Investigating Tangible and Hybrid Interactions to Augment the Reading Experience

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To Charlie, Lacey and "Mims"

"The most dangerous phrase in the language is
'we've always done it this way.'"

- Grace Hopper

Abstract

For thousands of years, we as humans have been passing knowledge and telling stories through tangibly rich methods, beginning with writing on walls and eventually evolving to printed books of today. However, the introduction of digital documents has recently created a world that has traded tangible richness for digital convenience. This thesis demonstrates innovative, tangible interfaces to help develop a possible future where digital documents can incorporate tangible elements. Furthermore, during our research, we discovered a pattern amongst people, where a hybrid approach to documents is becoming adopted. This discovery led to the investigation of hybrid experiences and the development of a system in which users can seamlessly switch between the physical and digital worlds.

Each chapter of this thesis investigates a function of reading and its method both physically and digitally. Firstly we investigate the act of turning a page, a simple yet integral task of reading a modern book. This chapter explores materials and methods of bringing a tangible page-turning experience to digital books, followed by a user study and evaluation. Following this, we explore the use of tangible materials for side of device interactions. For example, printed books have many, frequently hundreds of pages, often have their edges felt, ruffled and flicked. Several interactions can be invoked through page edges, which are entirely removed from digital books. We design, develop and evaluate a guitar string-based system as a metaphor for page edges on a digital device.

Many of us in this modern age carry on our person a smartphone, pretty much at all times. Smartphones have given us the ability to retrieve and read books wherever and whenever we please. However, the majority of people still prefer to read using physical methods. Having multiple formats to choose from has introduced a hybrid reading experience, where one might read physically at home and digitally whilst commuting, for example. We explore this experience, and the chapter follows a human-centred design approach to investigate, design, develop, and evaluate a digital bookmark system to switch between digital and physical books seamlessly.

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This thesis is dedicated to my family and friends.

Declaration of Authorship

This work has not been previously accepted in substance for any degree and is not being concurrently submitted in candidature for any degree. The work in this thesis has, however, undergone peer review and has been presented at major international venues. The publications noted below were prepared for submission during my candidature. Details of the papers and author's contributions are documented in Appendix A.

(P1) **Gavin Bailey**, *Deepak Sahoo, and Matt Jones. 2017. Paper for E-Paper: Towards Paper Like Tangible Experience using E-Paper. In Proceedings of the 2017 ACM International Conference on Interactive Surfaces and Spaces (ISS '17). Association for Computing Machinery, New York, NY, USA, 446–449. DOI:https://doi.org/10.1145/3132272.3132298*

(P2) **Gavin Bailey**. *2018. Augmenting the reading experience. In Proceedings of the 20th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct(MobileHCI '18). Association for Computing Machinery, New York, NY, USA, 425–427. DOI:https://doi.org/10.1145/3236112.3236178*

(P3) **Gavin Bailey**. *2019. Bridging the Gap Between the Digital and Print Reading Experience. International Journal of Mobile Human-Computer Interaction (IJMHCI), 11(4), 16-30. http://doi.org/10.4018/IJMHCI.2019100102*

(P4) **Gavin Bailey**, *Deepak Ranjan Sahoo, and Matt Jones. 2020. Digital Bookmark: Seamless Switching Between Printed and Electronic Books. Proceedings of the 2020 ACM Designing Interactive Systems Conference. Association for Computing Machinery, New York, NY, USA, 885–894. DOI:https://doi.org/10.1145/3357236.3395557*

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List of Abbreviations

PC	**P**ersonal **C**omputer
E-Reader	**E**lectronic **R**eader
LCD	**L**iquid **C**rystal **D**isplay
E-Ink	**E**lectronic **I**nk
E-Book	**E**lectronic **B**ook
UX	**U**ser e**X**perience
HCI	**H**uman **C**omputer **I**nteraction
TUI	**T**angible **U**ser **I**nterface
GUI	**G**raphical **U**ser **I**nterface
IR	**I**nfra**R**ed
FUI	**F**oldable **U**ser **I**nterface
NFC	**N**ear **F**eild **C**ommunication
LED	**L**ight **E**mitting **D**iode
AR	**A**ugmented **R**eality
GPS	**G**lobal **P**ositioning **S**ystem
TLX	**T**ask **L**oad inde**X**
OCR	**O**ptical **C**haracter **R**ecognition
LDR	**L**ight **D**etecting **R**esistor

Chapter 1

Introduction

For more than 5000 years, we as humans have been passing knowledge and telling stories in written literature, which has evolved from pictorial writings to the use of words as we know them today.

Up until the electronic reader (e-reader) creation in the late 1990s, all evolutions of reading mediums revolved around physical, tangible objects. However, the latest evolutionary step removes thousands of years of tangible development and replaces them with a completely original concept. As a result, all current e-readers on the market are flat screened devices that introduce a trove of digital conveniences with the sacrifice of tangible richness.

In this thesis, we investigate modern reading and envision a future where the best of both worlds can be achieved, harnessing the digital conveniences of e-readers and augmenting them with the tangible richness of physical reading mediums.

1.1 Conventional E-Book Reading

The modern book is an evolutionary step of the ancient Codex, which dates as far back as the 1^{st} century. This ancient art form has survived the test of time and still stands to this day as one of the more popular methods to consume media. However, the introduction of the personal computer (PC) and e-reader has brought the evolutionary path of the printed book to a shuddering halt, with all evolutionary development aimed at its digital counterpart. In the not so distant past, academics predicted that digital would become the dominant form to consume published works. However, as explored by Sellen and Harper [124] print is far from dead. In-fact recent figures have shown the printed book market is growing, while that of its digital counterpart is shrinking[1, 2].

In the late 1990s and early 2000s, e-readers became commercially available with the Rocket e-book and Softbook. The devices enabled the portable reading of electronic books (e-books), offering convenience with the ability to carry thousands of books at a time. Early e-reading devices utilised Liquid-Crystal Displays (LCD) to show content. Unfortunately, LCDs require a backlight, which is hard on the eyes and uses large amounts of power. As a result, these devices struggled to gain popularity among users. However, E-reading devices quickly became popular with the release of the Amazon Kindle and its low book prices, resulting in a sharp increase in e-book sales. Modern e-readers generally use an electronic ink (e-Ink) display which only draws power to change what is displayed and is illuminated by ambient light instead of a backlight. These features allow the devices to use very little power, allowing claims of the batteries lasting "weeks" on a full charge.

Current e-readers on the market offer the same physical experience to the reader, a flat digital representation of media. Yes, the form factor, screen type and interactions differ slightly between devices, but ultimately they are are all flat screened devices that require a button press or a swipe of the screen to navigate its pages. Printed books, however, offer a vast array of different experiences to offer the reader. With heft, cover type (hard/paper backed), paper quality/texture, smell and age, printed books incite different experiences over different readers and even different versions of the same book. These physical features tantalise several senses when one picks up a printed book. The smooth glossy cover and the thick premium quality pages excite the sense of touch, while the fresh perfume of a newly printed book or the dusty aroma of a book that has aged excites the sense of smell, this provocation of the senses builds towards the rich user experience of a printed book. Due to their flat screened nature, digital formats, unfortunately, lack these experiences.

E-readers can offer several functions and conveniences that the printed book cannot, including instant access to a library of millions of books at the touch of a screen wherever and whenever they want via e-readers and internet access, searching contents and features like Amazons X-Ray[3] which allow readers to explore the

[1] Simon Jenkins. *Ebook sales continue to fall as younger generations drive appetite for print*. 2017. URL: https://www.theguardian.com/books/2017/mar/14/ebook-sales-continue-to-fall-nielsen-survey-uk-book-sales.

[2] Adam Rowe. *Traditional Publishing Ebook Sales Dropped 10% In 2017*. 2017. URL: https://www.forbes.com/sites/adamrowe1/2018/04/29/traditional-publishing-ebook-sales-dropped-10-in-2017/#65fcf7b7943e.

[3] Amazon. *Kindle Features: Search, X-Ray, Wikipedia and Dictionary Lookup, Instant Translations*. 2020. URL: https://www.amazon.com/b?ie=UTF8&node=17717476011.

book further. Who knows, printed books may have such features one day if the development of an interactive dynamic paper was to occur. For example, the Harry Potter movies[4] demonstrate such paper via newspapers and paintings. However, unfortunately, such paper-thin displays are many decades or longer away from development.

1.2 Going Beyond the Flat Screen

As we go about our everyday lives, we are surrounded by vast amounts of flexible materials and surfaces offering an array of different textures for us to experience. Recently combining flexible materials and smart devices has become a popular research area [116, 148, 99, 127, 145], with a particular interest in how they can be used as input devices to add functionality and heighten the user experience (UX). However, adding sensors to flexible materials usually compromises their physical properties and presents the challenge of developing interaction detection techniques that will leave their physical properties intact.

Throughout this thesis, we investigate reading, so the flexible material of particular interest to us is paper. Paper has been made in some forms for thousands of years, and we believe it will not become obsolete in the medium to long term. Furthermore, many features found in software applications today have derived from our experiences with paper, such as highlighting or marking up documents and adding bookmarks. Pearson et al. discuss and provide guidelines for these features and more in Human-Computer Interaction (HCI) Design Principles for eReaders [103].

Recently, electronic media has become one preferred mode of communication. E-readers are commonly used to access information anywhere, anytime. For example, one can read an e-book on the go using an e-book reader, smartphone or tablet. Initial e-readers such as Rocket e-book and Softbook used LCD screens and were not popular. On the other hand, Kindle was almost instantly popular, and it uses an e-paper display that looks like usual paper and ink. However, these displays fail to offer the rich tactile experience received from a piece of paper.

Reading is a complex activity, where it is not a simple case of picking up a book or e-reader. For example, a study performed in 2014 by Mangen et al. [96] looked at the effects of the reading medium on the readers' narrative comprehension. The results suggested that participants were less likely to report narrative coherence

[4] IMDB. *The Harry Potter Saga: 2001 - 2011*. 2011. URL: https://www.imdb.com/list/ls000630791/.

when reading on a digital device (an iPad in this case). Most recent studies, e.g. [136, 31, 34], also show that *"that reading comprehension on paper is better than on-screen among (young) adults"* and Lauterman et al. [84] suggests that screen-based learners perform worse than those using paper. We also identified a single study that suggests that screen-based learners perform better [101].

The lack of tactile feedback from a touch screen has been referred to as "Pictures Under Glass" [141], where no matter the task, the tactile experience remains the same. Bringing the affordances and advantages of paper to the digital world has been a research area for many years [133, 50, 95, 43, 91, 42], with many identifying the importance of physical interactions and affordances for the flat digital world.

1.3 Intergrating Physical and Digital

Printed books have survived the test of time and still stand as the most common format to read books. However, since the introduction of e-readers, many people have opted to use its digital counterpart, e-books.

Despite their conveniences, it does not mean that the average person has an overwhelming preference for digital reading; in fact, data suggests otherwise. Surveys [22, 138, 76, 158], including our own (discussed in section 5.2), show that the majority of people tend to prefer to read printed books over e-books. However, despite this preference, many people enjoy the conveniences that e-readers offer, such as searching within the text. These factors have led to an influx of people using multiple formats, including printed, electronic, and audio, to consume media. Many often own the same book in more than one format. In addition, many people indicate a degree of flexibility between the two formats [89]. Zhang et al. [163] explain that the format used can often depend on a person's current situation. For example, one might read a printed book in the comfort of their home but may read using an e-reader while travelling for convenience. Companies such as Amazon and Kobo have identified this trend and offer significant discounts for digital books to those who own the print version [6, 80]. This trend creates the problem of keeping the printed and digital formats in sync.

Bookmarking is a method of keeping the reading position of a book dating back to the 6th century [83]. Some of the oldest evidence shows a leather strip attached to the spine of a book, and the reader would then insert this strip between desired pages to mark the position. We still frequently see this form of bookmarking today, usually using ribbon rather than leather and almost exclusively on hardcover books. We even see references to this form of bookmarking on e-readers, with the icon for bookmarks often being a ribbon. However, many bookmarking methods exist for books that do not have a ribbon built-in, including inserting a thin item between pages or creating a "dog-ear" (folded down corner) on the page.

Setting a bookmark in an e-book is a more straightforward affair, with the reader clicking a button or performing a gesture. However, the purpose of a bookmark in an e-book is somewhat different. A bookmark in a printed book is most often used to mark the current reading position. Less frequent use of bookmarks can be the reader using multiple bookmarks to keep a section that they found exciting, enjoyable, or even an area they wished to recall later. E-readers save the current reading position by default, thus eliminating the need for a reader to set a bookmark entirely. So, bookmarks of e-books only tend to be used for sections that the reader finds exciting, enjoyable, or wishes to recall later.

Most modern e-readers allow the synchronisation of progress and data between devices, allowing users to read on one device and then continue on another. An example of this might be a reader using a kindle at home and then continuing their book on their mobile phone on a lunch break. In addition, some e-readers allow the synchronisation of progress across digital formats, where a reader can begin reading an e-book using a kindle and then continue via an audiobook. The most famous use of this feature is by Amazon WhisperSync [3]. WhisperSync, however, requires an Amazon based device and exclusive use of the Amazon store. Aeneas [115], from ReadBeyond, is a software library that allows forced alignment between e-books and audiobooks, a less popular option but more accessible due to public licensing and no hardware or store restrictions.

1.4 A Vision for Future Reading Devices

The research of this thesis begins with a focus on bringing back the tangible richness of books. When we say "bringing back", we really mean to transfer the tangible elements of physical books to another medium, in this case, e-readers. Unfortunately, as we state above, all modern e-reading devices offer a flat slate-like interface. In the context of being tactile, this kind of interface is boring and plain.

The emergence of tangible user interfaces (TUI) [63] has brought forth a wave of tangible interfaces and created a whole area of research. We look to TUIs for our vision of modern and future e-reading devices. Through a TUI, we envision true book-like interfaces for digital reading devices. Within this thesis, we explore several methods of bringing this future to light, where we present many working prototypes that demonstrate tangible book like interactions with digital books is possible.

As we worked towards this vision, we discovered a path in our journey. A path that took us in another direction. To not add physical elements to digital books, instead, unite the experiences and create a system that allows hybrid user experiences among reading formats. What led to this path? First, we noticed that many modern readers identify as multi-format readers, using several reading formats whilst reading books.

As no automated method of switching from physical to digital formats exists, we conceptualised the idea of a digital bookmark. A device that looks and feels the way one would expect a bookmark to feel, small, light and rectangular. A device that, when placed into a physical book, would keep the readers' place. However, this bookmark would differ by having a magical way of knowing where it is placed and informing the readers' digital devices.

1.5 Research Questions

We begin this thesis by exploring TUIs and how they could improve the user experience for digital reading devices, with the following research questions:

Question 1: What are current reading habits and preferences in the range of readers we examined?

Question 2: What ways can materials be developed or augmented to create authentic book-like user interfaces?

Question 3: What interaction techniques can be used to create tangible user interfaces for digital reading devices?

Question 4: What interaction device/techniques can enable a hybrid physical-digital experience?

1.6 Research Contribution

We have explored several subject areas and developed systems that contribute the following insights:

1. An extensive exploration study into current reading habits. Through several online and lab-based research techniques, we present the results of our findings into the habits and preferences of today's readers.

2. Two novel input methods that allow the interaction between physical materials with digital devices. One of our input methods transforms traditional paper into an input device where bend gestures can be detected. The other takes an unusual approach, using materials not traditionally used as an input medium for digital devices, guitar strings and frets.

3. A prototype that creates seamless linking of digital and physical formats so that multi-format readers can switch reading mediums effectively.

4. An evaluation for each of the prototype devices we developed. The usability of each device is measured within the context of digital reading.

1.7 Methodologies

The work within the experimental chapters of this thesis can be split into two parts. Where:

Part 1: Uses a Material-Centred Design [35, 147] approach to bring the material used in digital reading prototypes to the forefront. Part 1 consists of Chapters 3 and 4.

Part 2: Uses a User-Centred Design approach to bring the user to the forefront of prototype and interaction design. Part 2 consists of Chapter 5.

Chapters 3 and 4 follow a material-centered design approach. Material-centred design is an approach taken when the material used within a device or product is placed at the forefront of development. In Chapter 3 we seek to mimic the texture and page-turning interactions of a physical book. So, what better material to have than paper? The material-centred design approach considers a material as a requirement (paper in our case for Chapter 3). Following the specification of this material, an iterative design process begins where each iteration is evaluated against the requirement. For this process to end the material must meet the requirements.

The user experience design of an activity such as reading is vital. A negative user experience could perhaps have negative implications on the media being consumed. The same consideration should be made for the material used for such activities. Throughout Chapters 3 and 4 we use the material-centred design approach to further align the experience with the act of reading. This alignment allows us to answer research question 3.

The material-centred design process during the chapters considering physical form has the added complication of each material needing to be able to be digitised. The material design process employed during Chapters 3 and 4 allow us to answer research question 2.

Chapter 5 differs from Chapters 3 and 4 by following a user-centred design approach. A user-centred approach allowed us to use multiple methods in a structured way, which put the user at the forefront of our user experience design. We used surveys to measure the scope of the problem, lab studies to measure its difficulty, iterative design to create a solution to solve the problem, followed by another lab study to measure the effectiveness of the solution. User-centred design allows us to answer research question 4 in Chapter 5.

During each lab study (Chapters 3, 4 and 5), we make use of surveys, questionnaires and semi-structured interviews to obtain quantitative and qualitative data regarding user choice and preference of reading mediums. In Chapter 5 we deploy a large-scale online scoping survey to gather this data, alongside questions to measure the scope of multi-format reading. The use of surveys, questionnaires and semi-structured interviews allows us to answer research question 1.

1.8 Chapter Overviews

Each experimental chapter outlines an experience missing from modern reading and contributes a new solution via a prototype and evaluation. Finally, each study is presented with its contribution to the research.

In Chapter 2 we outline the related work within the areas of digital reading, TUIs, augmented paper and digital bookmarking. Our literature review begins by looking at the features digital books have absorbed from printed books. This initial research then allows us to document relevant work in the TUI space within the context of bringing tangible features to digital books. We also review works in the area of cross-format interactions, where content is cloned or synchronised across digital and physical formats. The documented related work identifies a gap in the research for both TUIs for digital reading and hybrid reading experiences.

In Chapter 3 we explore methods of augmenting paper with sensors without harming its physical properties. This chapter also looks to mimic the physical page-turning experience whilst reading digital books on mobile devices. We do this via a low-cost augmented paper input device that can detect user input through bending. In a user study, we measure the usability of such a device and compare the experience to that of physical books. We learn that users enjoy using a paper interface device for e-book input and that the user experience of digital reading could be enhanced through such a device. However, despite receiving positive feedback, the device was somewhat impractical. Therefore, we go on to explore more compact book-like interactions.

Chapter 4 continues the research of TUIs for mobile digital reading. However, this time, we seek more compact methods. We identified that the edges of paper pager are a vital point of interaction for printed books, so this chapter looks to mimic page edge interactions using the side of mobile devices. We report on a series of prototype input devices, investigating several materials and techniques we envisioned could act as an edge of page input device. We achieve the input required via a fretboard interface, like that found on a guitar. In a user study, we ask participants to create gestures for a set list of four actions, where we find that the fretboard input device can achieve a reasonable level of accuracy. We find a pattern in reader behaviour through the discussions and interviews held during our TUI studies, where multiple formats are used. Therefore, we begin research within the area of hybrid user experiences.

We begin Chapter 5 with a survey, which investigates the reach and scope of multi-format reading, the act of reading a book in one format and then continuing later on another. The survey reveals that a significant number of people take part in multi-format reading, so next, the difficulty of the problem is investigated. Next, a lab-based user study is performed, with participants switching reading formats whilst seeking a particular event. The results of the lab-based format switching study show that the task of multi-format reading is both time consuming and mentally demanding. Following this, we present the design and technical information of a digital bookmark, where we first investigate several methods of detecting placement within a book. Finally, a user study is carried out where participants take part in a similar task to the format switching study, but this time, using the digital bookmark. We present the results of this study, finding that a digital bookmark can drastically reduce metal load and time taken to switch formats.

We complete this thesis in Chapter 6, where we summarise each chapter, outline key findings and discuss any limitations discovered.

1.9 The author's contribution

The vast majority of this research was undertaken solely by the thesis author, with the aid of a supervisory team. The author took on the roles of both an HCI researcher and a UX engineer. The role of the HCI researcher had the author investigate current HCI methods and interaction designs. The role of the UX engineer involved designing the overall user experience and developing hardware prototypes to meet these needs. The author held discussions regarding the concept and implementation of each system with colleagues and supervisors. All development of each system presented is the authors alone. The author designed each of the studies within the thesis and then discussed them with supervisors and colleagues; the author solely performed all studies and analyses of results.

Several pieces of work in this thesis have been published at conferences, a journal and a doctoral consortium.

Chapter 2

Related Work

This chapter outlines and discusses the related research within the scope of the work presented within this thesis. This thesis aims to augment the reading experience by following two distinct paths: to bring tangible interactions to digital books and create hybrid user experiences.

Since their inception, e-readers have attempted to replicate and mimic the features readers have come to expect from a printed book. However, some features have been more successful than others [106, 103].

In each of the following sections, we present key literature and then explain its relevance and how it inspires our work of physical and digital interactions (Chapters 3 and 4), and hybrid experiences (Chapter 5).

2.1 Digital Simulation of Physical Features of Books

Early e-reading based research concentrated on giving books realistic visual appearances whilst on a display. A range of projects [28, 29, 92] developed a graphical user interface (GUI) that show a realistic view of a physical book whilst in its digital form.

Projects concentrated on giving digital books the appearance of their physical counterparts by cloning the physical books' shape, size, covers, and pages onto the digital plane. Each project also modelled the action of turning a page, animating individual pages to bend and curve as the reader flicks through the book. In addition, The "Realistic Books" project surpasses the others by adding ageing effects to the books. Each time a book is read, it ages, and its appearance is altered, adding fingermarks and discolouration to replicate the appearance of a used physical book.

Whilst the above looked to simulate the look and feel of a physical book. Others attempted to replicate other features of paper. For example, Pearson et al. [104]

explored the area of note-taking using post-it notes. They designed, built and evaluated a drag and drop based interface for digital note-taking.

The literature presented in this section and the magnitude of existing e-readers and reading applications shows that extensive research and development have been performed to digitally replicate the reading experience. The work within this thesis does not investigate new methods of digitally displaying physical content. However, the literature in this section and existing devices inspire design and development in later chapters, such as the user interface presented in Chapter 3.

2.2 Tangible User Interfaces

One cannot begin to speak of TUIs without first mentioning the work of Hiroshi Ishii, the founder of the term TUI, with the Tangible Bits paper [63]. A Tangible Bit is a physical object or environment that a user can manipulate to interact with digital information. The introduction of the term TUI introduced a wave of research exploring physical controls for digital systems, including a follow up Tangible Bits paper [62].

A vast array of work explores the area of TUIs to create more exciting and tangibly rich interactions with flat screened interfaces. Possibly the most famous of these works is inForm [37]. A system that introduces the *"design space of Dynamic Physical Affordances and Constraints "*. inForm used 900 actuated pins to create a three-dimensional *"shape display"* that allows user interaction and provides various forms of feedback. Other examples of actuated tangible devices include [53, 111, 119, 52], where they all explore methods of creating tangible input controls for flat screened devices.

There are currently billions of smartphones in use today, most of those being touch-screen based. Unfortunately, GUI elements such as buttons, dials and sliders fail to provide any form of affordance that match their real-world counterparts. Robinson et al. present Emergeables [119] a concept device that brings physical dials and sliders to touchscreen devices. A similar concept is shown by Jansen et al. [64] and Yu et al. [159]. However, the concepts differ. Emergeables envision a future where *"tangible continuous controls emerge from the surface of the mobile device "* rather than them being an add-on device.

Using add-on devices to bring tangible controls to mobile devices has become a popular method of proving that a concept can work. Using the real estate on the side of mobile devices and bezel allows the addition of tangible controls whilst not causing any obstruction to the display. ShiftIO [134] show dynamic controls to make use of the side of mobile devices, giving use cases that include physical camera button and game controllers. A typical driver for side of device interaction is one-handed operation [51, 128, 59]. These devices look to use the pressure generated by squeezing a device to invoke interactivity.

Some side of device interaction devices also provide haptic feedback to the user. MimicTile [98] and SqueezeBlock [51] can vary the stiffness of interaction depending on scenario, such as pointing out a notification. Another approach is TeslaTouch [16], a system that is not a TUI. However, it uses electrovibration to create a tactile feedback system that gives a tangible impression. Where the electrovibration tricks the fingertips into thinking a physical object or texture exists within a flat glass screen.

This prior work was the starting point for the work within this thesis. We drew on the examples mentioned to add tangible controls to digital books in Chapters 3 and 4.

2.3 Tangible controls for Digital Books

Ever since the introduction of the e-reader, research has existed which looks to create an authentic book-like user experience for the digital reader. Early research looked at mimicking the form factor of a book [21, 57, 70, 11]. In addition, this early work looked at how users would interact with digital pages and projected content onto them.

In Contrast, Flippin [156] uses electronic circuitry embedded in the paper to allow physical interactions on printed books to interact with the digital world. As a result, users could interact with the printed book via touching at specified locations. For example, users could answer a quiz question by touching the paper, and a digital screen would then indicate if they were correct or not. In addition, Flippin was used as an input device for a large screen at a public exhibition.

It is often the case that electronic paper devices that take on the form factor of a book embed sensors to detect input from users. Tiny Dreamy Stories [154] uses a series of RFID tags to detect and identify when users *"shuffle"* paper page to create storylines. Apart from the texture and feeling of handling a book form factor, many devices lack the affordances of paper pages, and often the edges of pages are overlooked. Paranga [71] brings the tactile feedback and affordances of flicking through a printed book to digital devices. The device uses a display to show content to the reader whilst having a page-like interface for interaction.

Embedded onto the page is a *"page-flipping mechanism"*, which provides the tactile feedback of flicking through a book using the edges of pages.

2.3.1 Dual Screen Devices

The average book has more than one page visible at a time, mobile devices can do this in the landscape orientation, but this in no way resembles an actual book as the display is flat. FlexCase [116] is a flip cover for a mobile device. The project introduces the idea of adding a second screen to a device using an e-ink display. The e-ink display allows extra content to be displayed without using a great deal of power. FlexCase incorporates sensors to identify multiple forms of interaction, such as the touching and bending of the display. Others have explored how users would interact with dual-screened devices [47, 24]

In contrast to the above works, Choi et al. presented Peek-a-View [26], an interactive smart cover for a smartphone. The device shows and hides information by turning the cover like a page.

There is a body of work that explores digital displays as paper documents [81, 139, 45]. The work looks to allow the physical handling of digital documents as if they are paper documents. DisplayStacks [45] allows digital documents to be stacked and placed around one another as if they were pieces of paper.

2.3.2 Flexible Augments for Mobile Devices

As technology develops, devices are becoming smaller, thinner and lighter, which is also true for many forms of display. In addition, these developments have allowed several display types, such as e-ink displays, to become flexible, which has opened up a research area exploring how to best use this flexibility to enhance UX.

Both Tajika et al. [137] and Lee et al. [87] performed studies looking at how users will use bend gestures to interact with flexible displays. However, Tajika et al. performed the study using an LCD screen and a plastic sheet. In contrast, Lee et al. used several materials to study the "understanding deformation-based user gestures" of deformable displays.

A popular approach to this research is integrating bend sensors into a material or device to add functionality. For example, reFlex [135] and Lahey et al. [82] used bend sensors and flexible displays to create devices that allow the user to use bends as input. Like Lahey et al., Warren et al. [142] performed an extensive study of bend gestures for flexible displays. This extensive study resulted in their proposal of a bend classification scheme and design recommendations for bend gestures.

Bookisheet [143] is a prototype that uses thin plastic sheets and bend sensors to replicate the action of turning a page digitally. The device uses off the shelf bend sensors, light-dependent resistors and switches to detect input from the user. However, this device has no display as it relies on an external display. It also appears that due to the positioning of the bend sensors, the range of bends users can perform are pretty limited. As the device is made from plastic sheets, it does not explore the tactile experience of printed books.

Several pieces of work look to implement a flexible input display within a mobile device [122, 73, 72, 82]. In contrast, others look to implement bend gestures in other ways, such as adding flexible input devices to the side of a device [52, 56, 148]. BendFlip [148] is particularly interesting despite its somewhat poor results, as it looks to use several sensors to improve digital book navigation

2.3.3 Relevance and Use of Tangible Book Controls in our Work

In Chapter 3 we experiment with material. In our work, we extend the reading interactions of paper pages and replicate the form factors of physical books. We used the knowledge within the examples mentioned to decide what bend gestures to incorporate into our prototype.

2.4 Augmenting Static Content

A large body of work looks to use paper as an input device or as an ultra-thin display. Throughout our work, we often imagine paper as a display of content. We are presented with masses of static content throughout our daily lives, such as pages of books and advertisements we may see at the bus stop. Research has explored using digital devices to make this content more dynamic through several methods.

2.4.1 Augmenting Static Content via Projection

Early work investigates the use of projecting content onto materials, with many seeking to project onto paper as a metaphor for ultra-thin displays.

Due to its thinness, a popular approach with paper is to use Infrared (IR) light reflectors and projection mapping. Projection mapping allows the paper to keep its properties intact whilst exploring research areas. Gallant et al. [42] present a foldable user interface (FUI) input device derived from the folding of paper. The FUI has multiple IR reflective spots tracked by an IR camera, identifying many interactions, including top corner bends, folding and squeezing. Functions listed by Gallant et al. for the interactions include navigation, zooming and selection.

Holman et al. [58] present PaperWindows, another approach to the use and tracking of IR reflective pads. The IR pads locate the position of the pieces of paper so that a projector can display onto the paper. This technique allows paper to be used similarly as an additional monitor on a desktop computer. In addition, interaction techniques have been developed to use IR reflective tabs on the users' fingers, tracking hand movements such as tapping gestures.

A further system is PaperLens [129]. It also allows information and imagery to be projected onto paper using markers that can be tracked. PaperLens also implements a layering system, where users can move the paper into a different "layer" to be shown different content.

The projected interfaces above only allow for a fixed shape piece of paper due to how the projection area is tracked. Lee et al. [86] and Steimle et al. [133] present alternative methods of tracking materials for content projection, using infrared tracking and a Kinect device. This alternative tracking method allows dynamic paper shapes and interactions to be detected. For example, Steimle et al. present Flexpad, and due to the Kinect being used, the system can project onto paper that has deformations in real-time.

Every page of a book, often in the hundreds, contains static content. As a result, several projects have looked to augment printed books via projection. For example, Wu et al. [152] introduces the concept of windows and icons for printed books, where users can point to interact and retrieve different media. Dachselt et al. [33] also use projection onto a printed book. However, they use the system for annotation and note-taking.

Others have used projection to demonstrate entire concepts. For example, Paddle [114] is a highly configurable mobile device that is demonstrated entirely via projection. The device is used as a metaphor for a flexible smart device, which can *"leaf through an e-book more naturally"*.

2.4.2 Augmenting Static Content on Mobile Devices

More recently, research has investigated the use of smart devices over projection. Smart devices can detect content and determine what content to display without outside help. For example, the Next Generation Paper project [130, 13, 32, 41, 40] makes use of smart devices to augment the content supplied to the reader of paper and books. The project uses a mixture of image recognition algorithms and electronically augmented paper to detect page location and content detection. In addition, the content includes videos and audio files to provide further context to the reader.

Other systems use similar techniques, including near field communication (NFC), magnets and image recognition [17, 77, 25, 88, 153].

2.4.3 Relevance and Use of Augmenting Static Content in our Work

In the chapters considering physical form we take a similar approach to several pieces of prior work. Where Chapter 3 implements a paper input device and Chapter 4 uses the metaphor of paper. Within our work, we choose not to use projection, we prefer to use a mobile solution where a smartphone is used rather than an external projection device.

2.5 Electronic Paper

With the advancement of printed electronics, researchers have begun to use inkjet printers to create electronic circuits on flexible substrates such as paper [69, 140, 151].

A recent popular approach to electronic paper is the use of electroluminescent inks. Electroluminescent displays emit light when powered and printed within an addressable matrix, displaying shapes and patterns. Unfortunately, the pixel density of the matrix is unable to compare to that of an LCD or e-ink display, meaning text or images are not as sharp as users have come to expect. Nevertheless, several researchers [100, 74, 75, 160] use this method of using these inks to create electroluminescent displays on paper. This approach allows printed elements to be turned on or off by passing electronic current. The circuits can also detect touches from a user.

Due to the possible intricacies of modern printed circuits, it is possible to create thin-film shape-changing interfaces, such as reMi [27] and uniMorph [54]. Both systems use electronic circuitry and polyethylene to self actuate.

Printed electronics have a high entry cost due to the amount and expense of the equipment needed. For those unable to meet the entry requirements, handmade methods exist. One such method is the use of CircuitScribe Ink [30], a low-cost conductive ink ballpoint pen. PaperID [90] uses a conductive ink-based pen to create paper-based RFID tags. Qi et al. [113] use an alternative method for low-cost circuitry, copper tape. They demonstrate how copper tape can create flexible circuits on thin materials such as paper.

2.5.1 Input Detecting Inks

Several of the previously mentioned works in the area of paper electronics can detect a touch in a basic binary approach on flat surfaces. However, some work [150, 162] looks to break this barrier by allowing ink-based electronics to detect input on non-flat objects. Electrick [162] achieves this most convincingly. Where carbon is applied to objects, electrode pairs then read the electrical voltage to determine touch location. Several objects are demonstrated within the paper, including a drumset and a 3D printed dog. This technique was later applied to paper to detect input in pulp nonfiction [161], where in addition to touch, it can detect writing implements.

Even though the above systems can work on non-flat objects, the shape becomes fixed once the carbon is applied. On the other hand, printed electronics on thin-film materials allow for dynamic shapes and input detection. For example, PyzoFlex [118] allows printed electronics to take multiple shapes and be wrapped around objects, whilst analogue input via piezoelectric (pressure) sensing. Unfortunately, PyzoFlex does not have the ability to detect its shape. However, FlexSense [117] does. Using the same piezoelectric sensing technique, the thin-film FlexSense sheet can detect changes in its shape.

2.5.2 Material Synthesis

Numerous pieces of research look at incorporating technology into everyday objects to increase interactivity whilst also making technology less visible. This research has often led to finding new methods to make existing materials.

Nicholas A. Knouf [78] embedded light-emitting diodes (LEDs) into paper using Joomchi, a Korean method of making paper. They made two sheets of paper using the Joomchi method and placed a circuit of LEDs between them to create one paper sheet with embedded circuitry.

Textiles are one of the most prevalent materials within an average scene of everyday life. Textiles are found everywhere, from the chairs we sit on to the floor we walk on. The majority of people even cover most of their bodies with them. The Jacquard weaving technique has been employed on several occasions to incorporate technology into textiles.

Berzowska et al. used Jacquard weaving to create Karma Chameleon [18], a textile that is woven with protonic bandgap fibres to create a *"dynamic textile surface"*. This textile interface is dynamic where the colour and pattern can change depending on the ambient light level and light emitted by the fibres.

Poupyrev et al. at Google developed Project Jacquard [112], a method of creating interactive textiles. They developed a conductive yarn they call *"Jacquard Yarn"*, which can be weaved along with traditional textile materials to create interactive textile patches. These patches can then be incorporated into more significant textiles to add an invisible touch input device.

The above textile projects and along with [44] use traditional weaving techniques. Peng et al. [107] take an entirely modern approach. Where a method "3D printing" soft interactive objects is shown. In reality, layers of fabrics are laser cut and bonded together to create a 3D object.

2.5.3 Material Simulation

Rather than creating or manufacturing material, others have developed methods of simulating materials. Haptics allows the sensation of textures to be simulated. Disney Research created Revel [15], which provides tactile feedback for augmented reality (AR). Using an electronic field around a user's finger, they found that the textures of many objects can be simulated and perceived by the user. Using AR, they demonstrated this to show textures on a physical object that users can perceive using their fingers.

Strohmeier et al. introduce ReFlex [135], a bendable smartphone that provides active haptic feedback. They use the haptic feedback to simulate the "elastic and material sensations that occur while navigating a paper book". Through their experiments and feedback from the participants, Strohmeier et al. concluded that by using haptic feedback to simulate the material, they could enhance document browsing tasks.

2.5.4 Relevance and Use of Electronic Paper in our Work

In Chapter 3 we explore methods of creating digital materials, where sensors are placed upon substrates, such as paper to allow it to be used as an input device.

Printed electronics allow a vast array of shapes and sizes to be printed on many types of materials. We investigate this technique in Chapters 3 and 5. Ultimately, we choose not to use printing. However, the prior literature helps to frame and design the flexible electronics we use within our work.

2.6 Multi-Modal Experiences

Many empirical methods involve bringing physical traits onto digital devices or bringing digital traits onto the physical. However, this is not always the case. Some approaches look to create a hybrid experience allowing users to benefit from the advantages of both mediums.

Bridging Books synchronises printed books with a digital device in order to extend the content and pictures shown on each page [23, 110]. It uses the magnetometer in smart devices, e.g. an iPad. Hidden magnets inside the printed book change the magnetic field around the device, allowing it to detect the current page seen by the user. The extended content of the printed book is then shown on the iPad. In addition, readers can interact with the extended digital content via touch, bringing interactivity to printed books.

With smart devices becoming objects of everyday life, the opportunity to introduce more modalities to everyday content arises. For example, PaperChains [105] allows a user to add additional content to physical items via annotation and sound recordings. The authors present an example of adding content to a birthday card. Another example of adding sound to sentimental items is AudioPhotography, by Frohlich et al. [39], where they find that adding ambient sounds to photographs enhances the recall experience for the viewer. Adding audio information to other forms of static media has been explored [36, 41], such as news articles.

Other research looks to add multiple forms of modality to enhance the storytelling experience. For example, visual, haptic and auditory modalities are used [49, 121] to create more atmosphere during short stories.

The work presented within this thesis follows a multi-modal approach. Where we attempt to merge physical and digital mediums in Chapters 3 and 4. Where Chapter 3 has two modes using a paper input device and a smartphone, and Chapter 4 has two modes using a fretboard input device and a smartphone.

Chapter 5 explores multi-modal experiences, where users interact with the physical pages of printed books, and the e-reader display of e-books. They also interact physically with the digital bookmark device.

2.7 Linking Physical to Digital Documents

The subject of linking digital and physical formats has been discussed on many occasions. The area has been a research subject since the early to mid-90s. Initial research in linking printed and digital documents was using a hyperlink. Paperlink presented "VideoPen", a device to hyperlink printed documents to digital documents [10]. It was a modified highlighter pen with a camera to recognise the printed text optically. The device allowed any mark made on the print to link to a related location in its digital counterpart.

Memento explored the creation and linking of digital and physical scrapbooks [146]. It identified the advantages of reading from a printed book, such as tactile feedback. The disadvantages of printed books over their digital counterparts, such as not being able to search the contents, were also highlighted. It used the Anoto digital pen [8], an improved version of the VideoPen demonstrated by PaperLink, along with a website to create a digital representation of a physical scrapbook. This process was one way, and any changes to the digital document had to be manually replicated on the printed version.

Designing Pen-and-Paper User Interfaces uses the Anoto digital pen to create digital data to link printed documents [131]. The pen is used to add hyperlinks between printed documents in the digital space. It allowed documents to become associated or combined for a more straightforward analysis. They also used the Alto pen to add digital interactions to printed documents, such as clicking a print button.

Embedded Media Marker takes another approach where almost transparent marks are printed onto paper to signify the availability of additional media on a digital device [93]. Linked media includes videos and web pages to add further depth of information presented in the printed document. The process is somewhat similar to the modern QR code, where a camera phone is used to read the Embedded Media Marker, and the media is then presented on the device's screen.

When we think of digital notetaking today, most of us will begin to think of one of the many tablet computers that are compatible with a stylus. Tablet computers are another example of taking a feature of a physical item (e.g. paper or notebooks) and recreating it in the digital space. Unfortunately, like e-readers, tablet computers lose all the tangible richness of the medium they attempt to recreate.

A body of work looks to preserve physical notetaking and combine it with the portability and permanence of digital technology [91, 108, 149, 67]. PapierPoint [126, 50, 20] adds a further layer of interactivity to a notetaking system. The system allows a presenter to control a slideshow via printed buttons and annotate slides.

Other areas of physical to digital handwritten notes have also been considered, for example, whilst writing music. For example, PaperComposer [43] allows a user to write music using physical paper and then transfer it to a digital device.

This body of work represents the linking of physical documents or books to a digital copy. We can draw from this body of work in two ways. Where one method looks to add further context or content to physical documents using digital methods. And the other looks to create a digital copy of physical documents or notes. We take inspiration from these works in Chapter 5 where we explore methods of creating a seamless link between digital and physical books.

2.8 Digital Bookmarking

Since the introduction of the World Wide Web, users have been storing web addresses for revisiting or sharing, which is more commonly known as bookmarking. WebStickers takes the bookmarks of web addresses and creates barcodes that can be attached to everyday objects [94]. The barcodes, when scanned, load the web address associated with them. These barcodes allow users to physically share and organise their physical bookmarks on their printed books.

Printed books easily allow readers to flip back and forth between pages by simply placing a finger on each of the pages they wish to see. However, this action is somewhat cumbersome on an e-reader. Touch-Bookmark [155] introduces multi-touch navigation techniques for smart bookmarking on e-readers. Touch-Bookmark allows readers to quickly and casually flip between two positions within a digital book by bookmarking pages via simple swipe and touch gestures.

Bianchi et al. explored the use of a physical bookmark like device to support active reading on tablet computers [19]. The device consists of many features, including page navigation, screen capturing and visual helping. It uses conductive regions on the bookmark, which are detected on a tablet touch screen. The application then displays content depending on the context within the bounds of the device.

Bookmarking does not only refer to a position within a digital or printed media piece. iBookmark [123] introduces the idea of physical places as bookmarks where an e-reading device with access to global positioning system (GPS) coordinates can create stories based on past and present location.

2.8.1 Physical and Digital Content Synchronisation via Bookmarks

Research methods to keep digital and physical content synchronised has existed for many years. In 1997, Arai et al. introduced PaperLink [10], a camera-based approach at keeping documents in sync. When a user would markup a physical note, the camera would detect its location and transfer the written note to a digital version of the book.

More recently, researchers have looked into mimicking the physical process of bookmarking [132, 14, 12]. The most advanced of these is Magic Bookmark [14], published following the work of this thesis. The Magic Bookmark system uses a series of photovoltaic sensors to detect a binary pattern cut from each book page. This binary pattern is then converted to the decimal page number and transferred to its digital counterpart. The Magic Bookmark allows synchronising reading positions between digital and physical books.

2.8.2 Synchronisation of Digital Published Works

With the introduction of the internet, PCs, tablet computers and smartphones, the ability to consume digitally published works has become widespread. GlobalData Technology has recently reported that the number of connected devices is at an all-time high in the UK, with an average of 3.5 devices per person [46]. However, with many users having access to more than one device, the problem of synchronising media was introduced.

CloudBooks by Pearson et al. [102] introduces a method of reading from multiple tablet computers whilst keeping content in sync. Some of the more popular services available for accessing published works in e-book and audiobook forms include Amazon Kindle [2], Amazon Audible [7], Kobo [79] and Apple iBooks [9], each service offers cross-device synchronisation of media in the same format. Kindle, Kobo and iBooks offer e-book to e-book synchronisation, with Audible, Kobo and iBooks offering audiobook to audiobook synchronisation. These services do not offer cross-format synchronisation. However, Amazon does offer the WhisperSync [3] service to synchronise e-books and audiobooks purchased through its Kindle and Audible stores. In addition, libraries such as Aeneas [115] developed by ReadBeyond are available to create a forced alignment between e-books and audiobooks.

The above services offer media synchronisation of media purchased within the vendors' ecosystem. However, none of these services looks at synchronising physical media with digital.

2.8.3 Relevance and Use of Digital Bookmarking in our Work

In Chapter 5 we explore methods of synchronising reading positions across physical and digital mediums. The task has been somewhat trivial between digital mediums, where most of the existing research and existing products reside. Our work expands on this research to include physical mediums in the synchronisation ecosystem.

2.9 Summary

Throughout this chapter, we have presented the related work within the areas of digital reading, TUIs and augmented paper. We have observed that early work focused on simulating the visual reading experience of books onto digital systems [28, 29, 92]. This experience is still seen today through our e-reading devices with simple animations such as turning a page.

We observed a body of work that looks to replicate the physical features of books via tangible controls [21, 57, 70, 11]. Work ranges from attaching sensors to flexible materials [137, 87], creating flexible devices and even developing new methods of weaving textiles [18, 112]. Several features of books are explored, including interactions with pages and the tactile feedback they provide.

Several pieces of research look to augment the static content of books via projection [42, 58] or smart devices [130, 13, 32, 41, 40]. The use of projection onto flexible materials is often used as a metaphor for ultra-thin flexible displays that are not currently available on the market. Using this method allows researchers to demonstrate a future possibility that could be used when technology catches up. Until the release of ultra-thin flexible displays, several works used smart devices to add additional media and further context to static content via sensors and image processing.

We also explored related work within the area of content synchronisation, where we expanded the term "bookmarking" to encapsulate more than just keeping one's place within a book. Work began in this area in the 90s with the advent of the world wide web and hyperlinks. Early work made attempts to create hyperlinks between physical and digital documents [94]. More recent work focuses on the physical aspects of notetaking and creating digital clones for ease of access and permanence [91, 108, 149, 67]. Multiple existing services exist to create bookmarks between digital devices and digital media formats. However, no such system existed to create bookmarks between digital media and its physical counterpart.

The literature within this chapter can be combined into three main areas of contribution, **TUIs**, **Digital Materials** and **Linking Digital to Physical**. Figure 2.1 shows each of the three sets within a Venn diagram. The figure allows us to visualise where each area overlaps and helps to identify areas for further research to increase the knowledge. Each white circle within the figure represents our work and its position within the literature.

Firstly, we see an opportunity to further the research of digital materials within the area of reading devices. As we have presented, there exists very little existing literature demonstrating true paper book-like interactions for mobile devices. In Chapter 3 we explore methods of creating digital materials through the process of augmenting existing materials used for reading, such as paper. Existing literature looks to mimic the form factor [21, 57, 70, 11], interactions [156] or materials [71] of books, failing to combine the three. Our work in Chapter 3 looks to combine the three properties to create true book-like paper input devices.

Next, we identify a gap within the TUI space for mobile digital reading. A mobile reading TUI often seems like an afterthought or an example use case within the current literature [82, 135, 148]. The gap in the knowledge fails to explore the user experience and material design of a reading focused tangible mobile device. In Chapter 4 we seek to fill this gap by presenting a practical mobile reading device, where the design focus was reading first and not a use case or afterthought.

Finally, we explore a further opportunity to expand the research within the area of content synchronisation. An extensive gap exists in the research where physical and digital forms of published media can become synchronised. Existing literature focuses on the interactions and cloning of notetaking [146, 8, 108, 149]. In Chapter 5 we explore methods of synchronising digital and physical books using TUIs and conductive materials. Following the work of this thesis, more research has been performed within this area [14].

Each subsequent chapter explores an area of research with the knowledge gaps identified. In the next chapter, we explore using ultra-thin bend sensors to augment paper to create true book-like interactions for digital books via a paper input device. We explore the usability of such a device and make comparisons to electronic readers.

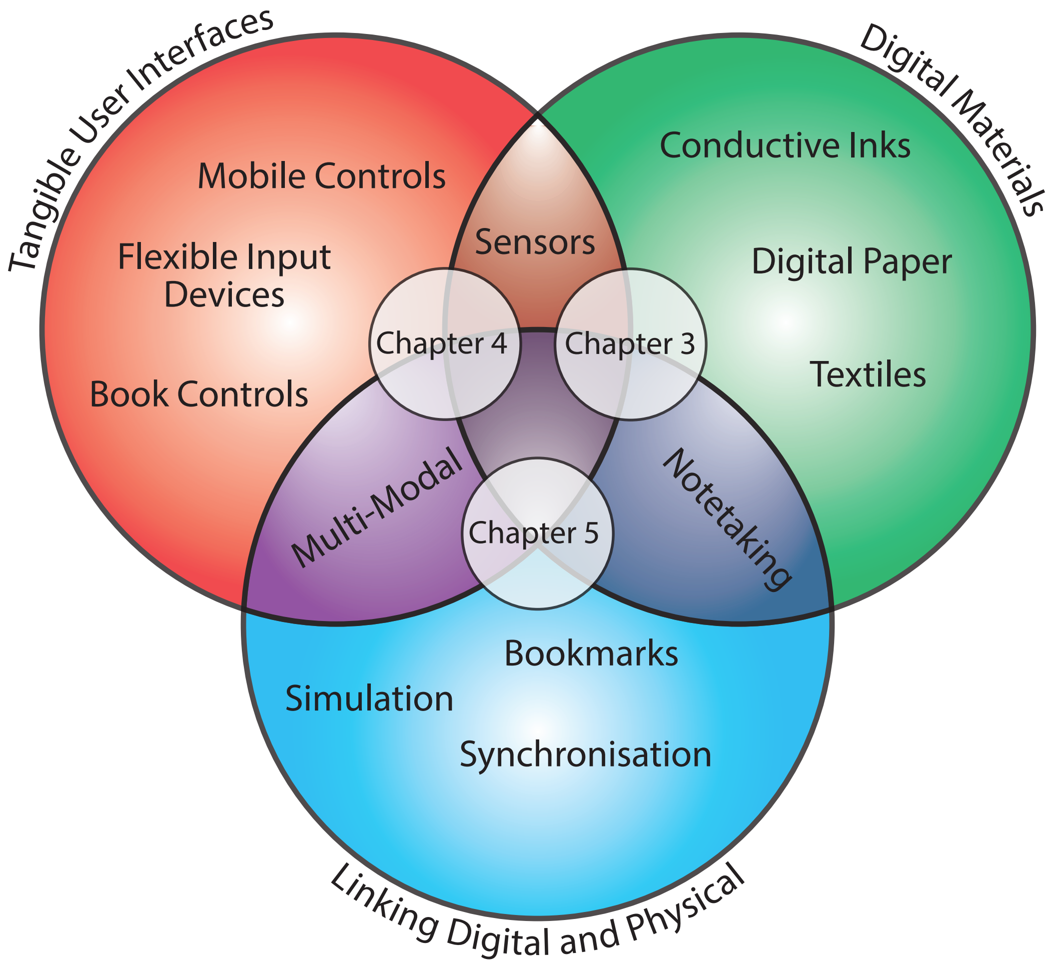


FIGURE 2.1: Diagram showing where each chapter sits in relation to the literature

Chapter 3

Physical Controls for Digital Books

This chapter focuses on paper and how embedded ultra-thin sensors could provide tangible elements to the digital reading experience. Physical documents offer a richer tactile experience than current e-readers [141], which typically only enable users to interact via a swipe or button press. We describe and evaluate a prototype device that uses a paper input device with embedded ultra-thin sensors, allowing interactions with physical pages to be digitally detected. The prototype allows a physical paper page interaction with an e-reading application, changing the displayed content through bend gestures.

We also present the results from a user study where we tested the usability and tangibility of the device. Our quantitive results show that the ultra-thin bend sensor embedded paper can accurately differentiate between bend gestures performed by users. We also held discussions with each participant, where the overall feeling towards the device was positive and that with further development, an improved digital reading experience could be provided.

We complete this chapter with discussions of our results and that with further technological developments, we could improve the paper-based input system to include any bend the user chooses and be more comparable to actual paper pages.

3.1 Introduction

Reading a physical book is a very tangible experience, with the turning and interaction with pages being pivotal. Thus when compared with e-readers, not only does the paper act as the "display", but it can also be said that it is the "input device". This is because the paper shows content to the reader, and the reader interacts with the pages to change the displayed page. So here, we loosely use the terms "display" and "input device" to compare physical books and e-readers. However, as we have mentioned above, e-readers do not offer a tangible experience that follows the affordances of a physical book. Therefore, this chapter focuses on exploring methods of bringing a tactile experience to digital reading with the affordances of physical books.

Firstly, we compare a subset of functionalities for both physical and digital books. In our comparison, we examine how each functionality is performed on different mediums. We found that some functionalities cannot be performed on physical books without the help of outside aid. We use the comparisons as a foundation for the functionalities of reading we believed would benefit from having physical controls within digital books.

We then investigate the design and development of ultra-thin bend sensors that can be applied to paper without affecting the physical properties. For example, such sensors would allow us to use paper as an input device to detect when a reader wishes to turn the page of a book. Finally, we developed a low-cost technology that provides an actual paper like tactile experience to interact with e-books without compromising the flexibility and texture of the paper.

Our first prototype replicates the physical reading experience for digital books. Using the methods of applying ultra-thin bend sensors to paper, we investigate sensor placement and shape, which is best for a paper e-reader input device. We carried out a user study for our prototype where participants were given tasks of bending each sensor embedded page for data collection and then asked to interact with a digital reading device using our sensor embedded pages as an input device. The results reported promising data regarding how participants bent each page, and the majority declared that such a device could improve their digital reading experience.

Following the feedback of our previous study, we developed a second prototype. Having sensors embedded onto paper led to areas of the page unable to receive input, and the middle of page bends being hard to differentiate from bottom corner bends. This second prototype eliminates these weaknesses, as we developed a fully interactive sheet where any bend can be detected. However, this innovation came at a cost. Current technology does not allow us to make a fully interactive sheet using paper without massively changing its physical properties. Despite this, we designed and developed a prototype fully interactive sheet. Finally, we gave the prototype to users, where they performed page bending tasks to build a model that would allow the identification of different bends. Results show that such a sheet can accurately identify different bend types and intensities.

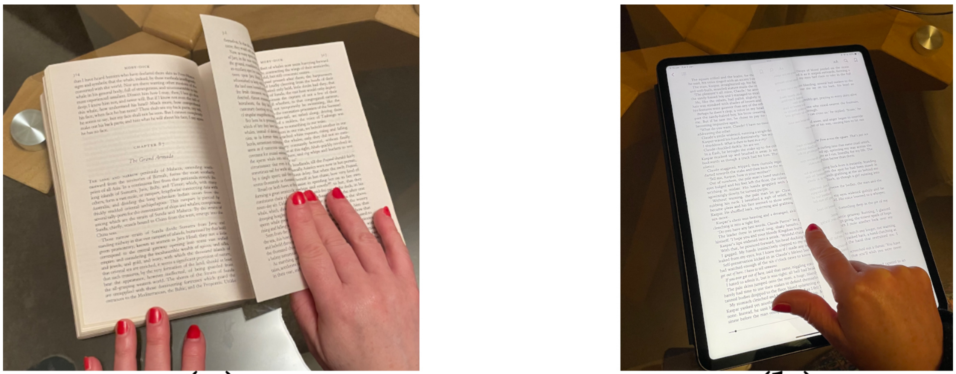
Our method of embedding ultra-thin sensors to paper and prototypes we developed, studied and evaluated illustrate how tangible user interfaces can augment the digital reading experience for the modern reader.

3.2 Functionalities of Reading Mediums

The primary function of any reading medium is, quite simply put, to be read. However, each reading medium has a treasure trove of functionality outside of reading, which unfortunately are often not associated with the medium's functionalities. This is more of a problem for physical books as a number of the functionalities we later discuss require outside aid and are not part of the design of a physical book. However, the functionalities of digital books are not overlooked as often, and this is due to the user interface having icons and prompts to make the user aware of such functionalities. Many functionalities of digital reading devices have been derived from physical books and paper, Pearson et al. [66] designed, developed and evaluated several functionalities of physical books for e-readers.

We identified and compared a subset of reading functionalities and put this concisely in Table 3.1. We formulated the list using several methods, including discussions with colleagues, acquaintances and friends regarding their reading habits. In addition, we examined several e-reader devices/applications, identifying which functionalities they incorporate.

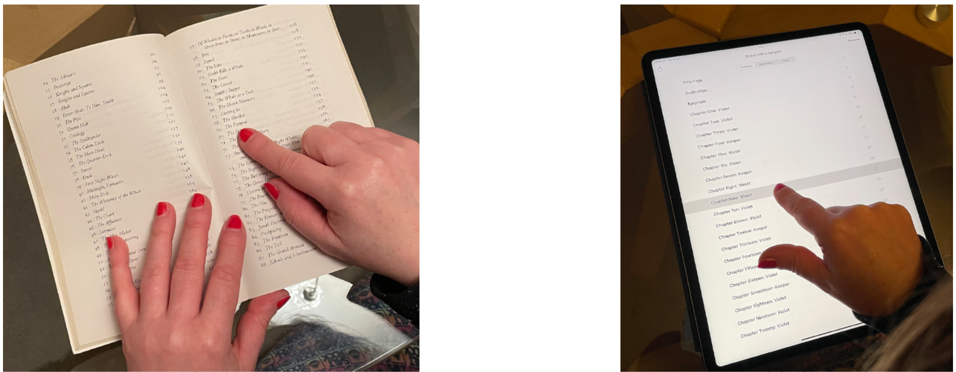
We present a brief description and comparison of functionalities across printed and electronic books. Many of these functionalities have been investigated by other researchers individually in great detail, most notably the PhD thesis of J.Pearson [106]. However, we are investigating tangible interactions to invoke several of these functionalities, so we did not investigate the functionality itself. So to help us understand the function and how it feels to invoke it currently, the author and colleagues performed each functionality and present them below.



(a) (b)

FIGURE 3.1: Changing a page of a (a) physical book (b) e-book

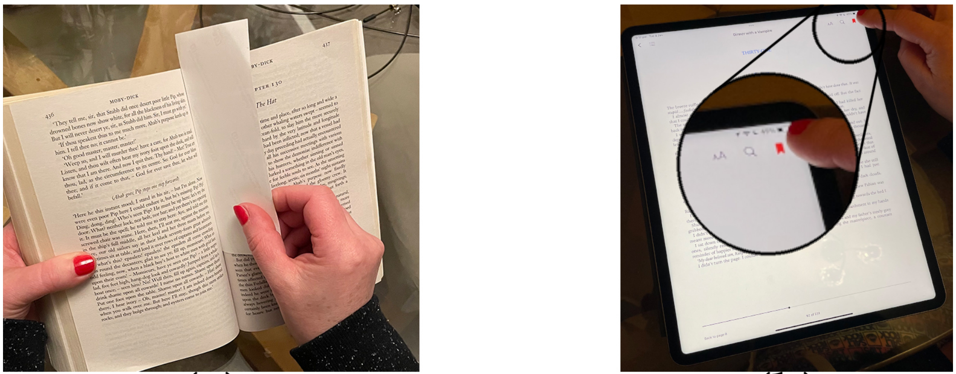
Change Page: The most primitive and basic of all reading functions, the act of turning a page allows the reader to view previous or new content. Whilst reading a physical book, the task is completed by picking up a page and then transferring it to the opposite side of the book. This function differs between e-readers, with most modern devices allowing the reader to swipe in their chosen direction using the touch screen. Other e-reader methods include using a directional pad and buttons at the side of the device.



(a) (b)

FIGURE 3.2: Selecting a new chapter using table of contents of a (a) physical book (b) e-book

Change Chapter: A function not performed as often as turning a page, but fundamental. A reader would perform this when jumping forward or back within the literature. Examples of this would be re-reading a chapter or resuming reading a book. Physical books have two distinct methods to achieve this. The first is to use the table of contents (if the book has one, usually at the beginning of the book) and page numbers to jump directly to the content. The second is to use a linear search method, where the reader flicks through pages until they find the heading of the chapter they seek. Like physical books, if the reader wishes, they can scroll through the book page by page or through the table of contents. However, most modern e-readers allow the table of contents to be shown at any point, thus skipping the stage of finding the contents page itself.



(a) (b)

FIGURE 3.3: Placing a bookmark in a (a) physical book (b) e-book

Placeholding: The act of keeping one's place when a reading session is complete has existed since the 6th century when pieces of leather were attached to the spine of a book. We still see this kind of placeholder today, usually in the form of a ribbon. Physical books usually use another object to hold a readers place, such as the leather/ribbon mentioned above, or an often rectangular piece of card or leather. If a reader wished to mark more than one location, they would need more placeholders or "dog-ear" in the corner of the pages. "Dog-earing" a page is the act of folding the corner of a page, creating a visible location to be found at a later stage. The act of "dog-earing" is permanent as even when folded back, a crease will exist. E-readers begin each reading session from the last page a previous session ended, eliminating the need to manually add a placeholder for most occasions. If the reader wishes, they can add a bookmark to any page they choose by clicking the bookmark icon.

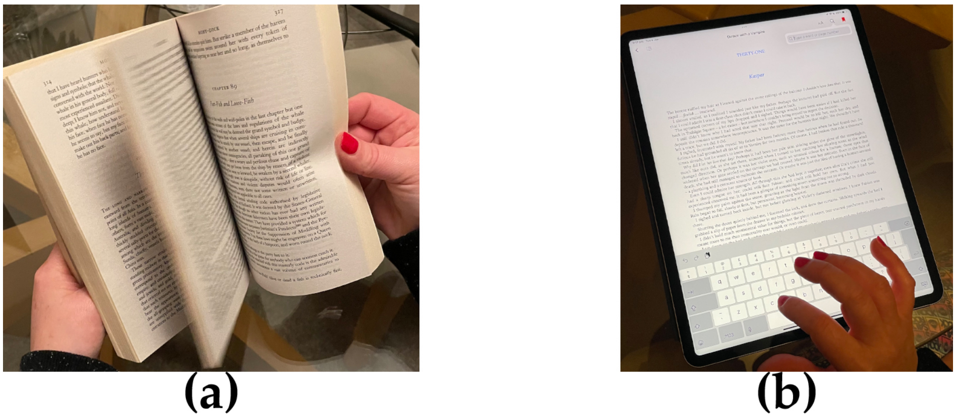


FIGURE 3.4: Searching the contents of a (a) physical book (b) e-book

Searching: Searching is often performed if the reader wants to return to, for example, the epic battle or the death of a character. This task is challenging using physical books, and we go into further detail and study this in Chapter 5. If the reader is fortunate enough to know the chapter number or the chapters are appropriately named, their search is narrowed. However, we found that it is mostly not the case, so readers flick through pages, glancing for information until they can find what they are seeking. Most e-readers, however, have an inbuilt search function, allowing readers to search words, phrases or even sentences.

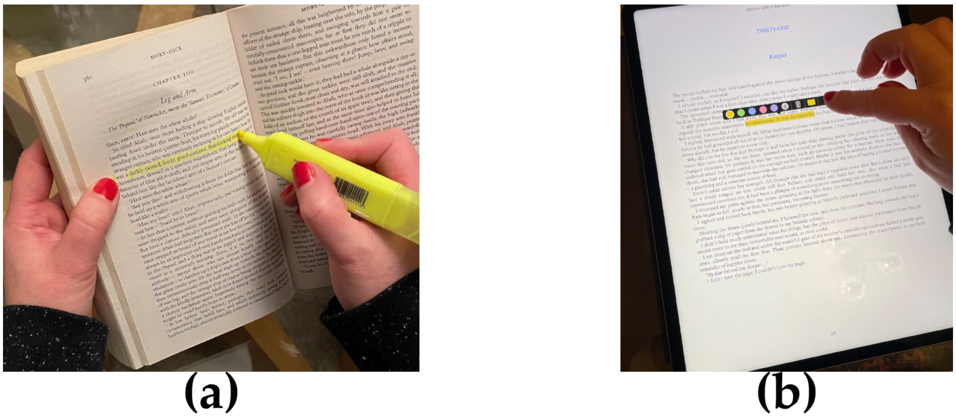


FIGURE 3.5: Highlighting content of a (a) physical book (b) e-book

Highlighting: Readers often highlight points within the literature that they deem essential or a pivotal part of the narrative. Highlights, like placeholders, make it easier for a reader to return. Most modern e-readers have a highlighting function built-in. These are easily visible and often are stored within a list of all highlights made, making it even easier to return. A reader needs to use a writing mechanism for physical books, such as a highlighter pen. The highlighting of a physical book is a permanent disfigurement of the book.

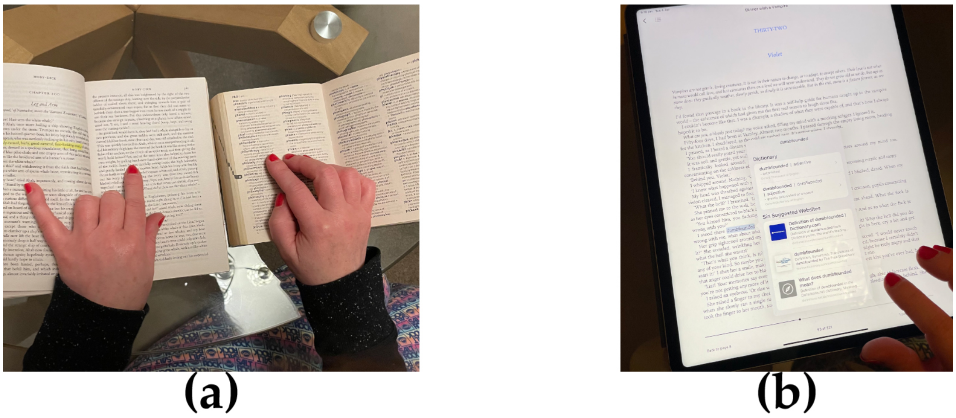


FIGURE 3.6: Looking up the definition of a word in a (a) physical book (b) e-book

Word Definitions: Sometimes, a reader may encounter words that they do not understand when reading. With many e-readers having a touch screen for input, the ability to touch words and instantly get their definition was introduced. This functionality is a stark contrast to that of physical books, where the reader needs a dictionary or digital device to achieve the same result.

FIGURE 3.7: Changing the fontsize of a (a) physical book (b) e-book

Adjust Font: Unfortunately, people's eyesight differs from defects at birth, illness or degradation with age; this introduces the issue of Font and Font size. There is no single font or size suitable for all readers. E-readers can change the size of the presented text quickly, and some readers even allow a reader to change the font. For physical books, this is impossible; the font and size of a printed book are final at the time of print. If a reader is unhappy with the font or text size of a book, they either have the option to use a magnifying glass to increase the font size, or buy a different version of the book.

(a) (b)

FIGURE 3.8: Enabling dictation of (a) physical book (b) e-book

Text to Speech: Having the ability to have the text of a book dictated to the reader is helpful for the visually impaired, those with learning disabilities or even for the occasion the reader wants to listen to the book. Luckily for e-book readers, most e-readers can convert text-to-speech, meaning that once an e-book is purchased, they can read or listen to it. This is feature should not be confused with audiobooks; these are entirely different and of higher production value as they are read by a person and not a machine. As for physical books, no such feature exists or is possible. The only solution is to purchase an alternate version of the book, either an e-reader and the digital version of the book or the audiobook format.

Our comparison of these vital and widely used features of reading mediums found that it is possible to achieve most on both physical and digital mediums, using outside aids, except for adjusting font on printed books. E-books are more convenient as they can perform all functions independently. On the other hand, physical books offer the most physical experience when performing some functionalities, such as turning pages or flicking through pages to search.

Using our comparison, we discovered the functionalities that could be enhanced with physical pages, such as changing pages/chapters and searching. These would be included in our prototype to combine the best of both digital and physical worlds, leading to a genuinely paper-like tactile e-reading experience.

	Digital Books	Physical Books
Change Page	Swipe/tap screen or press a button.	Pick up a physical page to change to the next.
Change Chapter	Select from menu of chapters.	Pick up multiple pages while looking at each to find the chapter required. Use of table of contents.
Place holding	Add bookmark to any page and lookup later from list of bookmarks.	Fold over a corner or a built in ribbon marker. Often done via a bookmark.
Search	Search words or page numbers using a text field.	The reader goes through the book page by page glancing for what they are searching for.
Highlight	Select words using a finger and select highlight or undo highlight.	Sections can be highlighted using a highlighter pen, a permanent defacement of the book.
Get word definition	Select words using a finger and select define to get the definition of the word.	No such feature exists. Look up words using alternative methods.
Adjust Font	Use the accessibility settings to select the preferred font and size viewed.	Fonts are permanent at time of print.
Dictation	Use the accessibility settings to select dictation, for a computer generated voice to read the text.	No such feature exists for printed books. Audiobook versions would need to be purchased.

TABLE 3.1: Table comparing the functionality of printed books against e-books in regards to the activity of reading

3.3 Paper as an Input Device

Using paper as an input device is not a new concept. Many [157, 149] have investigated the use of paper to interact with digital devices, with the majority looking at the use of conductive inks to detect touch or carry data of sensors. For our work, we wish to detect when a user turns a paper page, we do not require the sense of touch, but we do, however, require the ability to detect if and to what extent a page is bent. Previous works in this area use off-the-shelf flex sensors [144] made from plastic and are somewhat stiff. If these off-the-shelf flex sensors are placed onto a material, their stiffness drastically affects the properties of the base material. For our work, a primary objective was to keep the texture and flexibility of paper intact, making using off-the-shelf sensors impossible.

Unfortunately, when adding to its thickness, paper is a very unforgiving material, and even the smallest amount can drastically alter its flexibility. We refined an existing method of building bend sensors to allow a paper bend sensor to be produced with a thickness of 12mil, a 44% reduction from off-the-shelf sensors. This method allows custom ultra-thin bend sensors to be produced in various shapes and sizes at a fraction of the cost, costing pennies rather than pounds.

3.3.1 Ultra-Thin Bend Sensor Construction

The construction of our ultra-thin bend sensors took inspiration from the hobbyist and maker communities. The sensor is constructed using the carbon-infused piezoresistive polymer, Velostat. Velostat is traditionally used as a packing material to protect electrical components. However, it has gained popularity throughout the maker community due to its change in resistance when bent or pressed. This change in resistance allows the material to be used in custom bend and pressure sensors.

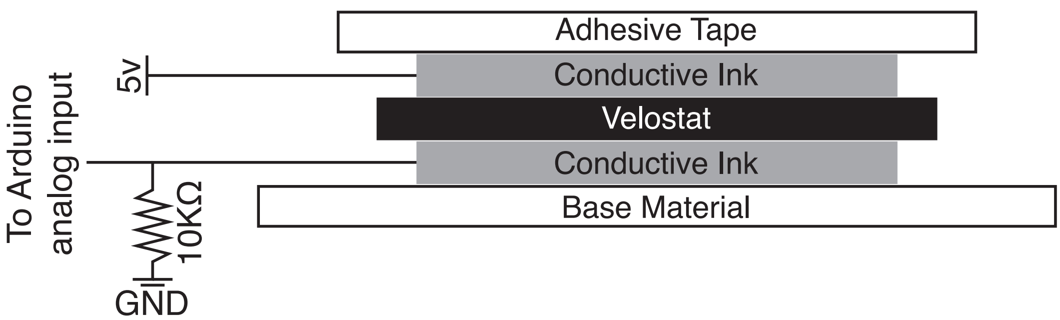


FIGURE 3.9: Ultra-thin bend sensor layer composition and wiring diagram

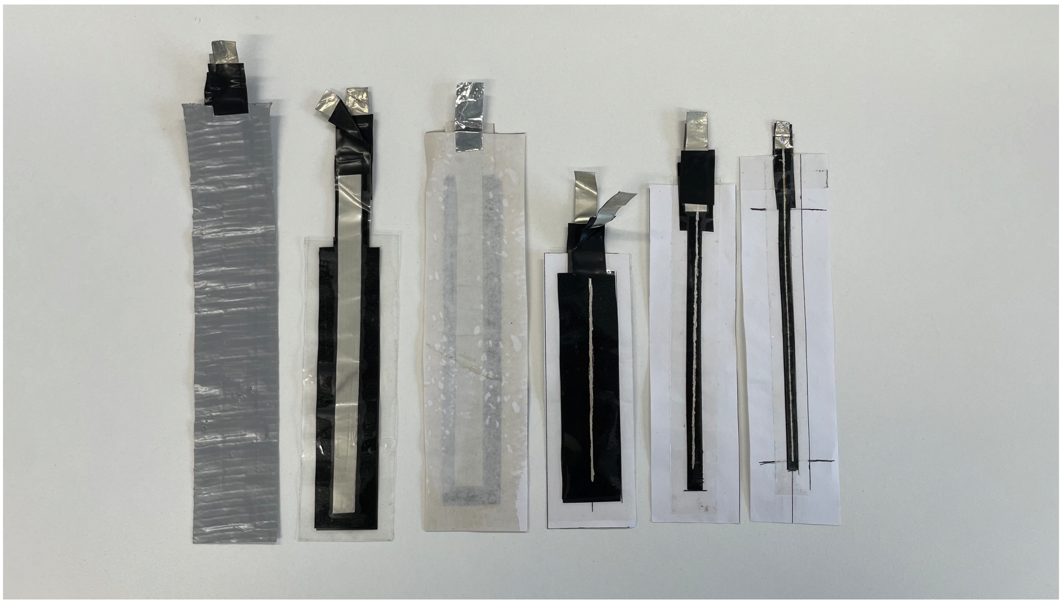


FIGURE 3.10: Ultra-thin bend sensor development iterations, earliest on the left, final on the right

We refined the process, exploring various adhesive and conductive materials until we could construct an ultra-thin and robust sensor. Figure 3.10 shows the iterative design cycle of the ultra-thin bend sensor, starting with thin, flexible tape in initial designs (left) and ending with paper and thin lines of velostat in the final design (right). For example, sensor iteration three shows a bend sensor encapsulated by paper, resulting in the paper becoming stiff and thick compared to standard paper, leading to subsequent designs following a single-sided paper and thin tape approach. The sensor materials are layered in the order shown in Figure 3.9 and described below:

Adhesive Tape - The tape adheres the Velostat to the paper and forms a protective layer over the conductive ink.

Power Conductive Ink - This conductive layer is the positive line, bringing power to the bend sensor. For this sensor, we used CircuitScribe conductive ink [30], as it allows a thin pen line of ink to be applied and is low cost.

Velostat - The pressure-sensitive resistance of the Velostat allows the bend to be detected by measuring the output voltage.

Ground Conductive Ink - This conductive layer is the ground and the input for the analogue signal, again using CircuitScribe ink.

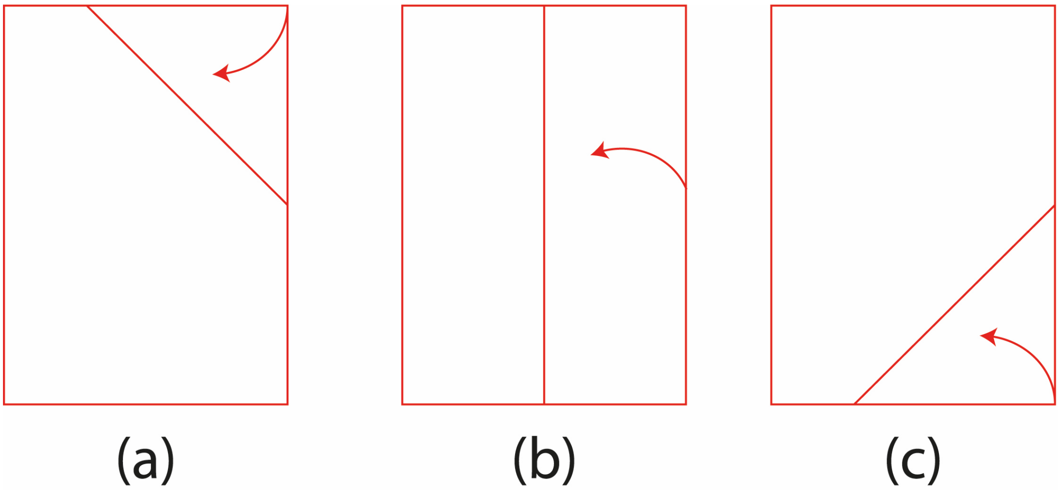


FIGURE 3.11: Bend gestures that were incorporated into the prototype device and that were based on existing research (a) Top corner bend (b) Middle page bend (c) Bottom corner bend

Base Material - The material to which all layers of the bend sensor is applied. A wide variety of flexible materials can be used for this layer, from paper to cloth. For our sensor, we used paper.

This method allows the bend sensor to be made in a wide variety of sizes and shapes. The sensor works by applying power to the top layer of conductive ink, and the pressure on the velostat directly affects the output voltage, allowing a microcontroller to read the amount of bend applied to the base material.

3.4 Prototype Device for Enhancing E-Reading

We prototyped a tangible device to augment the e-reading experience, bringing the page-turning interaction of physical books to the digital world. This section describes the design process of ultra-thin bend sensor shape for e-reading, prototype and interaction design.

3.4.1 Sensor Shape and Placement for E-reader Input

We analysed several research papers which carried out user studies of bend gestures for flexible devices [137, 87, 142, 82] to understand how users would bend the pages of a paper input device. The literature provides in-depth knowledge and insight of bending flexible input devices, and we felt that replicating this would not further the knowledge of the subject. We found that all the literature had a common subset of bends which could relate to the action of turning a page of a

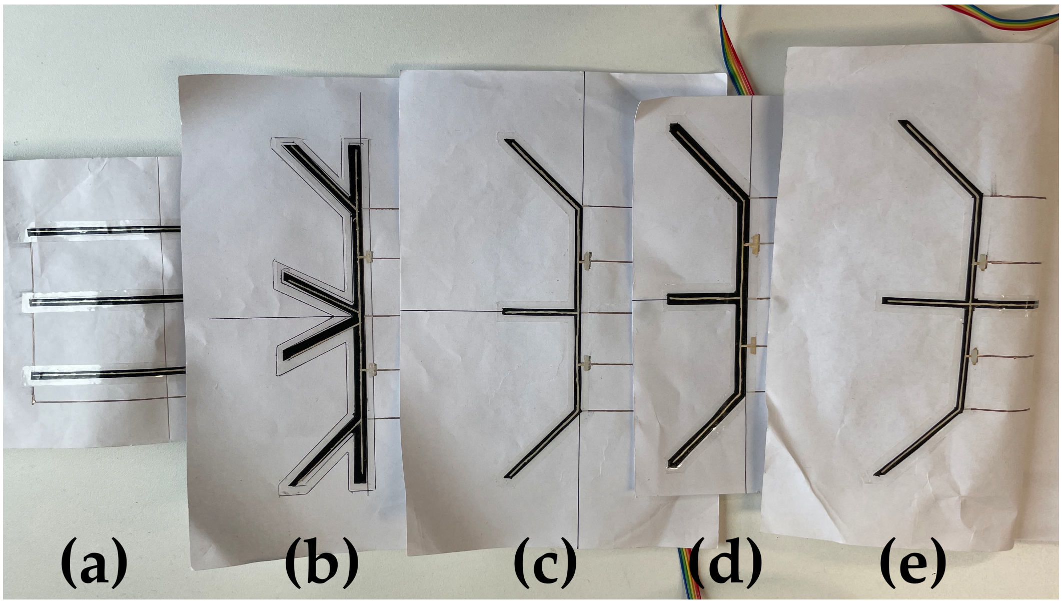


FIGURE 3.12: Ultra-thin bend sensor shape development iterations, earliest on the left, final on the right

book. This subset consisted of bends a, b and c of Figure 3.11. So, based on the literature and the purpose of the device, we concluded that the pages would be turned in one of three ways, as shown in Figure 3.11.

Each bend is defined by the point where the user picks up the paper, e.g. top corner, middle or bottom corner. Thus, as Figure 3.11 shows, the different pickup areas have drastically different bend shapes. Therefore, each paper page that was to be added to the prototype must have the ability to detect all three bend types. After many design iterations (Figure 3.12), we created a trident bend sensor (Figure 3.13) which can detect bends for all three locations. The trident shape allows the user to choose their preferred method of interaction.

Early designs incorporated multiple straight ultra-thin bend sensors across each page (Figure 3.12-(a)). Initially, this arrangement was successful. However, after several sessions, the paper would lose its crispness and develop slight folds and bends. These folds would apply pressure to the ultra-thin bend sensors and make it challenging to obtain accurate readings.

Following this, each sensor design used a single sensor with multiple data collection points (Figure 3.12-(b-e)). Having multiple data points allows the sensor to be polled in multiple locations to determine where and to what extent it is bent while ignoring false inputs caused by the gradual degradation of paper quality. The first iteration of the single sensor design was Figure 3.12-(b), a more complex design

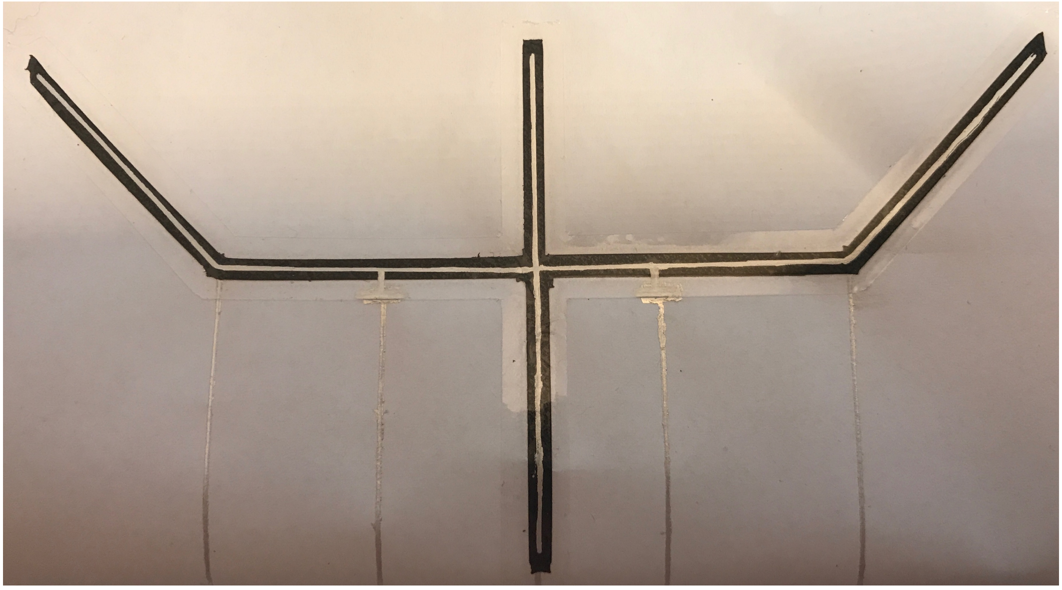


FIGURE 3.13: E-reading prototype ultra-thin bend sensor in the shape of a trident

than the final trident. Due to more sensor branches, bends were harder to detect at the data collection points. Data became noisy and led to more false-positive results for bend detection.

Sensor design was then simplified for designs Figure 3.12-(c-d), reducing the number of branches. Here we experimented with the width of each sensor, with (c) being the thinner design and most favourable. A negligible difference in performance between these sensors was detected, so (c) was favourable because it was thinner and had a more negligible effect on the properties of paper as it had a smaller footprint. However, this design failed to recognise a middle of page bend (Figure 3.11-(b)) accurately. The sensor would recognise the bend as it was happening, but then it would disappear when the bend became too great. As a result, the trident shape was created and became the final shape for a paper input device for an e-reader. Allowing accurate input for both top and bottom corner bends and large middle of page bends.

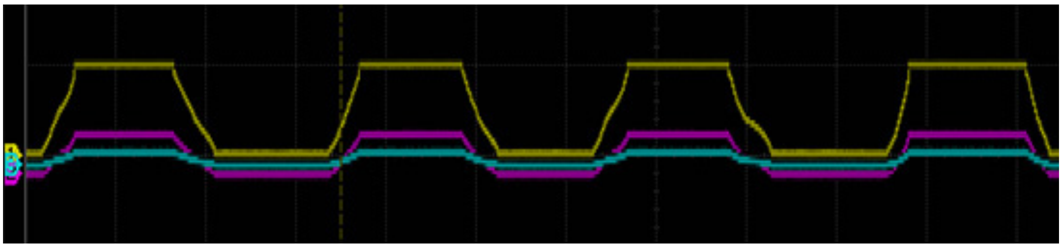


FIGURE 3.14: Oscilloscope data showing single page Top corner bend in lab. Yellow - Top corner, Purple - Middle, Blue - Bottom corner data points

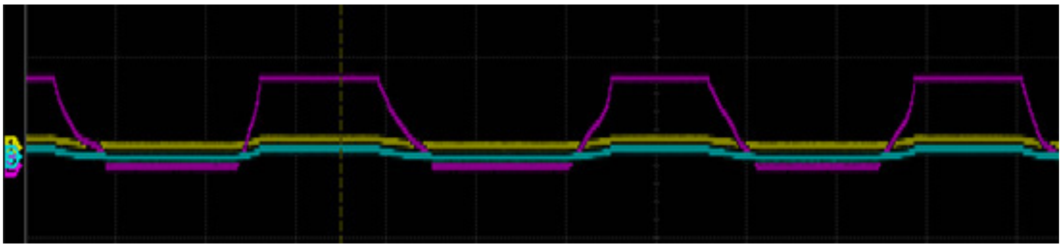


FIGURE 3.15: Oscilloscope data showing single page Middle bend in lab. Yellow - Top corner, Purple - Middle, Blue - Bottom corner data points

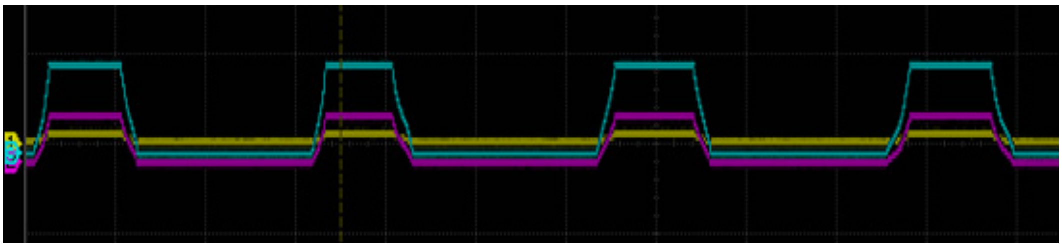


FIGURE 3.16: Oscilloscope data showing single page bottom corner bend in lab. Yellow - Top corner, Purple - Middle, Blue - Bottom corner data points

Figures 3.14, 3.15, 3.16 show the data signals recorded using an oscilloscope. The images present a clear difference between data signals for each gesture, showing that the trident bend sensor shape can differentiate between top, middle, and bottom bends in a lab setting.

3.4.2 Prototype and Interaction Design

As discussed in Section 3.2 our tangible digital reading prototype was to incorporate three interactions, changing pages, changing chapters and scrolling. Our initial idea was to use a single sensor embedded page on each side of the device to

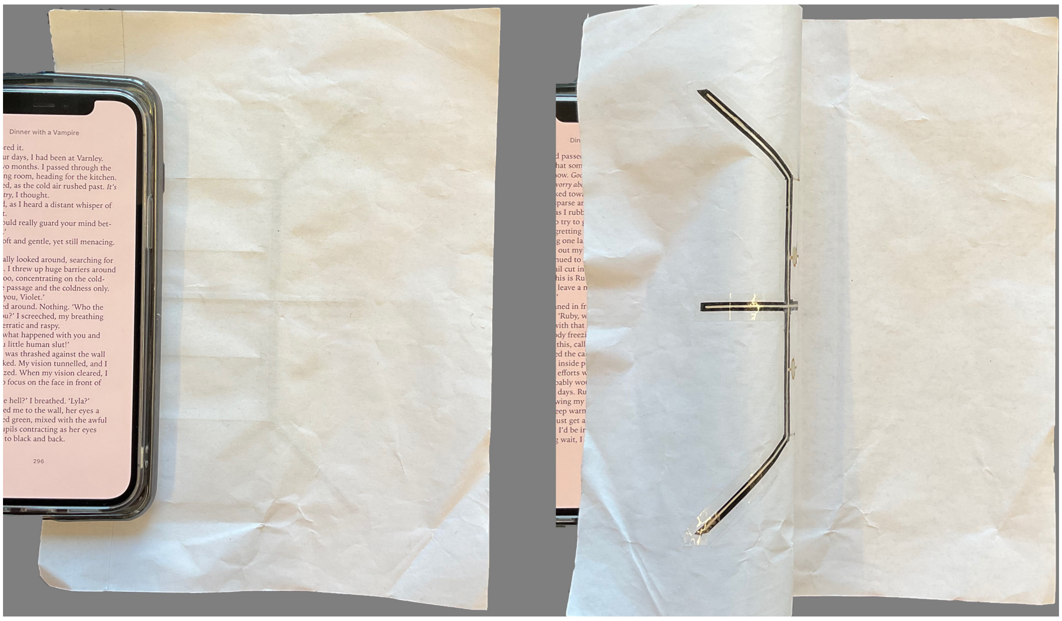


FIGURE 3.17: Prototype e-reading device with single paper page as the input device.

invoke these functionalities. This single sheet would have the bends of Figure 3.11 to perform each method. However, we discovered that was not possible during initial testing and piloting, which led us to take a multi-page interaction approach.

Single-page Approach

In Section 3.4.1 we discussed previous works in the area of flexible input devices and how they helped us to design the bend sensor used for the paper input device. The oscilloscope data showed that we could successfully create a custom bend sensor to differentiate between bending from different locations (top and bottom corners and middle of page). However, when the author and several colleagues piloted the single page prototype in the context of reading, the bends were not the same as the research suggested.

A prototype device was built incorporating a single sheet of trident shaped bend sensor embedded paper, as shown in Figure 3.17. The prototype then used a microcontroller with Bluetooth to communicate with a smartphone application. The application was a basic e-reader user interface, which listened for commands from the prototype. Three commands were included in the application:

(a) **Bookmarking:** When the sheet was bent on the top corner, the bookmark command would be sent. The top corner was chosen to mimic physical books'

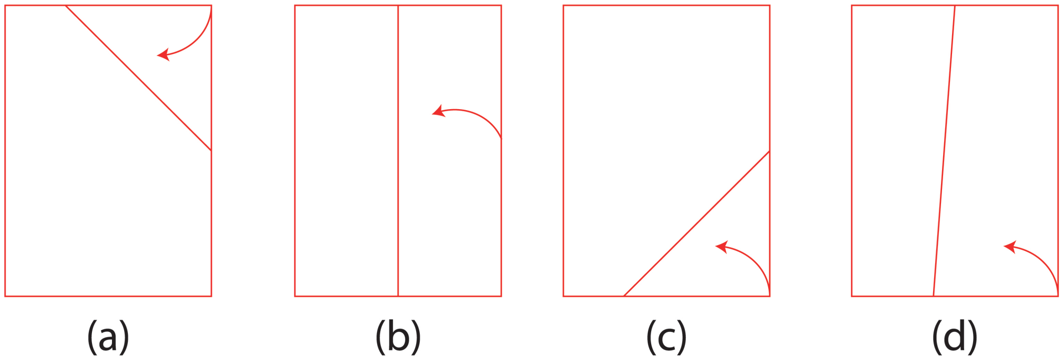


FIGURE 3.18: Graphic representation of bend location on paper.

"dog-ear" technique.

(b) **Change Page:** When the sheet was bent in the middle, the next page command was sent to the application.

(c) **Scrolling:** When the sheet was bent using the bottom corner, the scroll command was sent to the application. This function was assigned to the bottom corner to mimic the flicking of printed book pages.

From the existing research, we predicted that users would bend pages similar to bends a, b and c presented in Figure 3.11. The figure shows the ideal bend for the middle, top and bottom corners, where each bend is unique. However, this was observed not to be the case when performing real-world bends in the context of reading. The top corner and middle bends were as predicted, and the bottom corner bend, unfortunately, was not. From our observations, the author and colleagues would bend the top corner at an approx 45-degree angle. However, for the bottom corner, they would pick up the page from the corner and then pull in a direction almost parallel with the bottom of the page; this resulted in the page bending at approx 80 degrees, very similar to a middle bend. The bend in Figure 3.18-d shows the real-world bend location of a bottom corner bend. The figure shows that the predicted bottom corner bend c is massively different from the real-world bend d and that the real-world bottom corner bend bears more resemblance with a middle bend b. This resemblance made it difficult for the microcontroller to determine whether a change page or scroll command was sent to the application, and for a bottom corner bend, it was more often wrong than right.

We used an oscilloscope to record bend data, which backed up our visual observations of how pages were bent during testing and piloting. The top corner bends revealed that the bend was quite distinctively picked up by the oscilloscope and

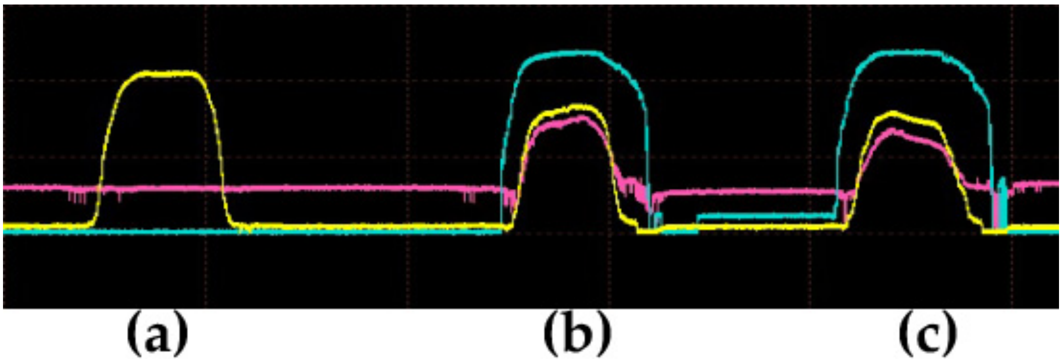


FIGURE 3.19: Oscilloscope data of real-world bends using single page prototype

easy to differentiate from the middle and bottom corner bends. For example, Figure 3.19-a shows a significant voltage change only at the top corner data collection point. The middle and bottom corner bends have shown to be indistinguishable from each other. Figures 3.19-b and 3.19-c show oscilloscope data from both the middle and bottom corner bends, respectively, which is almost identical.

Figure 3.20 shows a visual guide of how paper pages of books are bent, showing the pickup position and hands of the user. The Figure helps us visualise why the bends in Figure 3.18-c and d differ in a real-world scenario. In the lab setting, the literature [87, 142, 82] focuses on the bending of a single flexible substrate, which leads to the conclusion of bends being uniform and a bottom corner bend being an approximately 45-degree angle from the bottom corner. Tajika et al. [137] focus their bend finding exercise on actual books. However, they still classify turning a page from the bottom corner at almost 45 degrees (shown through imagery only).

Based on our research we would argue that a bottom corner bend should not

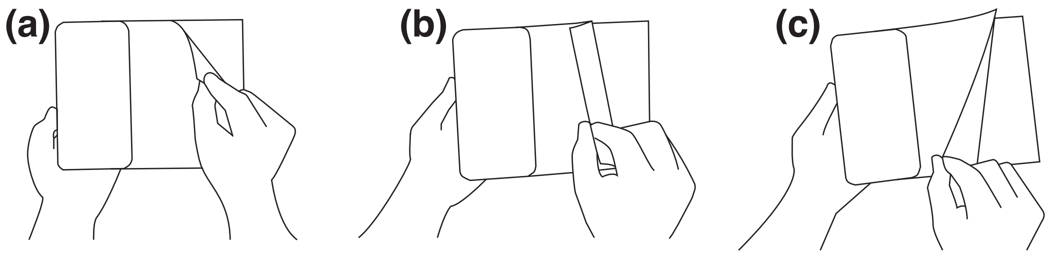


FIGURE 3.20: Bend gestures that were incorporated into the prototype device and that user study participants were asked to perform (a) Top corner bend (b) Middle page bend (c) Bottom corner bend

be classified as an almost 45-degree bend from the lower corner. Our data and observations show that it is more representative of an 80-degree bend, shown in Figures 3.18-d and 3.20-c

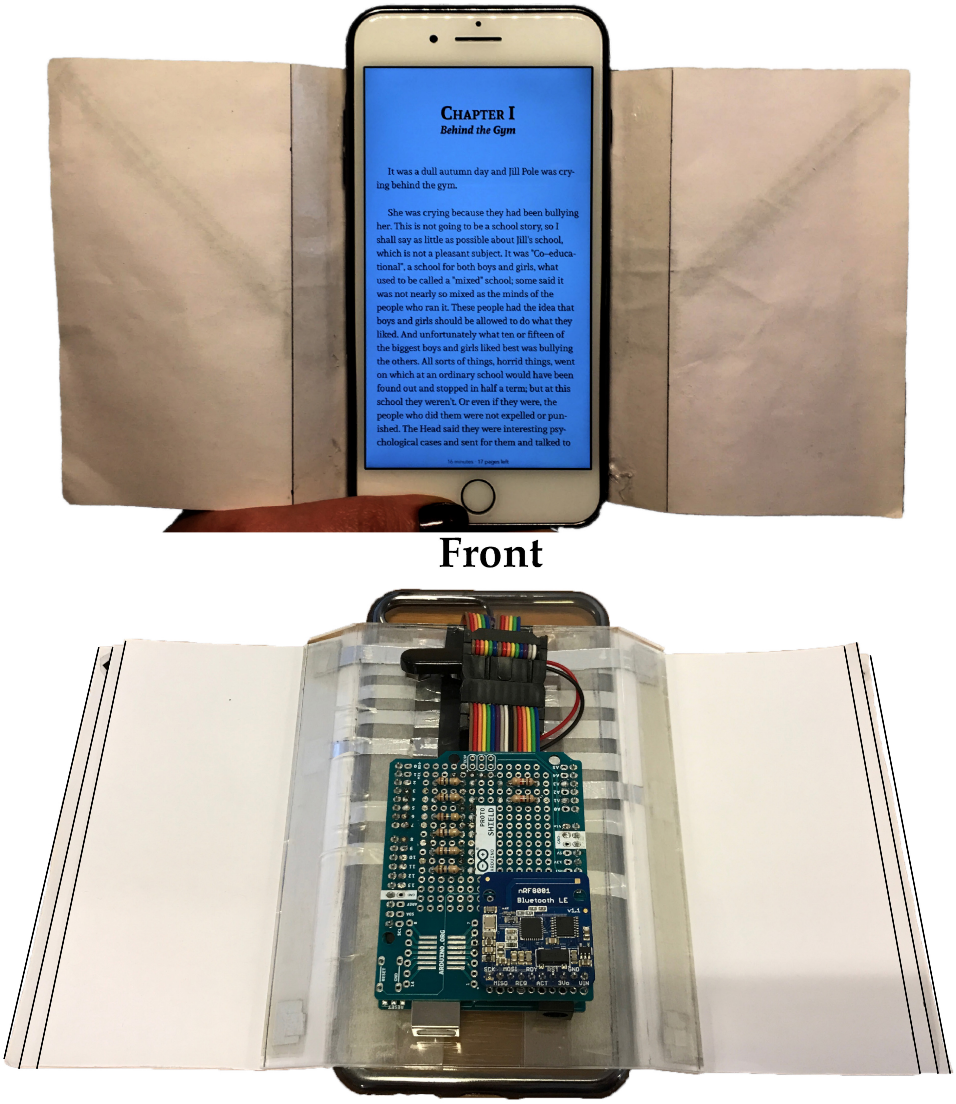


FIGURE 3.21: Multi-page prototype e-reading device with paper as the input device. The tiered rear of the pages is highlighted for illustration purposes.

Multi-page Approach

Due to the bottom and middle bends being indistinguishable, we took a multi-page approach and added three pages to each side of the device, where each page had a function assigned to it. The three pages appear on both sides of the device to allow forward and back navigation through an e-book, as shown in Figure 3.21.

Taking a multi-page approach allowed the data signals to become far easier for the device to differentiate, Figures 3.22 (change page), 3.23 (change chapter) and 3.24 (scrolling) show the oscilloscope data for each of the interactions. We describe the interactions for each page below:

(a) **Change Page:** When only the top page of either side is turned. Increments or decrements the current page number by one, where interacting with the left decrements page number and the right increments it.

(b) **Change Chapter:** When the top two pages of either side are turned. Increments or decrements the current chapter by one, where interacting with the left decrements chapter number and the right increments it.

(c) **Scrolling:** When all three pages of either side are turned. This scrolls through the pages of a book. Again direction is dependent on the side of the interaction. Where the left scrolls backwards and the right scrolls forwards.

We swapped one of the functionalities of the single page prototype as the interaction technique had changed. We felt that the bookmarking functionality did not feel intuitive with multiple pages. Instead, we incorporated the change chapter functionality, making more sense as picking up multiple pages jumped further in the book.

In order to make it easier for a user to select the function they wished, we tiered each page on the back of the device, as shown in Figure 3.21. The tiers introduced a 5mm ledge for each page from the page below it, giving an unmistakable tactile feel to the selected number of pages.

Collecting the data from each page is an Arduino microcontroller. The Arduino polls each data collection point until it determines that a page is bent. Page ID and bend data are sent via Bluetooth Low Energy to the smart device when this happens.

We created an e-reader application that listens for the commands sent from the paper input device. The application reacts to each command it receives by changing the page to the next/previous, changing the chapter to the next/previous, or performing a continuous scroll in the direction of the held pages.

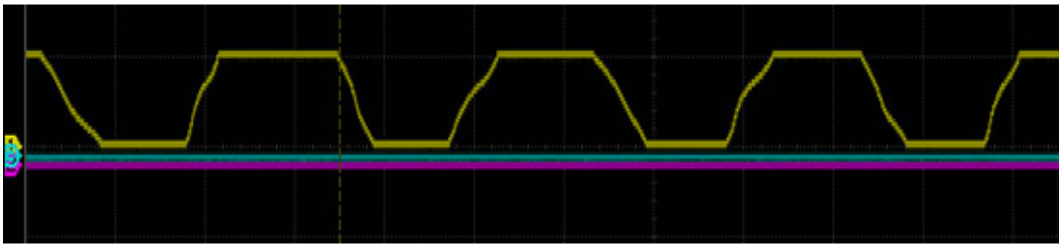


FIGURE 3.22: Oscilloscope data during the change page action of multi-page approach

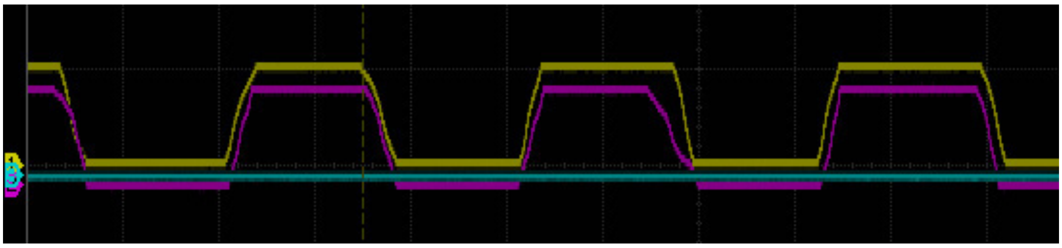


FIGURE 3.23: Oscilloscope data during the change chapter action of multi-page approach

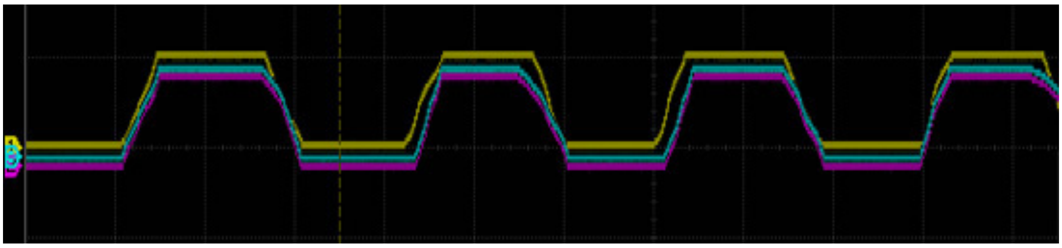


FIGURE 3.24: Oscilloscope data during the scrolling action of multi-page approach

3.5 User Study

We conducted a user study to test the usability of our multi-page device for e-reading across several users and variations of a predefined set of bend gestures. We recruited 8 participants (3F, 5M, 25-54 years), each specifying their right hand as the most dominant. However, all participants being right hand dominant was not intentional. Participants were recruited through mailing lists on a first-come, first-served basis.

Procedure

The participants were given a short questionnaire (Appendix B.1) to complete asking for demographic information and their experience using printed and digital books.

Once the questionnaire was complete, we introduced the participants to the prototype device. We thoroughly explained the device's features to each participant and how the paper input device interacts with the e-reader application.

Each participant had five minutes to use the device unaided to become familiar with how the application reacts to them bending the paper pages at the side of the device. Once the five minutes had passed, the task was fully explained.

Task

The task involved each participant performing a set of predefined gestures. The gestures we asked the participants to perform were those discovered during the development of the prototype, single-page turn, double-page turn and triple-page turn.

In turn, each gesture was explained to the participants. They were then given a further minute to become comfortable performing the gesture, so they felt comfortable. After the minute had expired, they were asked to perform the gestures for data recording and then performed the next gesture.

During each task, an e-reader application was shown on the display of the smartphone. When each gesture was performed, its corresponding action was shown on the display e.g. single-page turn went to the next page of the e-book. Showing an animated page-turning gesture.

3.5.1 Results

Pre-Task Questionnaire

The short questionnaire at the start of the study (Appendix B.1) revealed some interesting results. We asked the participants what mediums they use to read; 62% of them declared they use both printed and digital books, while the remaining 38% exclusively used printed books. Not a single participant reads exclusively via digital methods.

Following that, we asked what method they preferred to use. Unsurprisingly, the 38% that read printed books exclusively prefer to read printed books, along with the vast majority of those who use both reading methods, bringing the total up to 75% of participants preferring to read from printed books. A single participant brought an interesting point of view. The participant had no strong preference but did have preferences for different activities. The participant stated that if they are reading for work, they prefer digital methods to save using resources unnecessarily, and if reading for leisure, they prefer to use printed books.

Post-Task Questionnaire

The participants were asked to what extent they could feel the bend sensors with their fingers or by stiffness when compared to regular paper; 75% stated that they could feel the sensor very little or not at all. 87% of participants agreed that the paper interface could detect the bend very accurately, with many of them stating that it worked every time.

The participants were also asked if they believed a paper-based interface would enhance digital reading. Again, 87% of participants agreed that it dramatically enhances digital reading; this may be due to most participants preferring printed books. Appendix B.2 shows the post-task questionnaire.

3.5.2 Discussion

Our first discovery whilst developing the paper input device was the reclassification of bend gestures for book-like interfaces. Most notably, the bottom corner bend. Current literature [137, 87, 142, 82] all refer to a bottom corner bend as an approximately 45-degree bend from the bottom corner. This is somewhat true when the bends are performed on a single flexible substrate in a lab setting. However, when we focus on bending paper pages of books, like that of Tajika et al. [137], we found that is not the case. The focus of books introduces a new bottom corner bend, where the bend angle is closer to 80 degrees, which we measured with oscilloscope data (Figure 3.19) and visualise in Figure 3.20

The paper input prototype device for the digital reading brings the page-turning experience to e-readers. In addition, the use of ultra-thin bend sensors allowed the device to use actual paper as its input material, further mimicking its physical counterpart. The sensors only add 8mil to paper thickness, making the paper bend sensor 12mil, three times thicker than paper. However, this is where the narrowness of the sensor plays its part. The sensor is only 3mm wide, making the extra thickness almost illegible to the paper. Our study participants stated that they could not feel any reduction in flexibility of the augmented paper over standard paper. The sensors were placed 4cm away from the page edge, far enough away that the fingers would not accidentally feel them, with our participants stating that they did not feel the sensors.

FIGURE 3.25: Interactive Sheet Prototype

Scalability

The device can easily be scaled by increasing or even decreasing the number of pages on each side.

Increasing the number of pages could allow for more physical book like interaction modes with digital books, such as random access to pages, which would be an exciting physical/digital method for searching content.

Limitations and Further Functionality

The oscilloscope gave us an interesting insight into the bend sensors' data, notably how similar the middle and bottom corner bends are. This indistinguishability is unfortunate and can be considered a limitation. The limitation comes from how users bend a page from the bottom corner, making large sweeping bends that eventually turn into a middle page bend, unlike the top corner bend, which was done in a way that an almost right-handed triangle was formed. This triangle bend applied a large amount of pressure to the top part of the sensor, making it very distinguishable. Due to this, the top corner could be used to glance at the content under the current page. When the user begins to bend the top corner, the digital page will reveal what is underneath. This function could be helpful when a reader wants to peek at what is next, e.g. if the current page is the end of the chapter, allowing them to turn off, the pages left indicator to be more book-like.

3.6 Interactive Sheet

Following the user study of the paper input device and discovering its limitations, we began research on methods to overcome these; we developed the interactive sheet. The interactive sheet, in its essence, creates a bend/pressure sensor that covers the whole page. Creating an interactive sheet the size of a page allows the device to detect bends of any direction and amount across itself. We also discovered that the sheet could detect touch gestures, including multi-touch, bringing the possibility of further interactions.

3.6.1 Sheet Construction

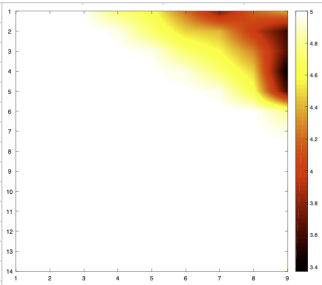
The construction of the interactive sheet follows a similar layer design to the ultra-thin bend sensors. The layer structure remained: **Base Material** -> **Conductor** -> **Velostat** -> **Conductor** -> **Top Layer**, this time however we took inspiration from touch screens. So, instead of a single conductor path with multiple data collection points, we used multiple conductor paths at 90 degree angles to create 14 X 9 (14 vertical conductors and 9 horizontal conductors) grid as shown in Figure 3.25.

The 14 X 9 grid introduces 131 intersection points, and each becomes a data collection point. For example, the previous ultra-thin bend sensors used just 5 data collections points. A far greater number of data collection points allows the sensor to detect voltage changes in 131 locations at once, detecting both bends and touches with an X and Y coordinate.

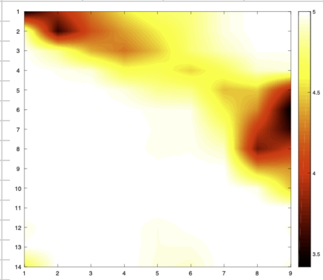
Unfortunately, it was not possible to make this sheet using paper. The conductor used was thicker, and the sheet required an airgap between the velostat and conductors. These changes resulted in the paper creasing and folding, causing data to be inaccurate. Also, due to its flexibility and thinness, the paper could not apply even pressure within the sheet. For this purpose, the interactive sheet was constructed using acetate sheets.

3.6.2 Bending an Interactive Sheet

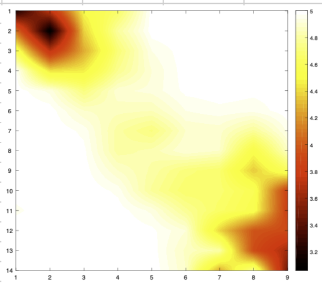
Carrying on the research we conducted for the paper input device for e-readers, we continued to identify the bends of **top corner**, **middle of page** and **bottom corner** as vital. We believed that these three bends would allow a real-world interaction technique for digital reading.



5	5	4.98	4.75	4.62	4.23	3.76	4.18	4.39
5	5	5	4.96	4.73	4.48	4.41	3.98	3.58
5	5	5	4.99	4.96	4.73	4.58	4.28	3.64
5	5	5	4.99	4.99	4.94	4.74	4.48	3.37
5	5	5	4.99	4.99	4.99	4.95	4.63	3.6
5	5	5	5	5	5	5	4.99	4.81
5	5	5	5	5	5	5	4.99	4.95
5	5	5	5	5	5	5	5	5
5	5	5	4.98	4.99	5	5	5	4.98
5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	4.99
5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	4.98
5	5	5	5	5	5	5	5	4.97



3.46	3.91	4.29	4.55	4.73	4.77	4.94	5	5
4.9	3.59	4.15	4.38	4.57	4.76	4.94	5	5
4.99	4.81	4.41	4.26	4.47	4.75	4.89	4.98	4.98
5	4.97	4.93	4.64	4.65	4.5	4.68	4.91	4.93
5	4.99	5	4.94	4.81	4.78	4.45	4.49	3.87
5	5	5	4.99	4.96	4.95	4.59	4.32	3.42
5	5	5	5	4.97	4.97	4.77	4	3.57
5	5	5	5	4.96	4.97	4.9	3.76	4.01
5	5	5	5	4.99	5	4.99	4.39	4.35
5	5	5	5	4.99	5	5	4.96	4.47
5	5	5	5	5	5	5	5	5
4.96	5	5	5	4.95	4.99	5	5	4.97
4.98	5	5	5	4.95	4.95	5	5	4.98
4.67	5	5	5	4.94	4.91	5	4.99	4.97



3.19	3.74	4.5	4.66	4.99	5	5	5	4.98
4.08	3.06	4.38	4.79	4.99	5	5	5	5
4.61	3.73	4.27	4.7	4.94	4.99	5	5	5
4.98	4.43	4.46	4.76	4.91	4.99	4.99	4.99	4.98
4.99	4.93	4.72	4.9	4.92	4.98	4.99	4.98	4.99
5	4.99	4.88	4.86	4.85	4.94	4.96	4.95	4.99
5	5	4.96	4.8	4.72	4.88	4.89	4.78	4.95
5	5	4.98	4.8	4.83	4.91	4.88	4.52	4.87
4.99	5	4.99	4.88	4.81	4.71	4.67	4.36	4.62
4.99	5	5	4.96	4.78	4.67	4.68	4.58	3.86
4.96	5	5	4.99	4.93	4.77	4.65	4.55	3.85
5	5	5	5	4.98	4.91	4.39	3.97	3.91
5	5	5	5	4.99	4.87	4.81	3.93	3.64
4.99	5	5	5	5	4.88	4.27	4.77	3.47

FIGURE 3.26: Heatmap and Data of a Top Corner Bend over time (Top - 200ms, middle - 600ms, Bottom 1000ms)

The interactive sheet allows a more considerable amount of data to be collected, allowing us to build a machine learning model to classify the bends for this prototype. The prototype polls each of the 131 data collection points every 200ms, with each point giving out a voltage reading, where 5v would mean that little to no pressure is applied, while anything below would mean pressure exists. For example, Figure 3.26 shows the data and corresponding heatmap of a top corner bend over one second from the dataset our colleague provided. Each table represents a snapshot of the data collected at different times (top - 200ms, middle - 600ms, 1000ms), and each cell represents a data collection point. The images show the area where the most pressure is applied, where the darker the colour, the greater the pressure. The raw data also shows this, where the lower the voltage, the greater the pressure.

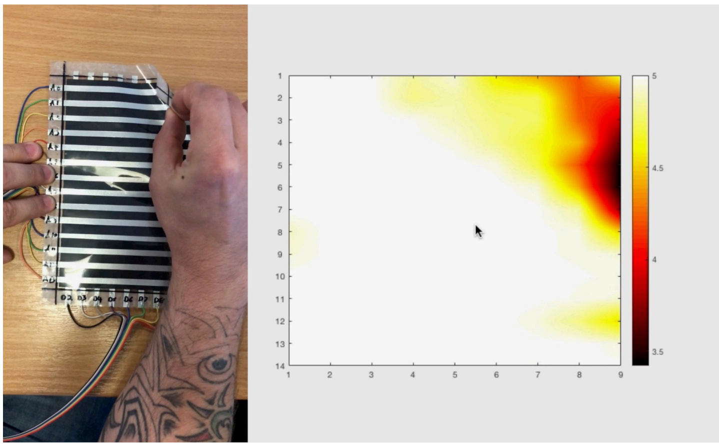


FIGURE 3.27: Heatmap showing Top Corner Bend

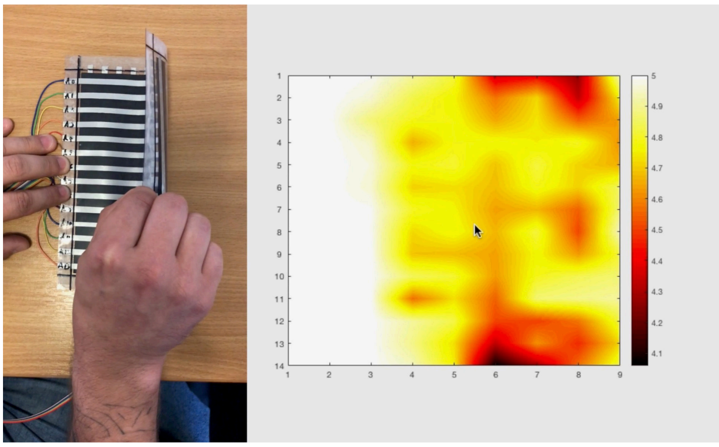


FIGURE 3.28: Heatmap showing middle Bend

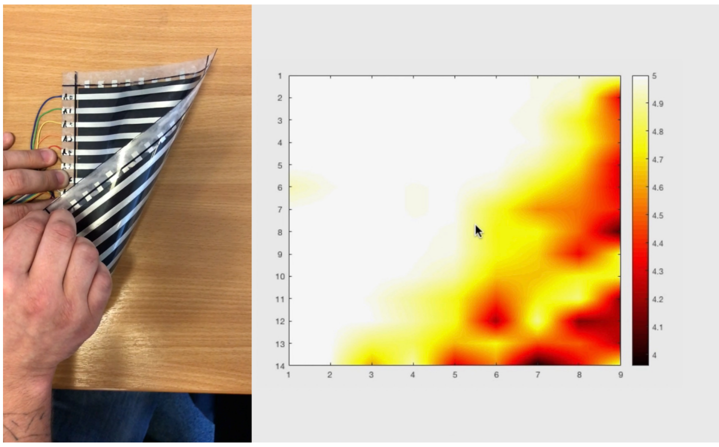


FIGURE 3.29: Heatmap showing Bottom Corner Bend

Figures 3.27, 3.28 and 3.29 show how the interactive sheet is bent in the real-world and a corresponding heatmap for each of the bend types. The Figures show the author performing top, middle, and bottom corner bends to test the machine learning model.

3.6.3 Modelling and Results

Creating a Model

We asked a single colleague to perform each bend multiple times to collect machine learning model data. As a result, we generated 60 data samples, where the colleague generated 20 samples per bend type.

60% of the data samples for each bend type were used to generate heatmaps and then saved as images. Following this, each image was stored in a corresponding folder of bend types, forming the training data set for a machine learning model with 36 images. Finally, 40% of the data went through the same process but was saved in its own file structure as testing data, consisting of 24 images.

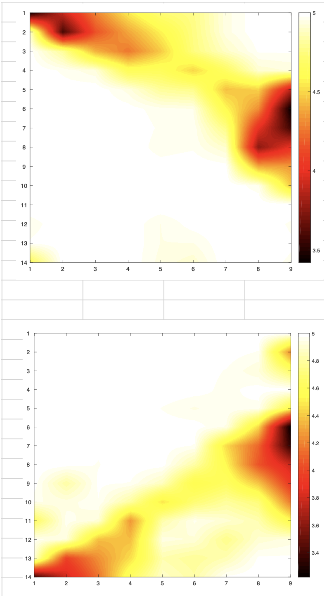
Finally, the CreateML[1] application, created by Apple Inc, was used to create the model. CreateML allows the creation of machine learning models quickly with its drag and drop interface and without the need for extensive theoretical knowledge.

Analysis

The author generated further data for each bend, and this data was to be used to test the confidence level of the machine learning model. Confidence testing revealed that high confidence is achievable through the machine learning model and an interactive sheet. For example, the machine learning model of data generated from a single user (a colleague) was able to classify each bend type of another user (the author) at confidence levels >80%, with each bend performing differently.

Middle Bend - The middle bend far outperforms both the top and bottom corner bends, with confidence levels at >90%. This performance is somewhat unsurprising, as this bend affects the largest area of the sheet. Figure 3.28 shows a heatmap of a middle bend. First, the heatmap shows a thin dark red vertical line representing the peak of the bend, and then two-thirds of the heatmap is yellow, meaning pressure is applied. Evaluation of confidence for this bend type reveals minimal confidence level for other bend types. Table 3.2-(b) shows a typical

[1] Apple Inc. *CreateML*. 2020. URL: https://developer.apple.com/machine-learning/create-ml/.



3.46	3.91	4.29	4.55	4.73	4.77	4.94	5	5
4.9	3.59	4.15	4.38	4.57	4.76	4.94	5	5
4.99	4.81	4.41	4.26	4.47	4.75	4.89	4.98	4.98
5	4.97	4.93	4.64	4.65	4.5	4.68	4.91	4.93
5	4.99	5	4.94	4.81	4.78	4.45	4.49	3.87
5	5	5	4.99	4.96	4.95	4.59	4.32	3.42
5	5	5	5	4.97	4.97	4.77	4	3.57
5	5	5	5	4.96	4.97	4.9	3.76	4.01
5	5	5	5	4.99	5	4.99	4.39	4.35
5	5	5	5	4.99	5	5	4.96	4.47
5	5	5	5	5	5	5	5	5
4.96	5	5	5	4.95	4.99	5	5	4.97
4.98	5	5	5	4.95	4.95	5	5	4.98
4.67	5	5	5	4.94	4.91	5	4.99	4.97

5	5	5	5	5	5	5	5	4.99
5	5	5	5	5	5	4.99	4.97	4.24
5	5	5	5	5	4.99	4.97	4.92	4.67
5	5	5	5	5	4.99	4.96	4.99	4.99
5	5	5	5	4.97	4.94	4.97	4.96	4.56
5	5	5	5	4.99	4.99	4.94	4.44	3.22
5	5	4.98	5	4.99	4.97	4.45	4.11	3.34
5	4.99	4.97	5	4.99	4.81	4.53	4.05	3.78
4.99	4.81	4.98	4.97	4.86	4.53	4.63	4.39	3.94
4.95	4.93	4.97	4.8	4.48	4.69	4.79	4.71	4.18
4.65	4.96	4.91	4.26	4.82	4.95	4.9	4.83	4.56
4.96	4.92	4.37	4.37	4.93	4.91	4.75	4.9	4.93
4.91	3.98	4.24	4.46	4.83	4.78	4.84	4.98	4.98
3.4	3.8	4.16	4.64	4.88	4.81	4.98	5	5

FIGURE 3.30: Heatmap and Data of Top and Bottom Corner Bends

Top Corner Bend	
Bend	**Confidence**
Top	83%
Middle	4%
Bottom	13%

(a)

Middle Bend	
Bend	**Confidence**
Top	2%
Middle	97%
Bottom	1%

(b)

Bottom Corner Bend	
Bend	**Confidence**
Top	16%
Middle	4%
Bottom	80%

(c)

TABLE 3.2: Typical Confidence decision of (a) Top Corner Bend and (b) Bottom Corner Bend

confidence decision for a middle bend, with top and bottom corner bends having less than 3% confidence.

Top and Bottom Corner Bends - Both of these bend types performed pretty much equally, with confidence levels being >80%. Top corner bend confidence slightly outperformed bottom corner bend confidence by ~2-3%, but we will discuss these together as they are similar. In theory, these bends are, mirrored images, as shown in Figure 3.30, which shows both heatmaps and recorded data of top and bottom corner bends. The data shows drops in voltages from the originating corner at the angle of the bend. If the image and data are mirrored, it could easily pass for the opposite corner bend, so it was explicitly stated that no mirroring or rotation should occur during the training process. However, this did not prevent the model from showing a confidence level for other bend types. Table 3.2-(a) shows a typical confidence readout of a top corner bend, where a very high (83%) confidence level for the top corner bend is shown, followed by insignificant readouts (13% Bottom, 4% Middle) for the remaining bends. Table 3.2-(c) shows a very similar result, but for that of the bottom corner bend, where the confidence levels for top and bottom are flipped.

3.6.4 Discussion

The interactive sheet can bring an accurate, genuinely flexible and true paper-like input device to digital reading devices. Unfortunately, at this time, technology does not allow the construction of an interactive sheet using paper, so the texture and feel of paper are lost. However, further research of printed electronics and material synthesis may someday yield an interactive sheet of paper. For example, maybe it is possible to take research from the textile industry and weave the required data lines into paper at the time of manufacture.

The results of the interactive sheet approach show a more accurate gesture recognition method, especially when we compare the interactive sheet to that of the paper input device. In addition, our machine learning model showed confidence levels for the defined gestures as >80%. Therefore, we theorise that a significantly larger dataset from multiple participants would yield greater confidence levels.

Scalability

We included three gestures in our prototype interactive sheet: top-corner, middle, and bottom-corner bend. We chose the gestures using our previous work on the paper input device. The interactive sheet can potentially be far more interactive than the paper input device due to the significantly increased data read points (paper input device: 5 read points, interactive sheet: 131 read points).

Further time and data collection would allow a more significant number of gestures to be included within the gesture detection model. The number of possible gestures is undetermined at this point, as the confidence levels of all gestures would need to be considered. We assume that adding too many gestures would begin to impact the confidence of existing gestures. Gestures would begin to collide, making it harder for the model to differentiate between them.

The interactive sheet opens the possibility of including touch gestures, and as touch is possible, it would also be possible to explore swipe gestures. Again, adding to the amount of interactivity such an input device can add. As touch is a possibility, we can explore the gestures that users have come to know through mobile devices.

Our previous work on the paper input device explored using multiple pages to invoke different interactions. So far, we have explored a single interactive sheet, if in the future, when it is possible to make the interactive sheet from a more paper-like material, interactions with multiple sheets will be explored.

Limitations

As discussed in the previous section, the interactive sheet detection model is currently limited to just three gestures. However, this limitation can quickly become significantly less limiting with more data and the introduction of other gestures.

From the outset, we strived to introduce physical controls for digital books that had the feeling and texture of actual paper. Unfortunately, due to the current limitations of electronic printing techniques and material production, it is not possible to manufacture an interactive sheet using such materials. The main reason for this is that the electronics require an airgap between the data lines and piezoresistive layer to detect resistance changes. Therefore, we consider the compromise in material texture and feel a limitation of our implementation. This limitation is significantly harder to remove; new methods of printing electronics and producing paper would need to be developed to produce a like-for-like device with the texture and feel of paper.

3.7 Summary

Throughout this chapter, we have explored paper as an input device for digital books, which led to creating two prototypes, the paper input device and the interactive sheet. Each prototype seeks to create an authentic book-like user experience for digital reading, where actions once associated with physical books are brought into the digital world. This section summarises and reflects on both prototypes and the lessons we learned from each and its corresponding studies.

At the beginning of this chapter, we introduced the concept of the paper input device. A device that embeds ultra-thin custom bend sensors onto paper to detect user input. We refined an existing method of making custom bend sensors, often used by members of the maker community. We were able to make the sensors as narrow and thin as possible, which led the sensors to make a minimal impact on the flexibility of the base material and minimise the chance of users feeling them. In addition, the device used a multi-page interaction approach to circumvent a limitation of the electrical signals generated by the top and bottom bends, which were unfortunately indistinguishable. During this time we discovered a new bend classification for paper pages, different from the existing literature. Three interactions were incorporated: single-page bend: change page, double-page bend: change chapter, triple-page bend: scroll through pages. Finally, we conducted a user study and recorded its results following the prototypes design and implementation. We learnt that users enjoyed the experience offered by a paper input device and that they felt that such a device could improve the digital reading experience.

Next, we describe the interactive sheet, a prototype device designed to overcome the limitations of the electrical signals of the paper inputs device. Ideally, we would have produced the interactive sheet using paper as its base material. However, current circuit printing methods do not allow this, so instead, we made the compromise and used acetate sheets. Next, we performed a data-gathering exercise where a single colleague executed different bends using the interactive sheet. This data was used to generate a machine learning model to identify how the sheet was bent. As a result, we learnt that the interactive sheet model could detect the bends and categorise them to a high confidence level.

As a whole, this chapter shows that an actual physical book like user experience for digital books is possible and that users feel that it is enjoyable and that it can enhance their digital reading experience overall, as identified in the study of the paper input device. We demonstrate that an interactive sheet can identify multiple bend gesture types using heatmaps and a machine learning model, and we discuss the addition of many more bend, touch and swipe gestures to increase interactivity. In addition, both prototypes open up interesting questions and avenues of exploration within the tangible user interface and material design spaces.

The next chapter explores tangible user interfaces for digital book interaction, examining book edge interactions and producing a solution for mobile devices. This chapter explored the more book-like side of device interactions, which could be somewhat inconvenient in a mobile setting. Our subsequent explorations look to bring tactile interactions to digital books in a more convenient mobile setting.

Chapter 4

Compact Side of Device Tangible Interactions

In the previous chapter, we explored using paper as an input device for digital books. Furthermore, we demonstrated how to augment paper with custom ultra-thin bend sensors to detect several bend types. Finally, we developed two methods of tactile input for a paper input device, a single-page approach and a multi-page approach. Unfortunately, our single-page system endured some problems that we quickly resolved following the development of the multi-page system and later led to the development of the interactive sheet. However, this chapter follows the physical controls with digital books concepts more compactly and practically.

This chapter explores the use of side of device interactions to invoke the functionalities of e-books. First, we present a novel interaction technique, where guitar strings are used for input as a metaphor for the edge of paper pages. We then document our design decisions regarding the form factor of such a device and explain how the iterative design process aided us in completing a full prototype.

We present the results of a user study, where we asked participants to explore different gestures. Participants were given a set of e-reader functionalities and were asked to create their own gestures to invoke these. The study tested the accuracy and usability of the device in the context of digital reading.

We complete this chapter with discussions of our results and that with further technological developments, we could improve the guitar string input system.

4.1 Introduction

In the previous chapter, we looked at paper as an input device, which we presented through a device with paper attached to a mobile device. Yes, our prototype showed that it is possible and that users believed it could enhance digital reading. However, the implementation is somewhat impractical. Furthermore, we do not imagine users walking around daily with paper flapping from the side of their mobile device, so in this chapter, we explore a more portable solution.

During this PhD, the author made continuous ethnographic and autoethnographic observations. The observations became part of daily life and took part in several settings, such as the office, public transport, and home. For example, the author observed how individuals interact with printed books and discovered that the edges of printed pages play a pivotal role in the reading process. When navigating a printed book, the edges of pages are used in several ways, such as flicking a page to change the visible content or folding over the corner to "dog-ear" a bookmark.

We conceptualised using the edges of pages as an input device. Our vision involved bringing the tangible interaction of page edges to mobile devices in a compact and portable form. Interactions with page edges have been investigated previously [71], looking at motorised paper slats to give the tactile feedback of scrolling through a printed book whilst reading an e-book. Also, many methods of side of device interactions have been explored, including [98, 122, 135], where flexible and pressure-sensitive materials have been used on the side of mobile devices to invoke interactions.

This chapter designs, develops and studies a compact side of device interaction prototype to bring tactile interactions to electronic books.

4.2 Page Edges as an Input Device

We learnt in the previous chapter that paper is an unforgiving material when trying to attach sensors, and that was on a large surface area. Moreover, the edge of the paper is extremely thin and fragile, ruling out the use of paper here. So our first thought was that of a loom (Figure 4.1), a machine used to weave fabrics. A loom has a series of threads running side by side. We imagined that running our fingers through these could loosely replicate the feeling of an edge of a book, which led to us exploring methods to use a system of parallel running threads to reproduce the edges of individual paper pages.

FIGURE 4.1: Loom device showing multiple threads. Image Source: People are weaving with traditional Thai Lanna weaving machines, Ananaline, Adobe Standard Licence, https://tinyurl.com/4adka68x

The first problem we incurred was how to detect interactions with a loom-like interface, and in this section, we document the materials and methods we explored.

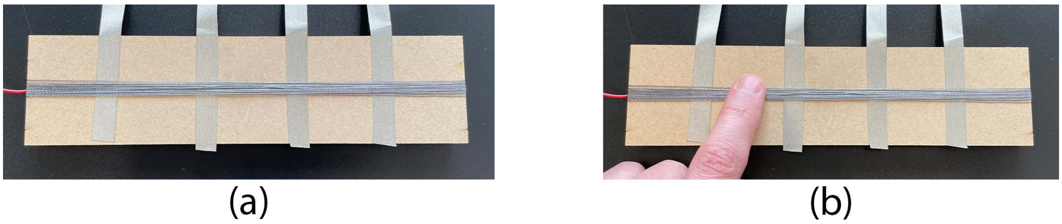


FIGURE 4.2: Prototype conductive string input device

4.2.1 Conductive Thread

Our first approach to the problem had us taking the idea of a loom literally. We built a prototype input device using conductive thread and tape. We wrapped the thread around a rectangular piece of MDF and attached strips of conductive tape at 3cm intervals, as shown in Figure 4.2-a.

The wrapped thread is connected to the 5v line of an Arduino, and each strip of conductive tape connects to an analogue port. The theory behind this prototype was that, when touched, the current would flow from the conductive string into the conductive tape, allowing us to infer the touch position. The prototype allowed seven positions along its length to be determined as a touchpoint. So, for example, if we placed a finger on a single piece of tape or between two pieces, the device could decide the touch location (4 strips + 3 gaps).

The prototype allowed the accurate reading of touch location along a single axis. Each strip of conductive tape was polled every 10ms, where the device recorded a voltage. The device would compare voltages, and touch location would be decided as follows:

(a) **Single Strip High Voltage:** If a single strip of the conductive tape showed a high voltage, where approx 5v is high. The strip was determined as the touchpoint.

(b) **Double Strip High Voltage:** If two strips were showing high voltage, the gap between them was considered the touchpoint. Figure 4.2-b shows finger position of double strip high voltage.

Conceptually we created a strip with seven buttons that felt very much like the edge of a book. However, this design was not suitable for several reasons. Firstly, the device could only detect on a single axis, allowing touch location to be found only along its length. For a natural edge of the book interface, the location would be required along two axes. Secondly, the durability of the thread was in question. After prolonged use, the thread frayed and eventually broke. For these reasons, we sought an alternative method.

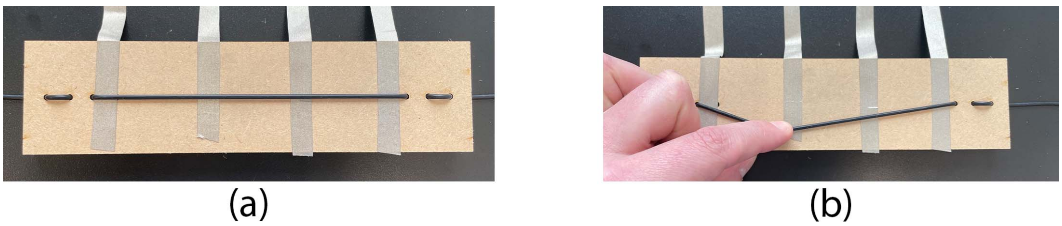


FIGURE 4.3: Prototype conductive rubber stretch sensor input device

4.2.2 Conductive Rubber Stretch Sensor

Following the thread prototype, our focus was finding a similar method using two axes. We explored using a series of conductive rubber stretch sensors in place of conductive thread. We built a prototype rig using a conductive rubber stretch sensor and conductive tape. It was mounted onto a rectangular piece of MDF like the thread prototype and had the conductive tape strips placed at 3cm intervals, as shown in Figure 4.3-a.

Detecting Touch

Firstly, we tested the capabilities of the rubber to detect the seven touchpoints we found using conductive thread. Unfortunately, the rubber failed to identify all seven points, as it only managed four. The conductive rubber worked well at carrying the electricity along itself. However, it did not transfer to the tape efficiently. A greater downwards force was required to allow the electricity to transfer to the tape, which only worked when the pressure was directly above the tape.

Detecting Pulls

Next, we tested the rubber's ability to detect stretch, which we would use to measure the second axis. The conductive rubber stretch sensor works similarly to a potentiometer, with resistance increasing as it is stretched. We set up the prototype device to monitor the resistance of the rubber stretch sensor whilst also polling the four conductive tape strips.

In the prototypes default state (Figure 4.3-a), all four tape strips show no contact, and the resistance of the rubber fluctuates at approximately 2Kohms. Unfortunately, not much changes when a slight stretch occurs. Figure 4.3-b shows the rubber under stress over a tape strip. The device can detect the touch over the tape strip. However, the resistance of the rubber barely changed approx 50ohms. If the resistance of the rubber were consistent, this would not be a problem. However, the fluctuations seen in the default state were often around 60ohms, making the stretch at this scope undetectable.

For the stretch of the rubber to be clearly detected, a far greater stretch is required, like that seen in Figure 4.4. The stretch in the figure increases resistance by 500ohms. However, the stretch is too big for a mobile device and makes the other axis undetectable. For this reason, we did not implement multiple rubber strips and investigated different input methods.

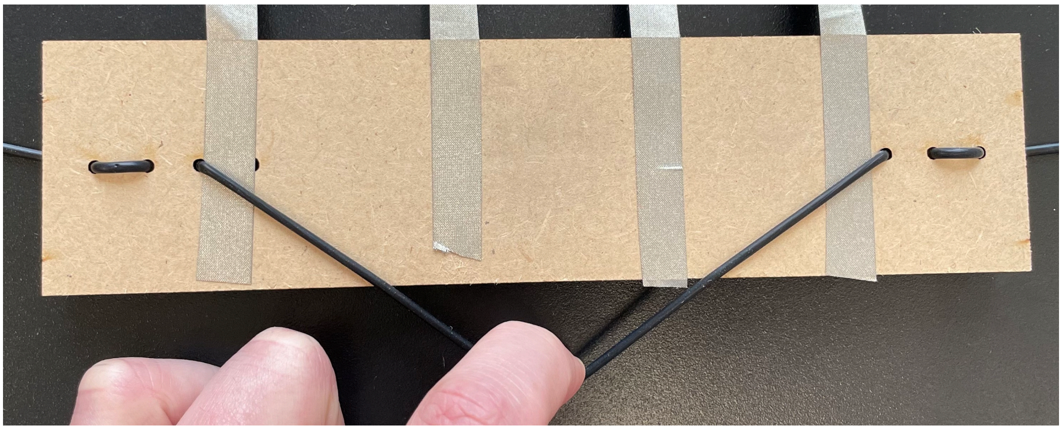


FIGURE 4.4: Stretch of conductive rubber stretch sensor

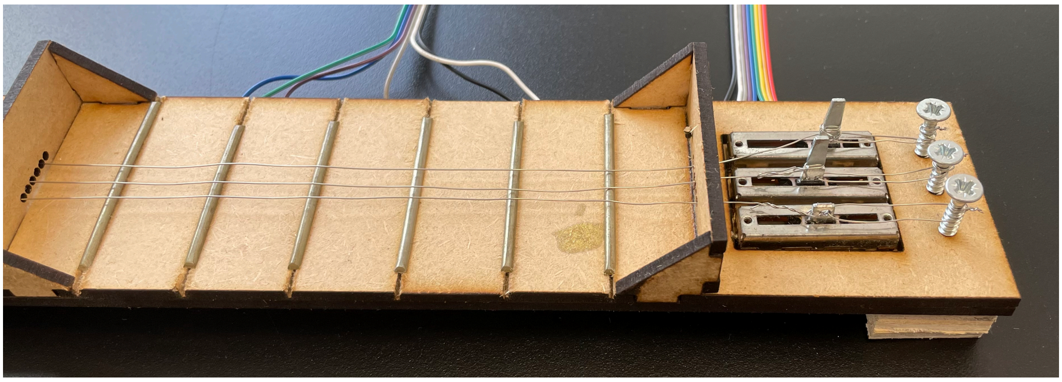


FIGURE 4.5: Prototype conductive rubber input device

4.2.3 Guitar Strings

Our final input method took inspiration from the guitar, where we created a guitar neck input prototype. This prototype was more complex than those that came before, as we had to explore methods of turning frets from an actual guitar into an input device. The device consisted of three guitar strings, three linear potentiometers and six guitar frets, as shown in Figure 4.5.

Using guitar strings or guitar frets as an input device has been explored several times in the past [48, 125, 97]. Unsurprisingly, all existing works regarding guitar strings and frets are within the context of music, particularly guitar trainers or aids. For our work, we investigated the use of guitar strings and frets to detect touches and gestures on the side of a mobile device.

Detecting Touch

Again, the first problem we tackled was the issue of touch. The power ran through the corresponding material in both the thread and rubber prototypes. However, in this prototype, a new approach was needed. We connected each guitar string to a linear potentiometer for this prototype. Unfortunately, this made powering the strings an issue, where the potentiometers detected interference. So to eliminate the interference, we no longer powered the guitar strings. Instead, we developed a method to make each guitar fret both an output for power and an input device.

Each of the six frets on the fretboard prototype had an electrical connection on its underside. These electrical connections then connect to a microcontroller. Next, the microcontroller switches each fret from an output to an input every 20ms, where only a single fret acts as input at a time. Figure 4.7 shows the switching pattern, where red wires indicate a powered fret and green wires represent an input fret.

With each fret switching from output to input every 20ms, in theory, we created a series of broken circuits that only exist for 20ms periods. Next, each circuit needed a method to bridge the connections to detect a touch, and for this, we used guitar strings. Guitar strings and frets are highly conductive, so they can bridge the circuits when pressed together. Figure 4.7 also shows the sequence of frets and the flow of electricity when pressed. When the guitar string bridges a circuit between two frets, the microcontroller detects the current, then the sequence continues. The prototype can determine the touch location over several cycles, Figure 4.7 shows a touch inside the middle frets. The touch location is determined in the following way:

0ms - No electrical current detected.

20ms - Fret 2 (green) detects electrical current.

40ms - Fret 3 (green) detects electrical current.

60ms - No electrical current detected.

As fret 2 and 3 detected electrical current during their input cycles, the prototype determined that the touch occurred between them. This technique works for all fret pairs.

Detecting Pulls

The prototype allowed touch detection along a single dimension via the electronically connected frets, and we required two-dimensional detection. We mentioned above that the device connected each guitar string to a linear potentiometer. The

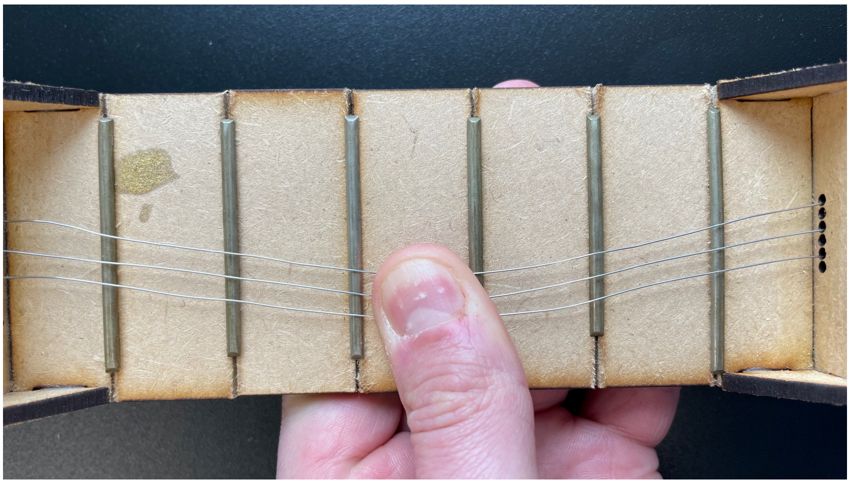


FIGURE 4.6: Bending of the guitar string interface.

prototype uses linear potentiometers to measure the tension of each string, an idea inspired by the conductive rubber prototype. The previous rubber prototype detected tension and stretch, but the readings were unpredictable due to fluctuations. Linear potentiometers eliminate the fluctuations, offering steady and accurate readings.

Each guitar string was tensioned with the linear potentiometer slid approximately halfway. A microcontroller connects to each potentiometer and takes readings every 100ms. Default readings sat at around 500, where 0 is the minimum, and 1024 is the maximum.

Figure 4.6 shows the guitar strings being pulled to one side. Pulling a guitar string affects its tension, thus altering the reading obtained from the linear potentiometers. As a result, the readings taken during Figure 4.6 were reduced by around 100 from default. This evident change in collected data allows the detection of string pulls of various degrees, giving the guitar fretboard prototype two-dimensional location detection.

4.3 Prototype

We prototyped a tangible user interface for the side of device interactions, mimicking book edge interactions to improve the tactile experience of mobile digital reading. This section describes the design process of a compact fretboard input device for digital reading, and we made three design iterations.

The fretboard interface device went through two hardware revisions. Each revision was decided by the device's form factor, which we discuss below in Section 4.3.1.

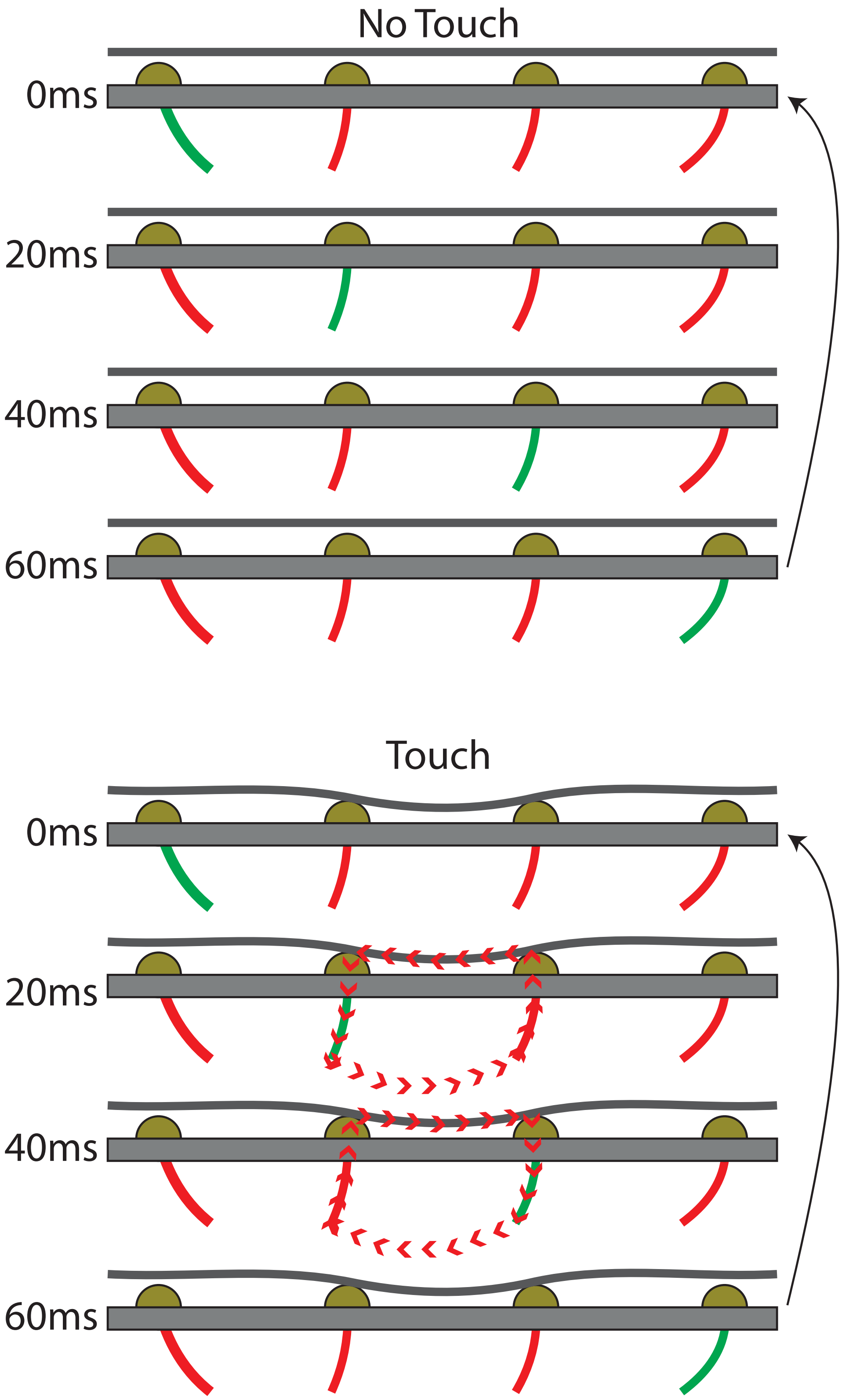


FIGURE 4.7: The switching sequence of frets from output to input, and we visualise a touch. (the arrow shows a repeat of the sequence)

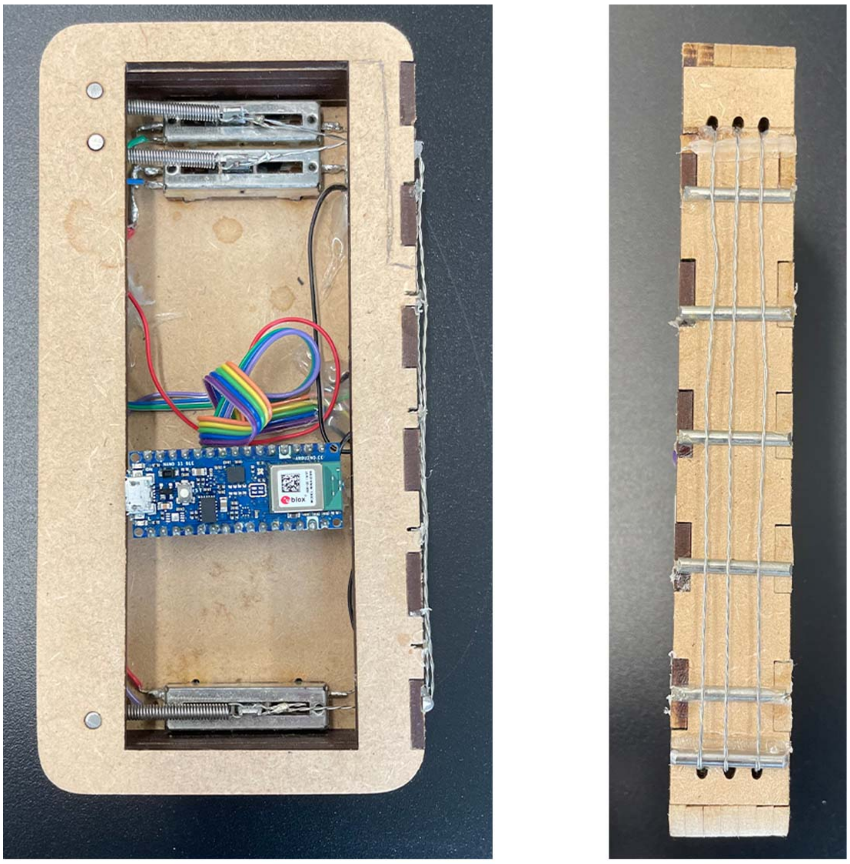

(a) (b)

FIGURE 4.8: Slim form factor with a linear potentiometer (a) top (b) right-hand side.

Each hardware revision was built using a microcontroller with Bluetooth connectivity, a custom printed circuit board, guitar frets, guitar strings and a battery. Early iterations used linear potentiometers to detect string pulls. However, these are omitted in the final design, dictated by the form factor.

4.3.1 Form Factor

Our goal for the input device was to make it as compact as possible whilst housing a mobile device, so somewhat of a smart device case. In addition, we wanted the form factor to be able to be used and be comfortable in the hands of users.

Slim Linear Potentiometer Design

Our first design iteration uses the fretboard interface as described earlier, with a difference. The original fretboard interface had linear potentiometers in line with

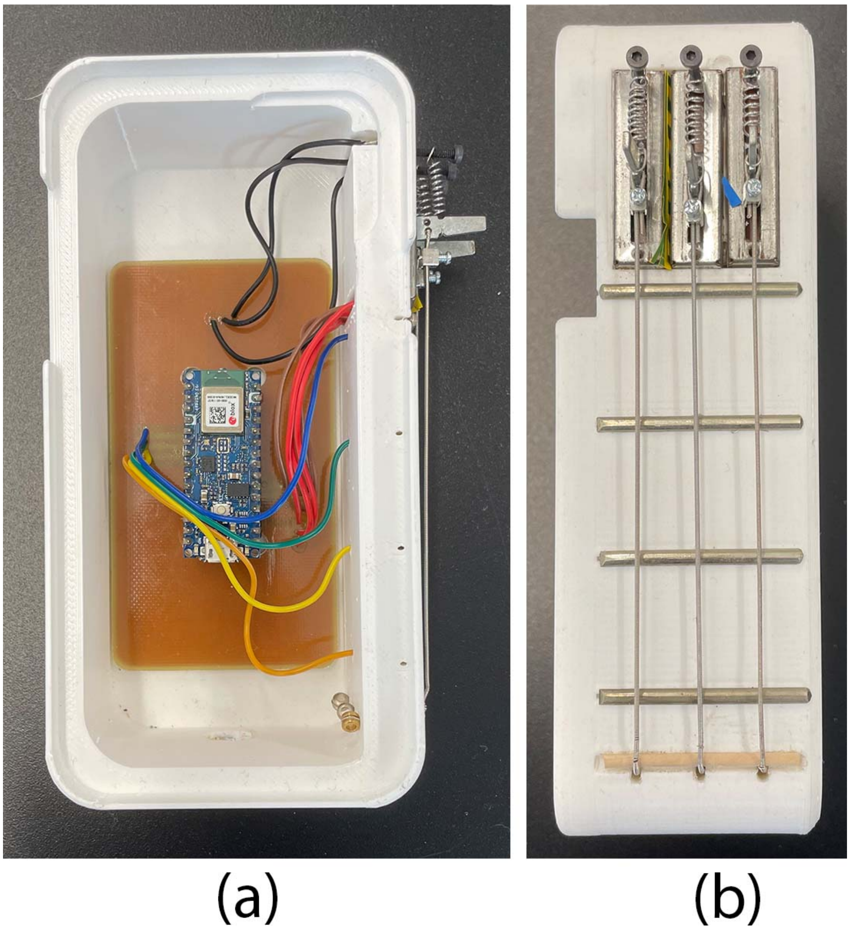


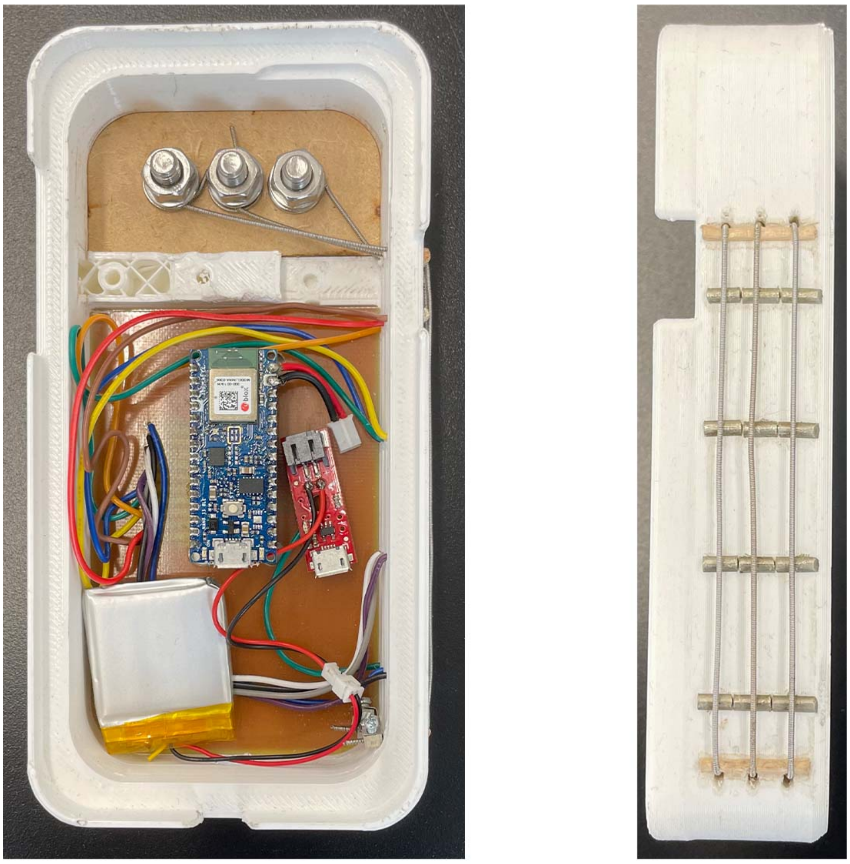
FIGURE 4.9: Inline linear potentiometer form factor (a) top (b) right-hand side.

each string. However, in the name of compactness, we moved the potentiometers in this revision, as shown in Figure 4.8.

Each string is located on the right-hand side of the device, and then it makes a sharp ninety-degree turn to be inside the device where the potentiometers are now located. Unfortunately, the turn became an issue that would make this revision unusable.

Guitar strings are made of metal, and metal has a point in which it doesn't want to return to its original shape. This property of the guitar strings, combined with the ninety-degree bend, prevented the guitar strings from returning once pulled. So, for example, when pulled, the guitar string would become slack and detect a constant pull, even after being released.

We added Springs to the device to rectify the issue. However, this made the guitar strings too tight and hard to pull with fingers. As the springs did not eliminate the



(a) (b)

FIGURE 4.10: Slim slit fret design form factor (a) top (b) right-hand side.

problem, we sought another solution.

Inline Linear Potentiometer Design

The following form factor iteration returned to the inline linear potentiometer design, eliminating the problems introduced when a bend was added. Figure 4.9 shows the guitar strings with inline potentiometers.

This form factor iteration allowed each guitar string to be pulled and then returned to its original position. However, the design introduced its own problems. The first issue presented was its sheer size. The device's height had to be substantially increased to incorporate the three linear potentiometers on its side. This increase in height made the prototype awkward to hold and made it hard to reach the uppermost guitar string without overextending, which introduced wrist strain after prolonged use.

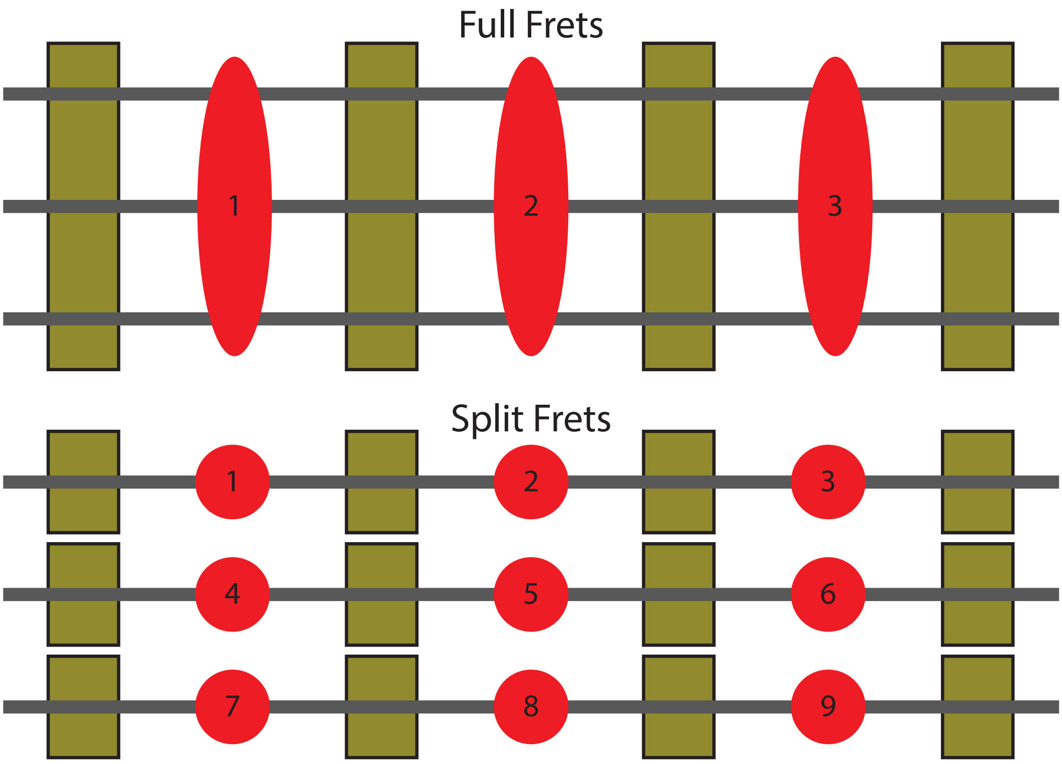


FIGURE 4.11: Fret designs for both full and split fret prototypes. Red circles represent touchpoints.

The author and several colleagues piloted this form factor, and by doing so, we discovered a usability issue with the linear potentiometer fretboard system. We envisioned the "pulling" of the strings to create gestures. However, when in a handheld device, the strings are instead "plucked" or "strummed", more like a guitar. Furthermore, the "plucking" and "strumming" of strings registered a far more minor change to the string's tension. Also, this occurred over a massively smaller timeframe, making it hard to detect by the microcontroller whilst also making gesture detection impossible.

Split Fret Design

The iterative design process allows for changes to be made whenever information comes to light that affects a design. Fortunately for us, the iterative design process allowed us to see an issue in the fret design which was not apparent earlier in the cycle.

Earlier designs of the fretboard input device used full frets. So, each fret spanned the width of the device edge and was shared by each string. The full fret designs allowed the device to have three input pairs of frets (where a guitar sting bridges

FIGURE 4.12: Tuning peg-like string tensioning device.

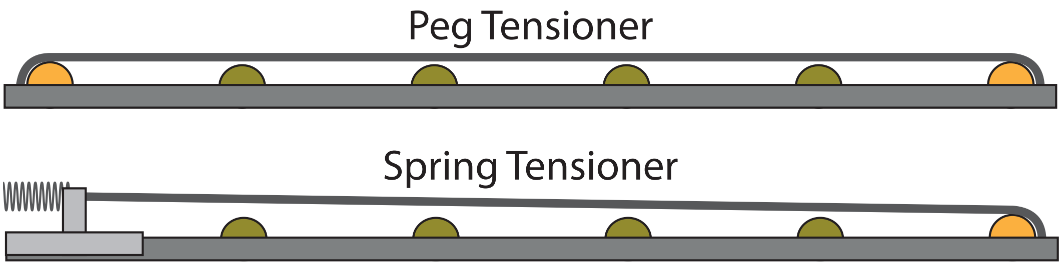


FIGURE 4.13: Diagram of peg and spring tensioner systems.

the circuit), making three touchpoints along the X-axis. However, after discovering that the string tension detection for the Y-axis was less than optimal in a mobile form factor, we designed an alternative solution.

As a solution, we developed a split fret design. So, instead of having four frets and three touchpoints, we used twelve frets, which created nine touchpoints. Figure 4.11 shows each fretboard design, with each red circle representing a touchpoint.

Removing the linear potentiometers and splitting the frets creates a 3x3 matrix of touch locations. In some way, this method is less dynamic, as the linear actuators allowed for more variable input when pulling stings. However, it offers more excellent responsiveness and the possibility of a more significant number of gestures, for example holding gestures in the form of guitar chords. In addition, the split fret design allowed better detection of "strumming" motions with the aid of a string tensioning system.

Earlier prototypes relied upon a spring attached to each linear potentiometer to apply tension to each string. However, the spring method made it difficult to use the same amount of tension on each string, setting the tension at prototype construction. So, again, taking inspiration from the guitar, we implemented a tuning

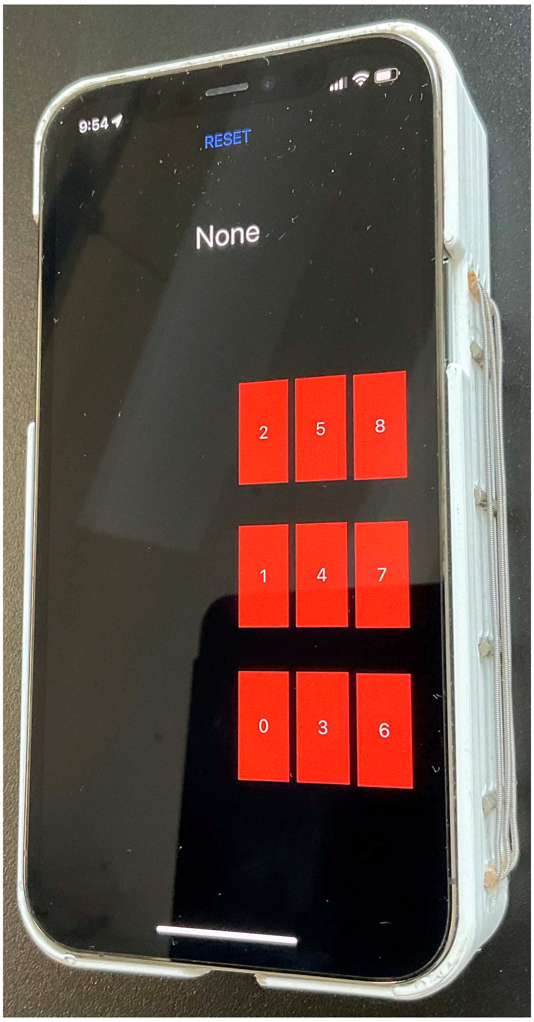


FIGURE 4.14: Final guitar fret prototype with mobile device.

peg-like string tensioning device, as shown in Figure 4.12. This tuning peg-like tensioning device allowed the tension of each string to be changed dynamically, whenever needed. However, its main benefit was its ability to pull the strings closer to the frets, making the required pressure less significant.

Figure 4.13 shows the difference in string height between the two tensioning systems. The peg tensioner offers a closer and more uniform string height because the string is pulled into the device against the non-conductive height setting frets. The spring tensioner is less consistent, with the strings set higher and at a slight angle. The angle meant that the string needed more pressure for the frets closer to the linear potentiometer.

Finally, we slotted a smartphone into the top of the device to act as the user interface, as shown in Figure 4.14.

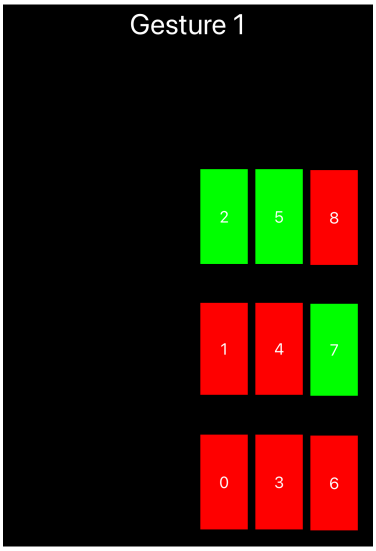


FIGURE 4.15: Prototype application showing hold gesture.

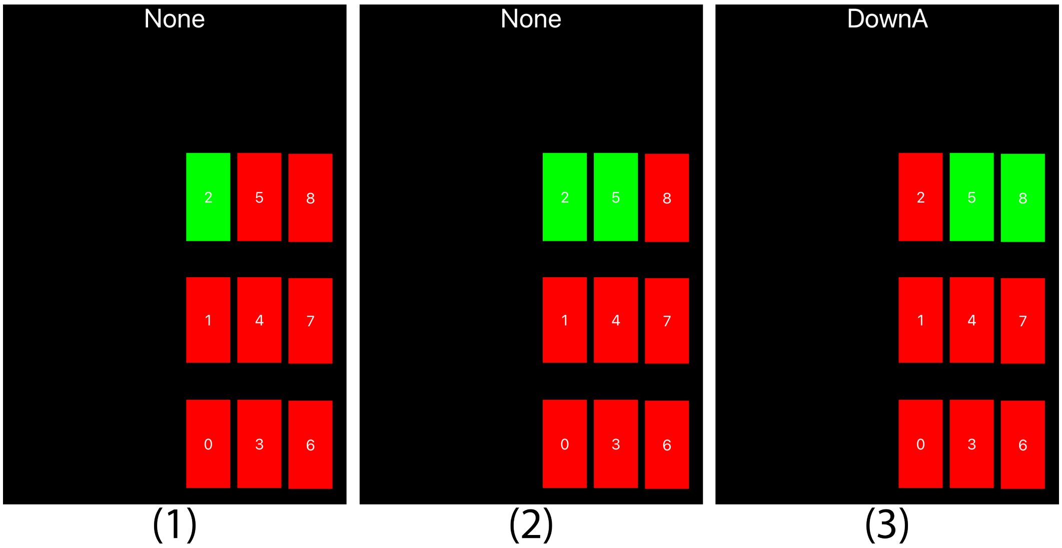


FIGURE 4.16: Prototype application showing downward strum gesture. Numbers showing order of touch detection. (3) shows a detected gesture

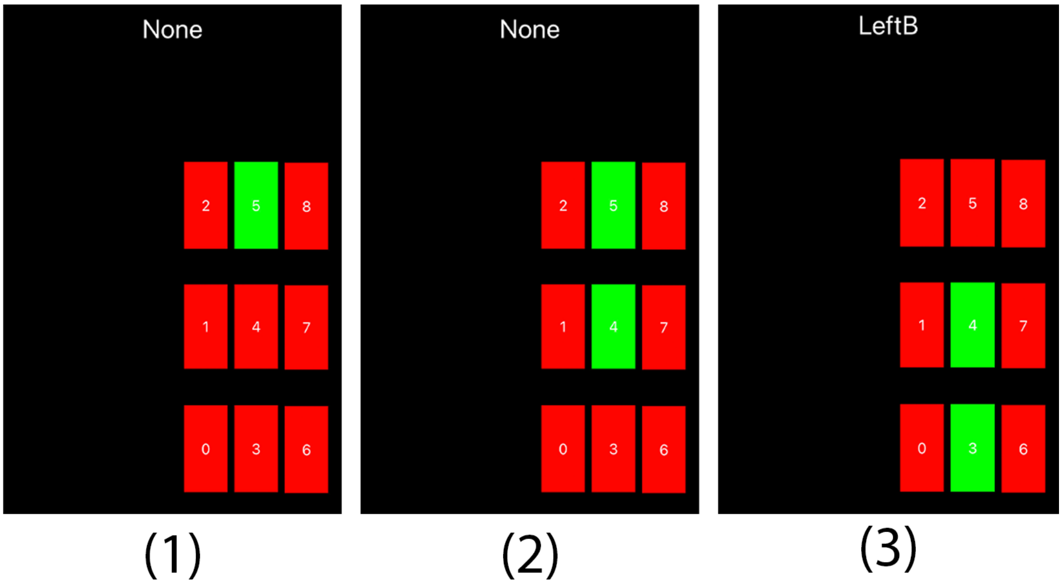


FIGURE 4.17: Prototype application showing slide gesture. Numbers showing order of touch detection. (3) shows a detected gesture

4.3.2 Application

This prototype's GUI focused on gesture detection rather than mimicking an e-reader application like our previous chapter. The GUI was simple, consisting of a textbox to display when a recognised gesture was detected and a 3x3 matrix of coloured blocks representing touchpoints. Each touchpoint was red when no touch was detected and turned green when it saw a touch. The default status of the interface can be seen in Figure 4.14.

The application communicated with the prototype via Bluetooth LE, where the smartphone was the central device, and the prototype was a peripheral. Several GATT characteristics were set up, representing the status of each fret and gesture detection. As the prototype is set up as a peripheral, it advertises any changes to its characteristics. The central (smartphone) instantly detects any changes.

The application reacts to each notification from the peripheral. Firstly, when a touchpoint advertises it is touched, the coloured boxes change colour. Secondly, if a gesture is detected, the text label displays the name of the detected gesture. The application reacts to touch, strum and slide gestures.

Touch gestures: A touch gesture is declared when a set of frets register as being touched at the same time. For example, both short and holding touches are recognised as touch gestures. We define a short touch as a fret remaining in the touched state for greater than 250ms. Figure 4.15 shows an example touch gesture, where

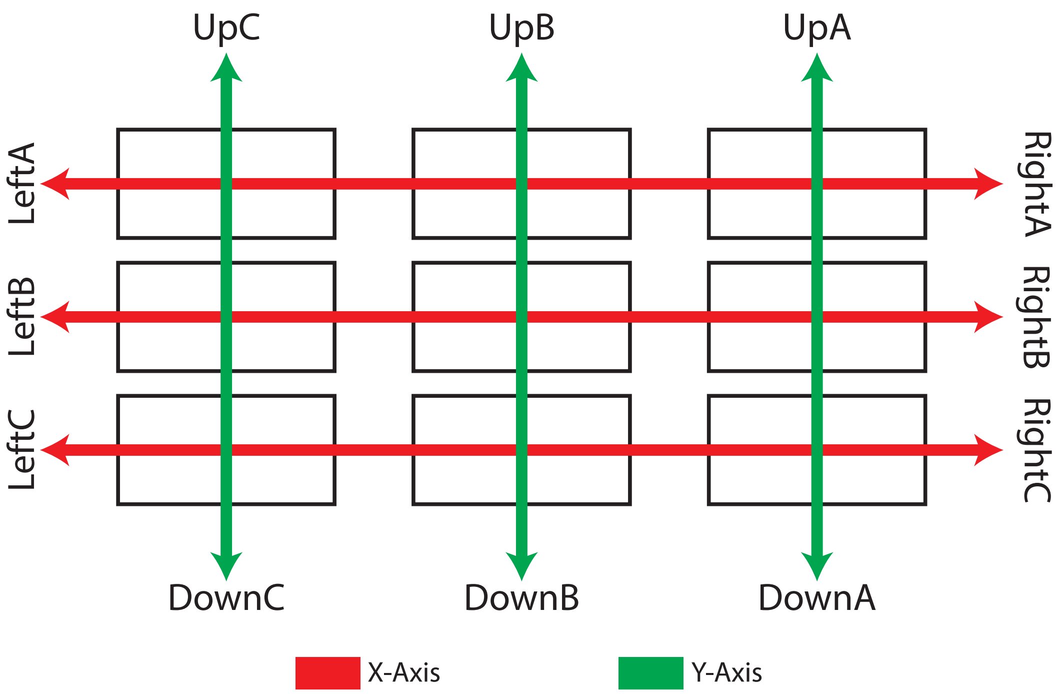


FIGURE 4.18: Visualisation of gesture directions across touchpoints. Where green arrows show strum gestures and red arrows show slide gestures.

frets 2, 5 and 7 are held, and the label displays "Gesture 1". We can later apply this gesture type to a functionality of the device.

The ability to detect both strum and slide gestures is achieved via the two dimensionals of the split fret design. Having a two dimensional design allows the detection of interactions along both the x and y axes. Without the splitfret design the device would find it difficult to detect which string is touched and in what order, almost completely eliminating the y-axis.

The y-axis allows the detection of strum gestures directed towards the back and front of the device, while the x-axis allows the detection of slide gestures directed towards the top and bottom of the device. These type of gestures are intuitive of a guitar fretboard like device.

Figure 4.11 shows the affect of the ability to detect interactions over both x and y axes. Without both axes, the possible interactions are reduced greatly, including the number of possible touch interactions. The total number of possible touch combinations for a two axis design is 511, where a single axis will allow 7.

Strum gestures: A strum is declared when different strings are touched in order over a short period. For example, Figure 4.16 shows the gesture "downA". The "downA" gesture is recognised when frets 2, 5 and 8 are strummed with no longer than 250ms between each touch and release. The application can detect strum gestures along the Y-axis. Slide gestures can be detected in both the **up** and **down** directions, as shown in Figure 4.18 as green arrowed lines. The application shows that a strum gesture is detected by displaying the strum direction and the fret, e.g. "DownA".

Slide Gesture: A slide is declared when different frets are touched in order over a short period, just like a strum. The difference between a strum and a slide is that a strum uses multiple strings, where a slide is performed over a single string. For example, Figure 4.17 shows the gesture "LeftB". The application can detect slide gestures along the X-axis. Slide gestures can be detected in both **left** and **right** directions, as shown in Figure 4.18 as red arrowed lines. The application shows that a slide gesture is detected by displaying the slide direction and the string, e.g. "LeftA".

Throughout this section, we discussed the design process of a fretboard input device prototype for a smartphone. We highlighted how form factors could influence prototype designs, and in our case, the device required changes to the input detection method. The iterative design process allowed rapid prototype development in stages until we developed a complete prototype. A disadvantage of this process was that we discovered issues when integrating the input method into a mobile form factor. However, the same process allows us to quickly reassess the requirements and fix any problems, as we did with the split frets.

4.4 Study

We conducted a user study to test the usability of the fretboard input device. The study also explored gesture design for such a device, where participants designed gestures for a set list of e-reader functionalities. We measure accuracy for the user-generated gestures and a small set of predefined gestures. We also hoped to receive feedback on improving the device in future iterations via user evaluations and discussions.

Procedure

We recruited 10 study participants (6M, 4F, 23-60). Participants were recruited from the university and acquaintances of the author, where two stated they were able to play the guitar to an expert level. We discussed the experiment with an information sheet and proceeded only after being granted informed consent.

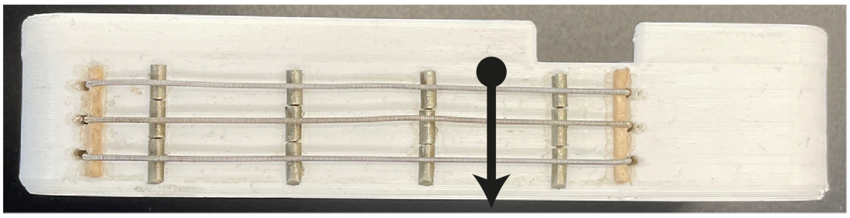


FIGURE 4.19: Predefined next page gesture. Strummed along arrow.

FIGURE 4.20: Predefined add bookmark gesture. Held along the line.

We designed the study to demonstrate how the split fretboard device works, to generate user-defined gestures and test their accuracy, following the described procedure:

1. Each participant completed a short pre-study questionnaire (Appendix C.1) for demographic and reader use/preference purposes. We also asked each participant to declare what expertise level they can play the guitar.
2. Participants were sat at a desk with the fretboard input device in front of them. The GUI was displaying the default screen. As shown in Figure 4.14.
3. Each participant completed task one described below.
4. Participants completed a Likert scale questionnaire to evaluate task one. They were also given time to add any remarks they wished to provide regarding the device (Appendix C.2).
5. Each participant completed task two described below.

After completion, participants completed a NASA task load index (TLX) assessment and a short discussion regarding their experience regarding the device.

Task One

Task one was designed to demonstrate how the prototype works and what sort of gestures can be detected by the device. We showed gestures for two predefined functions:

Goto Next Page: To invoke this function, the gesture **DownA** (seen in Figure 4.18) is performed. All three guitar strings are strummed in a downwards motion towards the back of the device, as shown in Figure 4.19.

Add A Bookmark: To invoke this function, we used a touch gesture. The gesture used here hoped to simulate the dog-earing of pages to create a bookmark. The gesture involved touching all three strings in the uppermost frets, as seen in Figure 4.20.

When we say "invoke the function", no actual book based function is completed. Instead, the interface indicates to the user that the gesture has been recognised and displays the gesture name.

The researcher demonstrated each gesture while holding the device in their left hand. In addition, the researcher demonstrated touch gestures with the fingers of their left hand and strum/slide gestures with the fingers of their right hand. Following each demonstration, the participants completed the gesture 10 times whilst we recorded the data for each interaction to test accuracy.

Finally, participants completed a Likert scale questionnaire for each gesture regarding their feeling of the device and the difficulty of their gesture (Appendix C.2).

Task Two

Task two was an exploration task, asking participants to generate their own gestures whilst also being an accuracy test. Participants were asked to create a gesture for the fretboard input device for the following functionalities: **Scroll**, **Skip Chapter**, **Activate Text to Speech** and **Increase Font**.

In turn, a gesture for each function was generated and then performed. The participants performed each gesture 10 times whilst we recorded the data for each interaction to test accuracy.

Finally, participants completed a Likert scale questionnaire for each gesture regarding their feeling of the device and the difficulty of their gesture (Appendix C.2).

4.4.1 Results

Pre-Study Questionnaire

Our pre-study questionnaire (Appendix C.1) consisted of just three questions following the demographic retrieval questions. Firstly, we asked two questions to help us understand our participants' use and preference toward reading. All 10 of

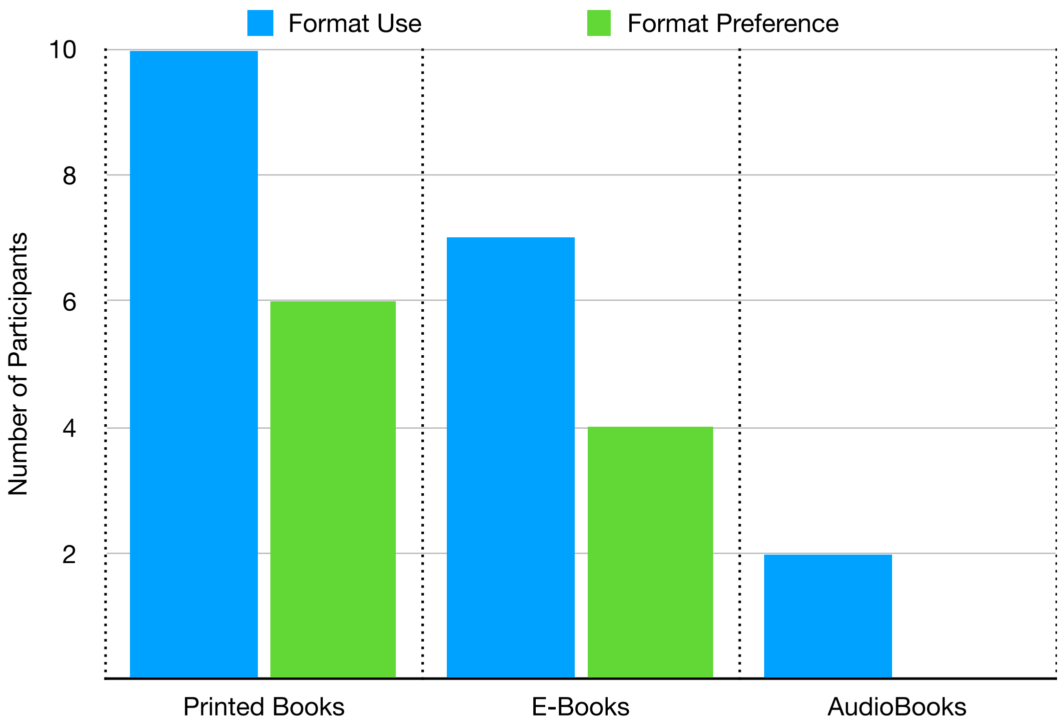


FIGURE 4.21: Graph showing format use and preference for participants of the Fretboard study.

our participants stated that they read from printed books. In addition, 7 participants said that they read using e-books. Just 2 participants declared listening to audiobooks. Participants were permitted to select multiple formats.

The preferred reading format of our 10 participants closely matched that of the paper input device study, with 6 of our participants preferring to read printed books, with the remaining 4 preferring e-books. Figure 4.21 visualises format use and preference among our 10 study participants.

Each participant declared to what level they could play the guitar for the final question. A question we asked as we believed that the input device resembles a fretboard. We also thought that more complex gestures would be generated by those who can play the guitar. Unfortunately, just 2 of our participants declared themselves as expert guitar players, and all others had none or very little guitar playing ability.

Predefined Gesture Task (Task One)

During the predefined gesture task, we took three measurements to measure the accuracy and usability of the split fretboard input device.

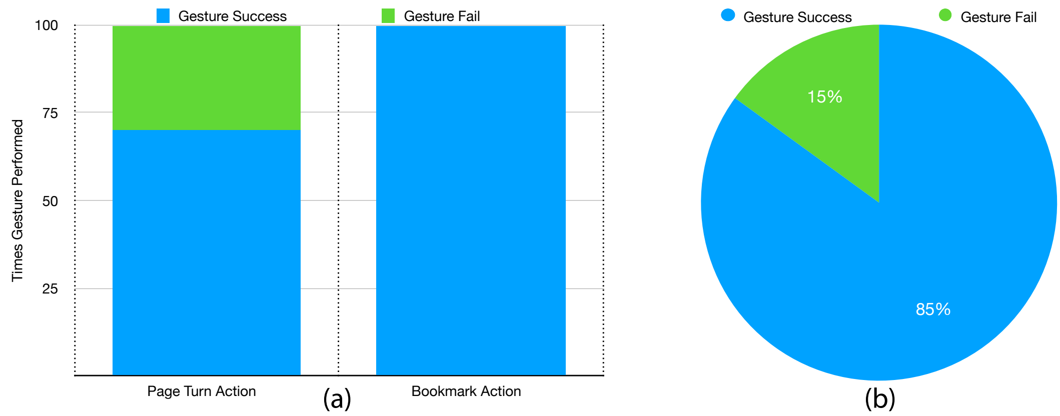


FIGURE 4.22: Graphs showing predefined gesture success and failure (a) per action (b) overall.

Accuracy

Each time a participant performed a gesture, we recorded the touch data. The data showed any frets that recorded a touch, the order of each touch, and any detected gestures.

Next Page Action - Firstly, we asked the participants to perform the next page action, a strumming type gesture. Over the 10 participants, this gesture was performed 100 times, with a 70% success rate. We define a strumming gesture being a success by the data showing all required frets recognising a touch in the correct order with no interruptions by other frets and within a short timeframe (250ms per touch).

9 participants achieved an accuracy of 60% or higher for this gesture type, our expert guitarist participants score 100% and 80% for this task.. However, the remaining participant scored zero. Therefore, we checked the device following the zero score to ensure it worked correctly. Fortunately, we found no issues with the device, so the zero score remained. The participant felt that they may not have applied enough pressure to the guitar strings during the task. If we were to remove the scores for this participant from this task, the accuracy for the next page action would rise to 78%.

Our expert guitarist participants score 100% and 80% for this task.

Bookmark Action - Following the next page action, we asked participants to perform the set bookmark action. The gesture was of the touch type. As with the previous gesture, the gesture was performed 100 times over the 10 participants. All participants achieved an accuracy score of 100% for the bookmarking action. We

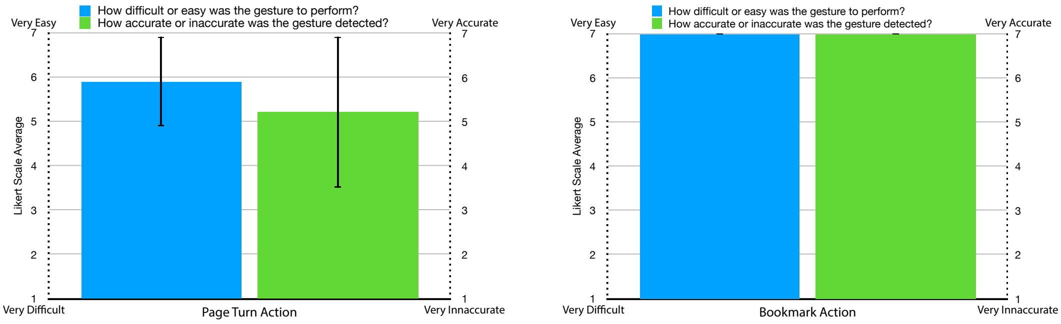


FIGURE 4.23: Graphs showing perceived difficulty and accuracy for page turn and bookmarking actions.

deem a touch gesture successful if all used frets are activated simultaneously for greater than 250ms, with no other frets recognising touches.

Figure 4.22 shows the accuracy of (a) both next page and bookmarking actions (b) accuracy overall, where participants achieved an 85% accuracy score.

Perceived Difficulty and Accuracy

The participants answered a Likert scaled question (Appendix C.2) regarding how difficult they found the gesture after each task. In addition, each time a participant performed a gesture, they were given visible and verbal confirmation as to whether the gesture was successful or not. Unsurprisingly, all participants found the touch gesture used for the set bookmark action to be very accurate and very easy to perform.

The next page action scored less for both perceived difficulty and accuracy, an expected result given the lower accuracy score. Participants gave the gesture average scores of 5.9 and 5.2 (1 min, 7 max) for difficulty and accuracy. Participants perceived accuracy closely aligned with the actual accuracy of the gesture.

Figure 4.23 shows the perceived difficulty and accuracy for both the page turn and bookmarking actions. Preliminary results show that touch gestures are easier to perform and are more accurate.

User-defined Gesture Task (Task Two)

Participants were asked to design and implement their own gestures for a subset of functionalities following the predefined gestures. For example, participants were asked to hold the device as if they were reading an e-book, and then when we gave the function to them, they should imagine that the gesture they designed would invoke said functionality. The gesture could use touch, strum and slide techniques,

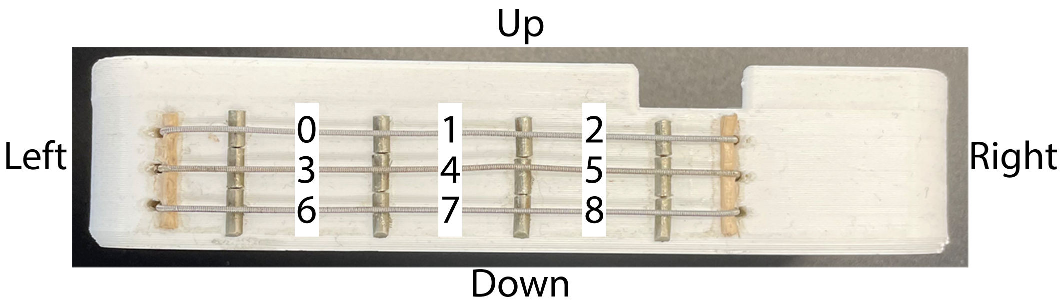


FIGURE 4.24: The fretboard input device shows directions and fret addresses.

or even a combination of the three. Each participant creates a gesture for all four functions, resulting in a maximum of ten gestures for each function.

Firstly, we discuss the gestures created by function, and we then go on to discuss by gesture type and direction. Figures 4.24 & 4.18 show the side of the fretboard input device, including gesture directions and fret addresses to help with explanations. In addition, each gesture is illustrated in Figures 4.27 & 4.28 & 4.29 & 4.30 for easier visualisation. Figure 4.26 shows a legend for the gesture images.

Scroll Action

Over the ten participants, eight unique gestures were made (where fret combinations, direction and type are different) for the scroll action, as shown in Figure 4.27 (all gesture descriptions in this section will refer to this figure). Participants took four separate approaches for gestures designated to invoke this action.

The first is the repeated scroll, where the user would perform a gesture repeatedly, in a similar fashion as one would make when using a mouse's scroll wheel. So, for example, the user would perform a gesture, which makes the pages advance faster than usual and then they would begin to slow down. Then, if the user wanted to continue scrolling, they would perform the gesture again. 3 participants created repeated scroll gestures, (a), (b) and (c).

1 participant suggested a strum and touch gesture (gesture (d)). Instead of repeatedly making the gesture, the user would perform the gesture once to begin scrolling the pages and then touch the frets when they wish the scrolling to stop.

3 participants suggested an alternative method of the strum and touch gesture, the strum and hold (gesture (e)). The device would be strummed downwards, and then the bottom string would remain held. The book's pages would then continue to scroll until the bottom string is released.

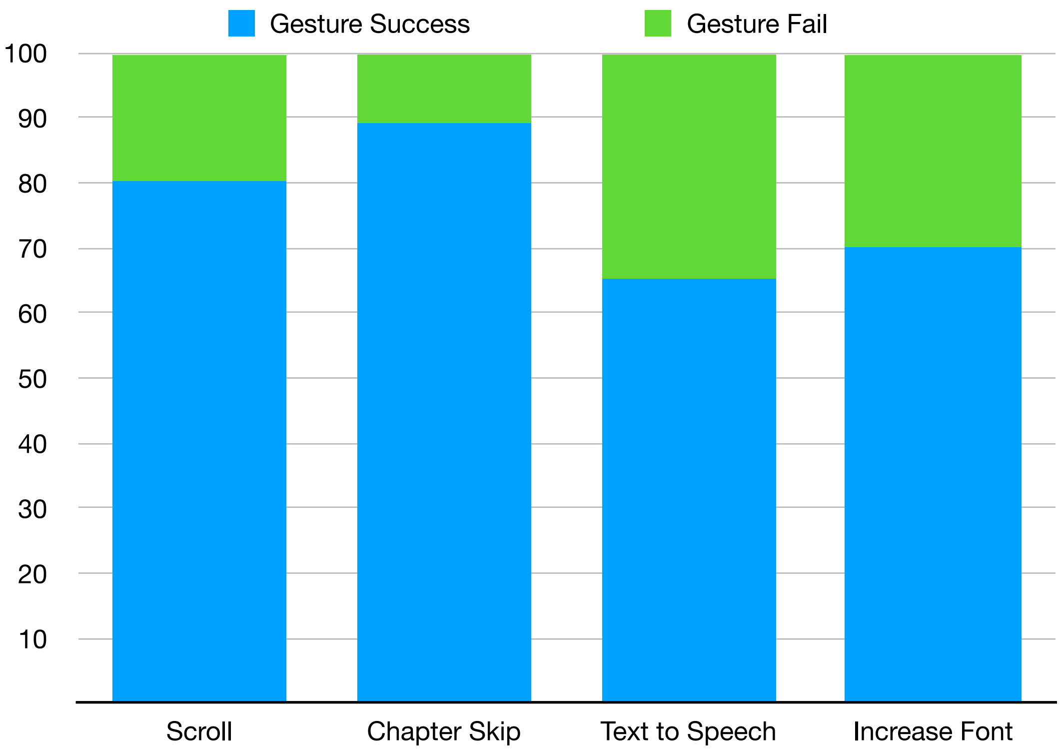


FIGURE 4.25: Gesture success and failures by Action.

The final 3 participants offered a touch and hold gesture where the pages would scroll while users hold the frets within a specific combination and then stop when released. These gestures are shown in (f), (g) and (h).

The fretboard input device achieved an 80% accuracy level over all participants, shown in Figure 4.25. In addition, the expert guitarists achieved 90% accuracy.

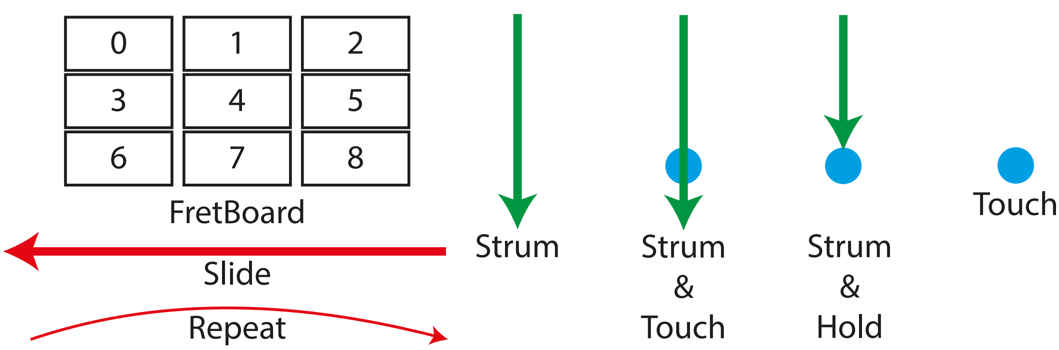


FIGURE 4.26: Legend for user defined gesture figures.

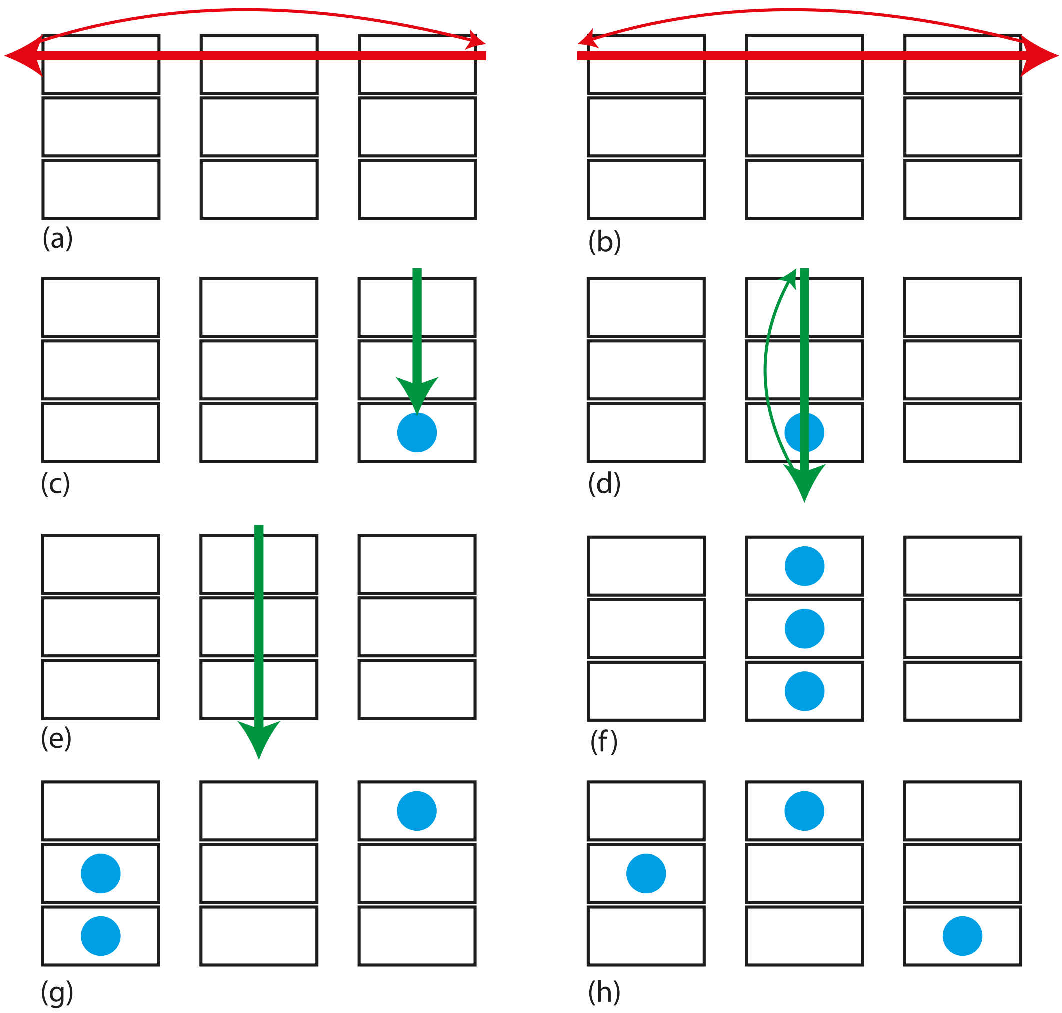


FIGURE 4.27: Gestures created by participants for the Scroll Action.

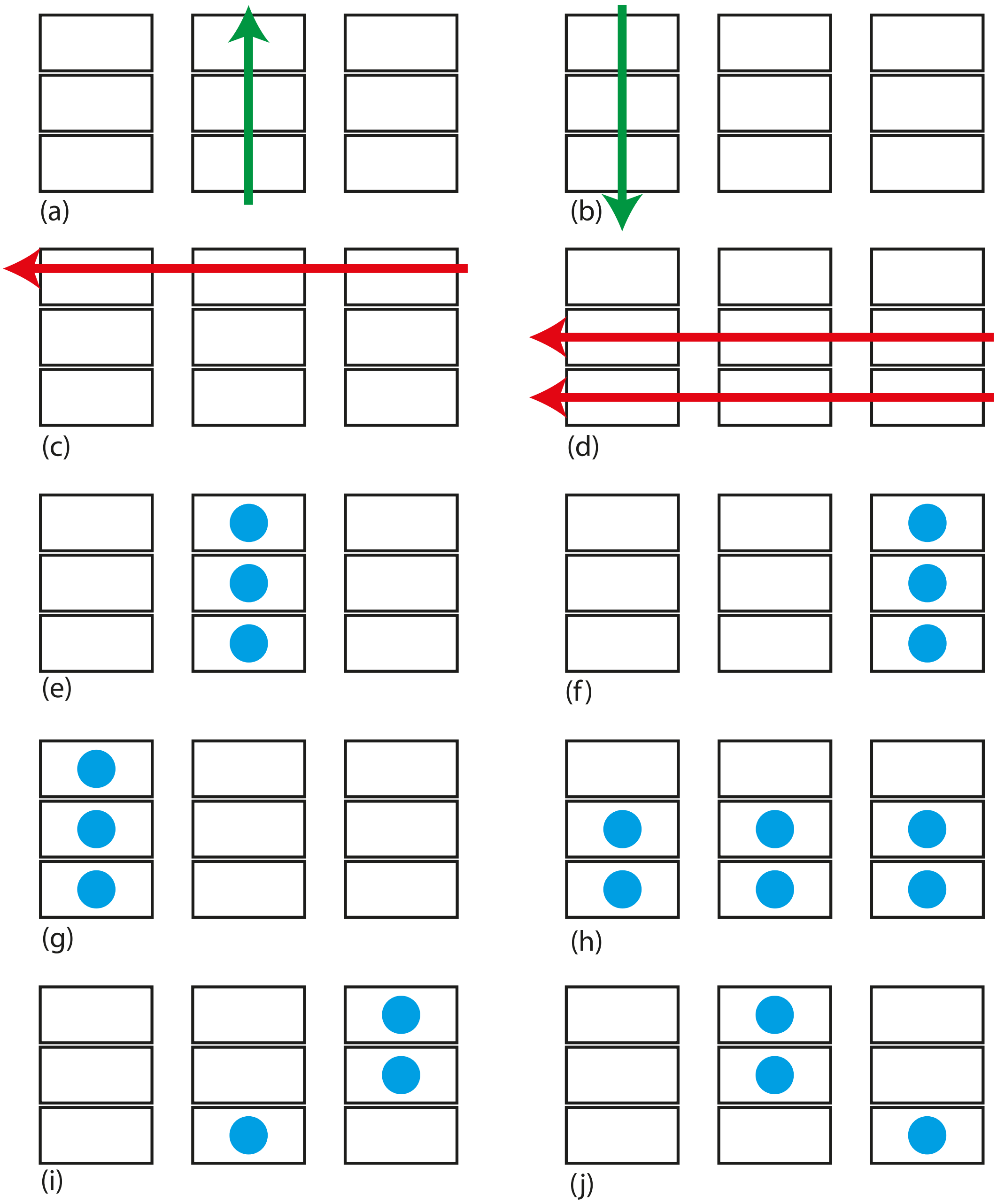


FIGURE 4.28: Gestures created by participants for the Skip Chapter Action.

Skip Chapter Action

Each participant created a unique gesture for this action, where no fret combination, direction and type matched, resulting in 10 gestures being made, as shown in Figure 4.28 (all gesture descriptions in this section will refer to this figure).

2 participants chose to implement strum gestures to invoke the skip chapter action, where 1 strummed upwards (a), and the other performed a downwards strum (b).

2 participants created slide gestures, where both gestures slid towards the right. However, the gestures differed in the string used, where 1 used the top string (c), while the other used both the middle and bottom string (d).

The 6 remaining gestures were of the touch type. The touch gestures for this action became slightly more complex, with a participant stating, *"I wouldn't want to use this often, so it should be trickier, so I don't accidentally do it"*. One participant suggested that their fret combination should be double-tapped (f).

For this action, the fretboard input device achieved an 89% accuracy level over all participants, shown in Figure 4.25. In addition, the expert guitarists achieved 100% accuracy with the gestures (i) and (j).

Activate Text to Speech Action

All 10 participants created a touch gesture to perform this action, where they made 9 fret combinations, as shown in Figure 4.29 (all gesture descriptions in this section will refer to this figure).

Of the 8 fret combinations, 3 ((a), (b), (c)) have been seen in previous tasks. However, gestures (a) and (c) stood out as they were used differently, offering a novel possibility. 2 participants introduced pin code-like gestures where users would touch frets in a specific order. This method differs from a slide or strum as they require frets to be adjacent. The pin code-like method would allow any fret combination order, for example, by pressing frets in the order 6, 0, 3.

One of the gestures (i) used a double-tap method, like the suggested gesture for the skip chapter. However, this gesture differed as the participant suggested squeezing the side of the device to activate several frets at once. This action was again referred to as something that users will occasionally use.

Other than gestures (a), (c) and (i), all 6 other gestures were simple touch gestures. For this action, the fretboard input device achieved a 65% accuracy level over all participants, shown in Figure 4.25. However, this result is severely hindered by both guitarists finding a limitation of the device, and we discuss this in detail in

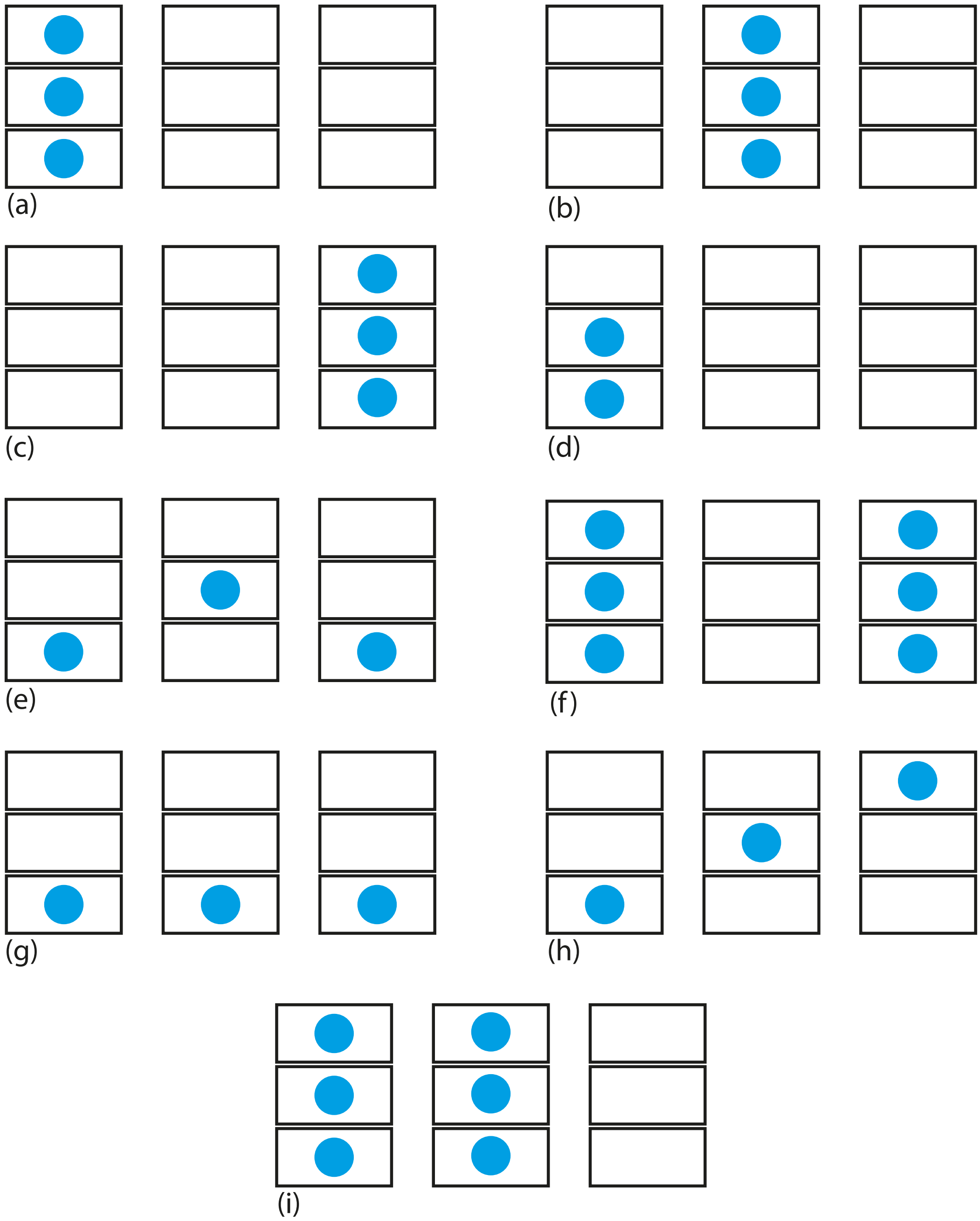


FIGURE 4.29: Gestures created by participants for the Activate Text to Speech Action.

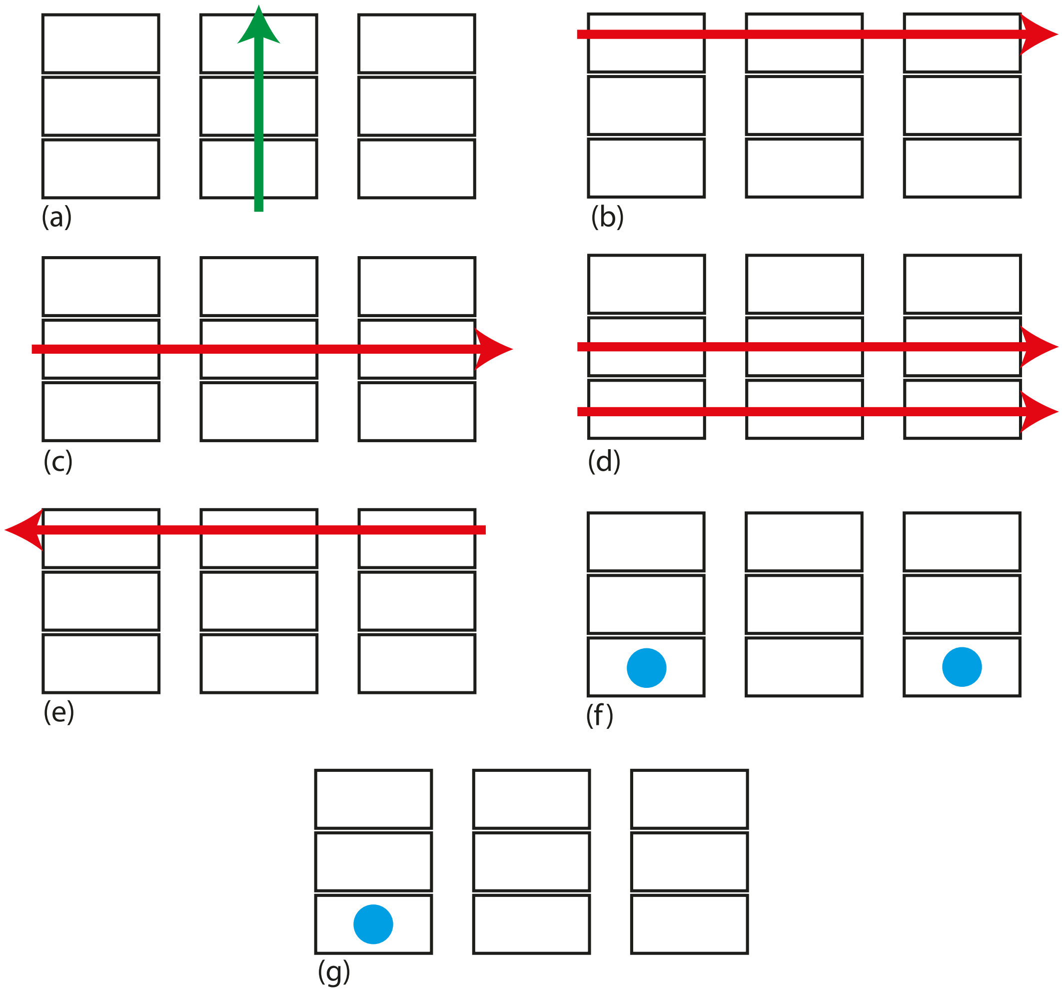


FIGURE 4.30: Gestures created by participants for the Increase Font Action.

Section 4.5.1. Both expert guitarists achieved 0% accuracy with the gestures (e) and (f). Removing the guitarists due to the limitation would raise the accuracy level for this action to 81%.

Increase Font Action

Over the 10 participants, 7 unique gestures were created, as shown in Figure 4.30 (all gesture descriptions in this section will refer to this figure).

Participants seemed to be in agreement over the gesture for increasing the font size, with 6 participants choosing to implement a sliding gesture to the right (2 X (b), 2 X (c), 2 X (d)). In our illustrations, sliding to the right translates to an upwards sliding motion when the device is in hand. So, an upwards sliding movement on the side of the device seems like an intuitive gesture for increasing the font size.

Another participant suggested a sliding gesture. However, they choose to slide to the left (gesture (e)), which translates to a downward gesture; it seems unintuitive.

1 participant suggested that a double-tap gesture (g) would work well here. They described that a double-tap could work similarly to images on a smartphone, where a double-tap causes the display to zoom in.

An upward strum of the middle frets was suggested by one participant (gesture (a)). They felt that this would work as it felt like they were *"lifting the words to make them bigger"*.

Our final participant created a touch gesture that highlighted the limitation found by the guitarists in the previous task, as seen in gesture (f).

For this action, the fretboard input device achieved a 70% accuracy level over all participants, shown in Figure 4.25. The participant who created a gesture outside of the limitation of the device scored zero. If this result were removed, the accuracy level overall would be 77%. In addition, the expert guitarists achieved 75% accuracy with the gestures (a) and (d).

Perceived Difficulty and Accuracy Per Action

Again, the participants answered a Likert scaled question (Appendix C.2) regarding how difficult they found the action after each task. In addition, as before, each time a participant performed an action, they were given visible and verbal confirmation as to whether the action was successful or not.

Overall, participants found all actions easy to perform. For example, all actions had an average Likert score of 5.8 or greater, as shown in Figure 4.31. In addition, participants found the gestures assigned to the skip chapter to be the easiest while finding the activate text to speech the hardest. Participants who performed a pin-code like input sequence found the action most challenging to achieve.

As a group, participants felt that all actions were accurate, with the skip chapter action the most accurate, aligning with the accuracy data in Figure 4.25. However, like the accuracy data, this result is possibly affected by the limitation discovered by the expert guitarists. Results can be seen in Figure 4.32.

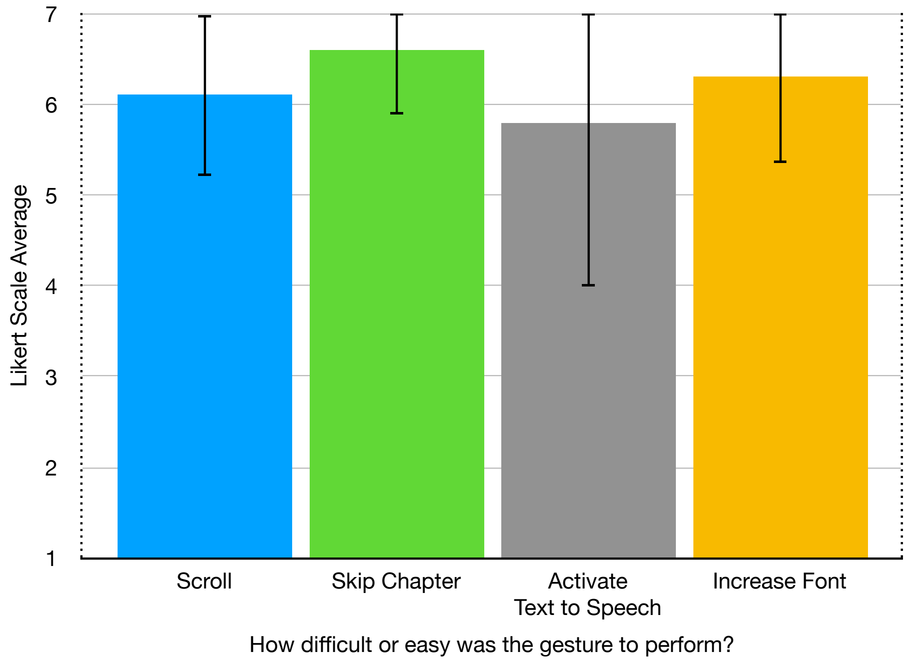


FIGURE 4.31: Graph showing perceived difficulty of user-generated gestures.

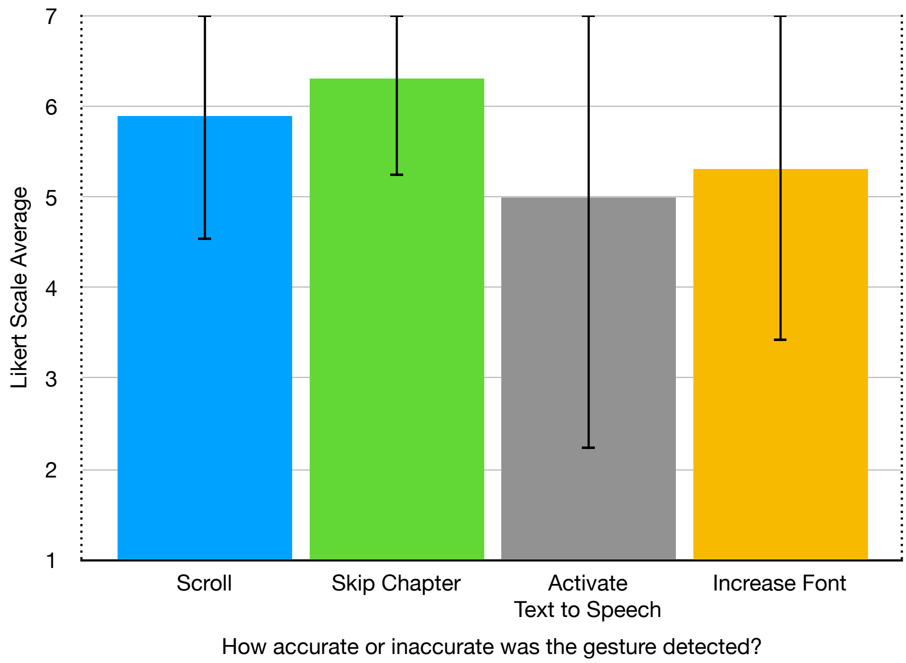


FIGURE 4.32: Graph showing perceived accuracy of user-generated gestures.

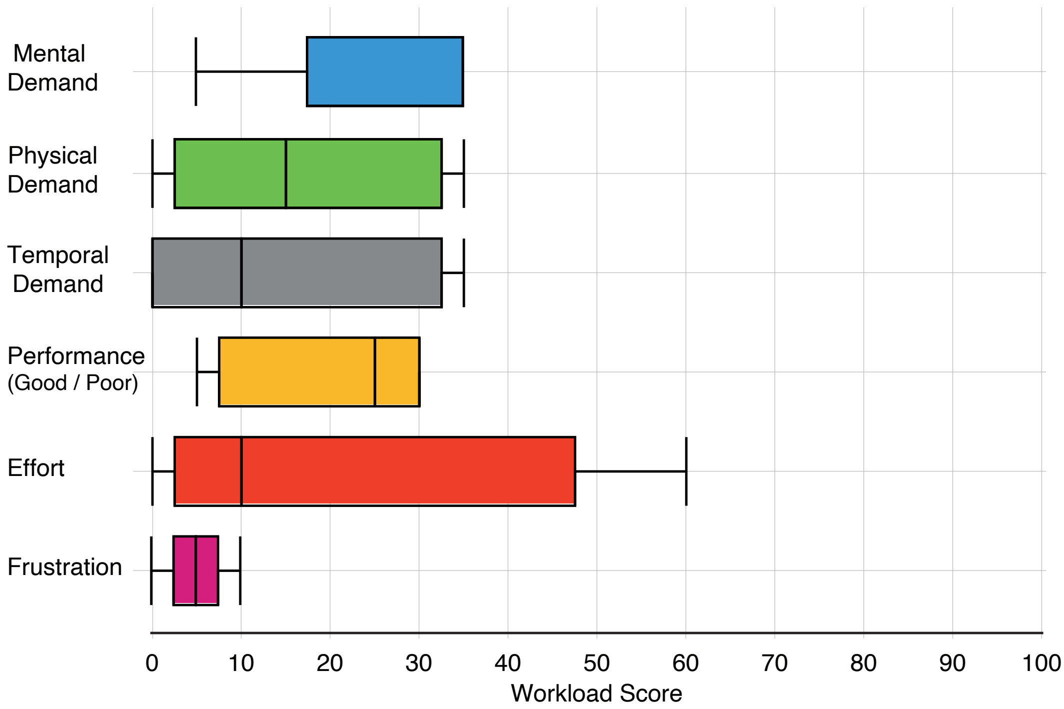


FIGURE 4.33: Box plots of post-study NASA TLX assessment, showing the median workload score, 1st and 3rd quartiles along with the upper and lower extremes.

Post-Study NASA TLX Assessment

We conducted the NASA TLX assessment to measure mental demand, temporal demand, performance, effort and frustration participants felt the tasks. We present the NASA TLX results in Figure 4.33.

- Mental demand had a median workload score of 25, demonstrating that the tasks were somewhat mentally demanding.
- Scores for physical demand had a median workload score of 15, demonstrating that the tasks were not physically demanding.
- The Temporal demand assessment yielded a median score of 10. As each task took very little time, each participant felt very little demand.
- The median score for performance was 25, where a lower score means a better perception of performance. This score aligns with the Likert scale perceived performance data.
- Participants found that the tasks required minimal effort, with the median workload score for the effort being 10.

- Participants found the tasks were not frustrating, with a median score of 5.
- Overall, the participants found the tasks needed minimal mental demand and were not frustrating.

Post-Study Questionnaire and Discussion

Following the NASA TLX assessment, each participant completed a short Likert scale questionnaire (Appendix C.3) and a brief discussion regarding their use of the device. Overall, participants felt that the device was easy to use and that the experience was enjoyable. Next, we asked participants whether such a device could enhance the digital reading experience. Participants were somewhat split on this, with an average Likert score of 4.9, where 7 greatly enhanced. A participant who felt the device would not improve the digital reading experience said *"I don't think the device adds much to a hardcore e-reader"*. On the flip side, several participants felt the device was *"fun"* and could add a *"gamification"* element to digital books.

Our guitarist participants discussed the possibilities of the device and enjoyed using the device. However, both guitarists felt that a strumming gesture over the fretboard was not intuitive, although, *"it is done, but not often"*. Hence them primarily creating gestures of the touch type. They revealed that several of the touch gestures they used were guitar chords, including open chords and an F5 power chord. When asked if they could perform other chords on the device, one stated *"As long as there is a Root, 3rd and 5th, a chord can be made"*, with reference to music theory.

Discussions were also held regarding the form factor of the device. Overall the device felt small enough in hand to be used whilst also feeling bulky enough to *"replicate a book"*. However, several participants agreed that to replicate the feeling of a book better; more stings should be used.

4.5 Discussion

Throughout this chapter, we have explored the use of compact side of device interaction with the context of digital reading. Firstly, we explored several methods and materials which could act as a metaphor for the edges of printed books. We built a series of prototypes using conductive thread, a conductive rubber stretch sensor and guitar strings as input methods. The prototypes investigate the viability of each material to provide multi-dimensional touch location data. We discovered that we could use all three materials as single-dimensional input. However, both conductive thread and a rubber stretch sensor offer limited functionality in the

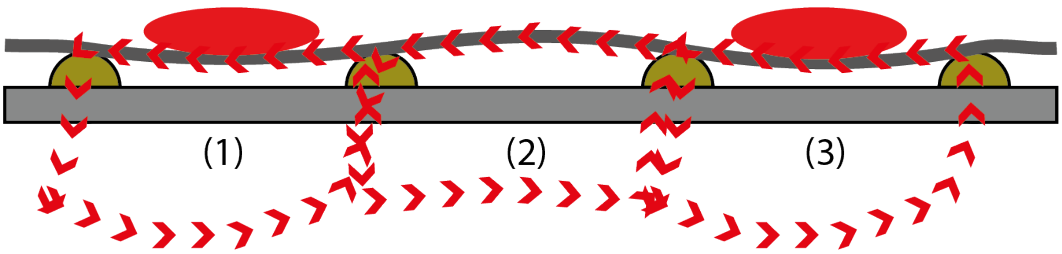


FIGURE 4.34: Input gesture limitation. Red circles represent touch location. Arrows indicate touch detection.

context of a multi-dimensional input device. As a result of the limitations of conductive thread and rubber stretch sensors, we develop the fretboard input device using guitar strings.

We investigated compact mobile form factors after designing and developing the fretboard edge of the page like input method. We discovered that the form factor of a device could affect system design, especially when using the iterative design process, adding features to each iteration. For example, compacting our input method into a smartphone-like case form factor affected our design, and rectifications were needed. As a result, our prototype design went through two input revisions and three form factor changes, resulting in the compact split fretboard design.

Following this, we carried out a user study of the fretboard input device to test its accuracy and for participants to generate gestures for such a device. First, participants were taught how the device works with predefined gestures. They then created their own for a set list of e-reader functionalities. Finally, for each action, the accuracy was recorded. Results show that all actions can be detected to a reasonable level of accuracy and that participants found the device enjoyable. However, participants were somewhat split in deciding whether such a device would enhance digital reading, with responses leaning more towards improving the experience.

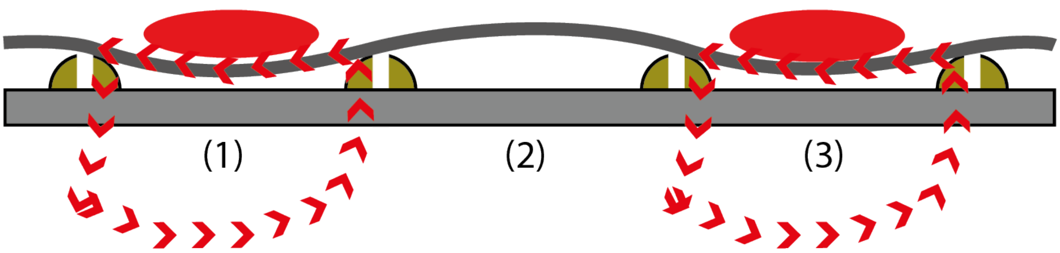


FIGURE 4.35: Input gesture limitation, split fret solution. Red circles represent touch location. Arrows indicate touch detection.

4.5.1 Fretboard Limitation

Two of our study participants discovered a limitation in the implementation of the device. The method of detecting when a fret is touched does not allow for all combinations.

For example, Figure 4.34 shows a gesture that is unable to be detected by the device. The figure shows a side view of a single guitar string, four frets, and three device touchpoints. The red circles represent a finger pushing the guitar string onto the frets. When a user touches points 1 and 3, all four frets become bridged, causing the device to detect a touch in all 3 touchpoints.

This limitation is complex to solve without completely rethinking the input detection. Even if we added more frets, the problem would still exist in the instance where a user touches a pair of touchpoints whilst leaving a gap between them. Initial thoughts pointed towards another input layer, where the device can detect the pressure for each touchpoint? However, if this were the case, would the current novel input method be needed? Probably not.

A future solution would be to split each fret again, this time along its length. Figure 4.35 shows a possible solution. Each fret would be split so that each touchpoint has a pair of frets. The device would then use this pair to locate each touch, and when a pair of touchpoints are bridged with a gap between, the fret pair of the untouched point will detect nothing.

Through this chapter and its predecessor, we had many interactions with readers. As a result, we begin to see a pattern where readers own and use more than one reading format. In the next chapter, we investigate this pattern and explore a method of creating a hybrid reading experience, where the modern reader can seamlessly continue reading from either a digital or physical format quickly.

Chapter 5

Synchronisation of Digital and Physical Formats

This chapter explores hybrid user experiences for the modern reader, taking a different approach from previous chapters. Previously we have designed, created and studied prototype devices that enhance the tactile reading experience of digital devices. However, as the number of reader interactions increased, so did our understanding of the reading habits of the modern reader. As a result, we notice a trend beginning to appear through discussions and general conversation, where the reader will switch between digital and physical mediums. This chapter focuses on the multi-format reading process. We follow a user-centred design approach to scope, design, implement and study a solution to make this experience seamless for the reader. Firstly we discovered the prevalence of multi-format reading, and we did this via scoping survey. Next, we perform a format switching study, where multi-format readers participate in a lab study in which they demonstrate the process of switching from one format to another. Results showed that the task of switching from one format to another could be complicated and takes a considerable amount of time.

We also present a digital bookmark prototype device, outlining the design decisions, interactions, and limitations. Finally, we perform a user study of the device, and results show a drastically reduced format switching time, with physical to digital switch time eliminated.

We conclude the chapter with a discussion of the results and limitations of the digital bookmark device. Finally, we suggest methods to improve the device and make it possible for such a device to become compatible with existing books.

5.1 Introduction

When writing this, there is no automated method for readers to transfer a bookmark from a printed book to a digital format. So currently, readers who use both printed and digital books must manually transfer their reading position across mediums. Unfortunately, manual transferring of location heavily relies on either having both formats side-by-side to compare content or the reader explicitly remembering their place. In addition, often, the pages of printed and e-books are not mapped one-to-one, making this task more difficult.

Throughout this chapter, we investigate hybrid reading experiences, where we explore the scope and difficulty of the problem, develop solutions and submit them to user evaluation.

Firstly, we carried out an online scoping survey, where we asked many people about their reading format preferences and their experience using multiple reading formats. The survey results showed that the multi-format reading trend is greater than the several participants and acquaintances we have spoken to locally and that the problem warranted further investigation.

Following this, we report the results of a laboratory study to quantify the format switching time and experience. Using experienced multi-format readers, we performed an investigation in which participants switched between reading formats, where participants were required to find known information within a previously read book. Results showed that such a task could be mentally demanding, frustrating, and time-consuming.

Next, we present a prototype device, a digital bookmark for printed books that synchronises the page numbers between the printed and electronic formats. The bookmark identifies and transmits the current page to a digital device when inserted into a physical book or displays the current page when reading has been completed on a digital book. This section also outlines the design process and explains design choices for the final prototype design.

Finally, we deliver the evaluation of the digital bookmark with the members of a reading group. The reading group used the digital bookmark to switch between reading formats, and results show a drastic drop in switch time and difficulty. We envision that a digital bookmark could enrich the reading experience for these reasons.

5.2 Scoping Survey

Throughout our previous work in this thesis, we held continuous discussions with study participants, colleagues, friends and acquaintances around the topic of reading. Unsurprisingly, whenever reading format was discussed, many would declare that they are not fixed to a single format and would often read or listen to different books on different mediums. However, what we did find surprising was a trend we discovered along the way. We found that increasingly, people are participating in "multi-format reading". So, what does the term multi-format reading mean? We use this term to describe the act of reading the same book across more than one format, such as reading on a printed book and then continuing where you left off on an e-book. An extensive literature search of the term "multi-format reading" points to a single location, a blog post from Joséphine at Word Revel[1] discusses their personal experience of multi-format reading. The blog discusses reading the same book across three formats of reading, printed books, e-books and audiobooks. Unfortunately, any mention of real-world readers switching formats outside of this blog is limited to e-books and audiobooks, with the likes of Amazon WhisperSync [3]. We believe this is due to a lack of an automated format switching system.

We launched an online scoping survey (Appendix D.1) to discover the prevalence of multi-format reading. The survey looked to explore many aspects of multi-format reading habits, including the practices of those who do not read this way. In addition, we designed the survey to group respondents by their format habits, allowing us to gain insight from several groups as to why they don't or how they switch formats. The survey had a maximum of nine questions, including demographic details. The majority of questions were checkbox-based, with a maximum of two text-based questions.

We recruited 100 participants, 51M, 45F and 4 undisclosed, to participate in our online scoping survey. All the participants were over 18, with the median age range being 25-34. We recruited participants through university-wide mailing lists, social media and survey distribution websites. We rejected 12 responses based on the answers supplied in the text-based question, where respondents entered random words or keys, so we deemed these to be spoiled.

Firstly, we informed the participants of the purpose of the study, what we would use the data for and when we would destroy it. Next, we collected demographic details and informed them of a prize draw. The prize draw was optional and required participants to leave contact details. We also asked participants if they

[1] Word Revel Joséphine. *5 Reasons for Multi-Format Reading*. 2015. URL: https://wordrevel.com/reasons-multi-format-reading/.

wished to be contacted further regarding further studies of reading habits, of which 22 agreed.

5.2.1 Questions and Responses

This section goes through the scoping survey's questions and our responses. Discussion of the questions and answers will not necessarily be in the order we asked the participants. However, discussing out of order and as a whole allows us to discuss the data in more detail.

Format Ownership and Use

Unsurprisingly, when asked what formats participants own and use to read, printed books were the most popular, with **89** declaring this. This question was checkbox based so that participants could select more than one format if needed. Following printed books, e-books were owned by 66 participants, and finally, audiobooks were least popular, with just **21** claiming ownership.

37 participants claimed ownership of a single format, whereas the remaining **63** declared ownership of at least two formats. We will refer to these as single-format owners and multi-format owners, respectively. Figure 5.1 gives a visual representation of the ownership data. The graph clearly shows the total ownership data for all participants whilst also depicting the ownership of formats by both single and multi-format owners.

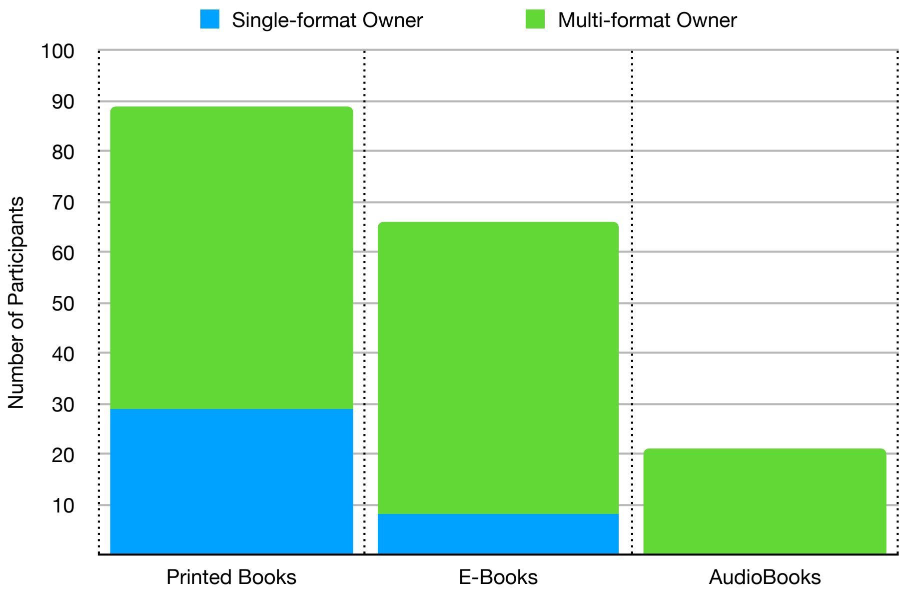


FIGURE 5.1: Scoping survey format ownership for total, single (blue) and multi (green) format owners.

61 (97%) of multi-format owners claimed ownership of printed books and at least one digital format, and the remaining **2 (3%)** used digital books exclusively. The most popular multi-format ownership combination was printed books and e-books, with **42 (67%)** of multi-format owners declaring this, Figure 5.2 visualises this.

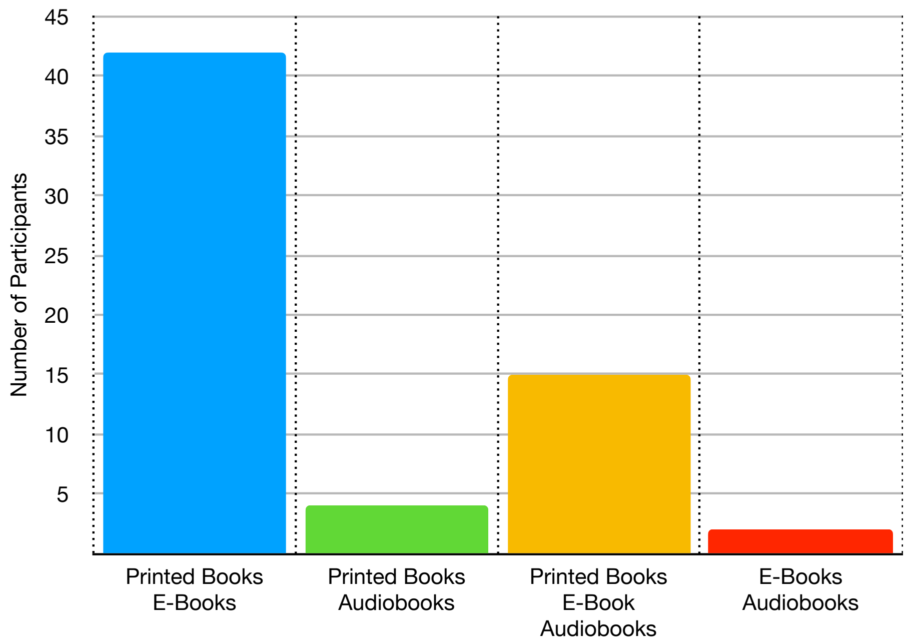


FIGURE 5.2: Scoping survey format combination ownership.

We asked the single-format owners if there was any particular reason that they only own books in a single format. Several reasons were given, with the most common being format preference, financial and physicality. A financial reason was often stated, with one saying *"I don't see the point of buying them twice"*.

50 of all participants **(79% of multi-format owners)** stated that they own a copy of the same book in multiple formats, e.g. Moby Dick in both printed book and e-book. In addition, **48** of those who own the same book in multiple formats reported ownership of a printed book along with at least one digital format. The most popular combination was printed books and e-books, with **40** participants saying this.

We can separate multi-format owners into two groups:

(a) **Single-Format Readers:** We describe this group as readers who own copies of a book in multiple formats. These readers, however, do not switch back and

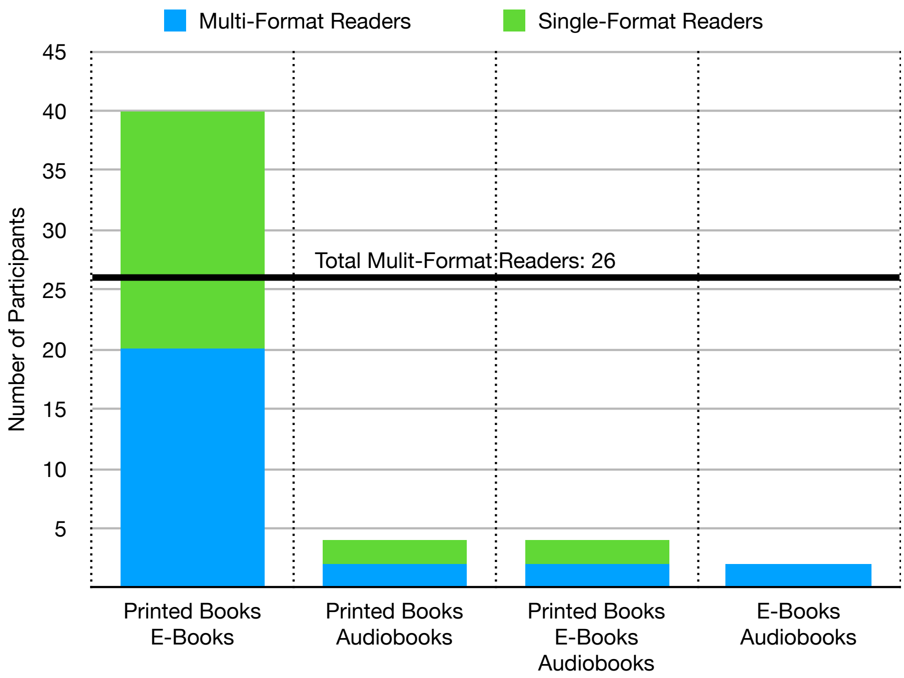


FIGURE 5.3: Scoping survey results of same book ownership across formats for single and multi-format readers.

forth whilst reading. The readers of this group will read a book in its entirety in a single format at a time.

(b) **Multi-Format Readers:** We describe this group as readers who own copies of a book in multiple formats. These readers will swap between reading formats whilst reading a book. For example, they may read a printed book at home and then switch to a digital book on their daily commute.

26 (52% of those who owned a book in multiple formats and 26% of total) participants described that they are multi-format readers, while the remaining **24** participants described themselves as single-format readers. Of those multi-format readers, **20 (77%)** switch back and forth between printed and e-book formats. Figure 5.3, shows the breakdown of the single and multi-format groups, showing the ownership combinations. Surprisingly, only **2** participants switch between e-books and audiobooks whilst reading. We would have assumed that this number would be higher given the automated methods available.

We explored why people own a book in multiple formats and not switch between them. We found that the majority felt that there is no easy way to quickly switch apart from memory, with a participant noting that switching would *"create chaos in my mind"*. This answer was not surprising, as all single-format readers stated they own a book in printed and digital formats (as seen in Figure 5.3), of which there is no transfer method.

Format Preference

Whilst exploring the ownership and use of formats, we were also interested in which format each participant preferred to use and why they had this preference. Figure 5.4 shows the preferences of participants by ownership group and total.

71 of all participants had a preference to use a book in printed format, with the majority **(61)** of those specifying that the preference was physical. Participants gave physical preferences such as the feel, smell and texture of printed books. A common explanation of this preference was that they were more familiar with printed books over other formats, with one saying *"A printed book seems more 'real', and it is what I have known all my life"*. Of the **37** single-format owners, **29** declared a preference for printed books, while **42** of the **63** multi-format owners declared the same.

The digital formats faired less favourably amongst participants, with **22 (8 single-format owners, 14 multi-format owners)** declaring a preference for e-books and just **2** multi-format owners choosing audiobooks. The most popular reason to prefer digital books was convenience, with **17** participants stating so. Participants like the fact that almost any digital device these days can become an e-reader or an audiobook player, meaning that they can have a *"library in their pocket"*.

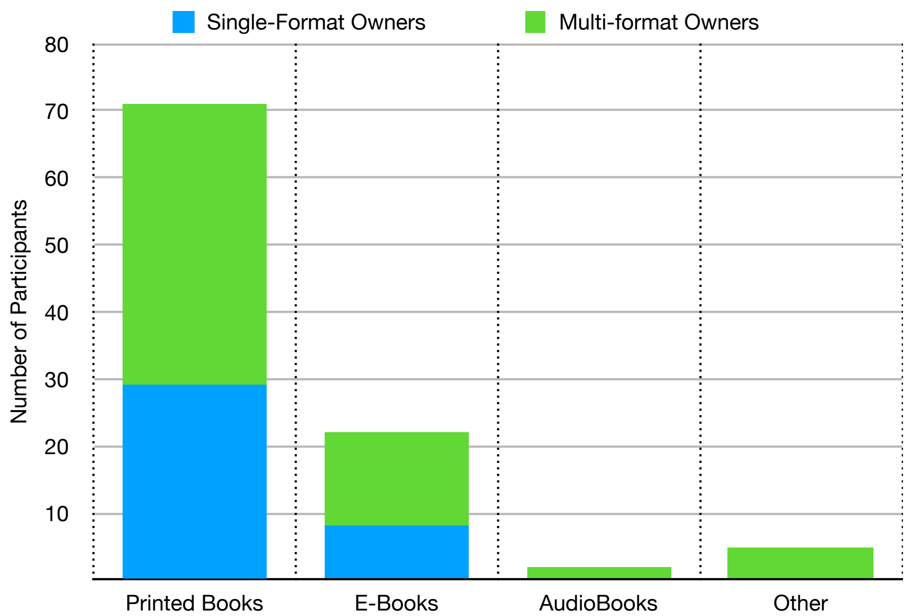


FIGURE 5.4: Scoping survey results showing format preferences.

We also had several participants **(5)** mention that their preference depended on the type of literature. They would read works of fiction digitally and reference books or research papers physically as they feel it allows them to comprehend more easily. Research of narrative comprehension between formats backs this claim [96, 84, 55], with evidence suggesting that reading printed formats allow better digestion of information.

Synchronise Technique

The final section of the survey looked to gain insight into how multi-format readers kept their position synchronised between reading formats. We can split the synchronisation information into two groups:

(a) **Digital Synchronisation:** This is the process of keeping an e-book and an audiobook in sync. We have previously discussed the automated methods for this, e.g. Amazon WhisperSync.

    4 participants declared that they are multi-format readers and use e-books and audiobooks. Here we had two distinct methods of synchronisation. We assume that **3** of the **4** use an Amazon WhisperSync based product or app as they say it syncs automatically, a participant wrote *"I do nothing, they just synchronise"*, and another explicitly mentions WhisperSync and Audible.

    The final participant of this group manually synchronises their e-book with their audiobook, where they read/listen to the end of a section or chapter. They mention that audiobooks are generally broken into tracks that correspond with a book's sections or chapters, allowing a fast transition between digital formats.

(b) **Physical to Digital Synchronisation:** This is the process of keeping a printed book in sync with either of the digital formats. Unfortunately, page numbers do not transfer across formats and devices, with the particular font, text size, and display are influencing the pagination of e-books. In addition, there is no automated method of transferring a printed book's progress to or from a digital device, so all synchronisation methods are manual.

    20 of the **26 multi-format readers** remember events currently occurring within the book. They then flick/scroll through the book, reading extracts, looking for a particular event. So, for example, the last event a reader remembers reading on the e-book is the death of a central character. They would then flick through a printed book seeking this to continue reading where they left off.

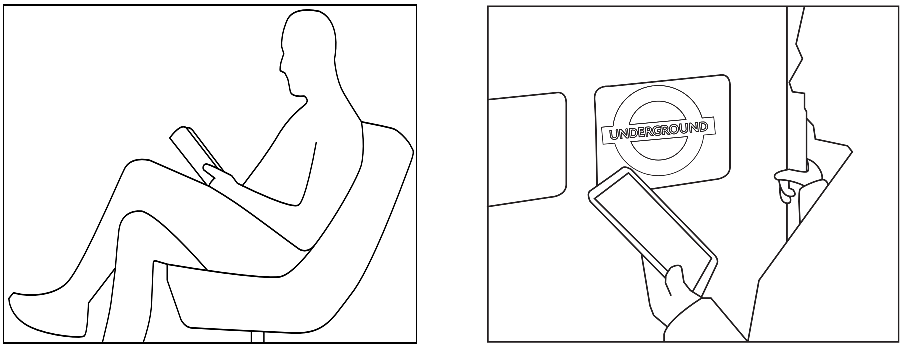


FIGURE 5.5: Multi-format reader scenario, showing reading printed books at home and e-books during a commute.

3 participants stated they would always try to end reading at the beginning of a new chapter but noted this was not always practical. They would often need to use a similar method to event remembrance, where the reader would begin at the start of the current chapter and flick/scroll until they find where they were.

The remaining **3** multi-format readers liked to get the book's side-by-side to compare the content to ensure correct continuation location. Having each book open before transferring progress eliminated the need to remember the exact location. However, transferring progress this way does introduce the need to synchronise when both formats are available.

5.2.2 Summary

The scoping survey has shown that the modern reader uses more than a single format, with **63 of the 100** survey respondents stating they are multi-format owners. In addition, **26 of our participants are multi-format readers**, meaning **26%** of our participants owned copies of the same book across formats and that they switch reading formats based on the current situation. **20** multi-format readers switch from printed books and e-books, with no automated method.

Scenario

Based on our survey results and the descriptions of the multi-format reader habits and switching techniques, we have formulated the following scenario:

> Lacey travels frequently and likes to read during the transit. She prefers reading printed books at home but wants to read from her e-book whilst travelling.
>
> She likes the digital features but misses the tangibility of her printed book, so she owns copies of books in both formats.
>
> She stops reading towards the end of her journey with an arbitrary memorable event.
>
> She searches for this event in her printed book when she resumes reading later that night. She flicks through the pages to find that event. She reads some text to find her reading location, which she did not read before. She does not like it.
>
> A similar experience repeats when she switches to her e-book the next day.

BOX 5.1: Scenario of the current experience of multi-format readers.

The survey allowed us to see the scope of the multi-format reading problem, which from our participants is significant. After discovering the extent of the problem, we designed and performed a laboratory experiment to analyse the users' time spent switching from one format to another. This experiment would help us understand the problem's difficulty and whether a solution is needed.

5.3 Format Switching Study

We are interested in understanding the performance of switching between the electronic and printed formats of reading books in daily life. Switching is a complex action to study as it depends on the user preference, prior experience and the use case scenario. Therefore, we designed the laboratory experiment to analyse the users' time spent switching from one format to another. Furthermore, to simplify the study, we only considered multi-format readers who use both formats to read. In addition, we experimented in the laboratory, which is controlled away from reading at home or while travelling. We believe that this initial experiment would help us understand the switching process outside the laboratory.

Procedure

We recruited 10 participants (3M, 7F, 25-64) for the experiment. We recruited each participant from the scoping survey respondents. Each participant identified as a multi-format reader and had permitted further contact regarding future studies. Along with being a multi-format reader, the study had two additional entry requirements: participants must have recently read or be currently reading a book in multiple formats. The second was they had to be able to attend in person. The scoping survey yielded 22 participants who permitted contact and wished to participate in further studies. However, only 11 were able to make it to the study location. We experimented with one participant per session, each lasting 45 minutes. We asked participants to bring a printed book of their choosing and their e-reader device.

We discussed the experiment with an information sheet and proceeded only after being granted informed consent. Each participant then completed a short pre-study questionnaire (Appendix D.2), asking for demographic details and reading information.

Next, we asked them to recall memorable events from their chosen book, which we noted as significant plot points and created a list of 10 events; we show an example of this in Table 5.1. Next, we randomised the list of events to develop the experiment order. The randomisation ensured that all experiments were fair, in case some participants were able to list events in chronological order and others were not. Finally, each event in the list was assigned a format switching direction alternating between **Print** → **E-Book and E-Book** → **Print**, to analyse the time spent switching between each format was measured.

We sat participants at a table with the printed book and e-reader in front of them, both showing the title page. Then, we instructed each participant to perform the tasks of the experiment, as described below.

Once the participant had completed the tasks, they completed a NASA TLX assessment and a short discussion regarding their experience during the experiment.

The tasks of the experiment were video recorded for analysis after the session. In addition, participants were given an Amazon voucher as compensation for their time.

I.D.	Description	Printed Book Page Number	Switch Direction	E-book Page Number
1	Lestat turns Louis into a vampire	24	→	25
2	Lestat then turns Claudia into a vampire "daughter"	102	←	101
3	As Louis and Claudia prepare to flee to Europe, Lestat appears, having recovered from Claudia's attack, and attacks them in turn. Louis sets fire to their home and barely escapes with Claudia, leaving a furious Lestat to be consumed by the flames.	173	→	170
4	Claudia convinces Louis to turn a Parisian doll maker, Madeleine	291	←	287
5	Claudia and Madeleine are locked in an open courtyard	324	→	322
6	Louis returns to New Orleans in the early 20th century	346	←	345
7	A devastated Louis finds the ashen remains of Claudia and Madeleine	328	→	327
8	Louis and Claudia meet Armand	251	←	248
9	Lestats accusations against Louis and Claudia result in Louis being locked in a coffin to starve	323	→	323
10	Louis returns to the Theatre late the following night, burning it to the ground and killing all the vampires inside, leaving with Armand	336	←	334

TABLE 5.1: Example list of events given by a participant for the book, An Interview with a Vampire. Page numbers were added during the experiment, once event was confirmed by both the participant and researcher.

Tasks

Using the list described above, the researcher called out a reading format and the event for the participant to locate.

The participants would then use any means at their disposal (mimicking their current method of switching formats), such as the search function or table of contents, to locate the information as if they were going to reread that section of the book. The task involved finding the beginning of an event that spanned multiple pages or the paragraph containing shorter events. Once found, the participants showed the location to the researcher to confirm.

Following this, the participants were allowed a short time to familiarise themselves with the event and surrounding information. Our primary interest lies in the second stage of each experiment, where participants were required to switch formats. We instructed the participants to close the book or return the e-reader to the home screen and find the same event in the alternative format; during this stage, we took several measurements, which we describe below.

Each participant performed the task a total of 10 times, where each time the switching direction would alternate with a different event to locate.

Measurements

During each task, we recorded several measurements, including the time taken to perform the switch, and pages glanced at to find events, allowing us to analyse the effects of switching direction.

We recorded qualitative data of each participant's technique to locate the event in each reading format. The researcher made notes during each session and further analysed the video recordings.

Finally, at the end of the study, we performed a NASA TLX assessment (administered using the NASA TLX iOS application) to measure workload during the task. We also recorded what format they thought was easiest to find the information.

5.3.1 Results

Pre-Study Questionnaire

Following any demographic questions, the pre-study questionnaire (Appendix D.2) consisted of just three questions. The first two questions helped us understand the use and preference our participants had toward reading. All 10 of our participants stated that they read from printed books regularly. In addition, 8 participants said

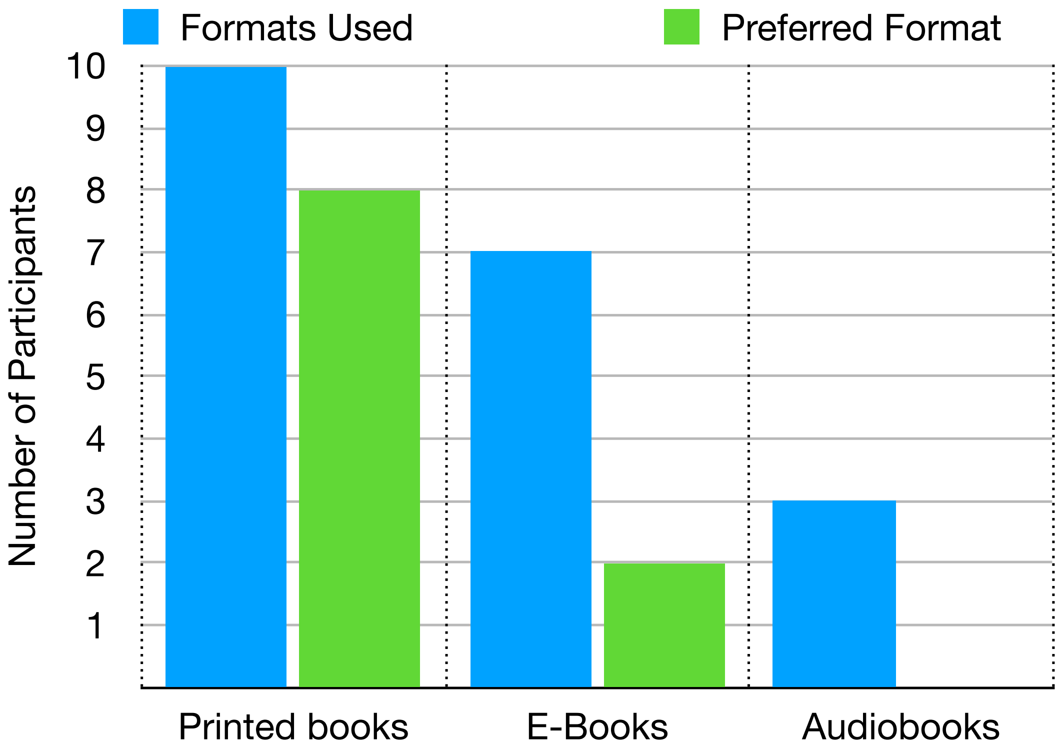


FIGURE 5.6: Graph showing format use and preference for participants of the format switching study.

that they also read regularly from e-books. Just 3 participants declared that they also listen to audiobooks and read from printed and e-books.

The preference of format types our participants had closely aligned with the scoping survey results, with 8 of our participants preferring to read printed books, with the remaining 2 preferring e-books.

Figure 5.6 visualises format use and preference among our 10 study participants.

For the final question, each participant declared the number of times they had read the book they brought to see whether it affected information retrieval. 8 of our participants had brought along a book they had read to completion once, with the remaining 2 participants having read their chosen book twice.

Task-Based Study

Switch-Time: We considered the *switch-time* as the performance metric to analyse the tasks. We describe switch-time as the time to locate the information needed while switching from one reading format to another.

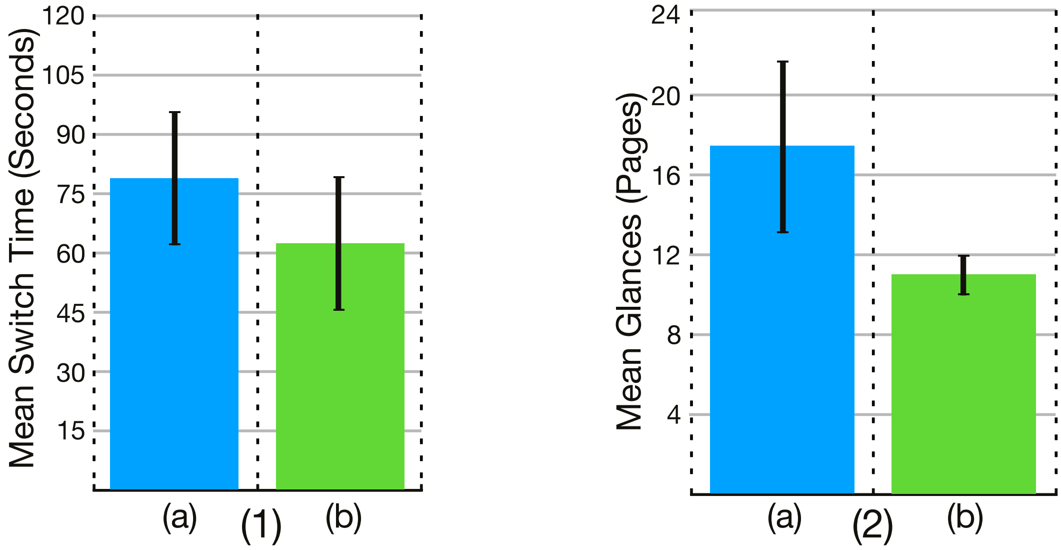


FIGURE 5.7: The mean switch-time (1) and glances (2) to locate information in previously read books are shown. Where (a) Switching to print format and (b) Switching to e-book format and error bars show standard deviation

We present the results in Figure 5.7, where the average switch-time for switching to printed books was 79 seconds (min - 4s, max - 7m47s), and switching to e-books was 62 seconds (min - 13s, max - 5m37s).

We analysed the switch-time of both printed and e-books using repeated measures ANOVA (RM-ANOVA) using the R environment. We found a significant main effect of switch-time ($F_{1,98}$ = 1.24763 and $p < 0.01$)

Switch Technique: Whilst switching to a printed book, all participants used a binary search-like technique, where they opened the book at a page they "felt" was in the general area. They would then read small extracts of a paragraph, just enough to understand what was going on and then move on. They would then change the page in the direction they believed the event would be.

Here is an example scenario if the event the participant had to find was the death of a character. First, they believed that the event occurred halfway through the book, so they opened it at what they "felt" was halfway, using sight and touch. Then, they quickly glance through the text of the first paragraph, which describes a funeral. Finally, the participant realises that the death occurred a while before the funeral scene, so they go backwards in the book by several pages. This technique would then repeat until the participant found the correct information on the page to describe the event.

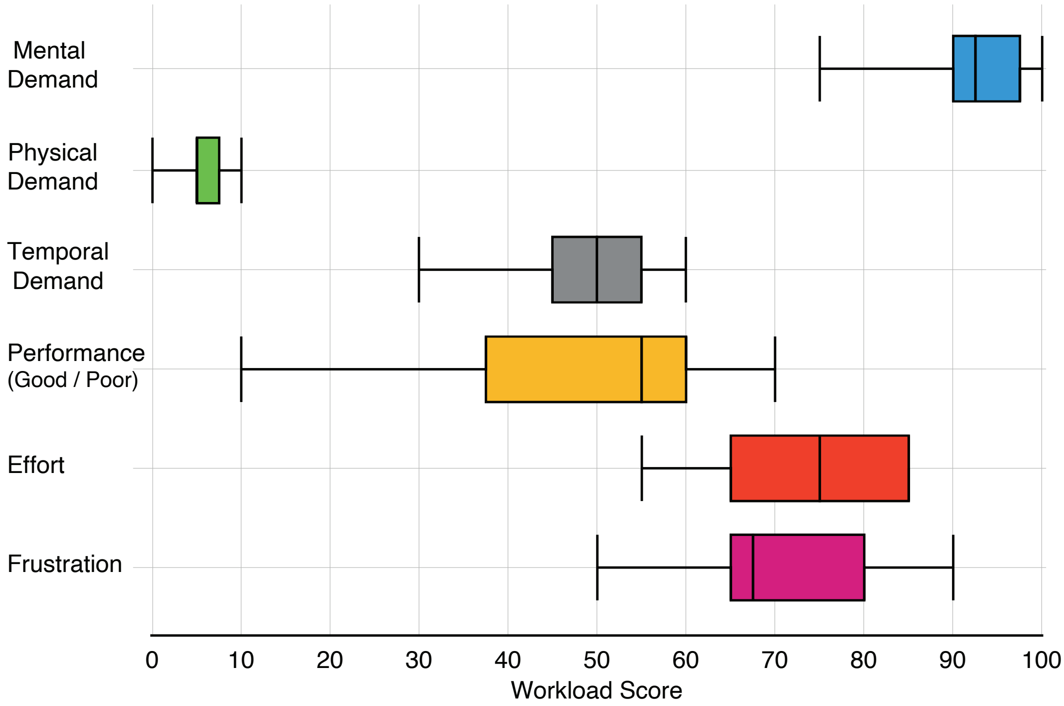


FIGURE 5.8: Box plots of post-study NASA TLX assessment, showing the median workload score, 1st and 3rd quartiles along with the upper and lower extremes.

3 participants also used this approach to find the information in the e-book version, where they would use the scroll bar to identify the position they "felt" was where the event occurred. However, most understood the features of an e-reader well and chose to use the search function to find the general area. First, participants would use keywords or phrases they believed would take them to the event they sought. If required, participants would then proceed with the binary search technique.

Glances: Firstly, let us define what we mean by a "glance". We define a glance as the participant pausing to actively read an extract of a page. Glances were counted during the task and verified via the video recordings.

The mean number of glances performed while switching to printed format was 17 (min - 1, max - 122) and 11 (min - 1, max - 83) while switching to e-book.

We analysed the number of glances while switching to both printed and e-books using an RM-ANOVA using the R environment. We found a significant main effect of glances ($F_{1,98} = 3.84538$ and $p < 0.01$)

Post-Study NASA TLX Assessment

The post-study NASA TLX assessment looked to measure mental demand, temporal demand, performance, effort and frustration participants felt the tasks. We present the NASA TLX results in Figure 5.8.

- Mental demand had a median workload score of 92.5, demonstrating that the task of switching from one format to another is mentally demanding. Discussions with participants revealed they felt it was mentally demanding because they had to remember the order of events of the book. Participants stated that they needed to remember events leading up to the event they were seeking, as it helped them locate the required event; 8 participants described this sentiment.
- Scores for physical demand were opposites, with a median workload score of 5, demonstrating that the task was not a physically demanding one. But, again, it is no surprise here as participants were reading a book.
- The temporal demand assessment yielded a median score of 50. The discussions revealed that participants sense of temporal load increased the longer they took to complete a task. Participants who completed the tasks faster had lower workload scores for the temporal load.
- The scores of participants' perceived performance correlated with the time taken to perform a task. The faster a participant could complete a task, the lower the perceived performance score (lower means better). The median performance score was 55, with a lower extreme of 10.
- Overall, the participants found that the task required much effort, with the median workload score for the effort being 75. However, the participants felt this effort unanimously due to the mental demand the task required.
- Participants found the task quite frustrating, with a median score of 67.5. In addition, participants found their search technique particularly frustrating, as their first estimate either fell before or after the event they were seeking where all future searching relied upon their memories of the first seen position.

5.3.2 Discussion

Overall, our lab study showed that the task of switching from a printed reading format to an e-book could take a considerable amount of time, requires high mental demand and is frustrating.

The direction of the format switch can significantly affect the amount of time it takes, with the average switch-time being 17 seconds longer whilst switching to a printed book. The switch-time disparity increases the longer a participant takes to find an event. The difference in the highest times is 2 minutes 10 seconds, again, with switching to printed books recording the most extended times.

Switching to printed books also had participants performing more glances, with an average of 17, 6 more than switching to e-books. All but 3 of our participants used the search feature of e-books to find the general area of an event, significantly narrowing the search area, thus lowing the number of glances made.

We analysed whether the difference in turning a physical page or flicking through an e-book affected switch-times. We found that the benefits/drawbacks of each format were able to balance each other out. For example, E-books can switch pages faster, but only a single page at a time, and physical books can have multiple pages skipped.

Based on the results of this study and our scoping survey, in the next section, we go on to design and develop a prototype device to keep printed and electronic books synchronised. Currently, readers synchronise printed and electronic books using memory, which we show the process needs high mental demand and can cause frustration. Furthermore, the switching process can also take a significant amount of time, so our synchronisation device looks to decrease this time drastically and remove the need for readers use of memory while reading on different formats.

5.4 Digital Bookmark Concept

Digital formats of printed works have had the ability to synchronise with one another for a long time, and this feature has been sadly overlooked for printed formats. However, as most of the market share is taken by printed and electronic books, a growing trend of readers owning copies of books in multiple formats occurs. Due to this, we came up with the concept of the Digital Bookmark.

Bookmarks of some form have been used in printed books for hundreds of years to allow readers to resume reading from their last position immediately. E-readers then implemented this concept in the digital era to save multiple pages. We are now at a time where both printed and electronic formats are prevalent, with people enjoying the physicality and feel of print and the convenience and cheaper digital pricing. Our concept allows readers to benefit from the advantages of both formats by allowing the immediate continuation of reading between both print and e-books.

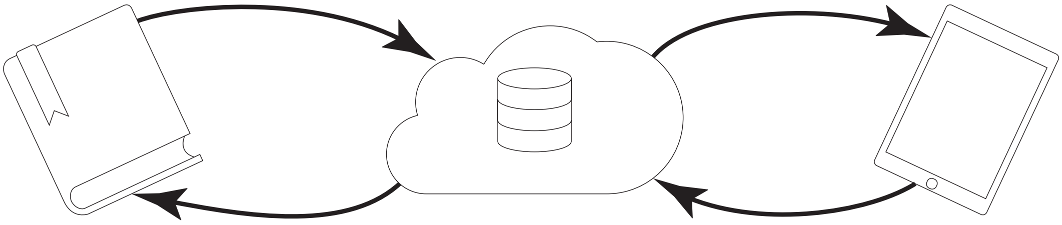


FIGURE 5.9: Digital Bookmark cloud synchronisation concept.

The online scoping survey and the laboratory study made it evident that switching between printed and electronic book formats was challenging, frustrating and time-consuming. Nevertheless, people like to read both printed and electronic books, and like the advantages of both forms. However, a gap needs bridging, making switching between the two formats easy, quick, and enjoyable.

We present the Digital Bookmark device for printed books, which allows easy and quick synchronisation of page numbers between printed and electronic books. Our concept of a digital bookmark involves readers inserting a device into a printed book page when they complete a reading session. The device is inserted to mimic the current experience of using a physical bookmark. The device is designed to resemble a traditional bookmark's shape, size, and design, except for a compartment to hold components.

The digital bookmark detects the page number and notifies a web server when inserted into a printed book. The web server allows digital devices to retrieve this information when needed. The device to server communication works both ways, so all devices know the current page of the book at all times, visualised in Figure 5.9. Many digital devices already use a similar feature to keep themselves in sync with one another. The digital bookmark allows printed books to become part of this ecosystem.

5.4.1 Digital Bookmark Scenario

Based on our digital bookmark concept, we have formulated the following scenario:

We believe that the scenario presented above offers a far greater user experience for multi-format readers than the scenario previously presented in Section 5.2.2.

Lacey travels frequently and likes to read during the transit. She prefers reading printed books at home but wants to read from her e-book whilst travelling.

She likes the digital features but misses the tangibility of her printed book, so she owns copies of books in both formats.

She stops reading towards the end of her journey and places her e-reader into her bag.

When Lacey resumes reading later that night, her digital bookmark clearly displays the page number from which she should continue reading. So she flicks through the pages to find the page number displayed on the bookmark.

Lacey simply places the digital bookmark into the open page when she ends her reading session and closes the book.

When Lacey switches to her e-book the next day, the correct page is instantly displayed.

BOX 5.2: Scenario of the experience of multi-format readers using a digital bookmark.

5.5 Digital Bookmark Prototype

We prototyped a content synchronisation device to transfer the reading progress across printed and electronic formats in the form of a digital bookmark. This section describes the design process for page detection of printed books, content matching across formats, prototype design and interaction design.

During the prototyping stage, our design choices heavily relied upon the user interaction design of such a device. For example, it's almost thoughtless when a reader inserts a bookmark or "dog ears" a page corner to mark their place within a book. Bookmarking is fast, easy, and self-explanatory, and we wanted this type of user interaction for our device. We wanted a user to see our device and instantly know what it was and how to use it. So, it was pivotal that the aesthetic and interaction technique mimicked that of bookmarks readers have always known.

5.5.1 Page Detection of Printed Books

The first problem we encountered was detecting a reader's progress at the end of a session. Our prototypes page detecting technique went through multiple design iterations, where we explored several solutions to determine the location within a book the reader had placed it. We explored the following methods:

Optical Character Recognition

We first explored the use of optical character recognition (OCR), which is the process of extracting written text from imagery. We envisioned taking a page snapshot via a camera, applying OCR, and retrieving enough information to determine location. We later discover that this process is entirely possible, with caveats.

Our first approach was to test the process with pre-built solutions to minimise development time. We came across multiple applications and chose to use OCR Scanner by LEAD Technologies Inc[2] for iOS. We decided on this application for several reasons: it was free to test, and an SDK was available for further development.

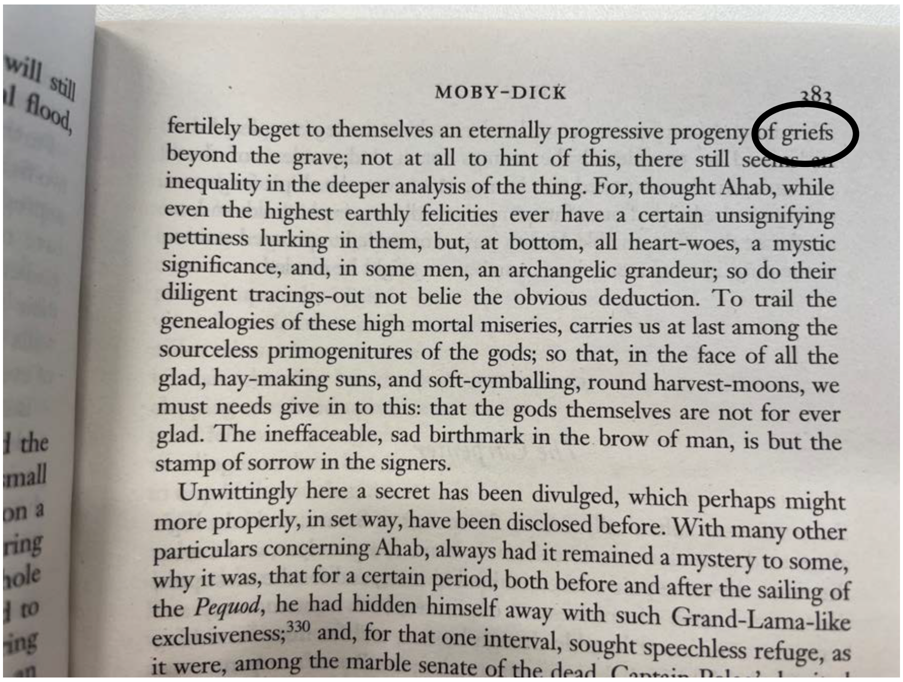
Initial tests were promising. We took a picture of the top half of the page, with the text spanning the image's width. The application detected the printed text and converted it to a digital form that resembled the original, as shown in Figure 5.10. We had several options to determine the book location from the converted text, such as taking the first line or even page number. Fortunately, we used a book where the number was at the top of the page, which is not always the case. Based on this, using the extracted text of the first line would be the most universal.

As a quick test, we used the search function of the iBooks e-reader application on an iPad. After searching for the first line in its entirety, the app found zero results. After that, however, We began to use less of the text, which gave us the exact location of the page, as seen in Figure 5.11. We found that the zero result search occurred due to the extracted text having a spelling mistake, where it extracted "Eliefs" rather than "griefs".

We discussed the possibility of the digital bookmark being an application. However, we quickly dismissed the idea as it went entirely against the grain of the user experience we wanted. Unfortunately, the reader would always require a digital device to take a picture of the page, which may be the case in most situations; however, the experience is unwanted.

Following the dismissal of an application, we explored small form factors that resembled a traditional bookmark. We investigated whether it is possible to attach a small camera to a bookmark form factor to take pictures whilst it is in the process

[2]Inc LEAD Technologies. *OCR Scanner with LEADTOOLS SDK*. 2020. URL: https://apps.apple.com/us/app/ocr-scanner-with-leadtools-sdk/id601177271.



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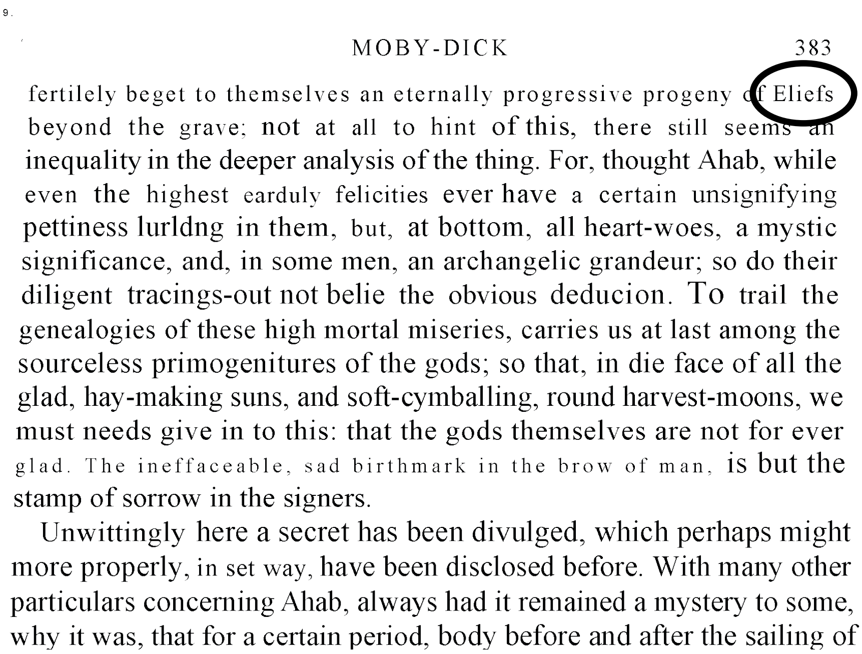
fertilely beget to themselves an eternally progressive progeny of griefs beyond the grave; not at all to hint of this, there still seems an inequality in the deeper analysis of the thing. For, thought Ahab, while even the highest earthly felicities ever have a certain unsignifying pettiness lurking in them, but, at bottom, all heart-woes, a mystic significance, and, in some men, an archangelic grandeur; so do their diligent tracings-out not belie the obvious deduction. To trail the genealogies of these high mortal miseries, carries us at last among the sourceless primogenitures of the gods; so that, in the face of all the glad, hay-making suns, and soft-cymballing, round harvest-moons, we must needs give in to this: that the gods themselves are not for ever glad. The ineffaceable, sad birthmark in the brow of man, is but the stamp of sorrow in the signers.

Unwittingly here a secret has been divulged, which perhaps might more properly, in set way, have been disclosed before. With many other particulars concerning Ahab, always had it remained a mystery to some, why it was, that for a certain period, both before and after the sailing of the *Pequod*, he had hidden himself away with such Grand-Lama-like exclusiveness;[330] and, for that one interval, sought speechless refuge, as it were, among the marble senate of the dead.

(a)



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(b)

FIGURE 5.10: Image showing (a) picture taken of book and (b) OCR output of iOS application. Images highlight incorrectly recognised word.

Chapter 106

Ahab's Leg.

The precipitating manner in which Captain Ahab had quitted the Samuel Enderby
unattended with some small violence to his own person. He had lighted with such energ
ivory leg had received a half-splintering shock. And when after gaining his own deck, a
vehemently wheeled round with an urgent command to the steersman (it was, as ever, s
inflexibly enough); then, the already shaken ivory received such an additional twist and
remained entire, and to all appearances lusty, yet Ahab did not deem it entirely trustwor

And, indeed, it seemed small matter for wonder, that for all his pervading, mad rec
careful heed to the condition of that dead bone upon which he partly stood. For it had not been very long prior to the Pequod's sailing from Nantucket, that he had been found one night lying prone upon the ground, and insensible; by some unknown, and seemingly inexplicable, unimaginable casualty, his ivory limb having been so violently displaced, that it had stake-wise smitten, and all but pierced his groin; nor was it without extreme difficulty that the agonizing wound was entirely cured.

Nor, at the time, had it failed to enter his monomaniac mind, that all the anguish of that then present suffering was but the direct issue of a former woe; and he too plainly seemed to see, that as the most poisonous reptile of the marsh perpetuates his kind as inevitably as the sweetest songster of the grove; so, equally with every felicity, all miserable events do naturally beget their like. Yea, more than equally, thought Ahab; since both the ancestry and posterity of Grief go further than the ancestry and posterity of Joy. For, not to hint of this: that it is an inference from certain canonic teachings, that while some natural enjoyments here shall have no children born to them for the other world, but, on the contrary, shall be followed by the joy-childlessness of all hell's despair; whereas, some guilty mortal miseries shall still fertilely beget to themselves an eternally progressive progeny of griefs beyond the grave; not at all to hint of this, there still seems an inequality in the deeper analysis of the thing. For, thought Ahab, while even the highest earthly felicities ever have a certain unsignifying pettiness lurking in them, but, at bottom, all heartwoes, a mystic significance, and, in some men, an archangelic grandeur; so do their diligent tracings-out not belie the obvious deduction. To trail the genealogies of these high mortal miseries, carries us at last among the sourceless primogenitures of the gods; so that, in the face of all the glad, hay-making suns, and soft cymballing, round harvest-moons, we must needs give in to this: that the gods themselves are not for ever glad. The ineffaceable, sad birth-mark in the brow of man, is but the stamp of sorrow in the signers.

Unwittingly here a secret has been divulged, which perhaps might more properly, in set way, have been disclosed before. With many other particulars concerning Ahab, always had it remained a mystery to some, why it was, that for a certain period, both before and after the sailing of the Pequod, he had hidden himself away with such Grand-Lama-like exclusiveness; and, for that one interval, sought speechless refuge, as it were, among the marble senate of the dead. Captain Peleg's bruited reason for this thing appeared by no means adequate; though, indeed, as touching all Ahab's deeper part, every revelation partook more of significant darkness than of explanatory light. But, in the end, it all came out; this one matter did, at least. That direful mishap was at the bottom of his temporary recluseness. And not only this, but to that ever-contracting, dropping circle ashore, who, for any reason, possessed the privilege of a less banned approach to him; to that timid circle the above hinted casualty—remaining, as it did, moodily unaccounted for by Ahab—invested itself with terrors, not entirely underived from the land of spirits and of wails. So that, through their zeal for him, they had all conspired, so far as in them lay, to muffle up the knowledge of this thing from others; and hence it was, that not till a considerable interval had elapsed, did it transpire upon the Pequod's decks.

But be all this as it may; let the unseen, ambiguous synod in the air, or the vindictive princes and potentates of fire, have to do or not with earthly Ahab, yet, in this present matter of his leg, he took plain practical procedures;—he called the carpenter.

And when that functionary appeared before him, he bade him without delay set about making a new leg, and directed the mates to see him supplied with all the studs and joists of jaw-ivory (Sperm Whale) which had thus far been accumulated on the voyage, in order that a careful selection of the stoutest, clearest-grained stuff might be secured. This done, the carpenter received orders to have the leg completed that night; and to provide all the fittings for it, independent of those pertaining to the distrusted one in use. Moreover, the ship's forge was ordered to be hoisted out of its temporary

FIGURE 5.11: Screenshot of OCR search of book using iBooks.

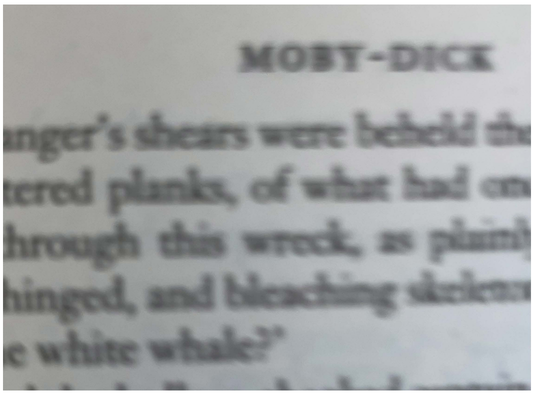


FIGURE 5.12: Image of blurred text while camera bookmark is being inserted.

of being inserted so its location can be inferred. We discovered that the form factor is possible. However, the interaction and OCR is not. Whilst the camera bookmark is being inserted into the book, it does not have enough time to focus, resulting in a blurred image, as shown in Figure 5.12. This blurred image then resulted in OCR not being possible.

The solution to the blurred image problem was to introduce a physical pause during the bookmark insertion process. So, for example, when inserting the bookmark, a user would stop and hold the bookmark over the book for several seconds until the device confirmed OCR was successful. This solution worked; however, the user experience was compromised and unnatural. So, for this reason, we sought another solution.

Light Detecting Resistors

Our second solution was to explore the use of light-dependent resistors (LDR) to detect the page where a user placed the bookmark. LDRs can detect both the presence and amount of light reaching its surface. We investigated the idea of using several LDRs to detect a unique pattern that would identify a page within a printed book.

We decided to create a binary pattern representing the number of the current page. So, for example, page 1 would be 0001, page 2 would be 0010, page 3 would be 0011, etc. The pattern would be represented on each page by a series of holes, and these holes would allow the LDRs to detect if light was present. If an LDR detected light above a threshold, it would mean there is a hole in the pattern, so a binary 1 is recorded. If not, a 0 is recorded.

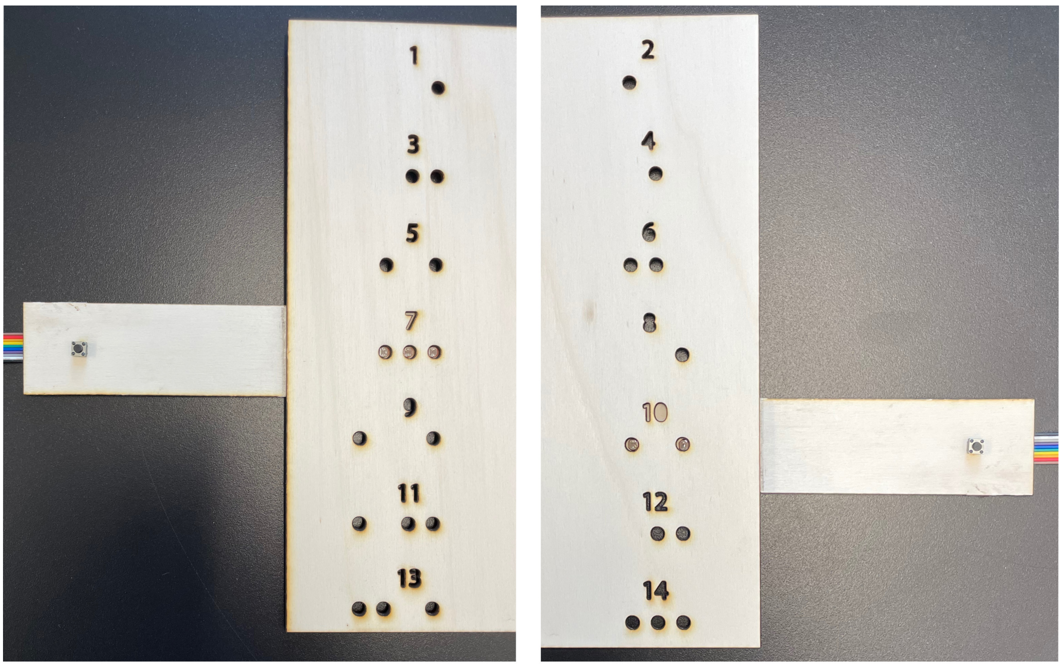
FIGURE 5.13: LDR bookmark and sheet containing binary patterned holes.

We created an LDR bookmark and binary sheet with several patterns to test the theory. The LDR bookmark consisted of four LDRs and a button, and each component was mounted onto a bookmark shaped piece of wood (Figure 5.13). Having four LDRs allowed the prototype to detect a maximum of fifteen different binary numbers. In addition, the button was in place to be pressed when the device should read the binary pattern. The binary sheet was a piece of laser-cut plywood with the binary hole combinations for the numbers.

To use the LDR bookmark prototype, we placed it under the sheet at the position of the desired number (Figure 5.14). Then, when the bookmark is aligned with the holes, the button is pressed to read the binary code. Finally, a microcontroller device controlled the LDR bookmark, and the serial console of a PC displayed the output.

The author and several colleagues tested the device concept in the lab. Results showed that with correct alignment, this method of page detection worked every time. So, following this, we investigated the user experience of an LDR bookmark.

Unfortunately, we found that the user experience for an LDR bookmark was less than optimal. The problem is how the LDRs read the binary number. So, to read the



(a) (b)

FIGURE 5.14: LDR bookmark and sheet (a) reading number 7 (b) reading number 10.

page number, the LDR bookmark needs a single page with a unique binary pattern placed on top of it. Getting the page number within a book is entirely possible. However, the steps a user needs to take can seem unintuitive and odd. We found two possible sequences:

(a) The reader would complete their reading session. They would place the LDR bookmark on the open page. The reader would then lower the previous page on top of the bookmark for the device to detect the unique binary pattern, thus saving the digital representation of the page number.

(b) The reader would complete their reading session. They would place the bookmark under the current page, which involves turning the book to the next page, inserting the bookmark, and returning to the current page. The device can then read the unique binary pattern to save the page number digitally.

The scenarios revealed two problems to use. The first was the suboptimal user experience, which would be unintuitive and alien to readers. The second was a more extreme issue: the bookmark could only work for half of the total pages in a printed book. As we have already discussed, the LDR bookmark requires holes in each page to represent a unique binary pattern. In addition, Pages in a book are, more often than not, printed double-sided, so each page would need two unique binary patterns to give the reader the ability to save both pages of a single sheet.

However, having two sets of holes introduces more issues. The first is the amount of space it takes, and the other is the user aligning the bookmark to the correct holes for the correct side of the page. Therefore, we declared that due to the unnatural user experience and the difficulty introduced, if all pages needed two binary codes, we would explore further reading location retrieval methods.

Later Bairaktari et al. [14] present the Magic Bookmark device. The magic bookmark introduces the same concept and uses the same technique as our LDR bookmark, using photovoltaics rather than light-dependent resistors. Unfortunately, they identified the same user experience issues as we did and could not achieve the *"zero-delta"* experience they desired.

Conductive Tags

The following solution explored using conductive materials to create the binary pattern rather than holes. We believed that using a conductive material that can be applied to the pages of a book; we could easily tag each page and allow all pages to be digitally saved via the bookmark.

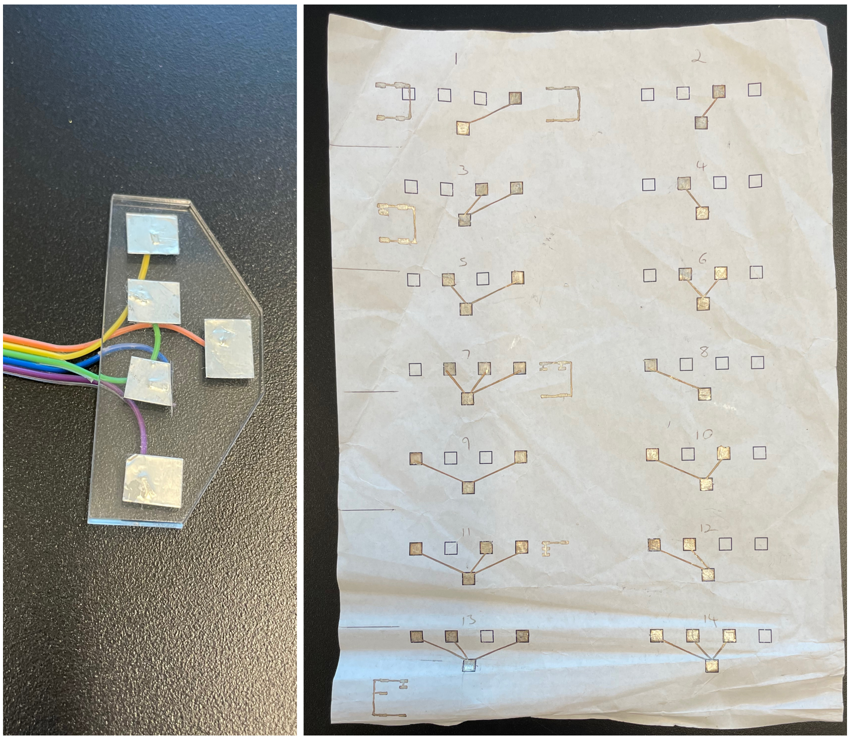


FIGURE 5.15: Conductive tag bookmark and sheet containing binary patterned conductive ink.

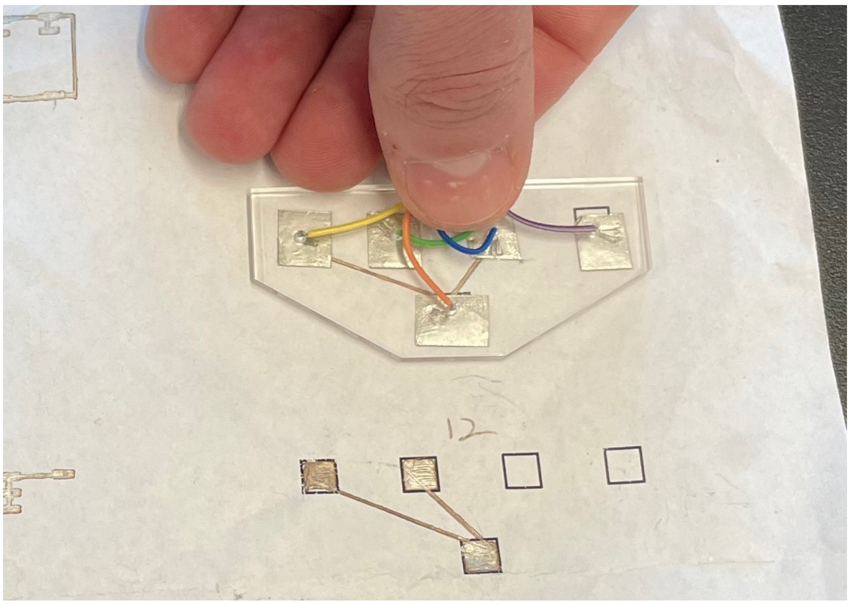
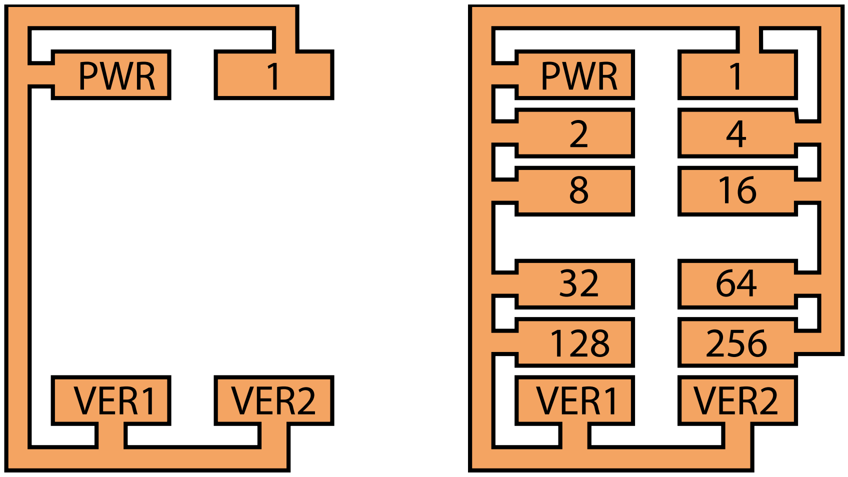


FIGURE 5.16: Conductive tag bookmark test.



(a) 1 (b) 511

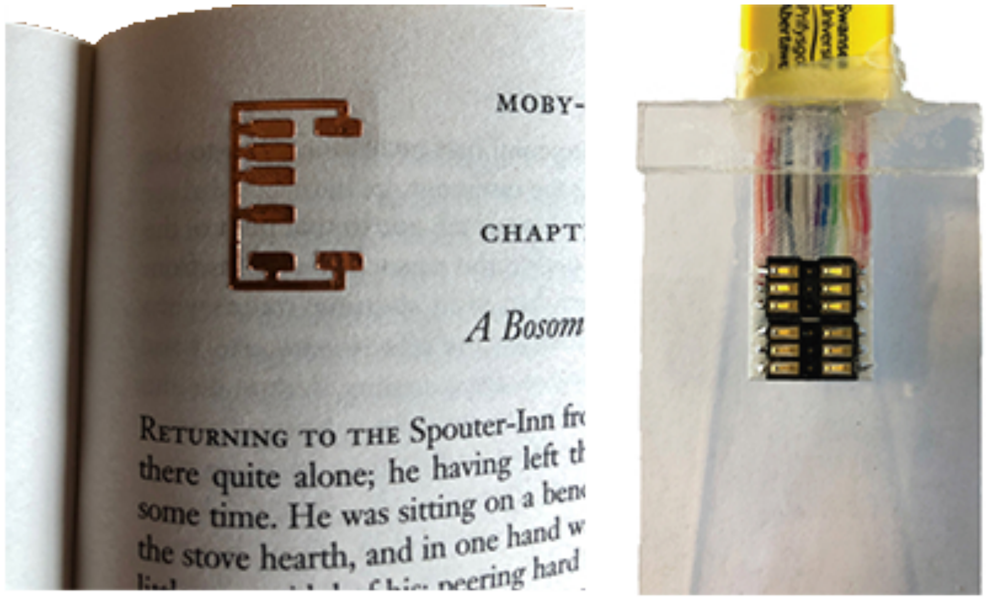
FIGURE 5.17: The conductive tags placed on each page are shown, where (a) represents the decimal number 1 and (b) represents the decimal number 511. VER 1 & 2 are used to verify correct placement of the digital bookmark over the conductive tag. Numbers on each contact pad represent the decimal weight of each binary bit.

Firstly, we built a small handheld tag reader prototype to test the method. The tag reader was simply a laser-cut acrylic sheet with five conductive pads. The tag reader allowed a four-bit binary number to be read, like the LDR bookmark. However, an extra tag was required to supply power to detect the pattern. A printed sheet was made using paper, and the sheet held the same fourteen binary number combinations as the LDR test sheet. Both tag reader and tag sheet are shown in Figure 5.15. The author tested the conductive tag method using the prototype, like the LDR bookmark; the tag was always read correctly when the alignment was correct. Figure 5.16 shows a test for the conductive tag handheld reader.

The Final solution was to use a conductive copper tag. A tag consisted of twelve contact pads. This number was decided by the method used to read the tags, a set of sim card readers. The twelve pads are used as follows:

- One pad conducts power.
- Two pads verify the correct alignment.
- The remaining pads form a 9-bit binary representation of the page number (five hundred and eleven numbers excluding zero).

Figure 5.17 shows two example tags for the numbers one and five hundred and eleven. In addition, we added a conductive copper tag to each page of a printed



(a) (b)

FIGURE 5.18: The conductive tag and reader is shown (a) showing the conductive tag on a page of a book (b) Showing sim readers of the bookmark which read the conductive tag data

book (shown in Figure 5.18 a) to detect its number with a sim card reader bookmark (Figure 5.18 b).

5.5.2 Pagination of Electronic Books

To display an e-book, e-readers dynamically paginate the content taking font and display size into account. However, an e-book contains no information regarding the pagination of printed copies, and the device needs this information for synchronisation. Therefore, we added tags to the e-book to create page-markers of the physical pages of the printed book. Then, we wrote a script that automatically added the page-marker tags, which:

1. Extracts the content of the e-book
2. Paginates the content to the same parameters as the printed book
3. Injects page-marker tags into the e-book

The tags allow the e-reader application to identify its current location within the printed book. It searches for the first page-marker tag behind the first word displayed by the e-reader.

5.5.3 Prototype Design

We built the prototype Digital Bookmark using off-the-shelf components, including a Raspberry Pi Zero W [38] and an Inky pHAT e-ink display module [109]. We also created an e-reader application using FolioReaderKit [1] as its foundation. The Digital Bookmark and e-reader application synchronise electronic books to their physical counterparts and vice versa.

Hardware

The bookmark consists of two parts: the controller and the reader. The reader, shown in Figure 5.18-b has a similar size and shape as a conventional bookmark, designed this way as it is the part placed inside printed books. In addition, Sim card readers are used to read the contact pads of a conductive copper tag on the paper.

The controller, shown in Figure 5.19, is the primary unit of the Digital Bookmark and houses the Raspberry Pi Zero W, Inky pHAT e-ink display and the battery. The display informs the reader of the page number they should resume reading from and updates whenever the synced page in the web server changes. The controller converts the binary data read by the reader to a decimal and transmits it to the webserver via WiFi.

The design of the Digital Bookmark mimics the experience of using a conventional bookmark with the addition of a display. With a current physical bookmark, a reader simply slots it into the next page to read, one simple step. Likewise, the user would slot the tag reader on the page they wish to bookmark to use the Digital Bookmark.

5.5.4 E-reader Application

The application design is to recreate the look and feel of any standard e-reader application on the market, such as Apples' iBooks[3] or Amazons' Kindle[4]. When the application enters the background, the current position of the e-book is synced to the cloud to allow seamless continuation. The application presents the user with the latest synced page across devices and printed books when brought into focus.

[3] Apple. *iBooks*. 2018. URL: https://www.apple.com/uk/ibooks/ (visited on 02/07/2018).
[4] Amazon. *Kindle iOS Application*. 2018. URL: https://itunes.apple.com/gb/app/kindle/id302584613?mt=8.

FIGURE 5.19: Digital bookmark prototype in a printed book, showing control unit.

5.5.5 Limitations

By far, the most significant limitation of this implementation is the need to tag pages of printed books. The tagging process is time-consuming and impractical for existing books. New books could have the tags added during the printed process with transparent conductive inks, but this would be costly and exclude all existing books. We believe that this hardware solution is not ideal for those reasons and would need to evolve if it became available to the mass market. This solution was not the only method investigated.

One other method investigated was the use of OCR to read the content of printed pages to infer location. This method does not require the tagging process and can work for all books. However, it comes at the cost of the user experience. For this reason, we chose to implement the conductive tag prototype to investigate if the concept of the Digital Bookmark could work and improve the user experience for multi-format readers.

5.6 Digital Bookmark Study

We ran a study with a small local reading group to get the digital bookmark device into the hands of users, where the study aimed at getting user evaluations from each participant regarding the digital bookmark. We also hoped to receive thoughts and ideas on improving the device in future iterations.

Procedure

The reading group had 10 members (6M, 4F, 18-64) who could participate in the study. We selected the reading group as each member is an active reader who often reads several books over many formats. We designed the study to show how the digital bookmark works, demonstrate how it can speed up the format switching process and remove readers' use of memory for finding their current position across formats.

We discussed the experiment with an information sheet and proceeded only after being granted informed consent:

1. Each participant completed a short pre-study questionnaire (Appendix D.3) for demographic and reader use/preference purposes.

2. Participants sat at a table with the printed book, e-reader, and digital bookmark placed upon it, with both books showing the title page and the display of the digital bookmark showing zero.

3. We instructed each participant to perform the tasks of the study, as described below.

After completion, participants completed a NASA TLX assessment and a short discussion regarding their experience during the experiment and the device. On completion of the study, participants were given a voucher as compensation for their time.

Tasks

As the bookmark requires a tagged book, we performed this experiment using a book of our choosing (Moby Dick by Herman Melville). Because of this, instead of finding 10 known locations, this study had participants going to any random location within the book and then verifying that the bookmark or e-reader seamlessly displays the same content.

To match the number of data points as the previous study, the participants had to perform the task of switching from one format to another 10 times (5 x print to e-book, 5 x e-book to print alternately). When switching from the printed book to the e-reader, the participant had to place the bookmark into the page they chose and then opened the e-reader application to verify that the content was synchronised and the same. When transitioning from e-reader to printed book, the participant navigated to a page of their choosing and returned the e-reader device to the home screen. They then checked the bookmark display and verified that the content on the displayed page was the same. We recorded the switch-time to analyse whether the bookmark speeds up the process like the format switching study.

5.6.1 Digital Bookmark Study Results

Pre-Study Questionnaire

The pre-study questionnaire (Appendix D.3) aimed to get our participants' reading preferences, where 8 of the participants declared the use of printed books, 7 reported e-book use, and just a single participant used audiobooks. Again, the preferred format of participants closely resembled that of the previous study, with 7 preferring printed books and the remaining 3 choosing e-books.

Figure 5.20 visualises book use and preferences for the study participants.

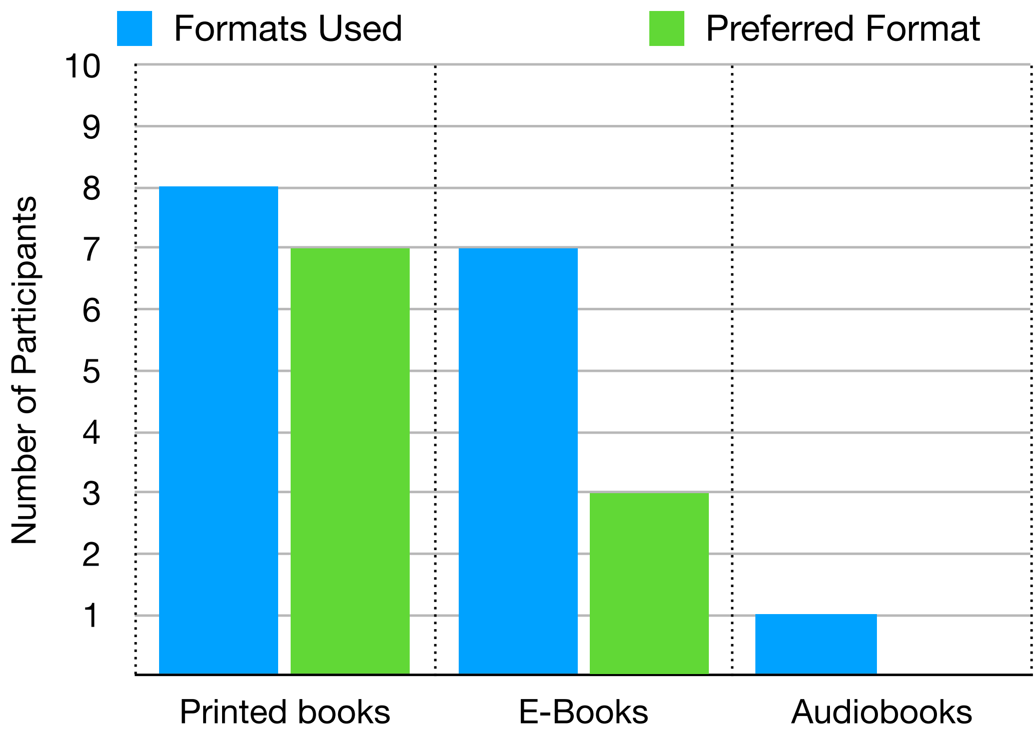


FIGURE 5.20: Graph showing format use and preference for participants of the digital bookmark study.

Task Based Study

Switch-Time: Like in the format switching study, we considered the switch-time as the performance metric to analyse each task. We present the results in Figure 5.21, where the average switch-time for switching to printed books using the Digital Bookmark was 8.92 seconds with a minimum of 2 seconds and a maximum of 15 seconds. The average switch-time for switching to e-books using the Digital Bookmark was 2.38 seconds with a minimum of 1 second and a maximum of 4 seconds. The Digital Bookmark presented the correct page to the participants almost instantaneously during each task. The time variance occurred and shown here is the time the participants took to confirm the correct event location in the book.

We analysed the switch-time of both printed and e-books using an RM-ANOVA using the R environment. We found a significant main effect of switch-time ($F_{1,98}$ = 1.24763 and $p < 0.01$)

Switch Technique: While using the digital bookmark, all participants demonstrated an entirely different search technique while looking for the location within a printed book compared to that of the format switching study. As the task had

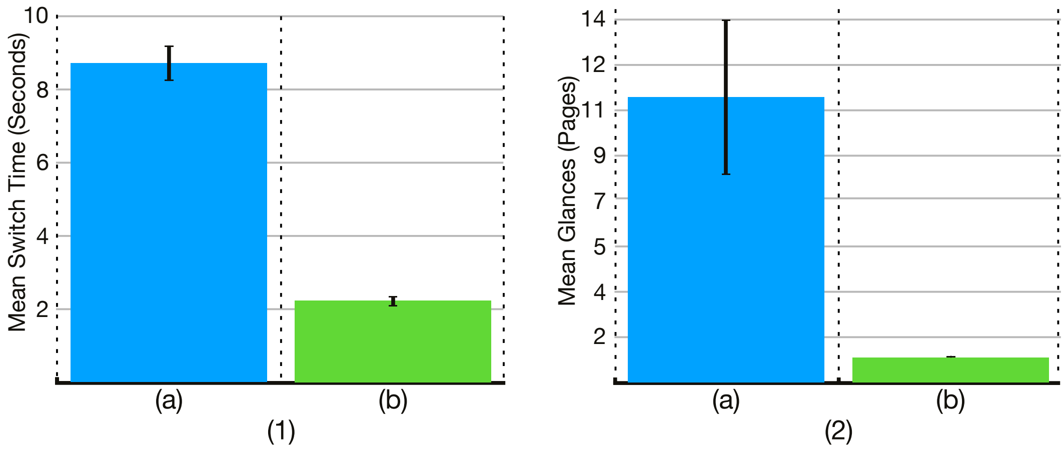


FIGURE 5.21: The mean switch-times (1) and glances (2) while using the Digital Bookmark are shown. Where (a) Switching to print format and (b) Switching to e-book format and error bars show standard deviation

now changed from an information-seeking task to merely a page number seeking task, all participants used the "flick" technique. The "flick" technique involved the participant holding the book with their thumb securing the edges of each page, and then bending the book to release the pages at the top of the stack. The flicking caused swift turning of pages while readers monitored the page numbers. Participants would then stop the flicking process either directly on the correct page number or within a few pages and simply turn to the correct page.

No switch technique was required while switching to the e-book, as the correct page was always instantly presented to the participant.

Glances: For this study, we had to redefine a glance as the participant only actively read an extract of the correct page. For this task, a glance was defined as a participant's pause to read a page number or a section actively, which were counted and verified via the video recordings. The mean number of glances performed while switching to printed format was 11 (min - 1, max - 17) and 1 while switching to e-book.

We analysed the number of glances while switching to both printed and e-books using an RM-ANOVA using the R environment. We found a significant main effect of glances ($F_{1,98}$ = 252.5 and $p < 0.00001$)

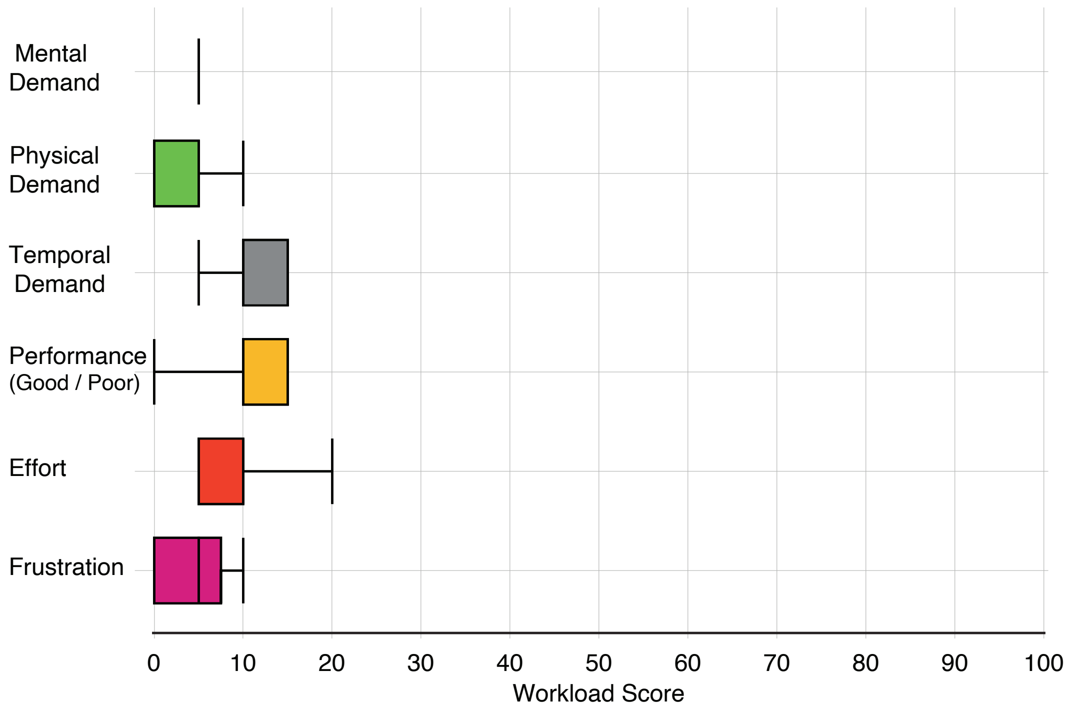


FIGURE 5.22: Box plots of post-study NASA TLX assessment, showing the median workload score, 1st and 3rd quartiles along with the upper and lower extremes.

Post-Study NASA TLX Assessment

We conducted the NASA TLX assessment to measure mental demand, temporal demand, performance, effort and frustration participants felt during the tasks. We present the NASA TLX results in Figure 5.22.

- Mental demand had a median workload score of 5, demonstrating that the task of switching from one format to another using the Digital Bookmark is not mentally demanding.
- Scores for physical demand had a median workload score of 5, demonstrating that the task was not physically demanding.
- The Temporal demand assessment yielded a median score of 10. As each task took very little time, each participant felt very little demand.
- The median score for performance was 10, where a lower score means a better perception of performance. The correlation that was seen in the format switching study continued, where the faster a participant was able to complete a task, the lower the perceived performance score.

- Participants found that the task required minimal effort, with the median workload score for the effort being 10. The task required very little mental demand, this then carried over to the effort the participants required to complete the task.
- Participants found the task was not frustrating, with a median score of 5. Participants felt that the task was least frustrating when switching to the e-book format, as the e-reader instantly presented the correct page. Participants felt slight frustration when switching to the printed format.
- Overall, the participants found the task needed minimal mental demand and was not frustrating.

Post-Study Discussion

Following the NASA TLX assessment, each participant discussed their feelings about using such a device, topics involving form-factor, usability, and whether they could incorporate it into their reading. We had several comments regarding the device's form factor, such as it being significant in size for a bookmark. We were expecting such remarks as the device was constructed using shop-bought components and were not demonstrating a finished product but a prototype for an exploratory study. However, participants liked that we attempted to mimic current bookmarks as it is quickly recognised, with one participant stating, *"as soon as I picked up the device, I knew how to use it."* In addition, participants unanimously agreed that being able to transition between printed and electronic formats instantly could improve their user experience while reading multiple formats. Participants also unanimously decided that they could incorporate such a device into their daily reading, with some improvements to the device, such as a more slimline form factor and the ability to use it on any book.

5.6.2 Summary

Our digital bookmark study has shown that the task of switching reading formats can be fast and require low mental demand when using a digital bookmark.

Switching formats in any direction using a digital bookmark takes less than ten seconds on average, with switching to e-books taking the least amount of time.

Switching to an e-book eliminates the switching process, with the only action needed by the reader being to open the e-book. However, switching to a printed book using a digital bookmark changes the type of search required altogether. The digital bookmark allows a reader to simply search for a page, making it easy for a reader to know which direction their search needs to continue.

5.7 Discussion and Future Work

Our format switching study has shown that switching from one format to another can be a mentally demanding and frustrating task, even in a short time frame in a controlled lab environment. In this environment, we could not reproduce the real world distractions we receive as part of daily life, such as interactions with others or concentrating on other tasks. These interactions and distractions may make the task even more difficult in a real-world scenario.

Most books have page numbers on each page. Unfortunately, page numbers of printed and e-books do not match due to several factors such as screen and font size. The digital bookmark allows readers to seek these page numbers on printed books as the device converts the digital position to the corresponding printed page number. The digital bookmark eliminates the seeking task for switching to e-books, with e-books seamlessly presenting the correct location.

Participants felt that the process of switching using the bookmark required very little mental demand and presented very little frustration. These results differed significantly from the study we held performing the same task without the digital bookmark. When discussing the device with participants, we received feedback that the control unit was "bulky". These comments were somewhat expected with a device made from shop-bought components and traditional bookmarks being a simple narrow card or leather piece. Future device iterations could easily allow a smaller form factor using custom-built electronics rather than off-the-shelf components. Participants' initial feedback indicated that a digital bookmark would improve their user experience across multiple formats.

Overall, a direct comparison of the format switching and digital bookmark studies is impossible as they are fundamentally different tasks. However, each study looks at the same problem - switching between reading formats. The digital bookmark has shown a drastic 90% reduction in switch-time, compared to the bookmark not being used when switching to printed books. Furthermore, the digital bookmark has shown an even more drastic reduction of 97% in switch-time compared to the bookmark not being used when switching to e-books. These massive reductions in switch times show that such a concept is worth investigating and developing further.

We can visualise a reduction in the workload scores between the format switching and digital bookmark studies (again, not directly comparable). These show that if a digital bookmark concept were developed and deployed, an improvement in the user experience is possible.

This chapter presented the concept of a digital bookmark device for seamless synchronisation and transition between printed and electronic books. Due to the lack of prior work, our online survey helped scope the research and development for improving the usability and user experience of reading books in multiple formats. It mainly identified memory use and a lack of a seamless switching method as inhibiting factors when choosing to read via multiple formats. Consequently, we designed a simplified laboratory study to quantify the switch-time and task workload required to switch between formats. We then devised the digital bookmark to address the main inhibiting factors of switch-time and memorising events and help understand the switching process and its user experience. We present the results of a small group user study of digital bookmark and reported significant improvement in switching time and task workload. Participants also reported improved user experience in multi-format reading. We conclude that a digital bookmark for seamless switching is required to improve the transition experience between printed and electronic books significantly.

Chapter 6

Conclusions

Throughout this thesis, we have explored several research areas within the context of reading, both digitally and physically. Our work has focused on two main ideas: bringing physical book-like controls to digital books and interactions to enable a hybrid reading experience. In each chapter, we have presented developments of new input techniques, prototypes and evaluations. This chapter summarises the work of this thesis and concludes its contributions to the research.

6.1 Chapter Summaries

Firstly, Chapter 1 introduced the concept of modern reading, where evolution has ceased for physical books in an ever-increasing digital world. Next, we outline the use of tangible user interfaces to enhance the user experience of digital books over the current flat glass experience received by users. Finally, we go on to discuss the possibility of unifying the experiences, where instead of forcing a physical experience to become more digital or a digital experience to become more digital. We envisioned a hybrid experience where digital and physical mediums communicated to allow synchronised content.

We present an extensive literature review in Chapter 2. This literature review allowed us to identify gaps in the research within the context of digital reading, where the majority of research looks to implement the physical features of a printed book within digital books and e-readers. We explored this gap to develop new tangible input methods for digital books and, eventually, a hybrid reading user experience.

In Chapter 3, we investigate the act of turning a page of a printed book and how we can mimic the experience for digital books. First, the work explores the physical properties of paper and how paper can be augmented with sensors to act as an input device for digital books. We achieve this by producing ultra-thin bend sensors, which allow paper bending to be detected whilst keeping its physical properties intact. Following the development of the ultra-thin bend sensor-augmented paper, we present an e-reading prototype that utilises this paper for the input device of an e-reader application. Next, we carry out a user study, where participants evaluate the usability of such a device. Participants agreed that the augmented paper accurately detected bends and that a paper-based interface could enhance the digital reading experience.

Despite the positive feedback, the paper interface was not without flaws, and the interface failed to recognise a difference between the bottom corner and middle of page bends. As a result, we present an alternative input method, the interactive sheet. The interactive sheet is a device that can differentiate between bend types using a machine learning model. However, the paper interface and the interactive sheet require significant additions to a mobile device, so next, we explored tactile interactions in a more compact and portable setting.

In Chapter 4, we explore the use of compact side of device interactions of a mobile device. Ethnographic and autoethnographic observations of readers' habits and interactions with physical books revealed the edges of pages to be a pivotal point of interaction. With this insight in hand, we explore methods and materials for side of device interaction, for a metaphor of page edges.

Through several iterations, we come to the development of a guitar fretboard like input device. The device utilises the conductive properties of guitar strings and frets to create a multi-dimension grid of touchpoints. The fretboard input device allows for a vast array of strum, slide and touch gestures. Next, we document the design and implementation of the fretboard input device into a mobile form factor. We discover that the form factor can play an essential role in hardware design during this process, especially when designing novel input methods. We show several form factor iterations and document hardware changes that were required.

After implementing a complete fretboard input device prototype, we investigate gesture combinations for such a device, where participants of a user study create and test the gestures they conceptualise. Participants achieved a reasonable accuracy score average of 77% while performing the gestures using the fretboard input device. Participants were somewhat torn over whether or not such a device would enhance the digital reading experience but were overall positive towards the experience it brought.

In Chapter 5 we research the concept of a hybrid reading experience, where we throw out the idea of adding physical elements to digital books or adding digital elements to physical books. Instead, we look to unite the experiences of physical and digital books by introducing a method to synchronise the formats. We would often hear descriptions from study participants of a process we call multi-format reading throughout our earlier work. Multi-format reading is when a reader reads the same book over multiple formats.

Firstly, we explore the scope of multi-format reading via an online scoping survey, where we discover that 26% of respondents identified as multi-format readers. We then study the problem with a format switching lab-based study, where we measure the time taken and mental load of the format switching task. Our results show that the task of switching from one reading format to another is time-consuming and mentally demanding.

Next, We built a system that automatically synchronises physical and digital books in the shape of a bookmark. We consider several methods of retrieving the reading position during its construction, with the final device using a conductive tagging technique. Finally, we repeat the format switching study using the digital bookmark. The study reveals that introducing a digital bookmark can severely lower mental demand and almost eliminate switch-time between formats.

6.2 Key Findings

Throughout this thesis, we have shown that digital reading has lost the tactile feedback and affordances that readers have grown to cherish. Through each chapter, we explored the ownership and preferences of readers, and each time readers have shown a preference for physical, closely aligning with existing market research of the area [22, 138, 76, 158]. Many reasons have been given for this preference. Most of all, participants stated that the feeling and smell of printed books brought forth feelings of familiarity and nostalgia. These features of printed books can tell their own story of where they have been and how they have been treated, features that are routinely missing from digital books, apart from the Realistic Books project [29].

In Chapter 3 our work has shown that bringing tactile feedback and affordances of books is possible. We have produced cheap and affordable input devices that mimic paper pages' feelings. Our prototype, the paper input device, produced low-cost bend sensors which can be embedded upon paper to allow true book-like interaction techniques with digital books. The work within this chapter contributes to several research areas. Firstly we contribute to the TUI area, more specifically the area of book-like controls for mobile reading devices alongside [21, 57, 70, 11].

Our work on the paper input device extends the subjects understanding of tangible mobile devices for mobile devices. We use the knowledge learned from the likes of PaperPhone [135] and ReFlex [82] to create flexible input devices for digital reading. We differ by the material we use, paper. Our paper input device more closely resembles the feeling of a book due to this material.

During the design process of the paper input device, we used existing research [137, 87, 142, 82] to determine what bends the device should detect, which in turn determined how the ultra-thin sensors should be designed. However, we discovered that these bends were insufficient in a real-world setting for the purpose of the device. The literature suggested that a bottom corner bend was performed at a 45-degree angle. However, during our studies this was found not to be the case, so we suggest a reclassification of bottom corner bends, to be around 85 degrees, extending the knowledge in the area.

In Chapter 4 we presented the fretboard input device, using more premium materials, guitar strings. The guitar strings were used as a metaphor for the feeling of the edges of paper books, a technique often used when the physical material is unable to be digitised [21, 57, 70, 11].

The fretboard input device takes inspiration from several one-handed side of devices [51, 128, 59]. We take the knowledge learnt from this literature and expand it to two-handed side of devices. Paranga [71] explored a similar interaction, where the feelings of page edges are used for book navigation. However, Paranga was somewhat impractical for a mobile setting. We expand on this work and bring the interactions to a mobile device.

Our work within Chapter 5 contributes to the knowledge of synchronising digital and physical books. Before our work, to our knowledge, there was not a method of synchronising the reading position of published works from digital to physical and vice versa. All methods before the one presented here looked to synchronise digital versions of media [102, 2, 7, 79, 9, 3, 115].

The existing work tends to seek to create a link between physical notebooks and a digital copy [91, 108, 149, 67]. Others have built on our ideas in their prototypes [14, 12].

A very significant finding within Chapter 5 is that our scoping survey revealed that **26%** of respondents identified themselves as multi-format readers. This reader owns and uses books over multiple formats and often reads the same book over different formats depending on their current scenario. The only other reference to this habit we could identify is an online blog post at Word Revel [68].

Our work within Chapter 5 has shown that synchronisation between digital and physical reading formats is possible using off-the-shelf components and that participants suggest that it would improve their user experience.

6.2.1 Recommendations to Industry

The work within this thesis explores two methods, physical/tangible controls and hybrid experiences. Based on our work we would like to make two recommendations.

Tangible Experiences
In Chapters 3 and 4 we explore physical interactions for e-reading devices such as Kindles, iPads and Kobos. We recommend keeping the integration of tangible controls such as buttons with current technology and then in the future when flexible interface technology improves, implement paper-like controls to bring the physical book-like feel to digital reading devices.

Hybrid Experiences
In Chapter 5 we explore the hybrid experiences and the synchronisation of physical and digital mediums. From this work, we recommend creating seamless transitions between technologies of the past (in this case, the book) and digital technologies. By creating a seamless transition, we encourage user choice and freedom. Users may be more inclined to partake in a hybrid experience if the process was easy and almost thoughtless. From an industry standpoint, encouraging hybrid experiences could lead to greater sales numbers. Gone would be the days when users would have to choose between formats, users could purchase and enjoy all formats, benefiting users and industry alike.

6.3 Limitations

Throughout this thesis, we have designed, developed, and evaluated a set of prototypes, which has helped us further the research within reading experiences. Our prototypes explore several materials, input techniques and form factors. In this section, we outline the limitations of the research within its current form.

Chapter 3 presents the paper input device and the interactive sheet. Our initial prototype could detect the bends outlined in several pieces of literature [137, 87, 142, 82]. However, real-world use did not reflect these lab based bends, so the input method was changed from single-page based to multi-page based. The change was required as our ultra-thin bend sensor experienced limited differentiation between middle and bottom corner bends.

One of the main goals of Chapter 3 was to create a paper-based input device that keeps the properties of paper intact. Due to the limitation discovered, we created the interactive sheet. This sheet eliminates the bend limitation of the paper-based system. However, it could not be made using paper.

Chapter 4 presents the fretboard input device for compact side of device interactions. Three of our ten study participants created a gesture that the input device could not detect. Any gesture that incorporates the first and final fret activates all frets along a string, making the device assume that touch also occurs in the middle fret.

The fretboard device is limited by the number of guitar strings it has, three in its current form. Several participants commented that the device would feel more like the edge of a book if there were more strings, making the gap between them smaller. It is entirely possible that a future version of the device could scale the number of guitar strings up to a level that makes the device edge feel more book edge-like.

Both studies carried out in Chapter 5 were entirely lab-based, which, when used, is often hard to replicate the actions of everyday life. For example, during the format switching study, we had participants switching from one reading format to another, finding a particular event. Ideally, such a study would have been performed in places where a participant would usually do them, e.g. in the house and on the train. Doing this would have resulted in the data directly representing the action. However, a study of this nature in practice would be complicated and a logistical nightmare. For example, would the researcher need to present at all times? Would be the data be accurate if the participant recorded it?

Chapter 5 presents the digital bookmark. The digital bookmark requires tagged pages in printed books to read the page number in its current state. Although the present method allows the bookmark to synchronise printed and e-book formats successfully, it is somewhat impractical due to books needing to be tagged.

All prototypes presented within this thesis were made using off the shelf micro-controllers, components and devices. These sorts of electronics are used for prototyping and tend to be less robust. Developing each device with completely custom electronics could make them more robust and resemble a finished product. For example, we received a comment stating that one of our devices *"was not a finished product"*, we understand this as they are prototypes. However, using custom electronics could prevent comments such as this.

6.4 Concluding Remarks

When the work on this thesis began, all e-readers were flat displayed devices, and now, at its end, they are still flat displayed devices. Over this time, several surveys [22, 138, 76, 158] have been carried out by others, and we carried out our own, where all have found that readers prefer to use printed books.

Within this thesis, we attempted to bring the tangible interactions of printed books to e-readers, and study participants stated that each device we developed helped make an e-book feel more like a printed book. We explored several materials and input methods to close the gap of tangible richness between printed and electronic books. We encourage others to explore tangible materials for digital book input devices to help bring the tangible richness of printed books to digital books.

While we wait for a book-like tangible e-reader to be developed, we would like to encourage users to participate in multi-format reading. Neither format is genuinely considered the best, as both have their advantages and disadvantages. We believe that a hybrid user experience is more beneficial and obtainable than an actual tangible e-book, as users get the best of both worlds.

Given the work of this thesis, we hope to have created a platform for future research within the areas presented where others may take the work we presented and overcome the limitations we discovered. We believe this has already begun with the Magic Bookmark [14, 12], a digital bookmark device using the same techniques as ours. In addition, they use custom electronics to become more compact and closer to our vision of the digital bookmark of being completely flat.

Appendix A

Contributing Publications

(P1) **Gavin Bailey**, *Deepak Sahoo, and Matt Jones. 2017. Paper for E-Paper: Towards Paper Like Tangible Experience using E-Paper. In Proceedings of the 2017 ACM International Conference on Interactive Surfaces and Spaces (ISS '17). Association for Computing Machinery, New York, NY, USA, 446–449. DOI:https://doi.org/10.1145/3132272.3132298*

Abstract
Our work presents a method to use paper as an input device while reading on a mobile device, where the user turns a physical page in the real world in order to turn a page in the digital world. Our goal in this work is to replicate the feedback and affordances one would receive from a printed book on a mobile device, where to fully replicate the reading experience the user would need to turn pages as they would naturally with a printed book. Through a small study we discovered a number of ways that pages are often turned and these techniques became vital to the project. We describe a prototype device which uses paper as an input device with transparent electrodes and bend sensors embedded to pages, so that the turning and bending of pages can be digitally detected and addressed. The prototype is able to detect the page turns and bends made by the user and the state of each page.

Author's contribution
The concepts, designs and implementations of this research was mine. The study was planned, run and analysed by me, and I wrote the paper with feedback from other authors. In addition, I demonstrated the prototype during the demo session at the publishing conference. I attended this conference and performed all demonstrations.

(P2) **Gavin Bailey**. *2018. Augmenting the reading experience. In Proceedings of the 20th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct(MobileHCI '18). Association for Computing Machinery, New York, NY, USA, 425–427. DOI:https://doi.org/10.1145/3236112.3236178*

Abstract
Our work presents a method to use paper as an input device while reading on a mobile device, where the user turns a physical page in the real world in order to turn a page in the digital world. Our goal in this work is to replicate the feedback and affordances one would receive from a printed book on a mobile device, where to fully replicate the reading experience the user would need to turn pages as they would naturally with a printed book. Through a small study we discovered a number of ways that pages are often turned and these techniques became vital to the project. We describe a prototype device which uses paper as an input device with transparent electrodes and bend sensors embedded to pages, so that the turning and bending of pages can be digitally detected and addressed. The prototype is able to detect the page turns and bends made by the user and the state of each page.

Author's contribution
This Doctoral Consortium extended abstract was presented in MobileHCI 2018 DC. I participated in a group consortium at this conference and presented a poster based on the paper. In addition, I created the concepts of this paper, and it was written by me, with feedback and advice from colleagues and supervisors.

(P3) Gavin Bailey. *2019. Bridging the Gap Between the Digital and Print Reading Experience. International Journal of Mobile Human-Computer Interaction (IJMHCI), 11(4), 16-30. http://doi.org/10.4018/IJMHCI.2019100102*

Abstract
This article outlines the research the author conducted to date during his PhD. His PhD, "Augmenting the Reading Experience," looks at methods to improve the reading experience for both digital and printed methods. So far, he has developed a prototype device that uses paper as an input method to interact with digital books. Turning a physical paper page causes an e-reader device to progress through the book, allowing the reader to have the user experience of a printed book, whilst also benefiting from the digital conveniences and features. Many modern readers own the same book in a number of formats and switch between them depending on the scenario. This introduces the problem of transitioning between formats. His current project the "Digital Bookmark" looks to allow seamless transitioning from one format to another by obtaining the latest page number and broadcasting it to all formats the reader is currently using.

Author's contribution
This journal article extends publication (P2), where a journal of Doctoral Consortium papers was published. Again, I created the concepts of this paper, and it was written by me, with feedback and advice from colleagues and supervisors.

(P4) Gavin Bailey, *Deepak Ranjan Sahoo, and Matt Jones. 2020. Digital Bookmark: Seamless Switching Between Printed and Electronic Books. Proceedings of the 2020 ACM Designing Interactive Systems Conference. Association for Computing Machinery, New York, NY, USA, 885–894.*
DOI:https://doi.org/10.1145/3357236.3395557

Abstract
Recently, people prefer to read books via a combination of formats - E-Books along with printed books. We conducted a scoping survey and a lab-study which informed various inhibiting factors associated with switching between formats to conveniently use multiple formats. To improve the switching experience, we present Digital Bookmark that synchronises the current page location digitally between both printed and e-books. The page number of the printed book is electronically read using a conductive tag and transmitted to the e-book via the internet. The current location on the e-book is converted to the corresponding page number of the printed book and presented on the display of the Digital Bookmark. We present the results of a controlled lab-study to assess the parameters of switching between printed and electronic books. The initial feedback from a local reading group suggests that our Digital Bookmark would encourage multi-format reading and improve their user experience.

Author's contribution
The concepts, designs and implementations of this research was mine. Each study was planned, run and analysed by me, and I wrote the paper with feedback from other authors.

Appendix B

Physical Controls for Digital Books - Study Questions

B.1 Pre-Study Questionnaire

Physical Controls for Digital Books Pre-Study Questionnaire

What is your Age:

- ▫ 18 to 24
- ▫ 25 to 34
- ▫ 35 to 44
- ▫ 45 to 54
- ▫ 55 to 64
- ▫ 65 or older

What is your current gender?

- ▫ Male
- ▫ Female
- ▫ Prefer not to say
- ▫ Other ….. (please specify) ______________________________

Which is your dominant hand?

- ▫ Left
- ▫ Right
- ▫ Both

What formats do you use to read books?

- ▫ Printed books
- ▫ E-books
- ▫ Audiobooks
- ▫ Other ….. (please specify) ______________________________

What format do you prefer to use?

- ▫ Printed books
- ▫ E-books
- ▫ Audiobooks
- ▫ Other ….. (please specify) ______________________________

What is the reason for this preference?

B.2 Post-Study Questionnaire

To what extent was the device difficult to use?

	1	2	3	4	5	6	7	
Very Difficult	▢	▢	▢	▢	▢	▢	▢	Very Easy

To what extent did you enjoy using the device?

	1	2	3	4	5	6	7	
Low Enjoyment	▢	▢	▢	▢	▢	▢	▢	High Enjoyment

To what extent could having physical pages could enhance the digital reading experience?

	1	2	3	4	5	6	7	
No Enhancement	▢	▢	▢	▢	▢	▢	▢	Highly Enhance

To what extent where your bends accurately detected by the e-reader application?

	1	2	3	4	5	6	7	
Not at all	▢	▢	▢	▢	▢	▢	▢	Very Accurate

To what extent did the paper restrict you bending it in a way you chose?

	1	2	3	4	5	6	7	
Not Restricted	▢	▢	▢	▢	▢	▢	▢	Very Restricted

To what extent could you feel the bend sensors as opposed to paper?

	1	2	3	4	5	6	7	
Not at all	▢	▢	▢	▢	▢	▢	▢	A Lot

Appendix C

Compact Side of Device Tangible Interactions - Study Questions

C.1 Pre-Study Questionnaire

Side of Device Interactions
Pre-Study Questionnaire

What is your Age:

- ☐ 18 to 24
- ☐ 25 to 34
- ☐ 35 to 44
- ☐ 45 to 54
- ☐ 55 to 64
- ☐ 65 or older

What is your current gender?

- ☐ Male
- ☐ Female
- ☐ Prefer not to say
- ☐ Other ….. (please specify) ______________________________

Which is your dominant hand?

- ☐ Left
- ☐ Right
- ☐ Both

What formats do you use to read books?

- ☐ Printed books
- ☐ E-books
- ☐ Audiobooks
- ☐ Other ….. (please specify) ______________________________

What format do you prefer to use?

- ☐ Printed books
- ☐ E-books
- ☐ Audiobooks
- ☐ Other ….. (please specify) ______________________________

To what level can you play the guitar?

Not at all	1	2	3	4	5	5	7	Expert

What is the reason for this preference?

C.2 Perceived Difficulty and Accuracy

Side of Device interactions Perceived Difficulty and Accuracy Evaluation Questions

Gesture X Evaluation

To what extent was the gesture difficult to perform?								
Very Difficult	1	2	3	4	5	6	7	Very Easy
To what extent was the gesture detected accurately by the device?								
Not at all	1	2	3	4	5	6	7	Highly Accurate

Any remarks you wish to add?

C.3 Post-Study Questionnaire

Side of Device interactions
Device Evaluation Questions

Device Evaluation

To what extent was the device difficult to use?								
Very Difficult	1	2	3	4	5	6	7	Very Easy
To what extent did you enjoy using the device								
Did Not Enjoy	1	2	3	4	5	6	7	Enjoyed a Lot
To what extent could having side of device interactions enhance digital reading?								
Not at all	1	2	3	4	5	6	7	A Lot

Any remarks you wish to add?

Appendix D

Digital Bookmark - Study Questions

D.1 Scoping Survey

Online Scoping Survey Questions

Section 1

Demographic details

What is you gender? *

- Female
- Male
- Prefer not to say
- Other

What is your age? *

- 18 to 24
- 25 to 34
- 35 to 44
- 45 to 54
- 55 to 64
- 65 or older

goto Section 2

Section 2

Reading Formats

What formats do you use to read books? *

- ☐ Printed Books
- ☐ E-Books
- ☐ Audiobooks
- ☐ Other: ______

What format do you prefer to use? *

- ○ Printed Books
- ○ E-Books
- ○ Audiobooks
- ○ Other: ______

Reason for this preference? *

Your answer ______

goto Section 3

Section 3

Multi Format Reading

Do you own copies of books in multiple formats? *

- ◯ Yes — goto Section 4
- ◯ No — goto Section 5

Section 4

Multi Format Reading

For which formats do you own the same book? *

- ☐ Printed Books
- ☐ E-Books
- ☐ Audiobooks
- ☐ Other: ____________

Do you switch formats whilst reading a book *

e.g. Read a printed copy at home, then continue with an Audiobook whilst travelling

- ◯ Yes — goto Section 6
- ◯ No — goto Section 7

Section 5

Multi Format Reading

What is the reason why you only own books in a single format? *

Your answer

End of Survey for this path

Section 6

Multi Format Reading

How do you ensure that your position within each format is synchronised? *

Your answer

End of Survey for this path

Section 7

Multi Format Reading

As you own copies of books in multiple formats, what is the reason why you do not switch between them?

Your answer

End of Survey for this path

D.2 Pre Format Switching Study Questions

Digital Bookmark - Format Switching Pre-Study Questionnaire

What is your Age:

- ▫ 18 to 24
- ▫ 25 to 34
- ▫ 35 to 44
- ▫ 45 to 54
- ▫ 55 to 64
- ▫ 65 or older

What is your current gender?

- ▫ Male
- ▫ Female
- ▫ Prefer not to say
- ▫ Other ….. (please specify) ______________________________

What formats do you use to read books?

- ▫ Printed books
- ▫ E-books
- ▫ Audiobooks
- ▫ Other ….. (please specify) ______________________________

What format do you prefer to use?

- ▫ Printed books
- ▫ E-books
- ▫ Audiobooks
- ▫ Other ….. (please specify) ______________________________

What is the reason for this preference?

How many times have you read the book you have brought along?

Did you enjoy the Book?

- ▫ Yes
- ▫ No

D.3 Pre Digital Bookmark Study Questions

Digital Bookmark Pre-Study Questionnaire

What is your Age:

- ◻ 18 to 24
- ◻ 25 to 34
- ◻ 35 to 44
- ◻ 45 to 54
- ◻ 55 to 64
- ◻ 65 or older

What is your current gender?

- ◻ Male
- ◻ Female
- ◻ Prefer not to say
- ◻ Other ….. (please specify) ______________________________

What formats do you use to read books?

- ◻ Printed books
- ◻ E-books
- ◻ Audiobooks
- ◻ Other ….. (please specify) ______________________________

What format do you prefer to use?

- ◻ Printed books
- ◻ E-books
- ◻ Audiobooks
- ◻ Other ….. (please specify) ______________________________

What is the reason for this preference?

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