Intelligent Classrooms need Intelligent Interfaces:
How to Build a High-Tech Teaching Environment that Teachers can use?

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ABSTRACT

With the introduction of increasingly sophisticated presentation technology into the classroom, including multimedia projectors, VCRs, document cameras, and digital whiteboards, a user interface is required to permit instructors control over the various devices. These interfaces typically suffer from inattention to human factors design principles or a general ignorance of the context in which they are intended for use. While the cognitive demands on an instructor necessitate a user interface that involves minimal interaction and poses minimal distraction, we often find that performing a task as simple as playing a video tape requires over a dozen steps through the classroom control system. Thus, instructors often find the interfaces distracting to the primary task, i.e. delivering an effective lecture, rather than encouraging the use of helpful visual aids made available by the technology.

Keywords

Intelligent environments, electronic classrooms, lecture capture

INTRODUCTION

As classroom technology has evolved from blackboards to overhead transparencies to computers and multimedia projectors, the potential for problems, ranging from simple equipment failure to instructor distraction due to interface complexity, has become a serious issue. State-of-the-art electronic classrooms, featuring diverse presentation media, typically include a powerful control interface to operate these devices, but insufficient thought has been given to the actual needs of the user community, that is, the lecturers. As a result, instructors often find themselves pressing dozens of buttons throughout a lecture, in order to raise and lower projection screens, adjust the room lighting as appropriate to the brightness of the media, and switching between the various input sources for display. All too often, such tedious interaction is not only distracting and prone to error, but worse, often unnecessary. Many of the operational sequences involved in controlling the classroom technology can be automated to a significant degree, while still permitting the user to invoke a manual override as desired.

A second issue of interest is the production and archiving of on-line lecture material for later review by students or for the purposes of distance education. This has motivated the development of lecture capture tools, spanning the range from simple videotaping of classes to sophisticated, computer-driven capture of slides, handwritten notes and annotations, as well as the audio and video of the lecture. Again, these tools typically demand an unreasonable amount of attention from the instructor (or skilled technician) to be widely accepted by the teaching community.

This paper describes our response to these problems, which has been to augment electronic classrooms in the Faculty of Engineering at McGill University with context-aware computer systems that assist the instructor in operating the equipment and facilitate the lecture-capture process. The challenges here are twofold: first, to make the use of electronic presentation technology as easy as the conventional overhead projector and second, to produce a reasonable electronic record of the lecture without the need to involve a camera operator or additional production staff, and most importantly, without burdening the instructor with additional responsibilities. This approach was motivated in part by previous success in augmenting a state-of-the-art videoconference facility with context-sensitive *reactive* systems [6] and by instructor demand for less cumbersome control interfaces. We were also curious to experiment with lecture capture software and to evaluate student reaction to its use in our engineering classes.

We begin with a review of related work, followed by a detailed description of our classroom's hardware and software architecture. Next, we describe how the lecture capture tools were integrated with this environment to facilitate the production of an on-line record of the class, both in terms of instructors' ease-of-use and quality of the end result.

RELATED WORK

A number of lecture capture systems have been developed by various groups, including North Carolina State University's Web Lecture System [13], the Berkeley Multimedia Research Center's Lecture Broswer [11], MANIC [13], AutoAuditorium [4], STREAMS [6],

Authoring on the Fly [2, 5], and the CollabWorx LecCorder [10].

One particularly interesting system is DePaul University's Course Online[8], as it stores a new screen capture every five seconds, either from the PC or the document camera, depending on which device has been selected. There remains a user interaction requirement with this system, as the instructor must manually select the desired source, but the capture process itself is automatic.

The system we are using grew out of the Classroom 2000 project from Georgia Tech [1], currently known as eClass. eClass offers two key advantages over other systems. First, instructors can mark-up or annotate their slides with digital ink during the lecture, and all such inkstrokes are saved as part of the lecture capture. Second, with the addition of a second multimedia projector in the classroom, eClass can automatically display both the current and previous slides on alternate screens. From the perspective of our students, this is the most popular feature of the system.

An eClass lecture capture provides students with a web browser view of the lecture slides along with any handwritten annotations made during the lecture, and an optional audiovisual recording of the instructor in a Real Networks player window.

Among the numerous designs for room control interfaces, the Centre for Educational Technology and Distance Learning at the University of Birmingham designed a reconfigurable graphical interface that provides users a different set of controls based on the *event* taking place (e.g. local meeting, videoconference). The benefit of this approach is that by minimizing the number of controls to those that are immediately relevant, the interface retains its flexibility while reducing complexity of operation. Unfortunately, the hierarchical structure of earlier interfaces remains, meaning that users still need to navigate between menus.

Figure 1. The AMX touch-screen interface, displaying the screen-control sub-menu of the hierarchical menu. In order to navigate to another function, the user must first press the EXIT button at the bottom left of the screen.

Work on room control interfaces has been led by AMX Corp. and Crestron Electronics, both of whom provide a wide range of touch screens (e.g. Figure 1), softwire panels, and remote control units. The latest in this evolution is a 10.4" touch screen LCD display that displays the control buttons as an overlay on the video input signal, thereby providing users with a view of the data being projected on the screen. While such systems may be ideal for a technician whose job it is to operate the equipment, one may easily question whether they are appropriate for an instructor who would much prefer to avoid the distraction of low-level device control.

One notable effort to automating or adding "intelligence" to a classroom can be seen in Northwestern University's Intelligent Classroom [9], which uses speech recognition to provide lecturers control over their slides by verbal command. Their system can also advance slides automatically by recognizing that the speaker is referring to content on the next slide. While automatic slide advancing simplifies one aspect of lecturing, this feature is less useful in an environment where instructors wish to annotate their slides as they are presented. In such a situation, direct control over the slide navigation via mouse button or digital stylus may be preferable. A second aspect of the Northwestern system relevant to our work is the use of image processing to track the instructor's position, allowing for the production of a high-quality video recording of the lecture.

CLASSROOM ARCHITECTURE

In order to simplify common tasks, most room control interfaces provide a number of high-level "presets" for typical room configurations, e.g. "play video tape" or "project laptop output." In our particular case, we have installed a second multimedia projector so that instructors can simultaneously display both the current lecture slide as well as either the previous lecture slide, a video clip, document, or the output of another device such as a laptop computer. Providing a control for each preset configuration in this case would again entail an unwieldy interface, in which visual search becomes a non-trivial effort. Regardless of the number of projectors, low-level overrides are still required, for example, to adjust room lights or volume levels.

Looking at the typical electronic classroom control panel, it is clear that the same criticism Norman levels against the computer industry, "creeping featurism" [12], applies here. Each new feature (or device option) entails additional controls, which invariably increase complexity. Once the number of these controls exceeds a certain threshold, the user, in particular one who is busy attending to other tasks, is confronted with a cumbersome interface.

The dilemma, of course, is that *someone* must control the technology and so, these features are in some ways necessary. Unfortunately, the responsibility of operation usually falls on the shoulders of the instructor, who should

not (and often does not want to) assume the additional role of a technician during a lecture.

Hiding the Interface

The alternative we propose is to shift the burden of control from the instructor to the classroom itself. This approach is based on the principles of Reactive Environments [6] in which the classroom technology becomes context-aware and can thus respond to device usage automatically. In this manner, high-level preset selection is performed by the technology without manual intervention.

For example, when an instructor logs on to the classroom computer, the system infers that a computer-based lecture will be given, automatically turns off the lights, lowers the screen, turns on the projector, and switches the projector to computer input. The simple act of placing an overhead transparency on the document viewer causes the slide to be displayed and the room lights adjusted to an appropriate level. Similarly, audiovisual sources such as the VCR or laptop computer output are displayed automatically in response to activation cues (e.g., the play button pressed on the VCR; the laptop connected to a video port).

These mechanisms assume the role of *skilled operator*, taking responsibility for the control of the technology, thereby freeing the instructor to concentrate on the lecture itself. While each of these operations could be performed by the instructor via a high-level preset selection using a conventional interface, why bother when the classroom can do this for you?

Furthermore, by avoiding the need for presets, the user interface requirements are reduced to low-level manual overrides, which one can completely ignore if satisfied with the default configurations. This allowed us to replace the hierarchical menu system employed by the graphical touch-screen with a simpler and faster physical button interface. The remainder of this section describes our approach in further detail. We begin by elaborating upon the hardware configuration in the classroom.

Hardware

Our intelligent classroom contains a desktop PC connected to both an LCD digital tablet[1] and an electronic whiteboard[2], permitting instructors the choice of either as a writing device. In addition, a VCR[3], equipped with an RS-232 interface, which permits the computer to query its current state, an electronic document camera[4] and a second PC can be used as alternative video sources. These devices are connected through a number of video splitters and multiplexers[5] to two LCD multimedia projectors. The first projector displays its output on a large, motorized screen,

while the electronic whiteboard serves as a smaller display surface for the second projector.

Other hardware includes a room control system,[6] a sound system, 35mm slide projector, and for recording the audio and video of the instructor, a computer-controlled motorized video camera, positioned in the back of the room, as well as a wireless microphone receiver.

We also designed a Motorolla 68HC12-controlled panel, pictured in Figure 2, to provide physical switches for manual control over the room lights, drapes, projector power, and screen, and a rotating knob that adjusts VCR and microphone volume, depending on which is in use. The controller also accepts input from a number of other devices such as light sensors embedded in the whiteboard pen holder, serving as switches to indicate that a pen has been removed.

Figure 2. The HC-12 controlled physical button panel as an alternative to a graphical touch-screen interface. This panel provides manual override control of the room lights, projector, screen, drapes, and volume, without the need for distracting, hierarchical menus. Furthermore, the volume knob is context-sensitive, adjusting either the volume of the VCR when a tape is playing, otherwise, that of the instructor's microphone.

This interface replaces the graphical touch screen previously used both to control these functions and to perform input device selection to the projector.[7] While the physical button panel performs almost all of the functions previously associated with the touch screen,[8] and occupies the same footprint on the podium, it requires considerably

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[1] Mutoh MVT-12S.

[2] Microfield Graphics IdeaBoard 200.

[3] Panasonic AG5710.

[4] Elmo HV-5000XG visual presenter.

[5] Extron P/2 DA2 splitters and SW 2.multiplexers.

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[6] AMX Accent3.

[7] Prior to our start of work on augmenting the room's technology, only a single multimedia projector had been installed.

[8] The notable exception here is the set of VCR controls. We did not see a compelling need to duplicate, on our new panel, the play, pause, stop, rewind, and fast-forward buttons that are readily accessible directly on the front of the VCR itself.

fewer button presses to accomplish the same task as did its graphical predecessor.

The reason for this is straightforward: whereas our button panel provides a direct interface to each of its functions, the previous interface required users to select the top-level menu, then a sub-menu, and finally, a function within that menu, in order to accomplish the same result.[9] Note that a graphical touch-screen interface could have provided a similar single-level menu as our button panel, but this would lack the affordances and tactile feedback of buttons and knobs and would require an expensive high resolution screen to approach the quality of physical labels. A further motivation for physical, as opposed to graphical buttons was that we were able to wire these directly to the room light relays, thereby obviating our previous (and dangerous) dependency on the electronic control system for this function.

Software

While the hardware infrastructure allows for device communication and computer control, the key to automating room control rests with the software agents that monitor each device. One such program polls the VCR to determine whether a tape is being played, another inspects the image under the document camera to check for regions of contrast, indicating the presence of a document or other object, while another polls the status of the light sensors embedded in the whiteboard pen holder to determine whether or not any of the pens are in use. In response to each such event, a request is made to select the appropriate device as an input to the main projector.

A projector control process keeps track of which devices are active at any time and displays the most recent source on the main screen. When a user logs on to the classroom's desktop computer, it registers itself as an active video source. A second PC, running a Java applet that displays the contents of the previous slide, is then made available as a secondary source. The typical configurations that arise from normal use of the room, with the instructor logged on, are as described in the Table, below.

active device	main screen display	electronic whiteboard
(desktop PC)	desktop PC	previous slide
laptop computer	desktop PC	laptop
elec. whiteboard	previous slide	desktop PC
VCR	VCR	desktop PC
document camera	document camera	desktop PC

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[9] The exception to this rule is when the interface is already displaying the desired sub-menu, in which case, only one button press is required.

The button panel, shown in Figure 2, is also monitored by a software process. One of the interesting design issues for this component dealt with the behavior of the screen control switch. Since users are likely to have one of two different conceptual models of the screen control via a return-to-center switch, we attempted to accommodate both in our design. For a user who simply *taps* the button, we raise or lower the screen all the way unless stopped, whereas for a user who *presses and holds* the button, we raise or lower the screen until the button is released. The problem with this approach, as discussed in a later section on evaluation, is determining the appropriate time threshold of a *tap*.

Similar use of both projectors could be achieved even if the instructor does not make use of the desktop computer, but for reasons of simplicity as well as hardware limitations, we only activate the main projector in this situation.

Manual Override

Along with such automation, the need for a seamless manual override mechanism becomes paramount. For example, if the instructor raises the lights, the technology must respect that preference. Furthermore, the ability to turn the lights on or off must not be dependent upon the automatic controller, as it was before this project began. As a default backup, manual controls for each device (lights, projector, VCR, etc.) should be accessible and functional at all times. Such manual controls serve as basic on/off switches as well as output enable/disable buttons. For example, a toggle button would allow the presenter to select whether or not the video clip being played on the VCR is projected to the class.

At this point, it is important to note that selection of the laptop output as a video source is presently handled by one of the video multiplexers in auto-sense mode.[10] Since this unit does not provide an output of its state, our system has no way of recognizing that a laptop computer is in use, but simply relies on the multiplexer to switch the signal as appropriate.

Furthermore, several possible configurations of the projectors cannot be invoked automatically but require manual control. For example, some instructors may prefer to display the desktop PC on the main screen and the document camera output on the whiteboard surface. We recognized from the outset that where more than one *sensible* configuration existed for a particular set of active devices, we would likely have to make a "best guess" as to the appropriate response.

However, we can do better. Our template-based user configuration file allows for the tailoring of room behavior

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[10] Auto-sense mode refers to the capability of the video switch to route a designated *priority* input to the destination device whenever it becomes active, even if another input is simultaneously active.
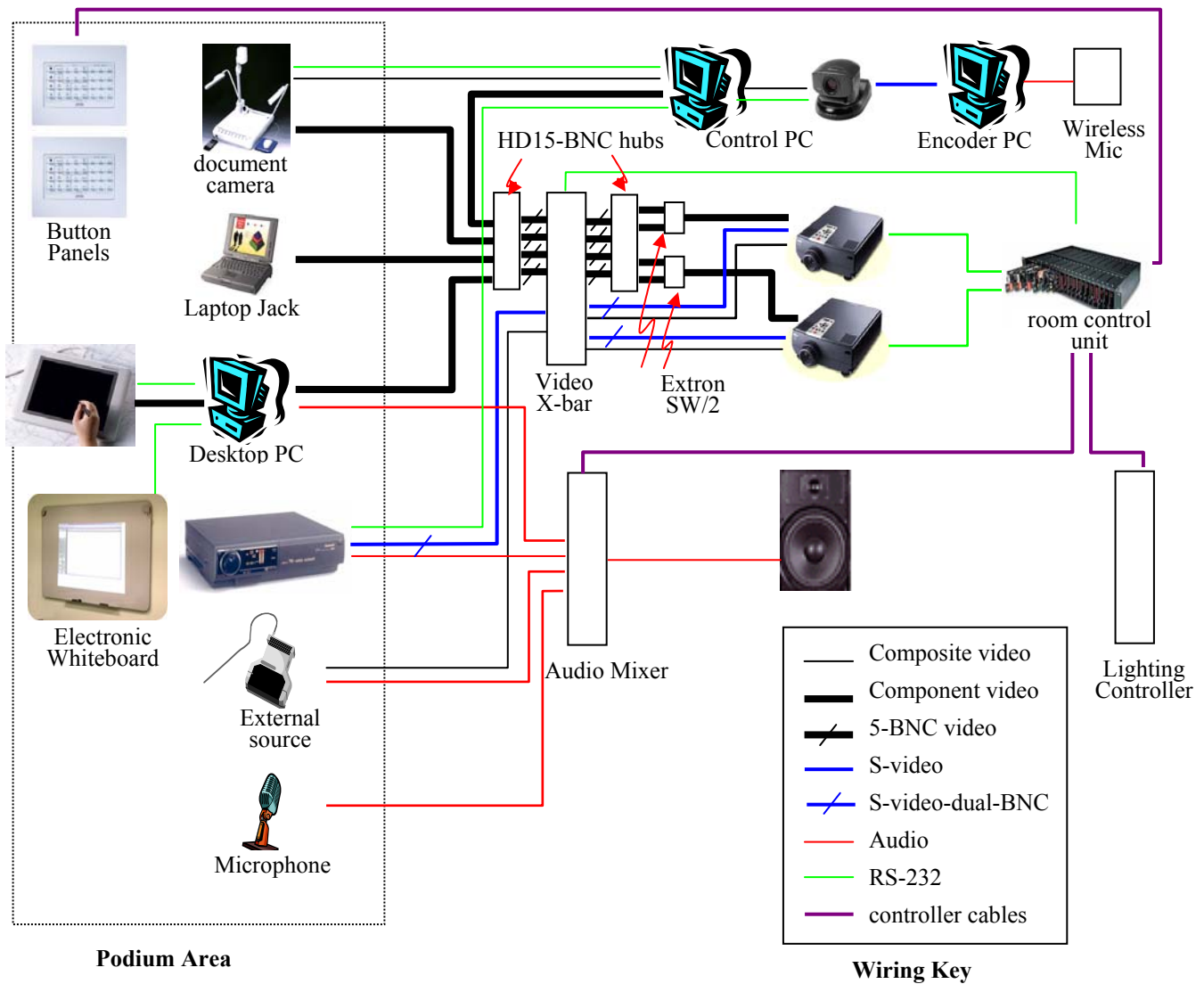
Podium Area　　　　　　　　　　　　　　　　　　　**Wiring Key**

Figure 3.　　Wiring diagram for the second intelligent classroom at our institution.　The use of a video crossbar switch permits the routing of any video signal to either projector, while the Extron SW/2 provides auto-sense capability for the detection and switching of a laptop connection.

to the preferences of individual instructors. By observing the use of these manual override mechanisms, the classroom system can adapt to these preferences over time and remember these settings for future use by the same instructor. At the end of each lecture, the system resets itself to a default configuration.

While the infrastructure for this adaptation has long been in place, we found that most instructors are quite satisfied with the default configurations selected by the system. Early interviews revealed that for most users, manual override functions were only required for the room lights and speaker volume, so these were made a top priority in replacing the touch-screen with our physical button panel. Our second intelligent classroom, described in further detail under Ongoing Work, will include an additional

panel for manual override input selection for each projector.

LECTURE CAPTURE
Having provided an overview of the classroom architecture, we now turn to the issue of capturing a reasonable electronic version of the class for the benefit of students who wish to review the material on-line. This process can be divided into two distinct components: preparation, and lecture delivery. While only the latter is directly integrated with the classroom itself, both are relevant in illustrating our general design goal of relegating low-level details to the background technology wherever possible. This section explores each component in turn.

Preparation

For many instructors, preparation for a class being taught in our intelligent classroom is no different from any other, except that with the increased choice of presentation technology available versus more conventional classrooms, use of a wider range of visual materials becomes possible. However, for those instructors who wish to display and annotate slides, typically from a PowerPoint presentation, taking full advantage of the eClass software facilities, an additional step is required.

The production of slides from a PowerPoint presentation for in-class use requires saving each slide to a separate GIF file and uploading these files to the appropriate directory on the server. While PowerPoint includes a function to accomplish the first task, the transfer of slides to the server requires the use of an ftp client. More problematic, however, GIF images produced by recent versions of PowerPoint are incompatible with the eClass software.

In response, we developed an applet that accepts uploaded PowerPoint files, invokes a converter, and transfers the resulting GIF images to the appropriate directory on the server. This program, which runs on a dedicated machine, is invoked automatically whenever a PowerPoint file is uploaded as part of the lecture preparation process. As a result, instructors need not worry about running the correct version of the software to convert their using slides and no longer require an ftp client to transfer the individual images.

Lecture Delivery

A primary concern in the classroom was to minimize the intrusion of recording technology. While a concession was necessary with regard to the use of lapel-clip wireless microphones in order to ensure a high-quality audio recording of the class, we did not want to place additional constraints on the instructor for video recording. At the same time, we also wanted to ensure a reasonable quality of recording, meaning that the camera should provide a close-up view of the instructor during most of the class. This left us with the challenge of locating the instructor in the scene and tracking the instructor's movements, using a motorized video camera, but without any explicit demands on the lecturer.

For videoconference applications, manufacturers offer various tracking cameras that follow an individual based on the signal from a clip-on radio transmitter, a calibrated color signature, or the strength of a voice signal as detected by a microphone array. In a classroom, however, each of these methods has its drawbacks. Transmitter-based systems, perhaps the most reliable in such an environment, suffer from the logistical headache of limited battery life and the need to secure the transmitter between classes. Color calibration requires the instructor to interact with the camera and suffers from a high failure rate in the presence of video projection. Finally, speech activated systems are not intended for environments in which loudspeakers are used to amplify the instructor's voice, as is often the case with large classes.

In order to provide a general-purpose solution to this problem, we developed a presenter-tracking algorithm [2] that follows the instructor's movements, even when walking in front of a projected video screen. Initialization is performed automatically when the instructor logs on to the classroom computer and recovery from a tracking failure is also invoked automatically, causing the camera to for motion indicative of human movement. The major drawback of this mechanism is that the algorithm is oblivious to whom it will track. If two people are standing at the front of the class, the camera could track either of them. We are currently implementing a module for the tracker that will incorporate a *learned* color model of the presenter in the first few minutes of the class so that the system will become less sensitive to such distractions.

Taking further advantage of the augmented classroom technology, the tracker also receives cues concerning device activity, for example, the instructor's use of a pen on the electronic whiteboard. Such cues can be used either to reset the camera position[11] or to invoke context-sensitive behavior. For example, when a video tape is played, the camera pans and zooms to a position that fills its field of view with the main screen, thereby capturing a lower quality version of the video clip. Since no explicit interaction takes place, the instructor can remain oblivious to the recording technology during the lecture.[12]

EVALUATION

Feedback from instructors has been quite varied. On the positive side, some professors who taught in the room in one semester asked to have their subsequent classes also moved into the intelligent classroom. Other faculty members have indicated their appreciation of the additional equipment available, in particular the document camera and the second multimedia projector. And while the sample size is too small to be of more than anecdotal interest, among the instructors who responded to the initial questionnaire we distributed concerning use of the room, three out the four professors who made any use of the technology indicated one of the reasons for doing so was "ease-of-use." In general, professors' comments regarding the

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[11] Since we are aware of the location of each device in the room, activation of any device implies that the instructor is standing near a know position.

[12] This is not entirely accurate. As a result of frame grabber driver issues when running the encoder under a non-Unix operating system, the recording process often failed to initialize, leaving the instructor unaware of the problem. We subsequently added a feedback message in the top portion of the eClass window, informing the instructor of the recording status at all times. Fortunately, we have found this feedback mechanism to be quite unobtrusive.

benefits of the technology relate to the ability of producing more *visual* and hence, more interesting presentations, as well as the possible benefits of student review of course material via lecture capture.

On the neutral side, many users of the room had no interest in the technology, preferring simply to write on the traditional whiteboard or requesting that these be replaced by chalkboards. Some other professors consistently bring in their laptops, activate the projector and screen manually, and never take advantage of any automatic control features of the room.

On the negative side, several users attributed the frequent mechanical failures of the drape motor assembly to unreliable software while a few instructors were confused by the dual modes of operation of the screen control button. This problem manifests itself with users who have initially learned the *tap* behavior described earlier, but are unaware of the *press-and-hold* behavior. If, at some point, such an individual intends to tap the button but keeps it depressed just in excess of our threshold, the software infers this to be a *press-and-hold* operation, instead. As soon as the user releases the button, the screen stops, and the user likely repeats the sequence. In the ideal, this sequence could be detected and averted by the software, but we are growing increasingly confident that it would be best to satisfy only the *press-and-hold* conceptual model so as to avoid any confusion.

A more annoying problem that we are hoping to resolve is the lack of bidirectional communication with the main projector. At present, we can only issue IR commands to the projector but have no way of verifying its state (e.g. power on, composite video input, computer input). As a result, when users turn the unit on and off within a short time frame, using the manual override, our internal representation of the projector state can easily go out of phase.

Perhaps the most serious criticism was received from one professor who never used the technology. He was irate because instructors who taught in the room prior to his class occasionally left the projectors powered on but he was not aware that they could be switched off by a manual override.

From the perspective of the students surveyed, a significant majority viewed the introduction of augmented classroom technology and lecture capture tools as a benefit. Of the 115 comments received, 77% were positive, with a total of 26% of the respondents citing positive impact to their learning. Most of the negative comments were specifically related to observed technical problems with the equipment or systems, suggesting that further improvements to stability would lead to greater student satisfaction.

While it is beyond the scope of this paper to discuss student usage of the automated lecture captures, the interested reader is referred to a preliminary study we conducted on this topic [15] for further information.

ONGOING WORK

Benefiting from several semesters of user feedback and recognizing the limitations of our previous design, we are now completing the installation of a second intelligent classroom, allowing for more flexible control over the presentation technology. This new installation, whose wiring diagram is shown in Figure 3, addresses the restrictions on video routing inherent in the first such room
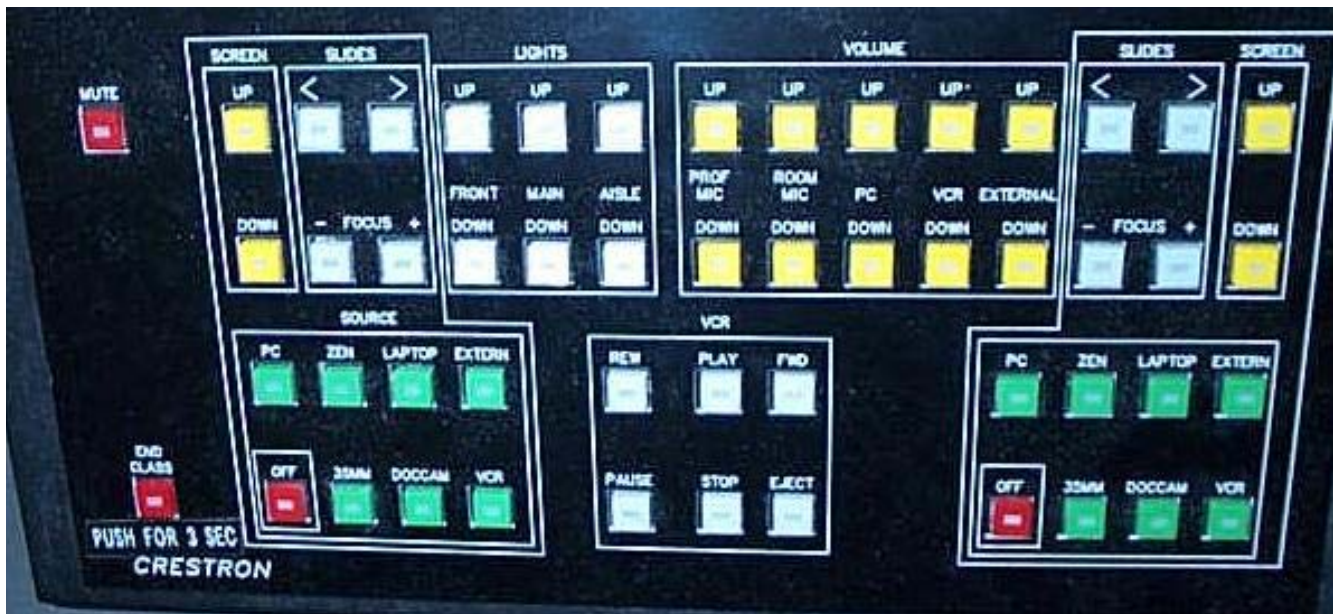

Figure 4. Layout for new button panel. Note that despite its seeming complexity, the groupings in each quadrant represent the equivalent of two sub-menus of the original touch-screen, shown in Figure 1. The lower two corner panels, providing manual source selection capability for each of the two projectors, also provide the requisite "off" control for the associated projector, while the screen controls appear in the upper two corner panels.

by replacing the 2-to-1 multiplexers with a full crossbar switch, capable of routing any video signal to either projector. However, one multiplexer with auto-sense capability is retained in order to allow for automatic switching to a laptop computer when connected.

The most serious visible change to the previous interface is the manual override button panel, whose new design appears in Figure 4. Despite our general success with the earlier minimalist design, we feel that a good argument can be made for carefully grouped sets of low-level controls, available to the instructor at all times, but only necessary when the default behavior of the system differs from the user's requirement. In order to provide users with full manual override capability for each device on both projectors, the two lower panels, comprising an additional 22 buttons, represent a clear tradeoff in simplicity. However, our previous experience has taught us the lesson that there will always be a particular configuration needed by instructors that we cannot provide under an automatic mode of operation. Furthermore, the manual override panel is necessary if the system is to learn the configuration preferences of different instructors.

In redesigning the panel, we opted for separate volume controls for each device, rather than a single, context-sensitive dial. This was in some respects a sacrifice of our earlier goals, but it was necessary to ensure a common mechanism for volume adjustment, regardless of source.[13]

Another area of current research is the automatic insertion of images taken from the document camera, reflecting a significant change of scene indicative of a new slide. The Course Online system [7] provides similar functionality, but in their case, the acquisition of images is insensitive to the contents of the document, thereby entailing much larger storage requirements.

CONCLUSIONS

The integration of lecture capture facilities with an intelligent classroom provides several benefits both to instructors and students. The electronic capture of course material is enhanced by a context-aware tracking camera, which provides students reviewing the lecture a more meaningful record of class activity. At the same time, the lecture capture software, by virtue of its current- and previous-slide views, improves the in-class experience by maximizing the use of both projectors.

The major focus of our research, however, has been on improving the ease-of-use of the classroom technology, both as a means of encouraging other faculty to take advantage of the rich presentation media available, as well as to make teaching in modern electronic classrooms a less

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[13] In the initial design, volume adjustments for the PC and external audio devices had to be done at the source, as the system had no means by which to determine whether the user was trying to adjust the microphone volume instead.

daunting experience for those who prefer to ignore the details of device control. As with any technology, training and practice with the system remain critical to success. While we still have obvious improvements to make in this regard, there is reason to be optimistic about the future of classroom technology.

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