions and develop Custom Macro B subprograms without risks to people or machine tool assets;
- Reduced training equipment cost by emulating multiple CNC and machine combinations using the Machine Composition setting tool, the Option Setting tool, keyboard and screen size selections, and actual CNC parameter settings, and by integrating custom screens developed and provided by the machine tool builder;
- Expanded training opportunities for more students and reduced testing bottlenecks by allowing online access to the CNC simulator software or hardware.
- Increased productivity by allowing users to attain "expert" level through repeated practice on the simulator before running the actual equipment;
- Complete CNC environment can be simulated in a single, user friendly interface that will be an excellent teaching tool and instructor aid[13]

  A HAAS dual system control simulator (Figure 4a) which is housed in a class room environment located at Burlington County Community College is being used in tandem with software based tutor/simulator based systems. In addition to the adoption and development of EMCO tutor systems, two software packages were integrated into manufacturing related courses. The software packages are Swansoft CNC and VERICUT which are used in machining and control operations simulations (Figure 4- b thru d). Another software package used in the CNC and manufacturing related courses is FeatureCAM Computer Assisted Programming software (Figure 4e). Students use FeatureCAM to draw the path geometry, obtain the cutter path and part program to mill a part design. Students verify the G-code program output of FeatureCAM using VERICUT and SwansoftCNC simulators. All software packages are installed in the networked virtual computer that allows online access to software from any computer that is connected to internet. For online teaching, students are able to access software using remote desktop connection using DU-VPN. A Remote Desktop client is built into all versions of Windows. To connect to virtual computer, student needs to enter the IP address of the remote computer, and it asks you for the login and password. Total machining process simulation that includes selecting the workpiece, zeroing the workpiece, select and measure tools, select the right operation mode for the machine and clearing all the alarms can be performed virtually using Swansoft software. One of the difficulties teaching in ET-mechanical laboratory is that students may not be able to see what the instructor showing on the machine control panel especially when the class size is big.

This problem is overcome by using simulation package of Swansoft CNC (SSCNC), which allows students to realistically practice how machine control interface is used to set-up machine tools which is very critical for successful machining operations[14]. Machine simulation includes real components like coolant, sound for machining operations and chips generation. It has over fifty different control models so that not only our students will get familiar with the HAAS CNC milling machine that exist in our laboratory but also other universal control models such as Fanuc (Fanuc USA) or Sinumerik (Siemens).



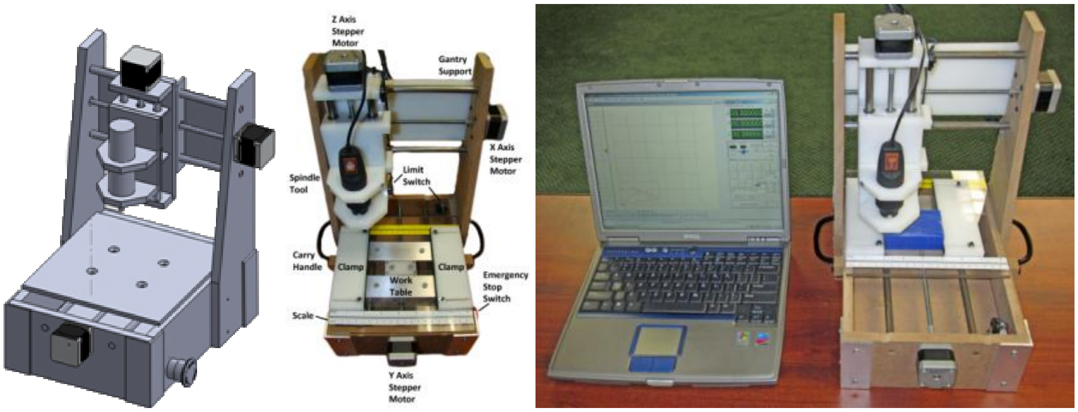
(a) **(b)** **(c)** **(d)** **(e)**

Figure 4. (a) HAAS dual system control simulator hardware. **(b)** Swansoft CNC simulation software showing machine control panel simulation for HAAS control. **(c)** Swansoft CNC simulation software showing machine control panel simulation on a tablet pc for Fanuc control. **(d)** VERICUT CNC machining and program verification software **(e)** FeatureCAM part program generation.

SSCNC can broadcast screen information to the students and remotely assist them via remote view and controlling of the student PC. It also provides question library management, test paper management, as well as the test process management for grading. Similar to Swansoft CNC, VERICUT software is used to simulate CNC machining in order to detect errors, potential collisions, or areas of inefficiency[15]. VERICUT enables NC programmers and process designers to correct errors before the program is ever loaded on the CNC machine, thereby eliminating manual prove-outs. VERICUT also allows users to build their machine with different controls so that simulations can be obtained for specific machine configuration. VERICUT also optimizes NC program cutting speeds for more efficient machining including for high speed machines. In addition to machining, VERICUT is used to simulate on machining probe cycles for quality control of critical dimensions on the parts. VERICUT's simulation of the machining and in-cycle gauging cycles is extremely important for successful process design, operations and part quality.

4. Desktop Mini CNC Mill Developed For MET316-CNC Course

The desired current set of skills required of modern engineers and technologists has been steadily expanding. In addition to familiarity with manual machining and fabrication techniques, mastering CAD/CAM, Computer Numerical Control (CNC), and automation methods are increasingly becoming essential tools in the design, prototyping and manufacturing of complex systems. An inter-disciplinary design project towards the development of a mini CNC milling machine was executed by senior ET students during the 2011-2012 academic year. Since purchasing and installing traditional CNC equipment is not an option for every campus of Drexel University or similar engineering schools, an alternative solution to providing hands on experience with CNC equipment is desirable. A CNC machine with a desktop form factor which would be easily transported between campuses would eliminate the need for multiple traditional CNC machines and would improve the quality of the MET316-CNC course by providing more hands-on lab experiences. The desktop CNC machine which was developed by student design team, fits on a standard desktop or table, and interfaced KCAM Computer Aided Manufacturing (CAM) software (Figure 5).



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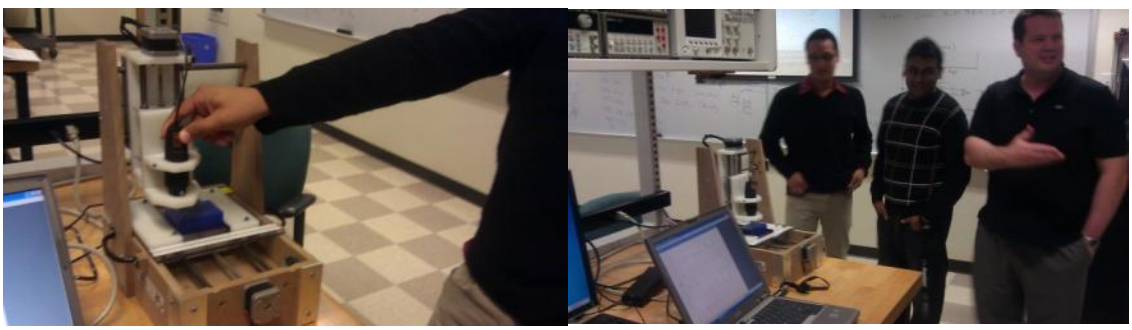
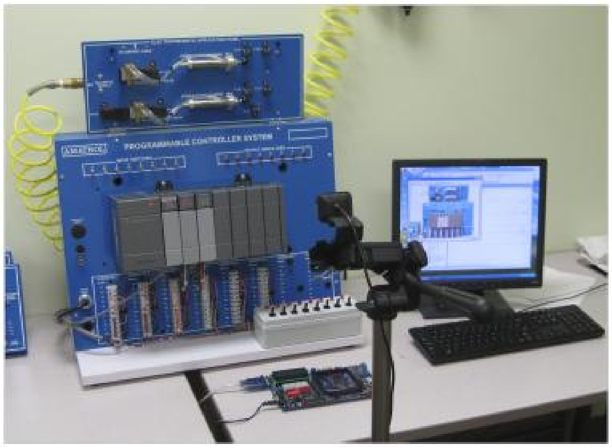


(b)

Figure 5. (a) CNC Desktop mini milling machine & control computer with Completed Working Table. **(b)** MET 316 CNC students running the desktop machine for G& M code testing.

Development is still under progress for a remote online laboratory for computer numerical controlled machines in Engineering Technology Laboratory. Desktop Mini CNC mill will be set-up similar to remote programmable logic controller (PLC) station (Figure 6c). Figure 13a shows the PLC workstation and host computer that are remotely programmed and used at remote labs at Drexel University. The web camera in the foreground allows the student to monitor the behavior of the system visually. The camera's image can be seen on the computer monitor. The panel at the top of the PLC station is the electro-pneumatic panel. A Remote Desktop client is built into all versions of Windows. To connect to laptop computer that controls Desktop CNC mill, student needs to enter the IP address of the remote laptop computer, and controls the machine using KCAM software (Figure 6c). Machine can be jogged remotely for set-up and a G-code can be executed remotely to machine a work-piece. For safety reasons, a lab technician monitors the CNC machine and laptop controller at all times.



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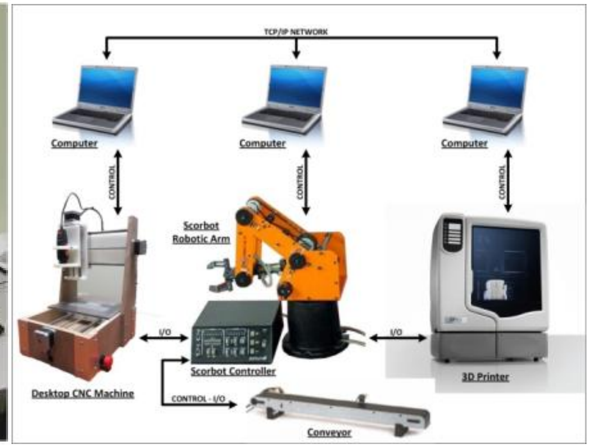

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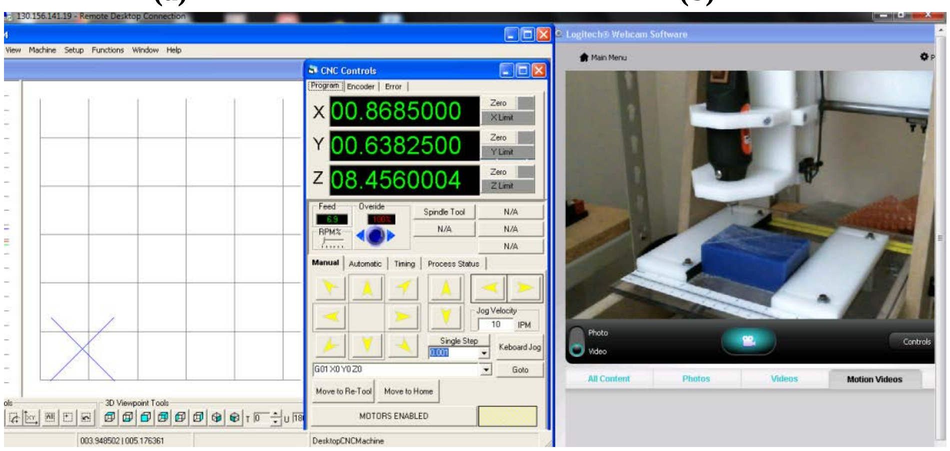

(c)

Figure 6. (a) Workstation used for online laboratory exercises at Drexel University. The board on the table is used in microcontroller experiments. **(b)** Future machine development remote Work Cell Example at Drexel University. **(c)** Remote online access to CNC mill located at BCC campus.

Figure 6 (b) depicts a concept of remotely operated manufacturing cell that is being developed. Remotely operated cell includes a desktop CNC machine that was designed and built by Drexel University senior Engineering Technology students. The CNC machine is used in conjunction with other machines in a work cell configuration for educational purposes. Multiple machine interoperability would include the desktop CNC machine, the Scorbot ER IV robotic arm, a 3D printer, and a conveyor or holding area. In this example the desktop CNC machine would be loaded with a 3D printer manufactured part, to perform a final milling step. The robotic arm would remove the part from the 3D printer after the printing process is complete and place it on the working table of the CNC machine. A machine controlled clamping system would be required on the working table of the CNC machine to fully automate this process. Once the milling process was complete the robotic arm would remove the part from the CNC machine and place it on a conveyor or in a separate holding area. The process could then be repeated[8, 9].

5. Development of an Agent-based Tutor & Training System

Development of an agent-based tutor and simulator training system (ATSTS) is in progress 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. Figure 7 indicates a screen view of online tutorial system that is being developed using Emco campus modules for machining applications.

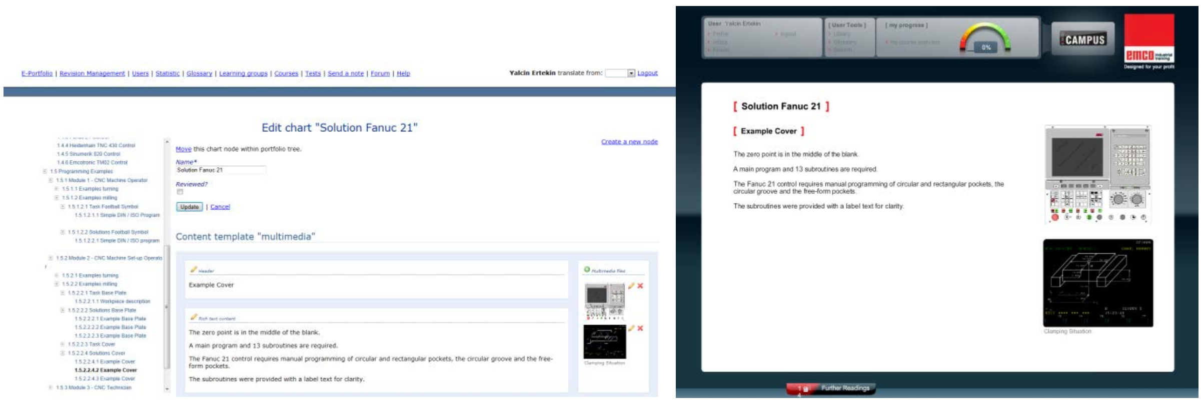

Figure 7. Example online tutorial system developed in cooperation with Emco company.

Conclusion

The laboratory development efforts for the integration of hardware and software simulators in engineering technology courses at Drexel University are described in this paper. Design and simulation should take place during new product development process as a cycle to prevent increase in prototype costs. Therefore, it is imperative to incorporate necessary technologies and tools into Engineering Technology curriculum to make sure quality control is natural part of an engineering technology major's curriculum. Until now, at least four ET undergraduate courses namely, MET316-CNC, MET4xx- Senior Design, MHT226- Measurement Lab and MET204- Quality Control and two graduate courses specifically ET635- Engineering Quality Methods and ET615- Rapid Prototyping are impacted by the new equipment and software tools of this project.

Students who were involved in the development and testing of the modern tools, equipment and software applications were very enthusiastic to learn more about discussed tools. ***The best aspects of the related senior design course, as perceived by students can be summarized as follows:*** Students were highly satisfied by the opportunity provided by this course to be creative and to use interesting materials and software. Students particularly embraced using SolidWorks® for product design and FeatureCAM for code generation. Being able to remotely operate a machine tool was highlight of the course. The senior design course really changed the way that they regarded design, simulation, prototyping and manufacturing. Quoting of several of the student reviews are provided below:

Question: What were the best aspects of the course?

- *Prototype assembly and testing.*
- *Developing and testing our project. Designing the circuitry*
- *Assembling and designing our project and actually see the project perform the task we wanted it to do*

Acknowledgement

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