Design of a Computer-Aided Point-of-Use Safety Training Environment for Laboratory Equipment

Joseph C. Musto[1]*

[1]Mechanical Engineering Department, Milwaukee School of Engineering, Milwaukee, WI 53201 USA

ABSTRACT

Increased awareness and regulatory scrutiny has given rise to an increase in the focus on safety training in engineering laboratories. The delivery of training, and the record-keeping associated with training activities, places an increased burden on laboratory administrators and technicians. In this paper, a new system for computer-aided safety training in a laboratory environment is described. The system makes use of computer-based training materials, coupled with novel computer-controlled equipment lockout hardware, to deliver and assess safety training at the point of use. The motivation for the new system is presented. The development of the novel lockout hardware and software architecture is described. An example implementation, involving a Charpy impact testing machine, is detailed, and testing of the system is described. A future large-scale implementation is conceptualized and described.

KEYWORDS: *Laboratory safety, lockout/tagout, MATLAB*

1.0 INTRODUCTION

The use of manufacturing and testing equipment in an engineering environment poses serious safety challenges. This is true in both industrial and university environments. These issues can be accentuated in university environments, where undergraduate students are expected to learn to use a wide variety of equipment and tools (such as machine tools, load frames, robotic systems, and many others) in a very short time and with minimal supervision.

In recent years, a number of high-profile incidents have highlighted the need to focus attention on health and safety issues in college and university teaching laboratories (Benderly, 2012; Benderly, 2010, US Chemical Safety Board, 2011). This has been shown to be an international issue, with no clear resolution (Zhu, et.al., 2016; Rezapour, et.al. 2017, Ismail, et. Al. 2016) Mandatory safety training has become common in teaching laboratories. The delivery of safety training materials, the assessment of safety knowledge, and the record-keeping associated with these activities have become a responsibility of faculty members and support staff that are involved in laboratories. With the large number of students generally using an academic laboratory, and the annual turnover in the student population, the traditional techniques for training and record-keeping can become a burdensome task.

In this paper, a new method for delivering, assessing, and monitoring safety training for student laboratories will be presented. The new method augments the evolving topic of

computer-based training methodology with physical computer-controlled hardware inspired by the logout/tagout systems used industrial safety applications. The new method allows what is called "point-of-use" safety training; safety training materials are delivered to students *at the site of the equipment* and *at the time of equipment usage*, and an immediate assessment of safety knowledge is performed. Only when the safety assessment has been completed and passed can the computer-controlled lockout hardware be removed from the equipment. While this paper focuses on a university laboratory setting, the method is broadly applicable to industrial laboratories as well.

The novel and key feature to this new method is the computer-controlled lockout hardware. The next sections of the paper will detail the hardware and software design. Following that, a proof-of-concept application will be described. In this application, a computer-aided point-of-use safety training application is developed for use with a Charpy impact tester in a university materials testing laboratory. Conclusions based on design and testing that are applicable to future implementations of the method will be discussed.

2.0   HARDWARE DESIGN

The novel component of this new method is the computer-controlled lockout hardware that interfaces with the computer-aided training and assessment technique. Lockout hardware is used extensively in industrial lockout/tagout programs. Many industrial safety organizations mandate the use of lockout hardware during maintenance of industrial equipment, requiring the use of keyed padlocks and positive locking mechanisms to disable valves, switches, and other control devices when equipment is de-energized for service (OSHA Standard 29 CFR 1910.147, 2011). In the design of the lockout hardware for this application, it was decided that the lockout hardware for computer-based safety training should comply with industry regulations. Therefore, the hardware was designed around an existing keyed padlock. The hardware would:

- Use a keyed padlock as the primary mechanism securing the lockout device, and

- Use a redundant computer-controlled locking mechanism to control access to the keyed padlock mechanism.

In the design of this prototype, it was decided that off-the-shelf interfacing hardware would be used to provide computer control to the mechanism. The Labjack U3 interface device was selected.

2.1 Mechanical Hardware

The prototype of the lockout hardware is shown in Figures 1 and 2. It is comprised of an off-the-shelf lock, and an ABS structure covering the body of the lock, a pivoting door that covers the keyhole of the locking structure, and a 9-volt pull-type solenoid that engages the pivoting door and prevents it from moving when the solenoid is de-energized.

Figure 1: The Locking Device – Top View

Figure 2: The Locking Device – Bottom View (Disassembled)

The power to the solenoid is provided through a connector. The solenoid functions as a redundant locking mechanism; in order to access and unlock the padlock, the solenoid must receive a 9-volt power signal, retracting the solenoid and allowing the door to be pivoted. After the padlock is relocked, the door can be pivoted to the closed position, and the de-energized solenoid engages and locks the door in place.

2.2 The Interfacing Hardware

The hardware to interface the control computer to the lockout hardware is shown in Figure 3. The main component is Labjack U3 interface board, which connects to a PC via a USB connector. Only one output channel from the Labjack board is used in this application. It is used to drive a digit relay connected to a 9-volt battery. The device provides a 9-volt power signal when the Labjack channel is set high. This is the signal that is used to drive the solenoid in the lockout hardware.
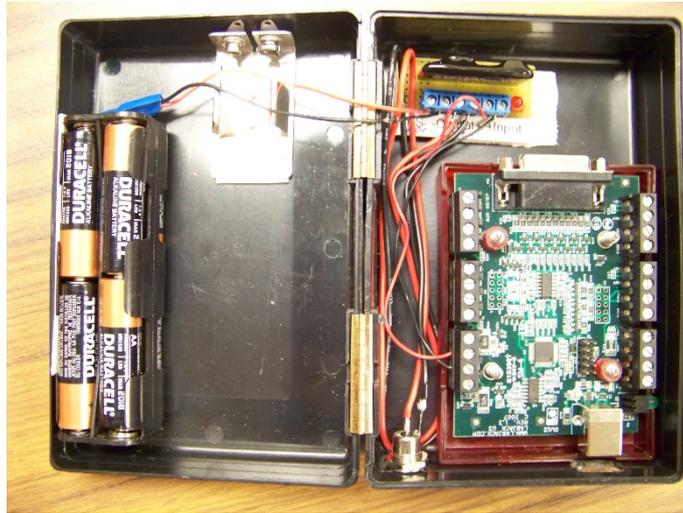
Figure 2: The Interfacing Hardware

The interface hardware is designed to allow the computer and interface hardware to be modular; in a lab setting, it is intended that a small number of computers and interface boxes would service a large number mechanical lockout devices.

3.0   POINT-OF-USE SAFETY TRAINING SOFTWARE

With the mechanical and interface hardware as described in the previous section, the role of the system software is to:
- deliver safety training information with regard to a particular piece of equipment, in the form of text and/or video,
- deliver assessment of safety knowledge (such as a multiple-choice quiz), and determine whether or not the person taking the safety assessment has received sufficient training, and
- send a signal to the lockout hardware to unlock the redundant locking mechanism and allow access to the equipment, in the event that the safety assessment has been successfully completed.

This new training method is called "point-of-use" safety training, since the purpose is to deliver the training at the site of the equipment that the user is being trained to use. This "point-of-use" has the advantages of traditional computer-based training (such as the ability to present audio/video training materials, the ability to give real-time feedback on training assessments, and the ability to track performance and training status of users), but has the following additional advantages:

- by delivering the training at the site of the equipment, the user has the ability to view the actual equipment in the setting of actual use; the interpretation of the information can be done in the context of actual use, and
- by coupling the training with the lockout hardware, access to equipment is strictly limited to those users who have recently completed training and passed the safety assessment.

In this implementation, the shell for the point-of-use training software was developed using MATLAB. This served as an ideal tool for the prototype application, since the GUI capabilities in MATLAB are well-suited for the delivery of training materials and the delivery of assessment quizzes. In addition, drivers are readily-available for control of the Labjack U3 interface device from MATLAB.

In an implementation, a user takes a computer and interface device to a piece of laboratory equipment, connects the interface device to the appropriate lockout hardware, and initiates the training software. The essential flow of the algorithm (shown in a flowchart in Figure 4) is as follows:

- Information on the user is collected, in the form of a name, ID number, etc. This facilitates record-keeping; the information on the user and the date of training is added to a data file. In certain applications, it may be desirable to track the performance and training status of individuals, and allow individuals with recent successful training to bypass the training materials.
- Training information is delivered to the user. The training is specific to the equipment to which the device is connected. In the initial implementation of the software, the training information is provided as an **.avi* file.
- When the training is complete, a multiple choice quiz assessing the user's knowledge of key safety points is initiated. A multiple-choice question is presented.
    - If the question is answered correctly, the user is given appropriate feedback and the next question is initiated.
    - If the question is answered incorrectly, the user is given the opportunity to review the training materials, and attempt the question again.

    This step is repeated for an appropriate number of questions.
- After the quiz is completed, the user's score is recorded in a database.
- If the quiz has been passed, a signal is sent through the interface device to retract the solenoid and allow access to the padlock. Once the equipment is unlocked, the user indicates this via a check box, and the solenoid is de-energized.

The user can then disconnect the interface device, and proceed with equipment access and usage.

Like any training application, certain details may vary, depending on the particular laboratory and particular equipment in question. For example, in certain applications, it may be desirable to track the performance and training status of individuals, and allow individuals to bypass the training materials and assessments if records show they have successfully completed training within a given time frame. In some applications, users may be allowed to answer multiple-choice assessment questions an unlimited number of times, ensuring that every user eventually passes the training. The new method and software has the flexibility to accommodate a wide variety of such training plans.
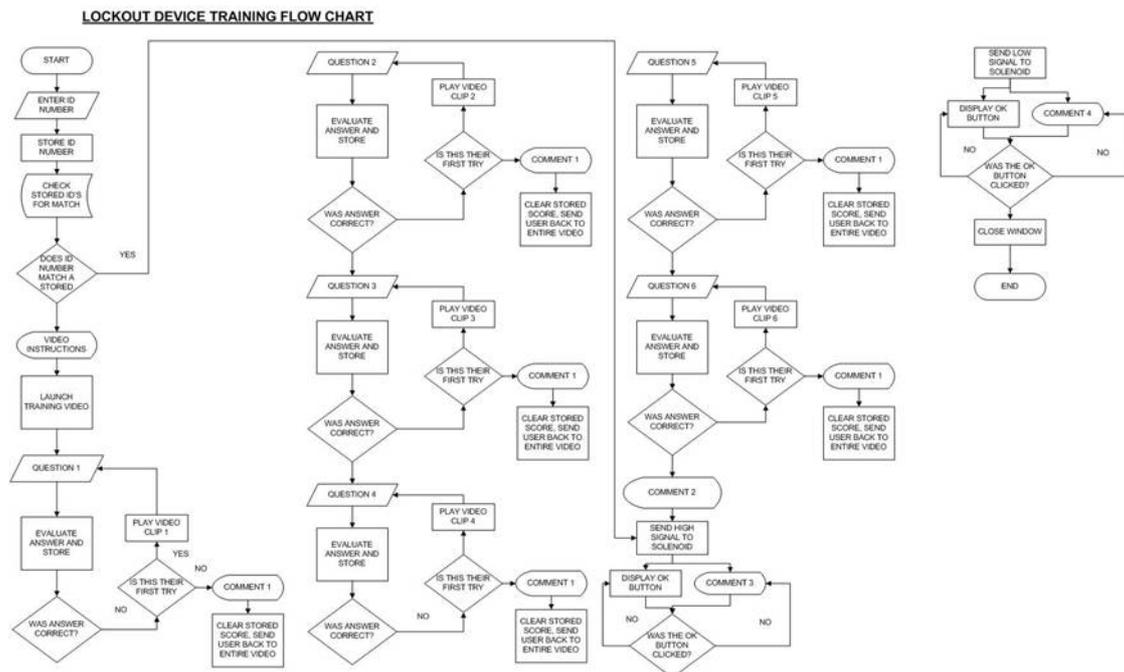
Figure 4: Software Flowchart

3.0   CASE STUDY: CHARPY IMPACT SAFETY TRAINING

3.1 Implementation

In order to demonstrate the details of the method, an example implementation will be presented.   In this implementation, a training program for use in an undergraduate materials science laboratory will be shown. The training will center on a Charpy impact tester, shown in Figure 5. The Charpy impact tester is used to test the impact strength of specimens, using a large swinging hammer to provide the impact. The height that the hammer reaches after impact is compared to the height at the start of the swing; the height difference is used to calculate the amount of energy absorbed by the specimen during the impact fracture. Since the tester involves a large moving component with significant energy, this equipment is a potential source of injury if used by untrained users.

The first step in the implementation was the design of a lockout mechanism which, when coupled with the computer-controlled lockout hardware, would prevent the use of the Charpy unit when locked. The device would essentially lock the hammer in a fixed position when engaged. The device that was designed is shown in Figure 6; it is shown locked in place on the Charpy impact tester in Figure 7.

Figure 5: Charpy Impact Tester
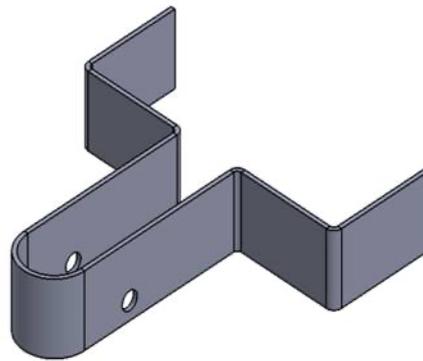
Figure 6: Lockout Device

Figure 7: Lockout Device (Installed)

The training materials for the Charpy impact tester were developed with input from the instructors that regularly teach students to use the equipment. The training materials included still photographs, text, and video, put together into a PowerPoint presentation. The slideshow of the presentation was saved as an *.avi* file, and integrated into the training software. The safety training materials closely mirrored the safety training currently provided to users in the laboratory, and included safe use of the equipment, laboratory rules, and emergency procedures.

In this example implementation, a user who desires to use the Charpy tester would approach the machine, plug a laptop computer into the locking hardware via the interface device, and initiate the training software. The user is prompted to enter their student ID number, and shown in Figure 8.

Figure 8: Initial Screen

In this application, if the user's name and ID number is found in the training database, and they have successfully passed the training assessment during the academic term, then the training and assessment modules are bypassed, and the computer-controlled locking mechanism is disengaged. This screen is shown in Figure 9. If the user does not have up-to-date safety training information on file, the *avi file containing the training materials is launched, as shown in Figure 10.

Figure 9: "Access Approved" Screen
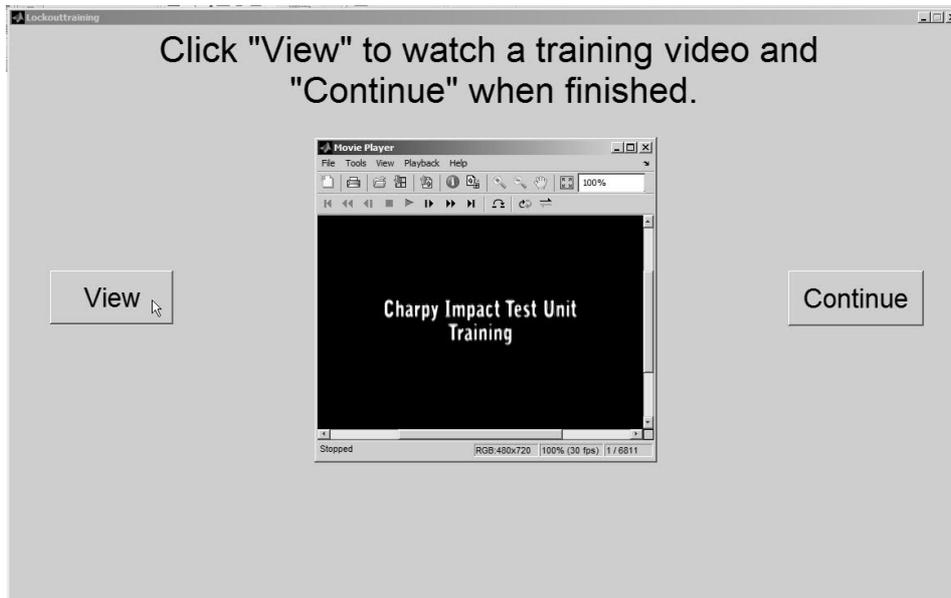
Figure 10: Training Video Screen

The user may replay and review the training materials; after they feel sufficiently trained, they proceed to the assessment quiz. The first screen of the assessment quiz is shown in Figure 11. If the user answers incorrectly, he or she is given a second chance to review the safety information and/or answer the question again (Figure 12). A successful answer is treated as correct. A second incorrect answer terminates the training, and records the appropriate information in the training database. These users are prevented from using the equipment without in-person training. If the user answers correctly on either the first or second try, then the information is recorded and the quiz proceeds to the next question.
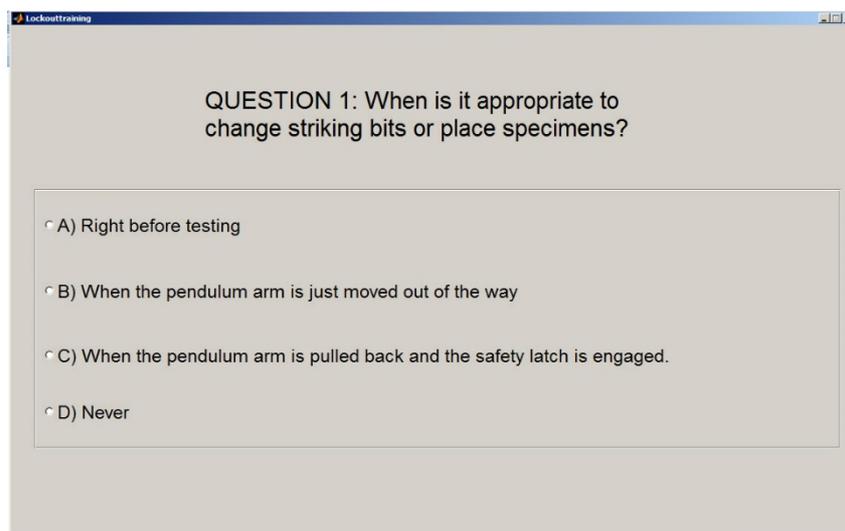
Figure 11: Safety Quiz #1 Screen
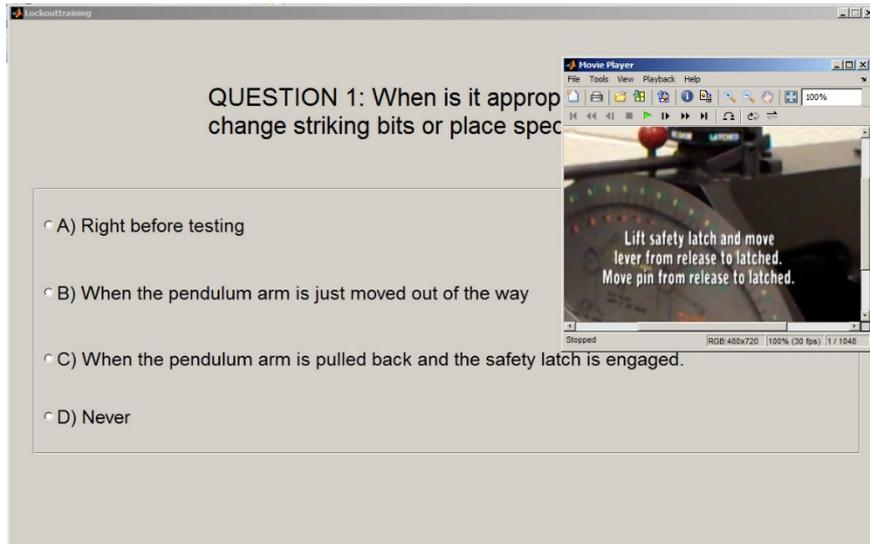
Figure 12: Video Review Screen

Additional questions are presented in sequence, as shown in Figure 13. When the last question is answered correctly, the user has passed the assessment (Figure 14). A passing score is recorded in the database.
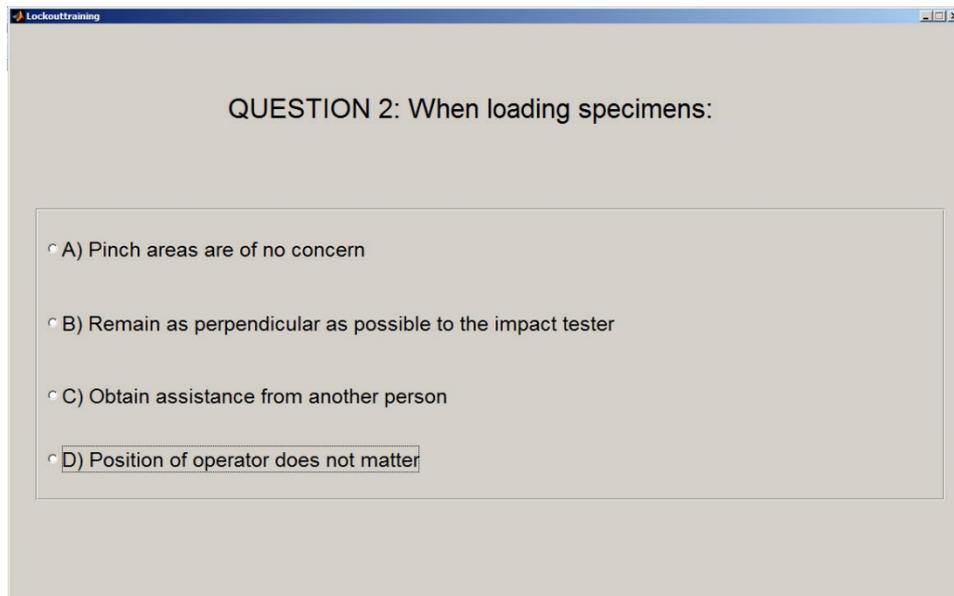
Figure 13: Safety Quiz #2 Screen
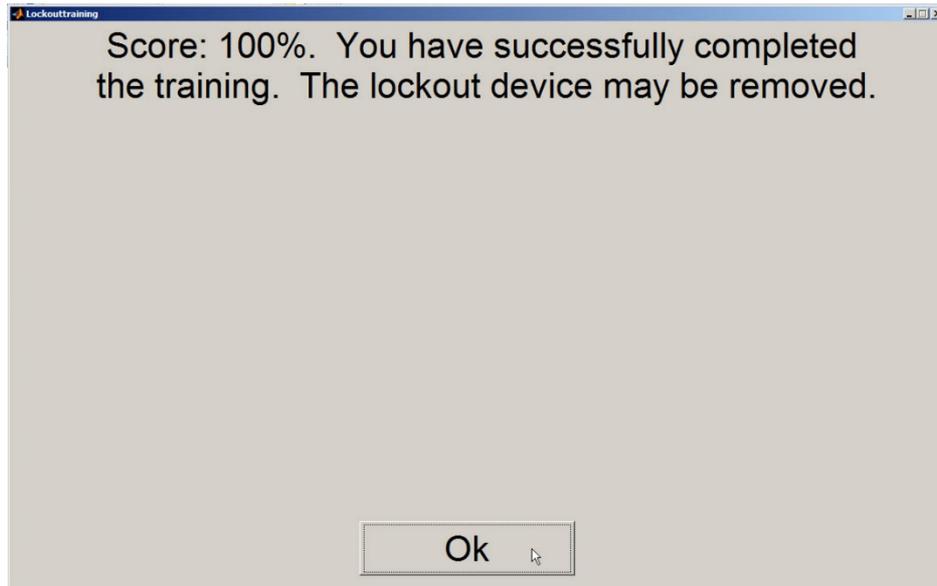
Figure 14: "Training Complete" Screen

At this point, the computer-controlled lock is disengaged, and the user is prompted to remove the lock and proceed with equipment usage, as in Figure 15.

Figure 15: Final Screen

3.2 User Feedback

In order to test the viability of the system as a safety training tool, undergraduate students from a Safety in Engineering class at {Author's University} were recruited to test and assess the method as applied to the Charpy impact tester. Four students were assigned to complete the safety training, none of which had familiarity with the Charpy impact tester. The remaining students observed the training, and performed other tasks with the

computer-controlled lockout hardware. A summary of the feedback received from the students is as follows:

- Each of the students who received "point-of-use" safety training was judged to be able to safely operate the equipment after receiving training.

- Each of the students who received the training, and each of the students who tested other aspects of the software, gave positive feedback on ease of use.

- Multiple students involved in testing various aspects of the system felt that the "speed" and "fluidity" of the process needed to be improved. This was attributed to the fact that both the hardware and software involved in the test was in the prototype stage.

5.0   CONCLUSIONS AND FUTURE WORK

The new point-of-use safety training application has been prototyped and implemented in an example application. While both the hardware and software for the test implementation were at the functional prototype stage, user feedback has indicated that the methodology is a useful tool for delivering training in a laboratory setting.

Future work will focus on taking the hardware and software from prototype to production quality. Porting the software to a networked handheld device, and eliminating the hardwired interface, are future targets for development. A wide-scale implementation, involving integration with the campus-wide data information technology system, is clearly feasible. In such an implementation, campus-wide data records detailing current training status for each student could be readily maintained. The benefits of such a system include standardization of training, compliance with regulatory requirements for record-keeping, and increased safety by ensuring that equipment is only available to properly-trained students.

In addition, the success of the device for "point of use" safety training has shown promise for adaptation to traditional industrial lockout/tagout procedures; maintenance workers could use a similar combination of hardware and software to be led through approved machine startup and shutdown procedures, with access to locks restricted by computer-controlled hardware to only those that have proper authorization and who have positively affirmed adherence to the approved procedures (Author et. al., 2012). This type of compliance tool may have wide industrial applications.

6.0   ACKNOWLEDGEMENT

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