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Digital Choral Folder

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DIGITAL CHORAL FOLDER

A Major Qualifying Project Report:

submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

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Date:

4/24/08

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1. digital
2. choral
3. folder
4. dcf

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Abstract

Choral folders have been used for many years. Digital music and E Ink paper technology combined enable a product that emulates a choral folder. This project describes the initial steps taken to design this product, a Digital Choral Folder (DCF). Prototypes of the DCF were created on which to perform experiments, and the resulting data was analyzed to provide a better understanding of how the final product should work.

Acknowledgements

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- Professor Delorey, for not only conceiving the Digital Choral Folder, but for always providing an enthusiasm for the work we were doing. It was a joy to help Professor

Delorey design this amazing device, and it seemed like the more I met with him, the more excited I got about the project. He has guided the project with great care, and I know he will make sure this device becomes a massive success.

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1. Introduction

Choral music has been with us for hundreds of years, and has become an integral part of our culture and history. The music is printed or written on paper and collected into a full choral score for singers to sing from. These scores are typically held in a choral folder while the singers sing the music. This is done to keep the music organized, to support it, and to make it easy to turn pages.

1.1 Problems with choral folders and scores

There are some problems that arise when groups of people use choral folders and choral scores. Several of these problems are as follows:

Weight

While Choral folders do not weigh much on their own, choral scores can sometimes be quite heavy. A choral score usually has a thick cover and can contain well over 50 pages. One such example is Handel's *Messiah*, which is over 250 pages in length. (Handel, 1992) The longer a piece takes to sing, the more a singer's arm will get fatigued.

Cost

Choral scores can be quite expensive. A percentage of the cost comes from the fact that they are made of sheets of paper that must be printed with ink, bound, and shipped.

Portability

Due to the nature of music rehearsals, choral scores need to be portable so they can be moved around a great deal and easily stored. However, a choral score's portable

nature presents a problem in that scores can be easily misplaced and lost. When a piece of choral music is lost, it costs money to replace the missing copy. However, if a copy is out of print from the publisher, it becomes extremely difficult to get a replacement for the missing piece.

Durability

Paper is easily susceptible to certain kinds of damage. Liquids that fall on paper can destroy it or make anything printed on it illegible. Paper is also extremely flammable.

Readability

In certain concert situations, low lighting or bright lighting may be used. In either case, text on paper can be difficult to read. Since printed music is not standardized, certain page layouts and small font sizes can also make a piece of music difficult to read.

1.2 The Digital Choral Folder

The problems mentioned above have plagued singers for years, with no hope of a solution. The goal of this project is to use modern technology to overcome the problems with choral folders and choral scores.

A Digital Choral Folder (DCF) is a device designed to combine a choral folder and choral music with modern technology in order to solve the aforementioned problems. Such a device accepts digital copies of sheet music, and can display the music using two screens. Buttons on the device allow a user to both turn pages and navigate through a menu containing the list of choral scores on the DCF.

The following points show where the benefits to using a DCF are:

Weight

Since the DCF will be using digital sheet music, there will be a significant decrease in the weight of the device. Thousands of pages can be stored in PDF format on a single memory card, and this will be a great benefit of the device.

Cost

Initially, the cost of a Digital Choral Folder would be more expensive than buying a choral folder. However, the benefit of having the DCF is that the DCF's music is stored digitally, meaning that digitally distributed music would cost less than printed music, reducing costs in the long run. Paper is no longer involved in the buying process, and all the costs associated with paper will disappear.

Portability

It is common for current technology to become lighter and slimmer. The DCF will take advantage of such improvements. By using a thin, lightweight display, the DCF can potentially be more portable than a choral folder with a choral score inside.

Durability

This is the one area where the DCF may not be better than a choral folder and score. Since a DCF houses sensitive electronic equipment, it is susceptible to fire, liquids, and damage from falling. While the electronic components may be water-proofed or fire-proofed, there is still a chance that dropping a Digital Choral Folder would destroy the device. The DCF can be made to be durable, but it will be durable in different ways than a choral folder and score.

Readability

Certain displays are readable from any angle, and can be backlit so a singer can see the music clearly in the dark, without the use of an extra light. Certain displays are also easily readable in bright conditions. By using a display with these qualities, the DCF can be just as readable as a choral score.

A summary of the benefits and shortcomings of the choral folder, choral score, and Digital Choral Folder can be seen in Figure 1.1.

	Choral Folder	Choral Score	DCF
Weight	Very light	Light to heavy	Very light
Cost	Inexpensive	Expensive	Initially expensive
Portability	Very portable	Very portable	Very portable
Durability	Very durable	Damaged by water, dirt, fire	Damaged by water or falling
Readable under most lighting conditions?	N/A	No	Yes

Figure 1.1 – Benefits and shortcomings of the different technologies

1.3 Project outline

The related work section presents details about technologies that are similar to the Digital Choral Folder, as well as technologies that will be employed on the DCF. The design section presents user analysis, task analysis, and design decisions with the rationale behind the decisions. It explains how the DCF will work and how the device will look and feel. In the design and implementation section, two experiments are described that were created to provide a better understanding of the Digital Choral

Folder. The section details the design and implementation of these experiments. The following section contains the analysis of the data obtained from the two experiments. The software development section explains how the DCF prototypes were created, and what features were implemented in the device. The conclusions and future work section details the project conclusions as well as what work is left to be done in the project.

2. Related work

Before describing the design and evaluation of the Digital Choral Folder, it is important to first take a look at the technologies that paved the way for the DCF concept. Some technologies are similar in terms of functionality, while others are similar in the way they look and feel. Both types of technologies will be discussed in this chapter. The chapter will also discuss technologies that were investigated for the purpose of incorporating them into the Digital Choral Folder.

2.1 Similar concepts

Over the last few decades, a few products have been created which are precursors to the Digital Choral Folder. While they are designed to display music, they fulfill different needs than those of choral singers. In this section two major products are discussed, along with their purpose, and why they do not accomplish what the Digital Choral Folder will.

2.1.1 eStand

E-Stand Inc.'s eStand Digital Music Workstation was created in 1992 by David Sitrick as a way for musicians to be freed from the hassles of dealing with paper sheet music and editing. (DeWolfe, 2002) The eStand acts as a digital combination of a standard musician's stand and their music. The main benefit of the eStand Digital Music Workstation is that music editing is taken care of by a librarian or conductor and any changes made to the music are transmitted to the rest of the musicians. If the music is edited in one place by one person, it will save the writer a great deal of time, and if the

change is being made by the conductor at a rehearsal, no time is wasted by instrumentalists parsing the conductor's change requests and writing them in.

There are two parts to the eStand Digital Music Workstation: the hardware and software parts. The eStand Digital Music Workstation hardware comes in a variety of configurations, the simplest of which is the eStand Performer (eSP) series. (e-Stand, 1) The eSP is a mobile PC with an LCD touch screen. Built on Elo Touchcomputer and Elo Touchscreen technology (which provides a Windows operating system), the eSP system contains USB, serial, and compact flash inputs to get music files into the system. (Tyco Electronics, 1) A second hardware configuration is the eStand mobile tablet which is essentially a Gateway M285-E tablet PC running Windows XP Tablet PC edition. (e-Stand, 2)

A version of the eStand software package (there are currently five) comes pre-installed on each piece of eStand hardware. The eStand software allows sheet music to be read into and displayed by the program. It accepts music in jpeg, PDF, and tiff format, and can also read music in Sibelius, Finale, and eStand formats. (e-Stand, 3) The software package allows for edits to be made on the music by a user, and a type of version control manages the changes on each piece of music. Page turning can be accomplished with touch screen controls, a keyboard, a mouse, or an optional footswitch. There are also a variety of page-turning options relating to page flip speed and transition type. (e-Stand, 3) The software can also be purchased individually and put on most Windows XP machines.

Two of the biggest drawbacks to the eStand system are the cost and portability. Since all of the eStand Music Workstations run on a mobile or tablet PC, the prices range

from \$1800 to \$5900 per unit. (e-Stand, 1) Also, the product weighs in at 6 lbs., meaning that while it is portable, it requires a stronger-than-average music stand to support it, and it is much heavier than a choral music score. These two factors make the eStand products unsuitable for choral needs.

2.1.2 MusicPad Pro Plus

FreeHand System Inc.'s MusicPad Pro Plus is another product designed to display sheet music for musicians. (FreeHand, 1) While much simpler than the eStand Performer, it does accept a variety of graphic formats such as PDF and .jpg as well as most sheet music editing software files from programs like Finale, Sibelius, and Encore. (FreeHand, 2) Music is displayed on one screen, and can be set to landscape mode to show two pages at once. Page turns are controlled by a foot pedal. Edits can be made to the music with a special pen.

The MusicPad Pro Plus unfortunately suffers from the same problems as the eStand Performer. At close to \$900, the device is still expensive when its only use is to display music. (FreeHand, 3) It also weighs over 4 pounds, which is still greater than a choral folder and a normal sized score. In addition, the small LCD screen and 1024x768 resolution would make it difficult to read most pieces of music if the device was set to display two pages in landscape mode. These problems make it unsuitable for choral needs.

2.2 Useful technology

This section contains technology that was investigated over the course of the project. Some devices included here were examined to provide an idea as to how the

Digital Choral Folder should look and feel. Others were examined in order to discover if their features could be incorporated into the final DCF design.

2.2.1 Choral folders

A choral folder is a simple device designed to hold choral music. It is normally slightly larger than a choral score and uses cords or strings to hold choral scores in place. Choral folders are lightweight, sturdy, and portable. Some even contain a hand strap on the back for singers to better support the folder.

According to Professor Delorey (Delorey, 2008), the Black Folder by Musicfolder.com Inc. is an example of a well-designed choral folder. It is 10 7/8 x 12 7/8 in. when closed, weighs 395 grams, contains a hand strap on the back, and holds common score sizes. (Musicfolder.com, 1)

2.2.2 E Ink paper

The E Ink Corporation was founded in 1997 as a “supplier of Electronic Paper Display (EPD) technologies.” (E Ink, 1) An EPD uses a proprietary material known as electronic ink to display an image. When an electric field is passed through the electronic ink in specific areas, the ink is pulled to the surface of those areas. This field can be controlled to display a grayscale image. (E Ink, 2)

E Ink’s EPD display (hereafter referred to as E Ink paper) has some unique characteristics. E Ink paper is a very thin, lightweight display that closely mimics paper. It can be viewed under most lighting conditions including direct sunlight. (E Ink, 3) It also does not need any power to maintain an image. All these characteristics made it seem very suitable for use in a Digital Choral Folder.

2.2.3 E Ink paper products

There are several products on the market that use E Ink paper technology, and three major products whose primary purpose is for viewing eBooks and other documents. These products are the iLiad, the Sony PRS, and the Amazon Kindle. These three products were important to investigate as they showed what kind of technologies and functionality could be created around an E Ink paper display.

The iLiad by iRex Technologies can display a variety of document formats, including eBook, PDF, text, bitmap, and RSS feeds. (iRex, 1) It utilizes memory cards for storage, and wireless internet to synchronize data with a PC. (iRex, 2) A special sensor board under the E Ink paper allows an included stylus to control menu navigation as well as document editing. (iRex, 3)

The Sony PRS (Portable Reader System) is another reader that can display a variety of formats such as eBook, PDF, bitmap, and RSS feeds. (Sony, 1) It is not only very portable, weighing around 9 ounces, but also offers a hard drive and memory card reader for storage. The PRS can also connect to a PC to transfer data to the device through a service called CONNECT.

Amazon.com's Amazon Kindle is the most recent reader to come out using E Ink paper technology. (Amazon.com, 1) In addition to displaying a variety of formats such as eBook, DOC, text, bitmap, and HTML, the Amazon Kindle can also play MP3s. It has 256 MB of storage in the actual device, and can use Secure Digital (SD) cards for additional storage space. It does not need to be connected to a computer, and uses its own wireless service to allow users to navigate the internet and purchase eBooks for the device.

2.2.4 Adobe PDF

The Adobe Portable Document Format (PDF) was created in 1990 as a way to “reliably view, print, and share information with other people.” (Adobe, 1) The PDF file format’s versatility was one of the reasons why it was investigated for use in this project.

The Adobe PDF is a multiplatform technology, meaning it can be viewed on a variety of operating systems. It is also incredibly extensible, with thousands of vendors offering “PDF-based solutions including creation, plug-in, consulting, training, and support tools.” (Adobe, 2)

One of the main reasons why Adobe PDF was seen as a possible technology to incorporate into the Digital Choral Folder was the fact that it is easy to store and distribute choral music in PDF format. The clearest example of this is seen at the Choral Public Domain Library, where hundreds of scores are available to download for in PDF format for free. (CPDL, 1) According to a few major choral music distributors, their music is either stored in PDF format when distributed to printers, or stored in Finale or Sibelius format, either of which can be converted into PDF format. (Appendix 9.1) If this is the case, the Adobe PDF would be an ideal way to store music on the Digital Choral Folder.

3. Design

Two important analyses led to the final design. A user analysis was important to accomplish for the project, as it defined the characteristics and skills of users that would be using the Digital Choral Folder. A task analysis was also important as it illustrates how various actions are accomplished on the DCF. Once the two analyses were completed, work began on the final design. These steps have all been outlined in this chapter.

3.1 User analysis

Choral singers are a diverse group of people. The age range of choral singers can be from children to elderly, and they can come from a wide variety of cultures. However, they all share some characteristics, hence the Digital Choral Folder will be created under the assumption that users will have the following characteristics:

- Users will either have eyesight strong enough to view the DCF clearly without any help, or they will be able to view the DCF with some visual aid (such as glasses).
- Users will be proficient in reading music, and will be able to sing any score given to them, regardless of the language it is in.
- Users will hold the DCF on their left arm, and use their right arm to interact with the DCF, regardless of their dominant hand.

3.2 Task analysis

A task analysis explains how different tasks are to be accomplished when using a product. It can detail requirements for a product as well as series of use cases. A use case is a simple step-by-step procedure that explains how different actions are performed with the device. This section contains requirements and use cases. The requirements and use cases were obtained after discussion with Professor Delorey, who envisioned the Digital Choral Folder.

3.2.1 Requirements

The DCF must

- Be able to display images from sheet music in PDF form.
- Be able to display images of music on two screens.
- Have an interface that allows the user to “turn pages” forward or backward by moving the music images two pages at a time with the push of a button.
- Change images in under a second when turning pages.
- Have buttons that are easy to access with the right hand, while the left hand is holding the folder.
- Display odd numbered pages of a music score on the right display, and even numbered pages on the left display as the default option.
- Be powered through an internal power source.
- Have a power button that turns the displays on and off.

- Display a menu on the left display and page one of the first piece of music on the right display when turned on for the first time. The same should happen when the DCF is turned on after being off for more than 2 hours.
- Return to the same set of images that were displayed prior to shutdown if the DCF has been off for less than 2 hours.
- Be visible under low and bright lighting conditions

The sheet music images must

- Be in PDF format, and converted into PPM format.
- Be in grayscale.
- Be paginated.
- Be 7 1/2 inches by 10 5/8 inches.
- Contain text no smaller than 8pt.

The DCF should

- Weigh about as much as a standard choral folder.
- Fold in half like a choral folder.

Assumptions

- The images of music given to the DCF will not contain any repeats, alternate endings, or any other musical notation that would cause the singer to go back several pages to continue singing. While this is an unrealistic assumption for

most choral music, it has been made to simplify the initial development of the device.

3.2.2 Use cases

This section contains a few use cases that show how a user would perform basic actions on the Digital Choral Folder. Flow charts have been included to illustrate some of the use cases.

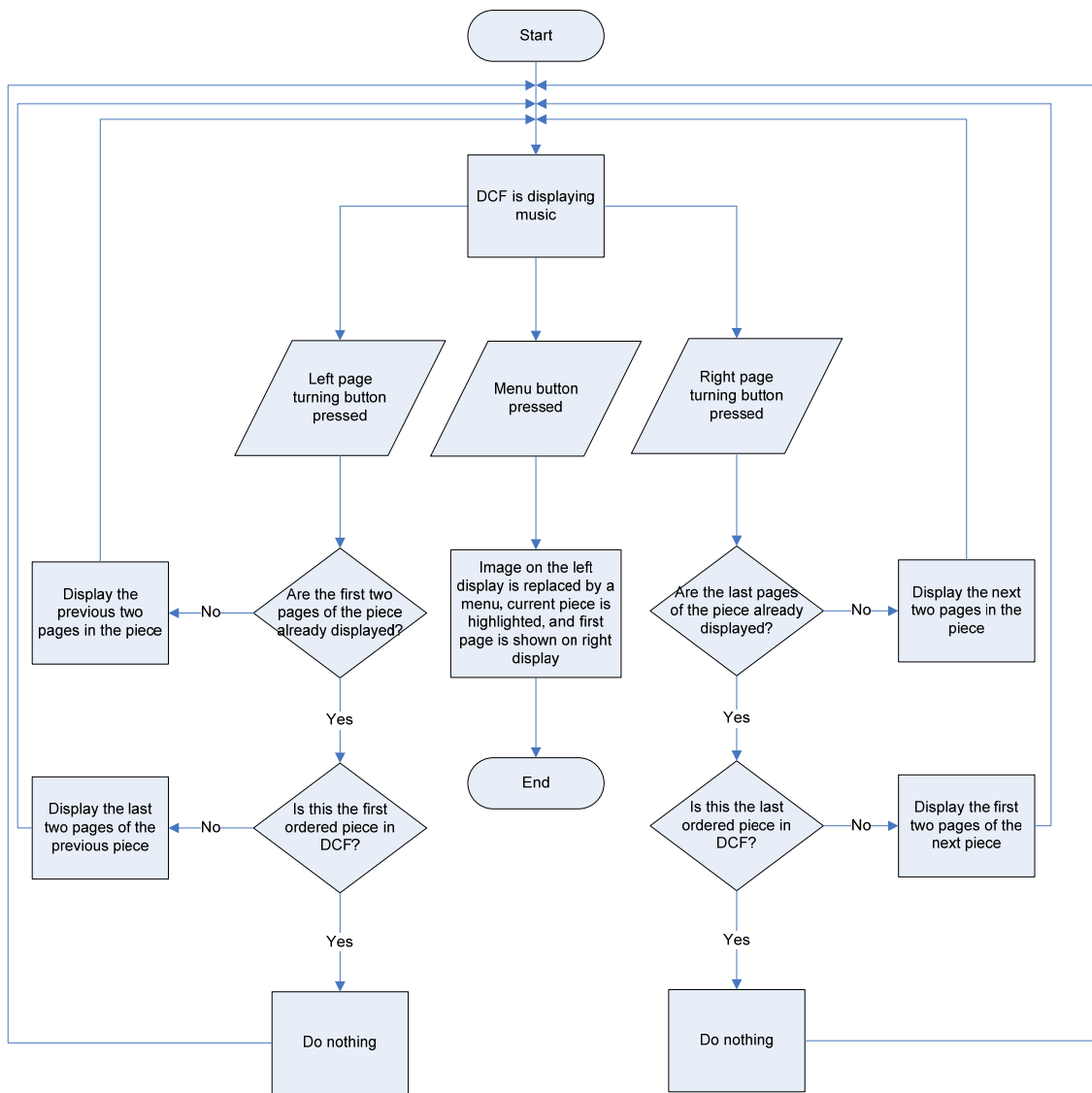


Figure 3.1 - Flow chart showing input possibilities when music is displayed

Use case: User turns pages in the DCF (illustrated in Figure 3.1).

Use case description: A user turns wishes to turn pages forward then backward.

Steps:

1. User presses the page turning button on the right side of the device.
 - a. If the music is not on the last page, the next two pages appear.
 - b. If the music is on the last page, it will open the first two pages of the next piece of music.
2. User presses the page turning button on the left side of the device.
 - a. If the music is not on the first page, the previous two pages appear.
 - b. If the music is on the first page, the last pages of the previous piece of music will be displayed.

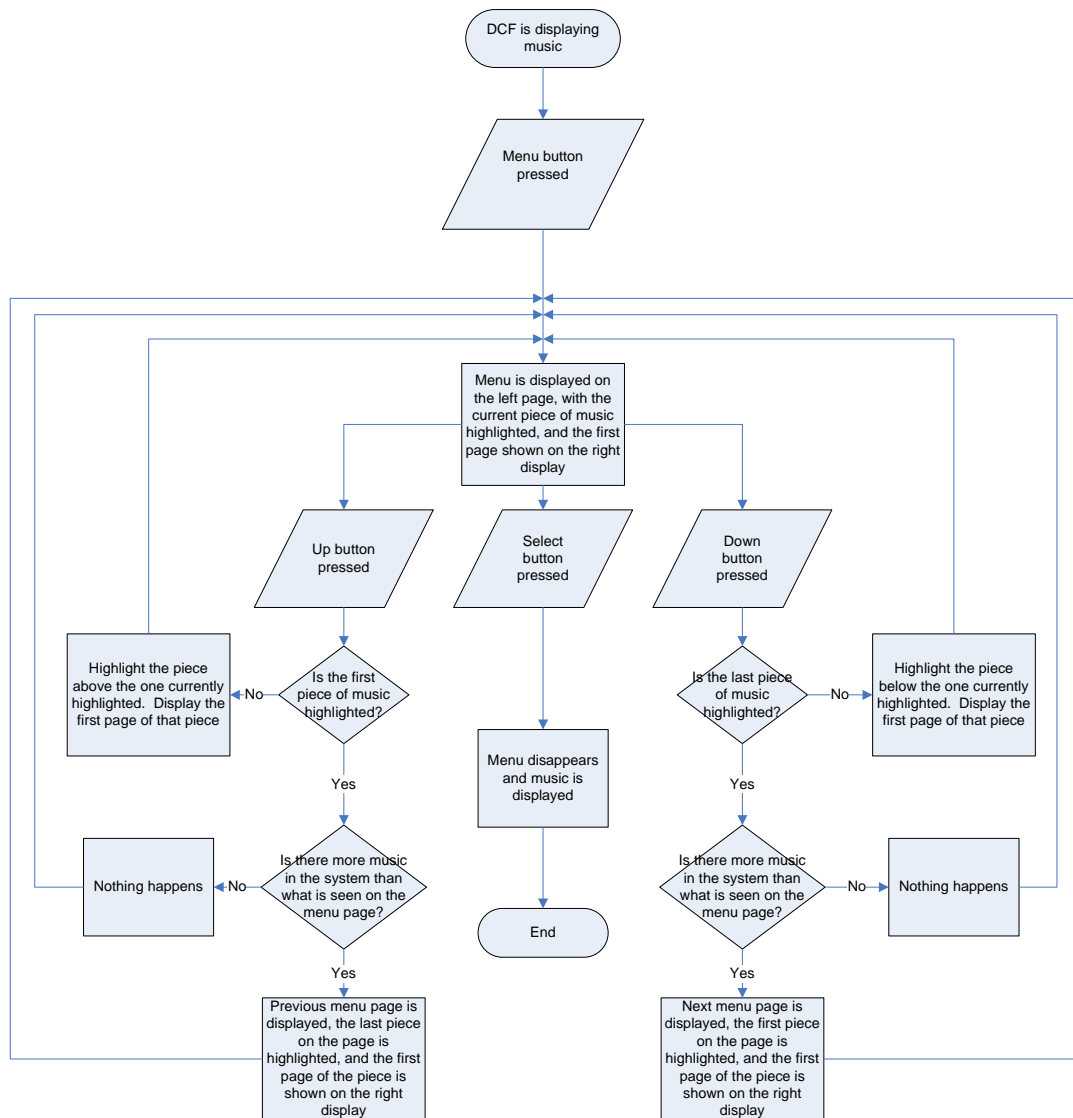


Figure 3.2 - Flow chart showing input possibilities when menu is displayed

Use case: User selects a piece of music to sing (illustrated in Figure 3.2).

Use case description: A user brings up the menu and selects a piece of music.

Steps:

1. User presses the menu button.
2. Menu appears on the left display, with the current piece highlighted.

3. User presses the up or down buttons to navigate the list. Each time a button is pressed, the next piece in order is highlighted in some way, and the first page of the highlighted score is shown on the right display.
 - a. If the score is not visible on the menu, but is in the DCF, pressing a page turning button will bring up another list of scores.
4. When user highlights the piece they want, the select button is pressed.
5. The menu disappears from the left display, and the piece of music is now shown on both displays.

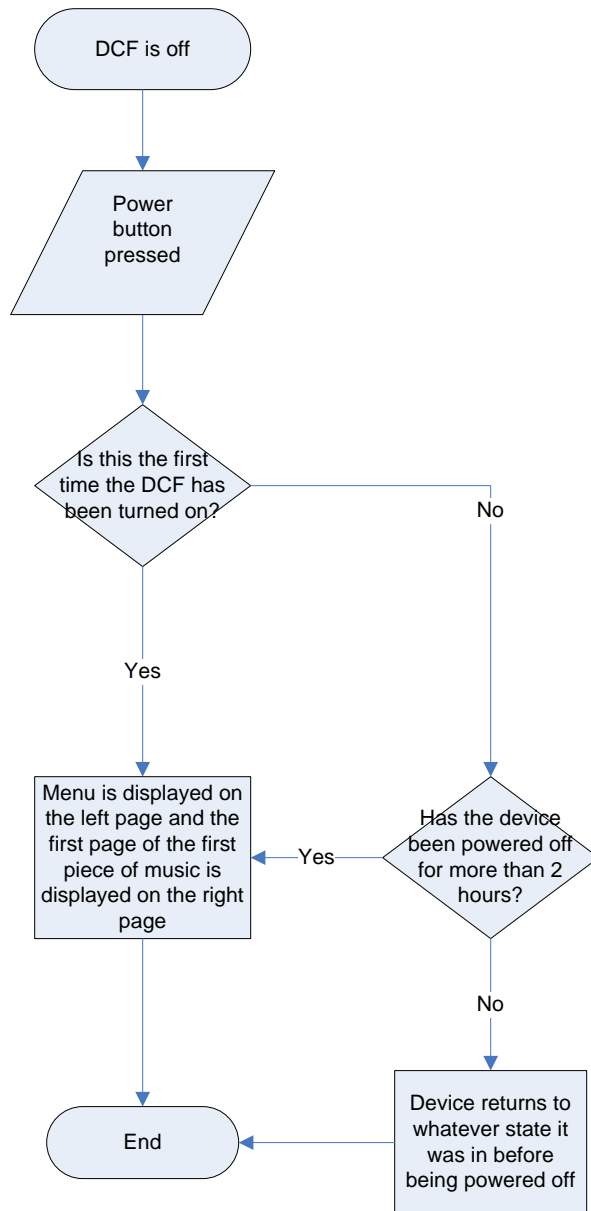


Figure 3.3 - Flow chart showing steps taken when device is powered on

Use case: User powers on the DCF (illustrated in Figure 3.3).

Use case description: A user presses the power button to turn on the DCF.

1. User presses the power button.

- a. If the device has not been powered on before, or it has been more than two hours since the last time it was powered off, the menu is shown on the left display and the first page of the first highlighted piece is shown on the right display.
- b. If the device was powered off in the previous two hours, the last images displayed on the DCF are shown again.

Use case: User powers off the DCF.

Use case description: A user presses the power button to turn off the DCF.

1. User presses the power button.
2. The images are removed from both displays.

3.3 Final design

While the initial designs for the Digital Choral Folder constantly changed through the course of the project, some major design decisions were finalized. The following section lists these decisions as well as the rationale behind them.

3.3.1 *E Ink paper displays*

After an investigation of display options for the Digital Choral Folder, it was decided that using two E Ink paper displays would be an integral part of the DCF's design. E Ink paper brings a variety of benefits which meet most of the DCF's requirements for a display. The display itself is lightweight, thin, and easily readable under a wide variety of lighting situations. The display is connected to a Linux-powered

minicomputer, which is not only lightweight, but also contains a Secure Digital (SD) card reader which can be used with an SD card to store choral music.

A problem with using E Ink paper as a display for the Digital Choral Folder is that whenever an image update occurs, there is a flash of black, a negative image appears, and then the requested image appears normally. This takes an average of 740 ms (approximately $\frac{3}{4}$ of a second) to complete according to the E Ink website. (E Ink, 4) This delay was long enough to warrant an experiment in order to discover how much users would be affected by the delay and how noticeable the delay was. The experiment design, implementation and results are detailed in chapters 4 and 5.

3.3.2 *User interface*

Due to the fact that users of the Digital Choral Folder can come from a wide range of backgrounds, a simple user interface (UI) needed to be designed and implemented for the two displays. One of the major goals of the UI was to include as few buttons as possible. Users need to be able to quickly familiarize themselves with the device, and they should be able to figure out what each button does in a matter of seconds. Since the DCF only requires the ability to traverse through pages of music and traverse through a menu containing a list of songs, buttons needed to be placed on the device to allow a user that control.



Figure 3.4 – The Digital Choral Folder interface

Figure 3.4 provides a simple drawing of the DCF interface. On the far left and right of the device, two buttons were placed to allow for page turning. When pressed, the button on the right turns the pages of the music so that two new pages coming up are displayed, and the button on the left turns the pages so that the previous two pages in the music are displayed. If the end of the piece is reached and the right page turn button is pressed, the next piece of music is displayed. This is so that singers can transition quickly to the next piece without needing to spend extra time in a menu.

The two page turning buttons were placed in these locations as those are the points on a normal choral folder where a singer’s hand would go if they needed to flip the pages in either direction. This makes the action of page turning on the DCF seem familiar to a singer who is used to a choral folder and score.

The three buttons in the center are for interacting with the menu. The Menu/Select button can be used for bringing up a menu and selecting a piece of music

once in the menu. While using the menu, the Up and Down buttons can be used to scroll through the pieces of music in the DCF. The three buttons have been placed there as it is very close to the location where a singer's hand would be holding the device. This allows the device to stay stable while a singer presses the buttons.

3.3.3 Inputting music

In a choral group, the conductor will decide the order of music to be sung in a rehearsal or a concert. The singers in the group will then bring the appropriate choral scores to the event, and the conductor will let the members know when to take out the right score. To prevent problems such as singers forgetting to bring the right pieces of music, or losing valuable scores, the conductor will have complete control over what music gets stored in the Digital Choral Folder.

As with many groups of musicians, conductors can range from being very comfortable interacting with computer programs, to very uncomfortable. Assuming that conductors have basic computer skills (opening programs, navigating folders in a file system, copying files, etc...), there needs to be a system of getting music organized and into the machine that is simple to use and minimizes user error. To meet these needs, a program needs to be created that can be put on the conductor's personal computer.

Conductors will first load music files in PDF format into a program named DCFLoader. From there, a conductor can organize the pieces of music into the order they prefer. Then the DCFLoader will convert all the PDF images into a format that the DCF's E Ink paper display can understand: PPM (Portable Pixmap). It will also create images to be used as a menu for the DCF.

Once all these images are created, the DCFLoader will group everything into a file structure that the DCF can understand. The file structure can then be copied to a memory card and inserted into the DCF. Once the DCF starts up, it can automatically detect the file structure and implement the menu system.

While the DCFLoader program was not implemented as part of this project, the aforementioned file system will be discussed in chapter 6, the software development chapter.

3.3.4 Menu system

The menu system is an important element of the Digital Choral Folder's design. What the menu does is display a list of all the names of the choral scores contained in the DCF, in the order determined by the conductor. The menu is accessed by pressing the Menu button on the DCF.

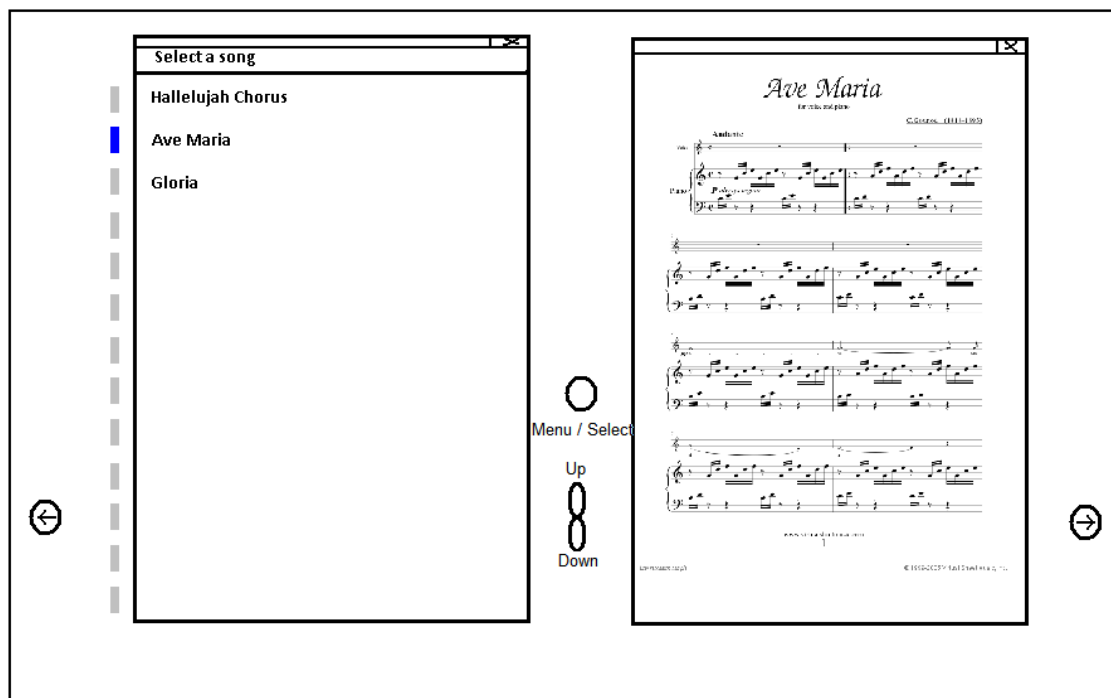


Figure 3.5 – The Digital Choral Folder with the menu system visible

As seen in Figure 3.5, the pieces of music stored in the DCF are displayed on the left screen and a series of LEDs are located next to display, each LED corresponding to a song in the list. Users can press the up and down buttons to traverse the menu, and after each button press the LED moves to show which piece is currently being highlighted.

When a piece is highlighted, the first page of that piece of music is shown on the right display. If there are more pieces of music in the system than there are LED displays, the page turning button on the right of the folder can be used to advance to the next list of choral scores in the menu, and the page turning button on the left of the folder will go to the previous list of choral scores. In order to select a piece of music to read, pressing the Select button will bring up the piece of music and allow a user to turn the pages of that piece.

4. DCF prototype evaluations - Design and implementation

New technologies allow for new ways of doing old things. Since the Digital Choral Folder frees us from choral music in book format, actions such as turning pages no longer have to be performed in the same way, or carry the same constraints as the old method. However, the new technology also brings its own constraints, such as the delay associated with page turning on an E Ink paper display. Over the course of the project two separate experiments were set up to get a better understanding of how users would respond to both the new methods of performing actions and the new constraints surrounding the DCF technology. The following explains the goals, designs, and implementations of the two experiments.

4.1 Page turning experiment

By using two E Ink paper displays, the Digital Choral Folder is free from the physical constraints associated with books. The DCF can still mimic a choral score by having some action display two new pages on the two screens. This is what we call the *book* method of page turning, as it works just like turning pages in a book. An alternative method is that the same user action can display one new page, shifting the right page to the left display and displaying the new page on the right. This is what we call the *shifting* method of page turning. Figure 4.1 illustrates how both of these methods operate:

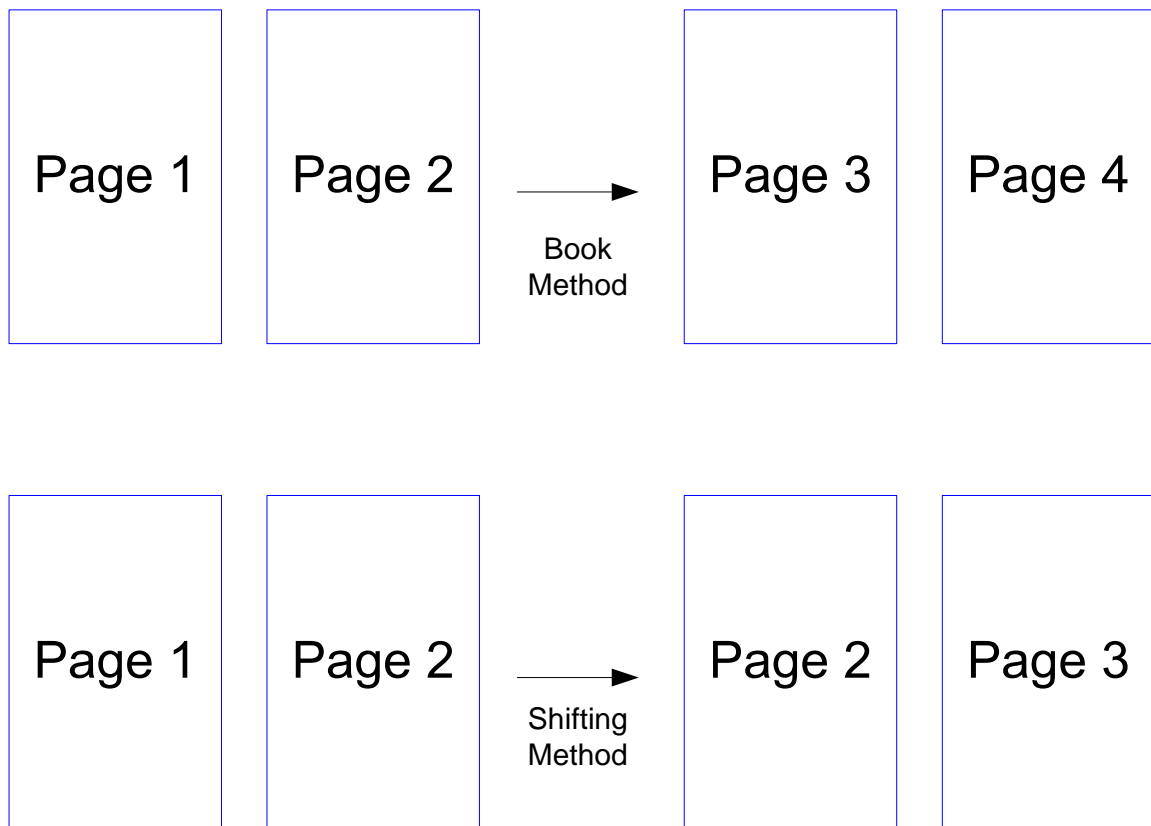


Figure 4.1 – In the book method, two new pages are shown each time. In the shifting method, only one new page is shown.

When it comes to new ways of doing old things, users tend to favor the method that seems most familiar to them. In this case, the book method was the familiar one. There were two goals for the page turning experiment. The first goal was to gauge how much resistance there was to the new shifting method. The second was to see how much users preferred one method over the other, in order to determine if either option was worth removing. With these goals in mind, a DCF prototype, shown in Figure 4.2, and a questionnaire were created.

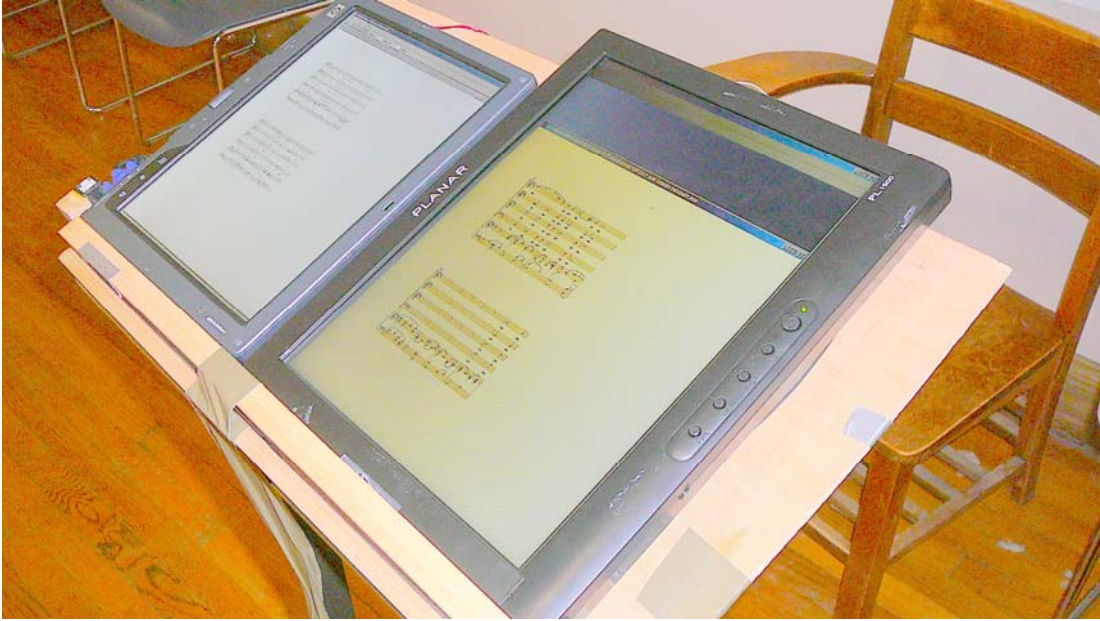


Figure 4.2 – The DCF prototype without the black case (page turning button not shown)

4.1.1 Experiment design

The best way to have users interact with a Digital Choral Folder prototype was to have them sing along with a choir or a recording as the sheet music was displayed on their device. This would emulate a real world situation where the DCF would be used. The choral music selected for the experiment needed to be less than 3 minutes in order to keep participants from becoming bored, but it needed to be long enough so that a few page turns could be done with either page turning method. A piece called *Ave Verum* by Mozart was selected based on Professor Delorey's recommendation. It was approximately two minutes long, and the music provided three page turns using the book method and six page turns using the shifting method.

In order for the experiment to work, designing and creating a prototype DCF device was crucial. On the software side, the prototype needed to be able to open a PDF of a piece of choral music, and be able to advance pages using the book method or the

shifting method. On the hardware side, the prototype needed two screens to display the PDF images and one button that would allow the users to advance pages. A button to turn back pages would not be programmed in as it was not needed for the experiment. The hardware also needed to provide a way for the person running the experiment to switch between the two page turning methods, and reset the PDF back to the beginning.

The experiment procedure was as follows, with some important design choices explained:

1. Users were told that the DCF is supposed to emulate a choral folder and score. They were also told that a button makes the page turn.
2. Users were assigned one of the page turning methods, and the method was explained to them. Half of the users were initially provided with the shifting method and the other half were initially provided with the book method. This was done to make sure that the first method users saw did not have an impact on the results.
3. Users were asked to push the forward button a few times to see firsthand how the page turning worked.
4. Users were asked to put on headphones and sing along with the piece, using the page turning button to advance through the music.
5. The person conducting the experiment used a laptop to start a recording which played through the headphones. The song users heard corresponded to the sheet music displayed on the DCF. This was done to emulate an actual performance environment for the user.

6. Users then followed along with the piece.
7. Users then took off the headphones and the other page turning method was explained to them.
8. Users were again asked to push the forward button to see firsthand how the other page turning method worked.
9. Users were asked to put on headphones and sing along with the same piece as before. They once again used the page turning button to advance through the music, using the second page turning method.

At the end of the experiment, the users filled out a questionnaire relating to the page turning methods. The questionnaire can be found in Appendix 10.2.1.

4.1.2 Experiment implementation

The software for the prototype was constructed in Visual Basic 2005 using the Adobe Acrobat Software Development Kit (SDK). One of the pieces of sample code provided by the SDK, a project called StaticViewVB, was used as a template for the DCF prototype. (Adobe, 3) The code was then changed so that the DCF could open up two different pages of a single music file in PDF format, allowing the music to be displayed across two different screens like a book. From there, the ability to advance through the music with a button press was added. Keyboard control was added to give the person running the experiment control over which page turning method was presented to the user.

The setup for the hardware was constructed using a variety of technologies. Two screens were required, so a Tablet PC was used as one display, and it powered an LCD

screen, used as the second display. To provide a page turning button for users to push, a wireless mouse was dismantled and restructured so one of the mouse buttons could be placed next to the display. A keyboard was attached to the Tablet PC and placed by the person conducting the experiment. This gave the person running the experiment control over which method was presented to the user and it allowed the displayed music to be set back to the beginning as the button to turn back pages was disabled. A laptop was also placed by the person conducting the experiment so that the music recording could be started and stopped when users put on the headphones. A wooden case was constructed and placed on a music stand to hold the hardware, and a black cover was put over the device so that the user would only see the two screens and the page turning button. When a user came to participate in the experiment, they stood in front of the device, and the person running the experiment stood behind the prototype with access to the keyboard controls.

The experiment itself was conducted according to the procedure defined in the previous section from February 14th 2008 to February 16th 2008 at the American Choral Directors Association Conference in Hartford Connecticut. Ninety-five people participated in the experiment.



Figure 4.3 – A singer prepares to start the page turning experiment

4.2 Delay experiment

A singer's ability to turn a page quickly enough to keep up with the music is essential. If the page turn is not completed in time, or not done fast enough, it could lead a singer to stop singing until they can see what music is coming up. Since the Digital Choral Folder should turn pages in a certain amount of time consistently, turning pages on the DCF needs to be done at least as quickly as a standard page turn so the singer will always have enough time to view the next pages.

However, one of the problems with using E Ink paper as a display is that there is a delay associated with any image update. Whenever an image is sent to be displayed by the E Ink paper, there is a flash of black, a negative image appears, and then the image

appears normally. According to the E Ink website this delay takes an average of 740 ms. (E Ink, 4) Additional time may be added to the delay if the Linux board is using processing power on other commands. The goal of this experiment is to get an idea as to how much of a delay users can tolerate in a page turn before the device becomes unusable.

4.2.1 Experiment design

The Digital Choral Folder prototype used for the experiment matched the hardware design described in the above experiment. One change in the software design was that every time a person pressed the next page button, a delay was added so that it took a certain amount of time before the new pages were displayed on the screen. The other change was that the DCF prototype was set up using only the book method of page turning, as it was the most familiar method of page turning for users.

As mentioned before, a typical grayscale image update on an E Ink display is 740 ms. If a black and white image is updated, the E Ink display typically takes 260 ms to update. (E Ink, 4) For the experiment, these two delays were the minimum and maximum delays tested. When E Ink was improved last year, the delay time decreased by around 20% to the current 740 ms value. (Block, 2007) Assuming that the next version of E Ink paper will have the delay decrease by 20% again, a 592 ms delay was also chosen to be tested in this experiment.

The experiment procedure was as follows, with some important design choices explained:

1. Users were told that the DCF is supposed to emulate a choral folder and score. They were also told that a button takes care of the page turning, and that it would take some time before each new page was displayed.
2. The DCF were then assigned only one of the three delays. The intention of the experiment was not to compare which delay was best, but to simply see if any delay was noticeable or bothersome. The delays were assigned in sequential order to better keep track of which delay the next participant would need.
3. Users were asked to push the forward button a few times to see firsthand how the page turning worked with the delay.
4. Users were asked to put on headphones and sing along with the piece, using the page turning button to advance through the music. The music that played on the headphones corresponded to the music displayed on the DCF. This was again done to emulate an actual performance environment for the user.
5. Users then followed along with the piece until the piece ended.

At the end, a questionnaire was filled out by the users in order to give an opinion on how the delay affected them and how noticeable it was. The questionnaire can be found in section 10.2.2.

4.2.2 Experiment implementation

The software was identical to what was used in the previous experiment, with the only major change being that the E Ink delay had been emulated, while previously there was no delay. Since all the hardware from the previous experiment was kept, it was all used again in the same way.

For the passage of music used in the experiment, Professor Delorey selected the piece *Ave Verum* by Mozart, also used in the previous experiment. It was approximately two minutes long, and the music provided three page turns using the book method of page turning. Each user only tried one of the three delays, and an equal number of users tried each delay. The experiment was conducted at Clark University on April 14th 2008 and at Worcester Polytechnic Institute on April 18th and 21st 2008. Thirty-two people participated in the experiment.

After the experiments were conducted, the data from both questionnaires were compiled and the data analysis was performed. This is found in the following chapter.

5. Analysis of the experimental results

The page turning and delay experiments were important to the Digital Choral Folder's final design. The page turning experiment provided an opportunity to see what method of page turning users wanted to see in a DCF, and how much they preferred the new and old methods. The delay experiment gave an idea as to how much of a page turning delay users could tolerate on a Digital Choral Folder.

5.1 Page turning experiment

5.1.1 Hypotheses

Before performing the experiment, a list of hypotheses were produced based on the author's experience as a musician, keeping in mind the people targeted for the page turning experiment. The hypotheses were as follows:

- Hypothesis 1: Users will prefer the book over the shifting method;
- Hypothesis 2: More users will prefer the shifting method if they see it first;
- Hypothesis 3: Most people who prefer the shifting method will spend 5 or more hours on the computer a day;
- Hypothesis 4: 75% will be able to quickly adjust to the shifting method.

5.1.2 Results

Ninety-five choral singers and conductors participated in this study. Demographic data was not collected, but the participants contained college students and older adults. As an incentive for participating in the experiment, users who completed the experiment could enter into a raffle for an iPod Touch. Of the 95 participants, three

failed to follow instructions and one participant failed to complete the survey. Therefore, the data are based on 91 participants. Each participant was capable of reading and singing along with the choral music presented.

Data

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Shifting method - liked/disliked	91	1 (disliked)	8 (liked)	4.80	2.367	5.605
How quickly users could get used to shifting method	91	1 (disliked)	8 (liked)	6.47	1.760	3.096
Book method - liked/disliked	91	1 (disliked)	8 (liked)	6.71	1.809	3.273
Hours	91	1	18	4.93	2.872	8.248

Figure 5.1 – Descriptive statistics

Figure 5.1 provides descriptive statistics for the different questions that were asked on the questionnaire. Since all the questions asked were on a scale, the chart shows the minimum and maximum values provided by participants, as well as the mean, standard deviation, and variance.

Which method did users prefer?

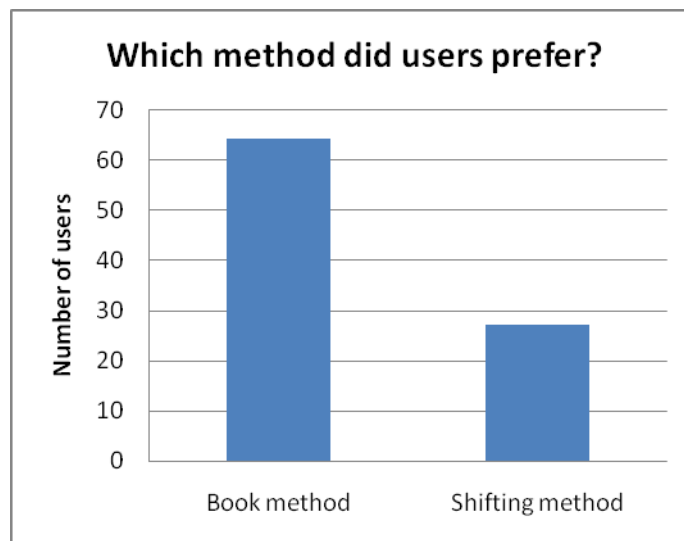


Figure 5.2 – User preference out of the two methods

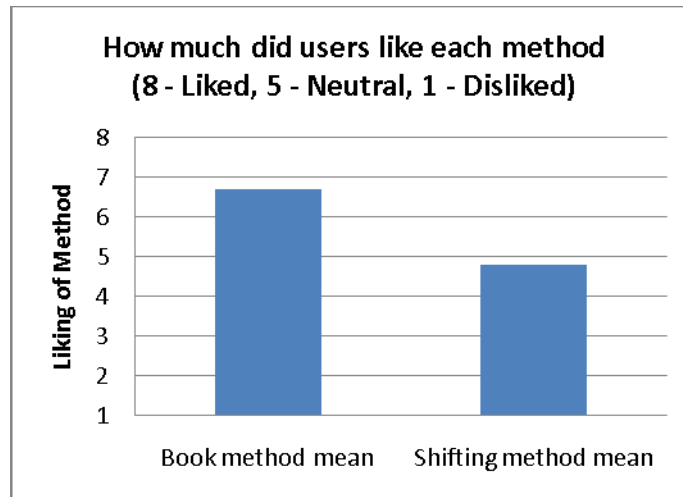


Figure 5.3 – Means of user preference for each method

In order to examine which method participant's preferred, a chi-square analysis compared those who preferred the book method and those who preferred the shifting method. As predicted, people significantly preferred the book method ($N = 64$) to the shifting method ($N = 27$), $\chi^2 (N = 91) = 15.05, p = .00$ (see Figure 5.2). Likewise, when rating the extent to which they like both methods, participants indicated that they liked the book method ($M = 6.71, SD = 1.81$) more than the shifting method ($M = 4.80, SD = 2.37$), $t (90) = -4.95, p = 0.00$ (see Figure 5.3).

Does order of presentation matter?

Contrary to the hypothesis, the order in which the participants interacted with the different methods did not influence their preferences. More specifically, of those who preferred the shifting method, 11 saw the shifting method first; whereas, 16 saw the book method first, $\chi^2 (N = 27) = 0.93, p = 0.34$.

Does amount of time spent on a computer matter?

As predicted, users who preferred the shifting method spent an average of 4.7 hours on the computer per day. However, those who preferred the shifting method ($M =$

4.74, $SD = 2.91$) did not spend more time on the computer than those who preferred the book method ($M = 5.01$, $SD = 2.88$), $t(89) = 0.40$, $p = 0.69$.

How quickly do people believe they can adjust to shifting methods?

In line with the prediction, 72.5% of users believed that they could quickly adjust to the shifting method (defined by a mark of 6 to 8 on the scale).

After reviewing the data analysis, it is clear that there is some interest in the shifting method of page turning. It may be worthwhile to include the page turning method on the final device and this is something that will need to be reviewed by future project groups working on the Digital Choral Folder.

5.2 Delay experiment

5.2.1 Hypotheses

The Delay experiment was simpler than the page turning experiment in terms of feedback from users, and as such there were fewer hypotheses. The hypotheses developed were as follows:

- Hypothesis 1: The 260 ms delay would be not very noticeable to users, but the 592 ms delay would be there point where users started to notice the delay.
- Hypothesis 2: For the 740 ms delay, 75% of users would not be bothered by the delay (4-5 range on question 2).

5.2.2 Results

Thirty-two choral singers participated in this study. Demographic data was not collected, but the participants were composed entirely of WPI students. As an incentive for participating in the experiment, users were given extra credit for their music class. Each participant was capable of reading and singing along with the choral music presented.

	N	Minimum	Maximum	Mean	Std. Deviation
Hours per day on computer	11	2	12	5.50	3.146
How noticeable the delay was	11	1	5	3.91	1.300
How the delay affected ability to keep up with music	11	4	5	4.64	.505
Difficulty of the piece of music	11	2	5	4.00	1.183

Figure 5.4 – Descriptive statistics for users who saw the 260 ms delay

	N	Minimum	Maximum	Mean	Std. Deviation
Hours per day on computer	11	2	16	6.23	3.823
How noticeable the delay was	11	1	5	2.36	1.120
How the delay affected ability to keep up with music	11	3	5	4.09	.701
Difficulty of the piece of music	11	1	5	3.91	1.136

Figure 5.5 – Descriptive statistics for users who saw the 592 ms delay

	N	Minimum	Maximum	Mean	Std. Deviation
Hours per day on computer	10	3	13	6.45	3.312
How noticeable the delay was	10	1	4	2.40	1.075
How the delay affected ability to keep up with music	10	3	5	4.40	.699
Difficulty of the piece of music	10	1	5	3.60	1.350

Figure 5.6 – Descriptive statistics for users who saw the 740 ms delay

How noticeable are the delays?

Participants in the survey found the 260 ms delay to be not very noticeable ($M = 3.91$, $SD = 1.30$). As predicted, participants found that the 592 ms delay ($M = 2.36$, $SD = 1.12$) and the 740 ms delay ($M = 3.91$, $SD = 1.30$) were both noticeable. It is interesting to note that while users did start to notice the delay starting at 592 ms, the 740 ms delay was almost equally noticeable.

Did the delay get in the way of keeping up with the piece?

For all three delays, users found that the delay did not affect their ability to keep up with the music. The 260 ms delay affect users the least ($M = 4.64$, $SD = 0.51$). Surprisingly, the 592 ms delay affected users the most ($M = 4.09$, $SD = 0.70$). As predicted, the 740 ms delay barely affected users ($M = 4.40$, $SD = 0.70$).

It is entirely possible that as long as users become familiar with the length of the page turning delay, it will not affect their ability to keep up with the music at all. However, the length of the delay did become more noticeable, and it will be useful for future project teams to try and reduce the delay just so that it does not bother singers using the DCF.

6. Software development

Three different prototypes of the Digital Choral Folder were created over the course of the project. Two were created solely for the experiments mentioned in previous chapters. The third was created with the help of Joe McCarthy on the E Ink development kit in order to show demo of the menu as well as page turning on an E Ink paper display.

6.1 The DCF experiment prototypes

The software used for the experiment prototypes was built off of a sample code project called StaticViewVB provided by the Adobe Software Development Kit. (Adobe, 3) The StaticViewVB project can open a single PDF and use a toolbar to zoom and flip pages. This project was turned into the software for the page turn experiment prototype. At the end of development, this prototype could display two pages of a music file in PDF format, and a button allowed users to turn pages forward using the book method or shifting method.

The first step to creating this project was to get two windows (pages) to appear when one PDF file is opened. By calling an open command on the same file twice, and having variables keep track of the two pages, the code can interact with the two pages separately or in tandem. When the open command is called, the code also initializes the two pages so that one displays a blank page, and the other displays the first page of the music.

Keyboard control was added to allow the person running the experiment to switch the page turning method from book to shifting, as well as reset the pages of the music.

Mouse functionality was added so whenever a user hit the left mouse button, the two pages would turn with whatever page turning method was activated.

The software for the delay experiment was a modified version of the above code. The important part was getting the device to introduce a delay and a flash that mimicked an E Ink paper display. This was accomplished through a series of timers and page draws. When the page turning button was pressed, the image on the left screen was turned completely white, and a timer was started. When the timer completed, the next page on the left screen appeared. Immediately after, the image on the right was turned completely white, and a second timer was started. When the second timer completed, the next page on the right screen appeared. The delays could be set through keyboard commands by the person running the experiment.

6.2 The E Ink demo prototype

In less than two weeks Joe McCarthy and I created a simple DCF demo using an E Ink paper display for project presentation day. While only utilizing a single E Ink paper display, this prototype was able to open a few choral scores through a menu, and advance through pages of the individual scores.

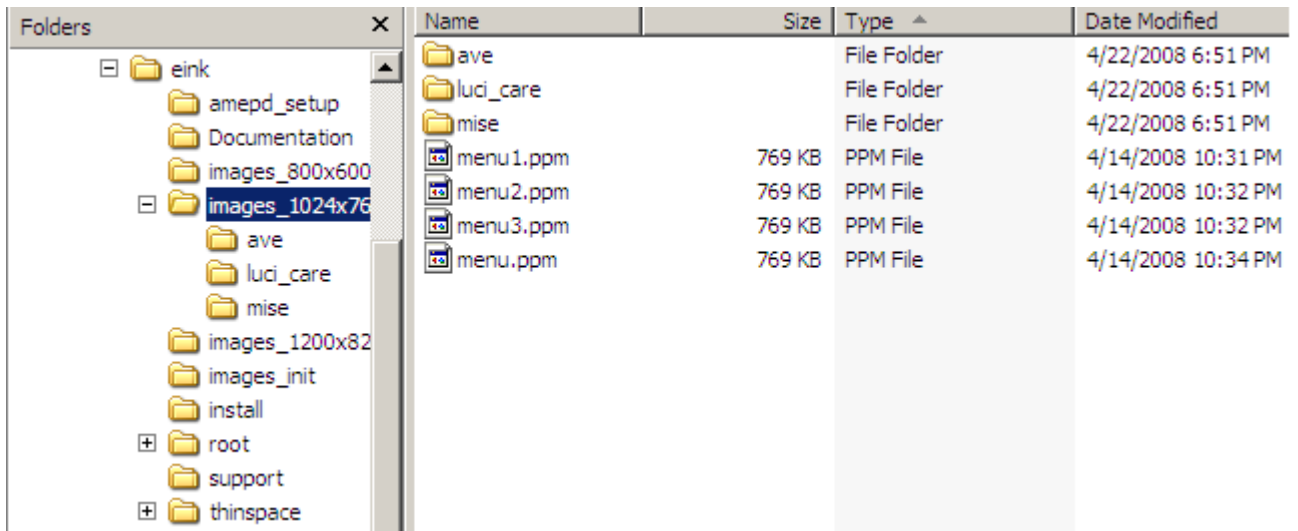


Figure 6.1 – The folder containing the menu and music files

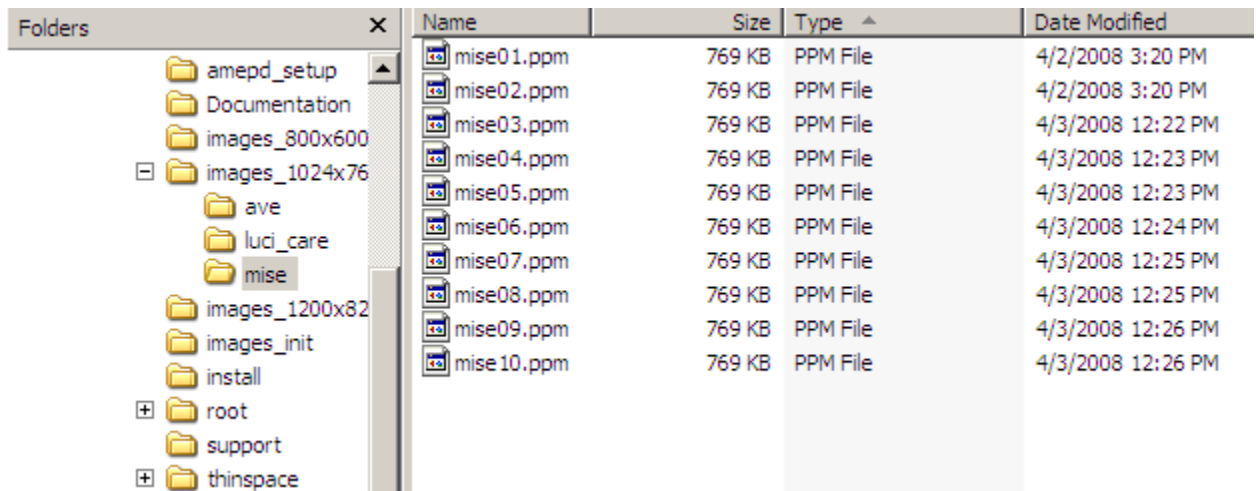


Figure 6.2 – A folder containing all the music files for a score

The DCFLoader program which organizes choral music into a file system that the DCF can read was not implemented as a part of this project. However, we did set up a file system which we felt would be close to the file system the DCFLoader would create. What we did was create one folder that stored all menu images, as seen in Figure 6.1. Inside that folder was another folder for each piece of music that we wanted displayed on the Digital Choral Folder. Inside each of those folders was the choral music, with a separate PPM file representing each page of the music. This can be seen in Figure 6.2.

Each filename was numbered at the end, with the number representing which page in the music it was.

The music files in PPM format were created by putting PDFs of music into a program called PDFtoPPM. Then, the PPMs were edited in a program called GIMP to scale them to a size the DCF prototype could accept and convert them into 8-bit grayscale.

The whole file system was copied to a Secure Digital card and placed in the DCF prototype along with two bash scripts we created to enable both menu and music navigation. A bash script is a file that executes commands in Linux, similar to a batch file in Windows.

The menu script presented a menu when the DCF was booted up or when the menu button was pressed while displaying a score. It did this by looking for the folder containing the menu images and displaying the main menu image. There was also an index that kept track of how many pieces of music were stored on the DCF. This index allowed the script to keep track of what piece in the menu was highlighted whenever the up and down buttons were pressed. When a piece of music was selected and the select button was pressed, the script passed the name of the folder containing that piece of music to the music navigation script.

The music navigation script takes in the name of the folder containing the piece of music to be displayed. It then looks in that folder, orders the files alphanumerically, determines how many pages are in the piece, and displays the first page of music. Pressing the one of the two page turning buttons allows the music to go to the next or previous page. An index keeping track of how many pages are in the piece makes it so

that the page turning buttons do not allow the DCF to look past the end or before the beginning of the piece of music.

7. Conclusions and future work

7.1 Conclusions

In this project, the groundwork was laid for future development of the Digital Choral Folder. From the designing of the product to the different prototypes and experiments, we now have a clearer idea of what the final product will be like.

Participants in the experiments have been very impressed by the Digital Choral Folder prototypes, and they really see the potential of the device. Quite a few people are simply excited about the fact that the DCF is simple to use, and it turns the pages without fail. This is something that was expected from the beginning. The DCF was envisioned to solve a lot of the problems that plague choral singers, and once the device is completed those problems will be gone.

There were a few important things that came out of the project that were not expected at all. One was how much people would actually like the shifting method of page turning. Results from the page turning experiment have made it worthwhile to investigate the issue further, with the possibility of including an option to switch between the two methods on the DCF. Another unexpected surprise was that Joe McCarthy and I were able to create a one page display DCF prototype with some menu functionality in less than two weeks at the end of the project. This was a large leap forward for the project, as we were finally able to show a working demo of the DCF with the E Ink paper display working after many months of waiting for the E Ink development kit.

7.2 Future work

The only place this project can go is *forward* as there is still much left to do before the Digital Choral Folder is finished and can be mass produced. DCFLoader, the program which will allow conductors to organize PDF files and get them into the DCF, still needs to be programmed. As of writing, we have not been able to get two E Ink displays working together from one Linux computer. Once this is accomplished, it will be another huge hurdle that has been overcome. We also need to see if it is possible to speed up the image refresh on the E Ink paper as it seems to take longer than the average update speed advertised on the E Ink website. While the user interface has been designed for the DCF, it still has not been implemented into an actual choral folder. The two experiment prototypes were incredibly bulky, and lacked most of the buttons that will be on the final device. It would be nice to actually hold a Digital Choral Folder with one hand and interact with it like that.

There are also other experiments that may be done to improve the device's design. Simple usability testing would be a great start. Different button configurations and layouts would also be great to experiment with.

I've spent a lot of time talking about this project with other musicians and friends, and there are a great many things that may be worth investigating. For example, having a speaker in the DCF which would allow you to hear the song you are currently looking at would be an interesting addition if it is possible. Also, setting up a sort of digital library where you collect a choir's DCF and they all get updated and charged would be doable. Perhaps a good idea would be having the DCFs wirelessly update with new music as they pass by the conductor's workstation, or enter a rehearsal. It is even feasible to imagine

that the Digital Choral Folder be expanded for percussionists as well as band members and orchestral players. Investigating an alternate solution to the menu/solution would also be a worthwhile venture. Joe and I spent some time discussing a system where instead of LEDs, there are buttons next to each score title that can be pressed. Also, since some people really liked the shifting method, it is definitely worth considering adding that method of page turning as an option on the final product.

8. The Project Experience.

While my project experience was a bit stressful at times, it was definitely a great experience. I really used this opportunity to strengthen my knowledge of Human-Computer Interaction and design, among other things. For two terms I investigated different technologies and spoke with Professor Delorey in order to completely visualize the Digital Choral Folder and come up with everything from the user interface to the file system. This was also the first time where I worked on a major programming assignment completely on my own, with an SDK I had never even looked at before. Early on, I wasted some time wading through the documentation for the Adobe Reader SDK, trying to figure out how it worked in my head. After realizing that it was going to take me forever to figure out by just reading the documents, I finally just started tinkering around on my own and that's when I began to understand how the SDK worked and came together. Designing, running, and doing data analysis on the two experiments was also a great experience. You never know how users are going to react to a new product until you see them experience it firsthand, and the comments they made were not only encouraging (I couldn't believe how much they liked using the bulky prototype), but sometimes they even had an influence on the design.

I had a great time learning from all the professors I met with throughout the course of this project, and I am really proud of the work that I helped start with this project. I can't wait to see singers all over the world using the device I had a part in designing.

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10. Appendix

10.1 Email exchange with sheet music publishers

Early in the project, I was interested in learning what format sheet music publishers store their format. If there was a format that most publishers used or recommended, I felt it might be worth investigating that format so that it might be integrated later into the Digital Choral Folder. The following shows my email sent to sheet music publishers as well as the three responses I received.

10.1.1 Initial email sent:

Hello!

My name is Jaime Barriga and I am a computer science student at Worcester Polytechnic Institute. I am currently working on a music-related project at my school, and was actually wondering if you could spare a moment to help. I'm trying to get an idea as to how major music publishers store music that they want to print, and what types of digital formats they use if any. For example, do you store scores as a scripting language file, midi, a Sibelius or Finale file, or do you store them graphically in a format like PDF? And do you use a different program to edit the scores? If you have a moment to spare, any help in this area would be greatly appreciated!

Thanks for your time,
-Jaime Barriga
WPI, class of 2008

10.1.2 Response from Lorenz Corporation

Dear Jaime,

In answer to your questions, we use Finale for our music files. Corrections are done in Finale. PDF are also used for certain products. The cover art is created in various graphics programs. In the prepress stage, the two files (Finale/pdf and Graphics) are combined and prepared for the

printing press.

I hope this answers your questions. If you have additional specific questions, I'm happy to forward them to the appropriate individual.

Debra Kaiser
The Lorenz Corporation
(800) 444-1144 ext 541

10.1.3 Response from Alfred Publishing

Hello Jaime,

Thank you for contacting Alfred Publishing. We store and print the majority of our performance music, but most of our books (methods, artist portfolios, etc.) are outsourced to printers. For the works that we print, we store them digitally in PDF format, though we often archive the Finale or Sibelius files (we use both, but mostly Finale these days) in case any corrections need to be made. Most of the artwork on our books is created using Adobe CS programs.

I hope this was helpful to you.

If you have any further questions or comments, you may contact me by email at customerservice@alfred.com or by calling 818-892-2452.

Sincerely,

Mindy M. Arner, Customer Relations Representative
Alfred Publishing
818.892.2452 | 818.830.6252 fax
www.alfred.com | customerservice@alfred.com
www.myspace.com/alfredpublishing

10.1.4 Response from the Hal Leonard Corporation

Dear Jaime,

Thank you for your interest in Hal Leonard and our digital delivery system. The majority of our digital archive currently is saved via Sibelius and Finale files. We are experimenting other technologies but for now, these two programs are working nicely.

We hope that this is of some assistance.

Sincerely,

10.2 Experiment questionnaires

10.2.1 Page turning experiment questionnaire

Survey questions:

How many hours per day on average do you spend using a computer?

Was the music large enough to be easily read?

- Yes
- No

If no, please write a reason why.

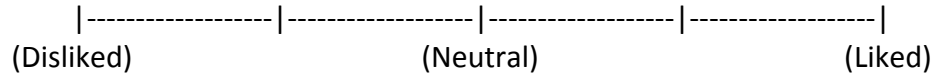
Which of the two page turning methods did you prefer?

- Book method (2 pages at a time)
- Shifting method (1 page at a time)

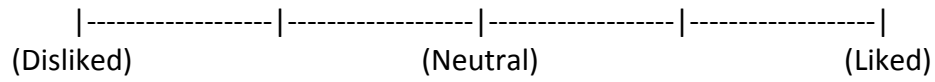
Please mark on the scale how quickly you think you could get used to the shifting method (one page at a time)?

|-----|-----|-----|-----|
(Not Very Quickly) (Very Quickly)

Please mark on the scale how much you disliked or liked the shifting method (one page at a time).



Please mark on the scale how much you disliked or liked the book method (two pages at a time).



Was the digital display acceptable?

What would you want to see in a digital version of a standard choral folder?

10.2.2 Delay experiment questionnaire

Survey Questions:

How many hours per day on average do you spend using a computer? _____

Please mark how noticeable you found the delay to be

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1	2	3	4	5
Very Noticeable				Not Very Noticeable

To what extent did the delay affect your ability to keep up with the music?

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1	2	3	4	5
Greatly				Not at all

How difficult was the piece to read?

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1	2	3	4	5
Very difficult				Very easy