The Note-Taker: An Assistive Technology That Allows Students Who Are Legally Blind to Take Notes in the Classroom

John A. Black Jr
Arizona State University
699 S Mill Ave, Tempe, AZ 85281
john.black@asu.edu

David S. Hayden
Arizona State University
699 S Mill Ave, Tempe, AZ 85281
david.hayden@asu.edu

Abstract

Note-taking is a fundamental learning activity that should be practiced by every serious secondary or post-secondary student. Research has shown that the mental processing that occurs during note-taking helps students consolidate and retain classroom instruction, even if they never study their notes afterward. However, students who are legally blind can have difficulty taking notes in the classroom. Even with a visual aid (such as a monocular) for viewing the front of the room, a fast paced class can make it difficult for a student who is legally blind to keep up with the lectures -- especially in more advanced classes. Some schools have attempted to help such students by equipping classrooms with audio or video recording systems, or by paying other students to take notes for them. However, these approaches do not actively engage the student in note-taking during the lecture. In this paper we discuss our research, which is aimed at developing a portable Tablet-PC-based Note-Taker that can be carried from classroom to classroom by the student, and does not require lecturers to adapt their presentations in any way.

1. Introduction

The term “legally blind” is used to describe a level of visual impairment that typically makes a person eligible for government benefits. Legal blindness is defined as: (1) a central visual acuity of 20/200 or worse in the better eye, with the best possible correction, or (2) a visual field of 20 degrees diameter or less. According to the American Foundation for the Blind [1], in 2008 there were about 1.3 million Americans who were legally blind. The National Center for Policy Research for Women and Families [17] says the high school attrition rate for students with severe visual impairment or blindness is 40%, compared to 25% for fully sighted students. High school graduates with severe visual impairment are just as likely to take college courses as fully sighted students, but they are less likely to graduate from college.

These statistics suggest that, as students with visual disabilities advance through their secondary and postsecondary schooling (when they are expected to take a more active role in their education, such as note-taking during class) they find it increasingly difficult to keep pace with their peers. Couple these statistics with the fact that only about 30% of legally blind working age people are employed, and we have a powerful argument for finding more effective methods for providing them with higher levels of education.

Classroom note-taking helps students concentrate and understand the central concepts presented during lectures. It has been shown that active note-taking in class helps students recall information, even if the notes are never subsequently reviewed outside of class [2]. It has also been shown that note-taking helps note-takers perform better on far-transfer tasks, such as problem solving in Science, Technology, Engineering and Mathematics (STEM) classes [3]. Note-taking promotes a deeper level of understanding because an assimilative encoding process is engaged [4, 5].

The Note-Taker project described here was born out of necessity, when an undergraduate math and computer science student who works in our lab (and who is legally blind) found that the pace of the lectures in his senior-level math classes had become too fast for him to take adequate notes. His professors typically filled several boards multiple times during a 45-minute class, proving lemmas and theorems that relied on previous lemmas. He found himself getting lost during the theorem proofs.

He was forced to either stop taking notes (which left him unable to remember the lemma by the time of the theorem) or to frantically try to write down everything, in which case he got virtually nothing out of the lecture. In either case, he wasn’t fully understanding the proofs. During high school and college he had already tried out numerous assistive technologies, so he knew that there wasn’t anything available that could fix his problem.

2. Popular Assistive Devices for People with Low Vision

The most widely used approach for helping people with low vision (including those who are legally blind) is to provide magnification. Magnifiers can be broadly classified into two categories: (1) those that are aimed at improving near-sight (for tasks such as reading, writing,
or manual tasks) and (2) 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 or a CCTV magnifier for 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. These are small, highly portable, optical devices that typically provide a magnification between 4x and 12x. Most are set to a fixed magnification level, although some allow for adjustment.

A variant to the handheld monocular is miniature monocular, mounted on a pair of glasses, such as the Ocutech VES - Mini [7]. Due to its small size, the monocular in this product provides less magnification—either 4x or 8x.

The Jordy and the FlipperPort are well known higher technology solutions [8]. The Jordy consists of a head-mounted goggle display that includes a video camera, while the FlipperPort consists of a head-mounted goggle display, with an up/down swiveling camera that sits on a desktop. Enhancements such as contrast, sharpness, and brightness can be applied to the video stream, and both products provide optical zoom of at least 20x. The FlipperPort is also capable of focusing at very close range, which allows it to act as a magnifier for reading text.

3. Problems with Classroom Usage of Popular Assistive Devices

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

While the glasses-mounted Ocutech monocular frees the users hands to take notes, its small size affords only a small field of view, and insufficient optical magnification. As a result, students must repeatedly take time to relocate the region of interest on the blackboard after looking down to take notes.

A handheld monocular helps alleviate eyestrain due to its higher (e.g. 12x) magnification. 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 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 Jordy (and other head-mounted devices) are 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 articulating camera) could (in principle) be swiveled upward to view the professor, the blackboard or PowerPoint slides, and then downward to view the notes. However, with the manual swivel and autofocus delays, the transition time between notes and the board is even longer than using a monocular. In addition, both the Jordy and the FlipperPort require the user to wear goggles, which prevent eye contact with others, thus impeding classroom interactions with both peers and the instructor.

Regardless of which of these four technologies is used during note-taking, students who are legally blind must constantly move between an upright position (to view the front of the room though the assistive device) and a face-down position (hovering a few inches over the page to view what is being written). These constant up/down movements (and the need to re-orient themselves toward the relevant target at the front of the classroom after each upward movement) add up to significant cumulative delays, preventing them from keeping up with fast-paced lectures. We call the delay incurred with each up-down cycle a Board-Note-Board delay. Going from the notes to the board is particularly problematic, because the student much do a search using a narrow field of view, to find the target at the front of the room.

4. Available Classroom Technologies

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

The LiveBoard [9] running the Tivoli [10] application was the first proposed digital whiteboard. Since its introduction, many other solutions have been proposed or introduced, in both research and commercial settings [11,12]. Most can also act as a computer display (using either forward or rear-projection), most can be written on with digital ink (using a sometimes awkward wireless stylus) and most generate a video output signal (representing what has been written on the board).

Some approaches, such as [12] employ a device that is fitted onto a conventional whiteboard. 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 whiteboard, (2) the device supports whiteboards of a rather limited size, and (3) the device takes time to set up, requiring that the student arrive at the classroom well before class, to attach a device to each of the whiteboards.

Apreso Classroom [13] and AutoAuditorium [14] 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 some 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 attendance. Furthermore, the low vision student would necessarily need to spend twice the amount of time as his peers in acquiring the same information, as he/she would still need to take notes from the recording.

Other systems have been proposed that go beyond simple recording of lectures. For example, the system described in [15] uses a consumer camcorder to capture video of overhead presentations, and then summarizes that video, using key frames.

Another system called PhotoNote [16] (which is designed to assist students with vision or hearing impairments) employs two camcorders and one still image camera. The cameras must be set up in the classroom prior to the lecture; one camcorder is aimed at the lecturer, and the other is aimed at a sign language interpreter (if required). The still camera takes a high resolution (8 Mpixel) photo every 3 seconds. All three of these image streams are then synchronized, recorded, and made available for the student after the class. Through the use of image processing, the system attempts to extract handwriting and text from a chalkboard/whiteboard, or from any projected PowerPoint slide, and these extracted images can be enhanced for students with low vision. This PhotoNote solution is less than optimal for several reasons. First, the three cameras must either be permanently installed in the lecture hall, or they must be set up and configured prior to each lecture. Second, the student has no control over the system during the lecture. Third, the student is dependent upon someone else to process and deliver the captured videos and still images. Fourth, the student is not able to view the captured video or images until after the lecture.

5. Use of Human Note-Takers
The low-tech approach to note-taking is the use of university-supplied human note-takers. (Availability of such note-taking services is mandated by the Americans with Disabilities Act [6] in the United States.) The human note-taker is typically another student in the class who is paid a stipend to provide the low vision student with copies of his/her notes. While possibly better than nothing, such note-taking services do not engage the legally blind student in classroom learning as effectively as active personal note-taking. One student we interviewed found them to be of limited value, as they were not his own creation, and did not reflect his way of thinking. In summary, he said that they were “at least as difficult to understand as a textbook – only less legible.”

6. Design Principles
Because none of the assistive technologies discussed above eliminate the Board-Note-Board delay, none of them equip a student who is legally blind to efficiently take notes during fast-paced lectures. Each of these existing technologies also has a significant overhead, including prior setup in a classroom, and many of them require the lecturer to adapt his/her presentation to accommodate the technology. Based on our observations and our discussions with low vision and legally blind students, we have developed the following principles to guide the development of a technology to assist them during note-taking:

1. The solution should not depend upon the presence of specialized (possibly expensive) equipment resident in the classroom.
2. The solution should not make the student dependent on others - including other students, the lecturer, or some member of the school’s technical staff.
3. The solution should not estrange the student, or interfere with his/her interactions with lecturers and peers (as might be the case with a 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 the student.
5. The solution should not be disruptive to the classroom environment. (For example, 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 about $3000.
7. The solution should provide the student with real-time visual access to all relevant aspects of the classroom presentation, including the lecturer, the whiteboard (or chalkboard) 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 the student’s classroom desk or table.
9. The solution should not interfere with other students’ ability to view the lecturer, or any other aspect of the presentation. For example, the solution should have a low profile, so that a student using it in the front row does not block the view of students behind him/her.
The solution should allow students who are legally blind to access information during class as easily as sighted students do. In other words, he/she should not need to spend extra time outside of class (listening or viewing recorded lectures) to learn the same information that sighted students learn inside the classroom.

Keeping these principles in mind, the objective of this research is to develop an assistive Note-Taker device that enhances the learning and note-taking capabilities of legally blind students during classroom lectures. To achieve this objective, research is being conducted to:

1. better understand the difficulties encountered by secondary and post-secondary students who are legally blind, as they try to take notes in their classrooms.
2. develop and deploy a portable device that does not depend upon any modifications or adaptations of the typical classroom infrastructure.
3. conduct formative evaluations and iteratively refine the hardware and software components of the device until it allows students who are legally blind to take notes as efficiently as fully-sighted students.

7. The Proof-of-Concept Note-Taker Prototype Hardware

To begin the process of developing an assistive device for note-taking tasks, a proof-of-concept Note-Taker prototype was developed. Its hardware consisted of:

1. a Sony TRV-22m consumer digital video camcorder that outputs (720x480 pixel) video at 30 frames/second, and provides up to 10x optical zoom, shown in Figure 1.
2. an Eagletron PowerPod servo-operated USB-driven pan/tilt mechanism, shown in Figure 2.
3. a Gateway CX210X Tablet PC, shown in Figure 3.

The camcorder and the Tablet PC use lithium-ion batteries, while the pan/tilt mechanism is powered by the PC, through a USB cable. The battery discharge time for the system under normal use is about five hours. The Tablet PC, camera, and pan/tilt mechanism fit easily into a student’s backpack, for transport to and from the classroom. Upon arrival in the classroom, the student clamps the pan/tilt mechanism to the edge of the desk, and then mounts the video camera on top of it. This whole process takes about a minute, and can be done while the
Tablet PC is booting up. An assembled proof-of-concept Note-Taker prototype is shown in Figure 4.

Figure 4. A proof-of-concept Note-Taker prototype in use

8. Proof-of-concept Note-Taker graphical user interface

The proof-of-concept Note-Taker application software was implemented in C++ on the Windows XP operating system. It employs Microsoft OneNote software, to allow for digital ink or typewritten note-taking. Figure 5, Figure 6, and Figure 7 show screen images that were captured while the proof-of-concept Note-Taker prototype was being used in a classroom. The Tablet PC displays a graphical user interface consisting of three movable windows. The right-most window shows live video from the camera, while the left-most window provides a rectangular notepad that allows the user to take notes with digital ink. A smaller third window provides up/down/right/left buttons that can be used to reposition the aim of the camera, by sending commands to the USB-driven pan/tilt mechanism. These three movable windows can be positioned to suit the user.

The student can view the professor, the board, or PowerPoint slides in the live video window, while writing notes in digital ink within the notepad window. Since the window enclosing the notepad is adjacent to both the window showing the live video and the window with the pan/tilt controls, there is no significant postural change or time delay when shifting attention from any window to another. This allows a student who is legally blind to follow the lecture while simultaneously taking notes.

In all three of these example screenshots, the view of the board is less than perfect, through no fault of the Note-Taker system. In Figure 5, the contrast on the whiteboard is less than optimal, and some glare is seen from a light source in the room. In Figure 6, the contrast between the chalked writing and the greenboard is less than optimal. In Figure 7, the chalk dust on the blackboard reduces the contrast. In the latter two cases, the view of the board is also somewhat distorted, due to linear perspective, and the fact that the student was seated left of center in the classroom. Although our students were able to effectively use this proof-of-concept Note-Taker prototype despite these limitations, solutions to these problems are planned.

9. Early Findings

The proof-of-concept Note-Taker was given to a student who is legally blind for use in four different STEM classes (statistics, number theory, analysis, and probability). The prototype was taken to class in a backpack, and used in classroom settings for a total of 182 hours over a period of 3.5 months. In the student’s own words “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 no review was even necessary."

An identical proof-of-concept prototype was then constructed and given to another computer science undergraduate who is also legally blind. Both students preferred the view provided by the Note-Taker video to the view through a monocular. They used less magnification because the video on the Tablet PC display gave them a wider field of view than their monocular – thus allowing them to make use of their peripheral vision. The students also commented that the video display produced less eyestrain and headaches than their monocular.

Another finding was that the desk-mounted proof-of-concept Note-Taker prototype eliminates the shakiness that the students experience when viewing the front of the classroom through a high-magnification, hand-held monocular. The zoom on the monocular also cannot be adjusted without entirely destabilizing the view, whereas the Note-Taker provides a smooth, hand-free transition from low zoom to high zoom, or vice versa.

Several user interface inefficiencies were uncovered through these case studies. Among them was the fact that button-based camera pan/tilt and zoom controls were clumsy. A more effective method was to allow the user to pan/tilt and zoom by simply tapping or dragging the stylus across the video window. This also allowed the screen real estate to be better used, by reducing the window count from 3 to 2 – one window to display the video, and the other to provide a note-taking surface.

10. The Phase II Note-Taker Prototype

Based on feedback from the two students who used the proof-of-concept prototype in the classroom, as well as four additional students who were shown the proof-of-concept prototype, and encouraged to try it, we developed a more rugged, faster, and more precise device, which we called the Phase II pan/tilt mechanism. (See Figure 8) This prototype employs a Sony industrial quality video camera with 36x zoom, two rugged servo motors, a USB hub, and a lithium battery to limit its power drain on the Tablet PC and to provide 5 hours of operation per charge.

In addition, we simplified the user interface in several ways. For example, the user can now aim the camera by simply tapping the desired point within the video frame. The camera quickly centers on that point, which becomes the focal point for subsequent zooms. A customized file management system has been developed to facilitate the capture, storage, retrieval, and display of notes, audio, video, and snapshots. Figure 9 shows the Phase II Note-
11. Ongoing work

As shown earlier, adverse lighting conditions in the classroom, the student’s off-center seating position, and lack of cleanliness of the chalkboard/whiteboard can result in a less-than-desirable video representation and recording. To solve these problems, real-time image processing techniques are being implemented to compensate for low light level, perspective distortion, low contrast, and visual noise in displayed/captured video.

In order to facilitate fast-paced note-taking, a method is being developed for insertion of video frames into the student’s notes in real time, which can then be annotated with digital ink.

Early results from our interviews of low-vision students have led us to re-examine some early design decisions. While handwritten note-taking is central to success in STEM classrooms (which typically employ mathematical notation) it is not clear that handwritten notes would always be the most desirable option for students taking non-STEM classes. (Type-written notes might be preferable for some students in some classes.) For students with very low vision, the design team is also planning to support audio recording without video.

Finally, many users make use of screen magnification software, such as AI Squared’s Zoomtext, Freedom Scientific’s Magic, and Dolphin’s Lunar. However, we have found that there are significant problems with using each of the above screen magnifiers to take handwritten notes on Tablet PCs. Specifically, when using these screen magnifiers, the strokes seen on the display surface of the Tablet PC are not aligned with the stylus position, making it impossible to take handwritten notes. We are currently planning to launch a project to develop magnifier software that will allow the use of magnification while taking handwritten notes.

12. Future Work

We believe that the note-taking process is such an important component of the classroom learning experience that it needs to be better understood and facilitated. By providing detailed electronic records of the note-taking process, the proposed Note-Taker could also be a valuable research tool for (1) quantitatively evaluating the benefits of note-taking, (2) training students in better methods of note-taking, and (3) studying the way in which students with different cultural backgrounds conceptualize and master novel concepts when those concepts are first encountered. The results of these studies could potentially have a significant impact on methods used for teaching, training, and learning for students, regardless of whether or not they have visual disabilities.

13. References


14. Acknowledgement

This material is based in part upon work supported by the National Science Foundation under Grant Number IIS-0931278. Any opinions, findings, and conclusions or
recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.