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Note-Taker: Enabling Students who are Legally Blind to Take Notes in Class

David Hayden
Arizona State University
699 South Mill Avenue
Tempe, AZ 85281 USA
dshayden@asu.edu

Dirk Colbry
Arizona State University
699 South Mill Avenue
Tempe, AZ 85281 USA
480-727-7147
dirk.colbry@asu.edu

John A. Black Jr
Arizona State University
699 South Mill Avenue
Tempe, AZ 85281 USA
480-727-7985
john.black@asu.edu

Sethuraman Panchanathan
Arizona State University
699 South Mill Avenue
Tempe, AZ 85281 USA
480-965-3699
panch@asu.edu

1. ABSTRACT

The act of note-taking is a key component of learning in secondary and post-secondary classrooms. Students who take notes retain information from classroom lectures better, even if they never refer to those notes afterward. However, students who are legally blind, and who wish to take notes in their classrooms are at a disadvantage. Simply equipping classrooms with lecture recording systems does not substitute for note taking, since it does not actively engage the student in note-taking during the lecture. In this paper we detail the problems encountered by one math and computer science student who is legally blind, and we present our proposed solution: the CUbiC *Note-Taker*, which is a highly portable device that requires no prior classroom setup, and does not require lecturers to adapt their presentations. We also present results from two case studies of the *Note-Taker*, totaling more than 200 hours of in-class use.

Categories and Subject Descriptors

H.1.2 [Models and Principles] User/Machine Systems; I.4.1 [Image Processing and Computer Vision] Digitization and Image Capture K.3.1 [Computers in Education] Computer Uses in Education

General Terms

Design, Experimentation, Human Factors

Keywords

Note-Taker, assistive note-taking, automatic note-taking, blind, lecture, lecture notes, low-vision, meeting, note-taking, notes, student

2. INTRODUCTION

Overhead projectors, digital projectors, whiteboards and chalkboards are often used to convey information in educational environments, such as classrooms. However, these visual display methods are not inherently accessible to individuals who are legally blind, and may put them at a disadvantage, compared to their peers.

Several methods have been proposed to make classroom presentations more accessible to students who are legally blind. For example, lectures might be recorded (for later review) or a human note-taker might be hired to take notes, which are then provided to the student. However, these approaches do not engage students who are legally blind in the process of understanding and participating in classroom presentations, and might even encourage them to skip class.

To improve accessibility of classroom lectures for students who are legally blind, and to encourage them to take notes, we have developed the *Note-Taker*. This device requires no existing infrastructure or prior setup in a classroom, and does not require the lecturer to adjust the presentation. However, it makes classroom presentations accessible to many students who are legally blind.

In developing the *Note-Taker*, we investigated the usability and the shortcomings of current assistive technologies that might be used by students who are legally blind in the classroom (Sections 3 and 4). Based on these findings, we prototyped a solution that addressed these shortcomings (Section 5), and conducted two case studies (Section 6). In the first case study, the first author (who is himself legally blind) used the *Note-Taker* for an entire semester; in the second case study, another student (who is also legally blind) used a second *Note-Taker* prototype in classes for one month.

3. PROBLEM STATEMENT

The *Note-Taker* project was born out of necessity when the first author, David, found that traditional methods of note-taking were proving unsuccessful. In his own words,

> *"Before senior-level math, I aced college by keeping up with note-taking in lectures as best I could. For some classes, mostly math, it was necessary that I spent extra time in the textbook or reading third-party material, but I always managed to get the grade.*
>
> *Senior-level math was like a slap in the face. Quite suddenly I had no way of keeping up with note-taking, but needed to. We'd fill the boards up half a dozen times proving lemmas and theorems that relied on those*

lemmas. I routinely got lost in the theorem proofs because in one case, I'd opt not to take notes (and thus forget the lemma by the time of the theorem) or I'd opt to take notes, which entailed such a frantic pace that the lecture was essentially useless. In either case, I wasn't getting the intuition behind the proofs that the lecture was so importantly attempting to provide.

Having had all of high school and most of college to try out the various classroom assistive technologies, I knew that nothing off-the-shelf was going to fix my problem. That's when I approached the lab and started bouncing ideas around."

Through a series of brainstorming exercises, discussions and informal experiments, we found that David's problems stemmed from one primary issue: As he used a monocular to view the board at the front of the classroom, there was a delay each time David switched from viewing the board to his notes, or from his notes back to the board. These delays stemmed from sitting up to see the board and then hunching down to within a few inches from his notes on the desktop. David especially lost time when trying to use his monocular to find and return to the relevant spot on the chalkboard (or whiteboard) at the front of the classroom. Over time, these *Board-Note-Board* (BNB) delays accumulated to the point that David was unable to keep pace with the lecture. Here is how David described the situation:

"Going from notes to the board was the big problem. I would say it was akin to finding Waldo while limiting your view to a square inch of the page. What I needed was something that allowed me to view the board and my notes near-simultaneously, like a fully-sighted student. Then I'd stand a chance at keeping up with the lecture."

A related problem was that David's monocular of choice, the Ocutech [2], provided only a fixed 6X zoom. This sometimes proved insufficient in classes where the board was filled multiple times, since his professors were writing smaller than he was accustomed to. Particularly when David used his Ocutech to try to keep up with notes, he frequently got eyestrain headaches that limited his subsequent ability to read – sometimes for up to 12 hours after the class. Despite a thorough literature survey and product review, we found no solution to be satisfactory, so set out to create our own.

4. RELATED WORK

It has been shown that active note-taking in class helps students recall information – even if the notes are not studied subsequently outside of class [1]. It has also been shown that note-taking produces a pattern of interaction in which note-takers performed better on far-transfer tasks, such as problem solving in STEM classes [2]. Note-taking also promotes a *deeper* level of understanding (rather than just more learning overall) due to the assimilative encoding process that is engaged [3,4].

4.1 Alternatives to Note-Taking

One common alternative to active, personal note-taking is university-supplied human note-takers. (Availability of such note-taking services is mandated by the Americans with Disabilities Act [5] in the United States.) These note-takers are typically another student in the class who is paid a stipend ($25 per credit hour at Arizona State University) to provide the student who is legally blind with copies of his/her notes. While sometimes helpful, such note-taking services do not engage the legally blind student in classroom learning as effectively as active, personal note-taking. For instance, David found that notes provided by university-supplied human note-takers were often of limited value because he did not create them, and they did not reflect his way of thinking. In his own words, David found these notes "*as foreign as a textbook – only less legible."*

4.2 Popular Assistive Devices for People with Low Vision

The most widely used approach for helping people with low vision (including legal blindness) is to provide *magnification*. Magnifiers can be broadly classified into two categories: those that are aimed at improving near sight (for tasks such as reading, writing, or manual tasks) and those that are aimed at improving far sight (for tasks such as identifying an approaching bus, watching a movie, or simply enjoying scenery).

Designing a magnification device for improving *near* sight is relatively simple. Many near sight tasks (such as reading and writing) are done while seated, so the size and the weight of the magnifier is less critical. It is even practical to use AC power to run a device such as a magnifier lamp, as shown in 2(a), or a CCTV magnifier for reading, as shown in 2(b). Even a computer can be used to facilitate reading if the document is available in electronic form, and if magnification software such as ZoomText (shown in 2(c)) is used to enlarge the text on the display screen.

(a) Magnifier light (b) CATV magnifier (c) ZoomText
Figure 1 Examples of popular assistive devices used to help reading

However, designing a device for improving *far* sight can be more difficult. Users typically want a device that is portable, lightweight, and (if electronic) that has a battery life long enough to last for an entire day. Many people who have low vision, or are legally blind, use handheld monoculars, as shown in 3(a). These small, highly portable, optical devices typically provide a magnification between 4x and 12x. While the higher magnifications are needed by some users, they

result in smaller fields of view. Most monoculars provide a fixed magnification level, but some allow for adjustment. Costs range from $20 - $300.

(a) Handheld Monocular (left)
(b) Ocutech Glasses-mounted monocular (right)
Figure 2 Common assistive devices used in the classroom

A variant to the handheld monocular is a glasses-mounted monocular, such as the Ocutech VES - Mini [6] shown in 3(b). Due to its small size, the monocular in this product provides less magnification – usually 4X or 8X. It is often used as a general aid by people with low-vision, and it costs about $700.

Higher technology solutions employ wearable video display systems. The Jordy shown in 4(a) and the FlipperPort shown in 4(b) (both by Enhanced Vision) are the best known examples of these technologies [7]. The Jordy consists of a head-mounted goggle display that includes a video camera, while the FlipperPort consists of a head-mounted goggle display and a swiveling camera that sits on a desktop. Both of these products provide the user with real-time VGA-resolution video. Various enhancements and filters can be applied to the video stream in real time (allowing for modification of contrast, sharpness, and brightness) and both products provide an optical zoom of at least 20X. The FlipperPort can also also focus at very close distances, which allows it to act as a magnifier for reading text. Costs for either product range from $2000 - $3000.

(a) The Jordy   **(b) The FlipperPort**
Figure 3 Higher technology video based assistive solutions

4.3 Problems with Popular Assistive Devices

Secondary and post-secondary students who have low vision, or are legally blind, face a particular challenge because classroom note-taking requires the student to repeatedly and rapidly switch back and forth between far sight tasks (such as viewing the professor, the blackboard, or a PowerPoint slide) and a near sight task (i.e. note-taking).

The relatively high magnification provided by a hand-held monocular helps alleviate eyestrain. However, a simple adaptation to free the hands (such as mounting the monocular on a stand that clamps to a table) is unsatisfactory because it still requires the student to continually shift positions (i.e. to

straighten up to peer through the monocular, and then hunch down to take notes).

The Ocutech frees the hands to take notes, but its small size affords only a small field of view. As a result, students may have difficulty quickly re-locating the professor (or the region of interest on the chalkboard/whiteboard) after looking down to take notes.

The Jordy is simply impractical for classroom note-taking because the goggles need to be at least partially removed in order to take notes. The FlipperPort (with its desktop swiveling camera) could, in principle, be swiveled upward to view the professor, blackboard, or PowerPoint, and then downward to view the notes. However, its autofocus feature takes much too long, making the transition time even longer than using a monocular.

In addition, both of these assistive devices have rather ominous-looking head-mounted goggles that are rather alienating to all involved. Regardless of how comfortable or uncomfortable the goggles are for the user, they prevent eye contact, making it awkward to ask questions of the lecturer, or to interact with peers.

Regardless of which of these four technologies are used during note-taking, students who are legally blind must constantly shift back and forth between an upright posture (to view the front of the room though the assistive device) and a face-down posture (hovering a few inches over the page to view what is being written). These constant movements (and the need to re-orient to the front of the room each time) add up to significant BNB delays, preventing the students from keeping pace with the lecture.

4.4 Available Classroom Technologies: Digital Whiteboards and Lecture Recording Systems

Digital whiteboards (sometimes called interactive whiteboards) can be used to automatically transfer the writing from the board into an electronic representation. Digital whiteboards are often used in business settings (such as conference rooms) where they can be used to facilitate teleconferencing. However, digital whiteboards are considerably more expensive than standard chalkboards or whiteboards, and their relatively small size means that more boards are needed to provide an adequately-sized writing surface in a classroom.

The LiveBoard [8] running the Tivoli [9] application was the first proposed digital whiteboard. Since its introduction, many other solutions such as [10,11] have been proposed or introduced, in both research and commercial settings. Most of these devices can act as a computer display, using either forward or rear-projection; most can be written on with digital ink (using a somewhat awkward wireless stylus); and most generate a video output signal representing what has been written on them.

Some approaches, such as in [11] employ a device that fits onto a conventional whiteboard, to add digital whiteboard

functionality. While this is a portable solution that might seem appropriate for a student who is legally blind, it is impractical in most situations because: (1) each device only supports a single board, (2) the device supports only boards of a certain (smaller than standard) size, (3) the device takes take time to set up, and (4) the set up requires that the student enter the classroom early and attach a device to each board before class. Furthermore, accuracy is sometimes less than desired, and the stylus that lecturers must use are commonly regarded as awkward.

Apreso Classroom [12] and AutoAuditorium [13] offer automatic recording of lectures through the use of semi-permanent camera setups. These systems do not summarize a lecture – they simply record it. While the recordings can be of value, they do not encourage the students to actively participate in class, and some would argue that recording lectures may even discourage participation and/or class attendance.

Other systems have also been proposed for recording lectures. The system described in [14] uses a consumer camcorder to capture video of overhead presentations, and then summarizes the video using key frames. PhotoNote [15] is designed to assist students with disabilities – particularly those with vision or hearing impairments. The PhotoNote system requires that two camcorders and one still image camera be set up in a classroom prior to the lecture – one camcorder is aimed at the lecturer and the other is fixed on a sign language interpreter (if required). The still camera takes a higher resolution (8 Mpixel) photo every 3 seconds. All three streams are synchronized, recorded, and made available for the student to review after class. Through the use of image processing operations, the system attempts to extract handwriting and text from a chalkboard/whiteboard or from a projected image, and these extracted images can also be enhanced for students who have low vision, or are legally blind. This PhotoNote solution can be used as an alternative to university-supplied human note-takers. However, it still does not engage students who are legally blind in active personal note-taking, or in active participation during the class lecture.

5. Design Principles
None of the existing classroom technologies provide students who are legally blind with adequate real-time access to classroom lectures. Many of these existing technologies have significant overhead, such as prior setup in the classroom, and many of them require the lecturer to adapt the presentation, and none of these classroom technologies deal with the BNB delays faced by students who are legally blind. Based on our observations, and our discussions with David and other legally blind students, we have developed the following principles to guide our design of technology to assist students who are legally blind during note-taking activities:

1. The solution should not rely upon the presence of previously installed equipment in the classroom.

2. The solution should not make students who are legally blind dependent on others (including other students, the lecturer, or a member of the technical staff).

3. The solution should not estrange students who are legally blind, or interfere with their interactions with lecturers and peers, as might be the case with an obtrusive, head-mounted camera system.

4. The solution should not require lecturers to change their presentations in any way. Ideally, lecturers should not even need to be aware that a special solution is being employed by students who are legally blind.

5. The solution should not disrupt the classroom environment. For example, it should not obstruct the views of other students, and it should not be noisy.

6. The solution should not be significantly more expensive than other types of assistive technology. This sets a ceiling cost of $3000.

7. The solution should provide students who are legally blind with real-time access to all aspects of the classroom presentation, including the lecturer, the chalkboard/whiteboard, and any projected images.

8. The solution should be portable, should not take more than a couple of minutes to set up, and should fit within the footprint of a student's classroom desk or table.

9. In accordance with our BATE (Beyond Accessibility To Efficiency) principle, the solution should allow students who are legally blind to access information during class, just as fully sighted students are able to do. In other words, students who are legally blind should not be required to spend extra time outside of class listening to recorded lectures, in order to learn the same information that fully sighted students can absorb during class.

5.1 Infeasible Setups
Students who are legally blind need some means of seeing both the front of the classroom and their notes concurrently. This could be done with two cameras - one aimed at the front of the room, and another aimed at a sheet of paper on the desktop. However, a head-mounted display would then be needed so that the student can see both video streams, to eliminate the BNB delay. In addition, taking notes while viewing one's hand on a video screen is less natural than writing while directly viewing the hand.

An alternative solution is to use a single video camera, with a manually adjustable pan/tilt mechanism to aim the camera toward the front of the classroom. The video output from the camera could be routed to a small, battery-powered 7-inch

flat-panel LCD display, similar to those used in automobiles, which could be laid on the desk, next to a pad of paper for note taking. However, this would require the student to manually adjust the aim of the camera whenever the instructor moved, or whenever attention needed to be shifted between the board and a projected slide. While this approach also proved infeasible, it suggested an alternative approach that we ultimately adopted as our solution, which we call the *Note-Taker*.

5.2 The Note-Taker

The *Note-Taker* is comprised of a servo-operated pan/tilt mechanism, a consumer camcorder, and a 13-inch Tablet PC with a 1280x768 screen. This entire *Note-Taker* system fits easily into a typical-sized student backpack, and is entirely battery-powered. Upon arriving in the classroom, the student clamps the pan/tilt mechanism to the desk, installs the camera onto the pan/tilt mechanism, and then connects both to the Tablet PC through USB cables, to produce the configuration shown in Figure 1. With practice, this whole set-up process takes about a minute, and can be done while the Tablet PC is booting.

Figure 4: The first author using the *Note-Taker*

As shown in Figure 5, the *Note-Taker* user interface has three windows: (1) a window that displays the 640x480, 30FPS live video from the camera, (2) a window that is used as a digital notepad, and (3) a window that provides up/down/left/right/zoom controls for the pan/tilt mechanism that aims the camera. These three windows can be arranged on the display to suit the student. (In Figure 5 they were arranged by a left-handed student.)
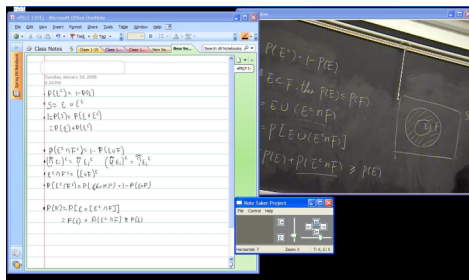

Figure 5: The *Note-Taker* user interface

During lectures, the student views a live video camera feed of the front of the classroom in one window, and takes notes by writing into the digital notepad window. The digital notepad is typically positioned in close proximity to the camera control panel, which simplifies camera aiming and zooming. Optionally, a student can choose to record both audio and video while taking handwritten notes. Time coding of both the notes and these recordings allow cross indexing between them, for later playback, study, and review.

Note-Taker Hardware

The *Note-Taker* uses a commodity digital video camcorder (Sony TRV-22), an off-the-shelf servo-operated pan/tilt mechanism (Eagletron PowerPod) and a Gateway CX210X Tablet PC. The camcorder and Tablet PC use lithium-ion batteries, while the pan/tilt mechanism is bus-powered, over USB. Battery life for the system is about 5 hours per charge. Total cost of prototype components was $2500. However, this could be reduced by using a cheaper Tablet PC.

The camcorder streams VGA resolution video at 30 FPS, and allows for up to 10X optical zoom. Initially, we sought a camera with higher optical zoom, similar to that provided by a hand-held monocular. However, for reasons that will be explained later, we found that less zoom was needed with a video display.

A primary concern in choosing a camcorder was that it must allow remote control zooming. Some consumer cameras (particularly those from Sony and Canon) were manufactured with a LANC port (also known as control-L) that allows focus and zoom to be controlled remotely. Unfortunately, more recent Sony and Canon consumer camcorders no longer have this port, which is now available most on much more expensive, less portable, prosumer models.

As a potential alternative, many digital video camcorders also have a IEEE1394 Firewire port. However, to the authors' knowledge none are fully compliant with the DCAM protocol. In fact, the only existing digital video cameras we found that can be controlled through firewire are Canon ZR series cameras.

As a result, in future iterations of the *Note-Taker* we might opt to purchase used camcorders, or to employ machine vision cameras, which can be equipped with remote control zoom. While this latter option is feasible, it will increase the cost of the camera from $200-$300 to $500-$700, as motorized zoom lenses are not standard features on machine vision cameras. Also, this approach will require us to devise an additional battery pack, further increasing costs.

Software

We used Windows XP and programmed in C++, using two free libraries – WxWidgets for the application design, and OpenCV for the video processing. Note-taking was supported in the prototype using the readily-implementable Microsoft OneNote software. However, in order to add desirable features we plan to develop our own custom note-taking software in the future.

6. Case Studies

The first *Note-Taker* prototype was developed during the summer and fall of 2007. The first author then used the prototype in a 3-month case study, during the Spring 2008 semester. Midway through that semester, a second prototype was constructed, and was provided to another student. This student (who is also legally blind, and who will be referred to as "M") used the *Note-Taker* in a month-long case study.

During both case studies, data was collected on how the users typically took notes, and whether or not they felt the *Note-Taker* was helpful. Both users were given the hardware to use both in and out of the classroom. When using the system in the classroom, both students sat in the front row, as close to the center as possible. Furthermore, both kept their monocular available, in the event that they needed to switch back for any reason.

6.1 Case Study 1: David

As discussed in Section 2, David had used an Ocutech with paper and pencil prior to using the *Note-Taker*. He had also used copies of notes from university-supplied note-takers, although he felt they were often difficult to study from. David also studied the textbook, and sought out third-party materials where necessary. David had prior in-classroom experience with all of the assistive technologies mentioned in Section 3.1, except the FlipperPort.

David regularly used the *Note-Taker* in four of his five classes: Biology, Statistics, Analysis, and Probability. Although he did not need to take notes in Biology, he did need to view projected slides, and found the *Note-Taker* more convenient for this task than his monocular. In his fifth class (Number Theory) lectures were uncommon, so David used the *Note-Taker* only occasionally for this class. In total, David used the *Note-Taker* for 150 hours in real classroom settings.

Initial use of the *Note-Taker* was an unexpectedly dramatic change for David,

> *"The first time I used the Note-Taker in the classroom I was overwhelmed. Never before had I so effortlessly kept up with notes in a math class. It seemed almost casual. I left that class feeling as though I understood everything presented, and that no review was even necessary."*

Most of David's experiences with the *Note-Taker* were similarly positive during the case study. Only on the occasions when he encountered software bugs did David feel that the *Note-Taker* was less beneficial than his traditional methods.

The *Note-Taker* largely eliminated the BNB delay, although some time was still required to adjust the camera through the control interface. Fortunately, the times required for camera adjustment were usually only significant when the professor changed his location within the classroom – not when he simply wrote on the board in one location

Set-up initially took two to three minutes for David. However, with practice that set-up time was reduced to about one minute – roughly the same amount of time that it took to boot the Tablet PC.

Interestingly, David found the *Note-Taker* to be much less obtrusive to the classroom environment than anticipated. Most professors didn't even realize anything special was being used, despite the fact that David sat in the front row. Informal polling of nearby students on multiple occasions indicated that the *Note-Taker* was never a significant distraction to them.

In some situations the combination of lighting, angle, and poor contrast (particularly on dusty green chalkboards) made the boards difficult to read. David felt that contrast enhancement of the displayed video would be helpful in these cases.

One interesting finding from this case-study was that David reported very rarely using anywhere near the full 10x optical zoom of the camera while taking notes. This was surprising since he routinely required 10-12X optical zoom to see smaller details on a board with his hand-held monocular.

Also, one day David forgot one of the two USB cables, and was consequently unable to use the *Note-Taker* in his classes. Having a handheld monocular with a variable 8-12X zoom, he proceeded to take notes as he had done in the past. Having watched the *Note-Taker's* stable video for many classes, he became newly aware of how unsteady his view through the monocular was. He then began to suspect that this unsteadiness might have been the cause of his earlier eyestrain headaches. In the future we plan to instrument a handheld monocular, an Ocutech, and the *Note-Taker's* camera with accelerometers, to collect accurate data on how steady (or unsteady) each is during classroom use.

Besides software bugs, David's most significant complaint was that when he panned the camera a significant distance to the left or right, its aim tended to drift downward. This will need to be corrected in future prototypes.

David's evaluation of the overall performance of the *Note-Taker* was remarkably positive for a prototype unit. He plans to continue using the *Note-Taker* throughout the remainder of his undergraduate education, and has stated that it "*saved my math degree.*"

6.2 Case Study 2: M

A second prototype of the *Note-Taker* was tested by M for a one month period. M was a sophomore in computer science. Prior to using the system, M did not take any notes – opting only to watch the board through a monocular (but not write anything down). M had experience with all of the technologies mentioned in Section 4.2 except the Ocutech and FlipperPort. M did use university-supplied note-takers routinely, but was still struggling with college courses – perhaps due to the lack of active note-taking. In conversation, M indicated that note-taking was not seen as useful because it

was too difficult to both keep up with note-taking, and understand the lecture. It should be noted that, beyond a one-hour introduction to the prototype, M had never used a Tablet PC before.

By the time this second case study was started, software bugs encountered by David had been largely corrected. Brief, daily thoughts on the *Note-Taker* were collected and compiled from M.

In reading the daily thoughts, it became clear that both the Tablet PC and the OneNote digital ink software represented a steep learning curve for M. David agreed with this, but said that he had become accustomed to both the Tablet PC and the OneNote software before his case study, as he worked with them during the development of the *Note-Taker*. In addition to this learning curve, M experienced a hardware failure in the Tablet PC pen, and a broken USB cable during the month-long study, leading to some additional frustrations with the *Note-Taker*.

Although M concluded that the *Note-Taker* had overall been more of a hindrance than a help during his one-month case study, he was very optimistic about its potential. He felt that the problems were due more to the interface learning curve than to the *Note-Taker* itself, which M found useful.

The two largest problems M experienced with the software were:

1. Moving the camera aim by a significant distance sometimes required repeated tapping with the stylus on the control buttons, which made the initial setup cumbersome.

2. Methods for organizing his notes took some forethought, and were not immediately obvious. He did not devise a suitable organizational method until midway through the case study.

M's largest problems with the hardware were:

1. The pan/tilt mechanism allowed the camera aim to drift downward when panning. We found this problem to be inherent in the low-cost pan/tilt mechanism that we used. In more conventional camera aiming applications this problem would probably not be noticed. However, when the camera is highly zoomed (as in our application) even a slight downward change in the tilt causes visible changes in the view. We anticipate that this downward drift can be compensated for in the software.

2. The Tablet PC was sometimes unresponsive and sometimes inaccurate to the stylus. The lack of response was found to be caused by a faulty stylus, and was resolved when the stylus was replaced during the second week of the case study. The inaccuracies were found to be inherent in the Tablet PC model that we used (Gateway CX210X) and could be fixed by using a different Tablet PC.

3. M did not like the fact that the seating arrangement in one of his classes was not ideal for the *Note-Taker*. In this instance, M could not obtain a clear view of the board with the camera because another student was in the way,

Despite these problems, M felt strongly that the *Note-Taker* could be helpful, given some refinement, and he actively and passionately engaged in discussions about its potential. Perhaps most importantly, having used the *Note-Taker*, M now feels that note-taking is a useful activity, and is interested in continuing to use the *Note-Taker* with some further refinements.

7. Discussion

When the *Note-Taker* was initially deployed in quiet classrooms, the PowerPod pan/tilt servo motors were found to be somewhat noisy, causing one professor to ask whether someone was "drilling". To compensate for this, the software was modified to limit the pan and tilt speeds, thus lowering the loudness and the pitch of the sound emitted by the servos to an acceptable level. The PowerPod's movements are also somewhat imprecise, allowing the camera to tilt slightly downward as it pans. We expect that a software solution can be found to compensate for this tilt problem. Given that the PowerPod is currently the only off-the-shelf electronic pan/tilt mechanism in its low price range, we find these issues to be acceptable for now. However, given sufficient resources we would consider building our own pan/tilt mechanism.

With regard to the Tablet PC, we found that the Gateway Tablet PC that we used had pen-input issues that did not seem to be evident in the Lenvo X-series Tablet PCs. It is interesting to note that the Gateway uses Finepoint digitization, as opposed to the very popular Wacom technology. In large part, this Gateway model was purchased over other Tablet PC models due to its larger screen size – a feature that neither David nor M felt was necessary after using it, and comparing it to a smaller 12.1-inch Tablet PC screen. In both cases, these students needed to be very close to the screen, so differences in screen size seemed less important than reliable pen input for this application. The *Note-Taker's* camera is best positioned in the center of the front row of the classroom. However, this was not seen by our users as an unreasonable constraint, given that they typically sit there anyway.

The addition of multiple control methods for the camera would be beneficial. The prototype provided only one means for aiming the camera – repeatedly tapping of directional buttons (left, right, up, down). Future prototypes should provide multiple ways to aim the camera, allowing users to choose the method that best suits the situation.

In addition to these mechanical and software enhancements, we have a number of additional features planned for the *Note-Taker*. We will add image warping to compensate for the linear perspective seen when the board is viewed obliquely, as can be seen in Figure 5. We will also

experiment with computer vision techniques to automatically follow the professor, while allowing the student to take manual control of the camera as necessary. In doing so, we hope to decrease the time expended in controlling the pan/tilt mechanism. To assist during times when the professor occludes information on the board while the student is still copying it, the *Note-Taker* could keep a history of frames, and allow the student to "rewind" with simple pen gestures. We also plan to use computer vision techniques to help the *Note-Taker* decide when to provide a live video feed, and when to show an older frame, with less occlusion.

Beyond enhancements to the *Note-Taker* prototype, we wish to test it on a larger population of students who are legally blind, and we are actively dialoguing with the disability resource centers at our university, and at local community colleges. We would like to construct several additional prototypes and provide them to these schools. Students would then be able to check out a *Note-Taker* for periods of time, to test it out and provide us with feedback. Since there is a clear learning curve for the *Note-Taker*, we would need to train these students (or write tutorial software) and we would need to allow for at least week-long use periods.

We are also exploring ways to further facilitate note-taking. This approach would equip the *Note-Taker* prototype to automatically track the professor, find the writing on the board, and convert it to digital ink. (This approach is similar to converting bitmaps to vectorized images – it does not involve optical character recognition). This approach might not be feasible with a VGA resolution camcorder, requiring instead a second, higher-resolution camera. Given the benefits of student-generated notes, we do not intend to replace the note-taking activity entirely. However, this could allow students who are legally blind to pay more attention to the lecture, while capturing and annotating board and projected content in real-time.

Regarding the design constraints of the *Note-Taker*, we cannot overemphasize the importance of developing assistive technologies that are portable, and that require no significant set-up. While some interesting things can be done with solutions that require prior set-up in a classroom, we feel that most of these approaches will ultimately prove to be impractical because different students have different needs. Furthermore, portable solutions like the *Note-Taker* allow students who are legally blind to access virtually any presentation, including guest lectures, conference presentations, and even special events, or live performances. We also feel that, by allowing students who are legally blind to fully control the assistive technologies upon which they rely, we can provide them with a level of independence that they would not otherwise enjoy.

8. Conclusion

Overall, we are pleased that both of the case studies yielded encouraging results. Even in its early development, the prototype *Note-Taker* became an integral component of the first author's classroom workflow, and he feels that it is an essential tool for the completion of his degrees in computer science and mathematics. M felt that the *Note-Taker* had significant potential, given refinements. Based on these two case studies, we feel that the *Note-Taker* provides a better solution than existing technologies to the problems that these students who are legally blind encounter in their classrooms.

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