Universal Design of an Automatic Page-Turner

By

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Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of .....**M.eng**......is entirely my own work and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

Signed: ____________ ID No.: 97188999 Date: 27 December 2004

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Nomenclature

F^V	Normal force applied to the page
F^H	Horizontal force applied to the page
$\mu_{sp}R$	Frictional force at a skin – paper interface
$\mu_{pp}R$	Frictional force at a paper – paper interface
$\mu_{SC}R_C$	Frictional force on the guide rail
$\mu_{SP}R_P$	Frictional force at the page

Table of Contents

List of figures

Abstract

Chapter 1. Introduction 1

Chapter 2. Literature Review 5

2.1 Mainstream Design Methodologies 5
2.2 Customer-Centric Design 7
2.3 The USERfit Methodology. 8
2.3-1 Problem Definition 9
2.3-2 Functional Specification 10
2.3-3 Test. 11
2.4 Design for All (Universal Design) 11
2.4-1 Universal Design as an Evolving Paradigm. 12
2.4-2 Fiscal Benefits of Integrating a Universal Design Strategy 14
2.5 Summarising the Methodological Approach Used 15
2.6 Defining Disability 18
2.7 'Identifying the Need' 19
2.7-1 Disability Statistics at a National Level. 21
2.7-2 Disability Statistics at an International level. 22
2.7-3 Scope of NSPDD and ICF 23
2.7-4 United States Survey 24
2.7-5 Disability and Age. 25
2.8 Assistive Technology 27
2.8-1 Categorization 28
2.8-2 Commercialization vs. Customization 29
2.8-3 Availability and Standards of Assistive Technology 30
2.8-4 Advancement of Assistive Technology 32
2.9 Automatic page-turners as Assistive Technology 32
2.9-1 'DUNE' Project 33
2.9-2 MIT Page-turner development (Professor E. Blanco) 34
2.9-3 'Compagnie' Page-turner 35
2.9-4 'Quest Enabling Designs' (QED) Page-turner. 35
2.9-5 'GEWA' Page-turner 36
2.9-6 'TURNY' Page-turner 37
2.9-7 'Touch Turner' Page-turner 38
2.10 Patent Searches 38
2.11 Further Reading 41
2.11-1 Paper Frictional Analysis. 41
2.12 Human Haptics 42

	2.12-1 Human slip detection	43
2.13	Machine tactile sensing 'haptics'	44
Chapter 3.	**Product Review and PDS Development**	**49**
3.1	Review of Previously Designed Device	50
3.2	Review of Commercially Available Products	51
3.3	Identified Paper handling methods	54
	3.3-1 Pneumatic Approach	55
	3.3-2 Friction Approach	55
	3.3-3 Adhesive Approach	56
3.4	Group Discussion	57
3.5	Task Analysis / Direct Observation.	58
3.6	User Requirements	60
3.7	Preliminary Product Design Specification	61
Chapter 4.	**Concept development**	**66**
4.1	Pre-existing DCU page turning device	66
4.2	Further Page Separation	69
4.3	'What humans do'	70
4.4	Concepts for Fingers	72
	4.4-1 Force Sensor options	73
	4.4-2 Force Sensing Resistors	74
4.5	Secondary finger concept	77
4.6	Finger movement	80
4.7	Book Clamping	81
4.8	Frame and Baseboard	84
Chapter 5.	**Refining Concepts - Mechanical Analysis**	**88**
5.1	Frictional analysis	89
5.2	Vertical force	90
5.3	Finger development	91
5.4	Force Transducer design.	93
	5.4-1 Force transducer resolution	94
5.5	Finalising the finger assembly	96
5.6	Horizontal drive system	100
Chapter 6.	**Electronics and Control**	**104**
6.1	Overview of Control	104

6.2	Selecting a Microcontroller	105
6.3	Motor Selection	107
	6.3-1 DC Motor Characteristics	108
	6.3-2 Stepper Motor Characteristics	109
6.4	Motor Drivers & Control	110
	6.4-1 DC Motor Drivers & Control	110
	6.4-2 Stepper Motor Translator/Drivers & Directional Control	112
	6.4-3 Positional Encoder Development	113
6.5	Strain Gauges and the Wheatstone Bridge	115
6.6	Bridge Amplification	118

Chapter 7. Assembly and Testing **122**

7.1	Finger Assembly	122
7.2	Carriage Control Board Development	129
7.3	Horizontal Drive Mechanism	129
7.4	Force Transducer Testing	130
	7.4-1 Measuring the applied force	131
	7.4-2 Force transducer resolution	133
7.5	Device Testing	134

Chapter 8. Conclusions and Recommendations **143**

Bibliography

Appendices

List of Figures

Figure 2.1 Product development processes. 6
Figure 2.2 Illustration of the 9 USER*fit* tools. 9
Figure 2.3 Bullet points of USER*fit* problem definition and user analysis Tools 10
Figure 2.4 Bullet points of USER*fit* Testing Tools. 11
Figure 2.5 Economics of the Universal design cycle. 14
Figure 2.6 Results from NCHS Survey 1994. 24
Figure 2.7 Proportion of people in Ireland with a disability 25
Figure 2.8 Functional Limitations as a Function of Age. 26
Figure 2.9 Progression from commercially available products to modified and custom devices[36] 30
Figure 2.10 Roughs from the Dune page turner and DUNE prototype [42] 34
Figure 2.11 Ernesto Blanco stands by a page turner he invented [43] 34
Figure 2.12 'Compagnie' Automatic page-turner [44] 35
Figure 2. 13 QED page-turner [45] 35
Figure 2.14 GEWA Page Turner BLV-6 [46] 36
Figure 2.15 The basic TURNY unit [48] 37
Figure 2.16 Variety of stands for TURNY[48] 37
Figure 2.17 Touch Turner- Model CR [49] 38
Figure 2.18 Examples of page-turner patents for musicians 39
Figure 2.19 Example of page-turner patent as assistive device 40
Figure 2.20 Highly magnified pictures of paper [51] 41
Figure 2.21 Advanced Paper Tribometer[50] 42
Figure 2.22 Dynamic COF for paper on paper with decreasing force [50] 42
Figure 2.23 Human fingertip showing friction ridges [55] 43
Figure 2.24 Design of fingertip using accelerometers [54] 45
Figure 2 25 Optical Mouse sensor technology [56] 45
Figure 2.26 Optical Mouse sensor on sole of quadruped foot [57] 46
Figure 2.27 Structure of Acoustic Resonance Tensor Cell (ARTC) Sensor [58] 46
Figure 2.28 Randomly distributed sensors in a soft fingertip [59] 47
Figure 2.29 Soft Haptic robotic Fingertip complete with fingernail [60] 47

Figure 3.1 Single friction wheel 50
Figure 3.2 Secondary page flipping mechanism 50
Figure 3.3 Excessive pressure from friction wheel 50
Figure 3.4 Complete previously designed device 51
Figure 3.5 Three identified approaches to page turning 56

Figure 4.1 Older page flipping component 66
Figure 4.2 Test piece for new page flipping component 67
Figure 4.3 Page weight as an obstacle to page flipping 67
Figure 4.4 Touch Turner illustrating the extended page flipping arm 67
Figure 4.5 Redesigned page flipping mechanism 68
Figure 4.6 Rotation sequence for new page-flipping design 68
Figure 4.7 Four devices that use friction as their method of page separation 69
Figure 4.8 Single point of force causing a fanning effect 70

Figure 4.9 Human approach to page separation 70
Figure 4.10 Two point force on page causes buckling 71
Figure 4.11 Initial concepts for finger mechanism wire-frame 72
Figure 4.12 Initial concepts for finger mechanism rendered solid model 72
Figure 4.13 Early finger concepts 73
Figure 4.14 Miniature button load cells 73
Figure 4.15 Force Sensing Resistor 74
Figure 4.16 FSR output response 74
Figure 4.17 Fingertip concept using an FSR 75
Figure 4.18 Fingertip positional correction mechanism 75
Figure 4.19 Benefits of bending beam over FSR force transducer concept 76
Figure 4.20 Entry point for secondary finger 77
Figure 4.21 Secondary finger concepts 78
Figure 4.22 Conceptual finger sequence during page turning operation 79
Figure 4.23 Finger concepts 80
Figure 4.24 Lightweight guide-rail and carriage 81
Figure 4.25 Timing pulleys and encoder concepts 81
Figure 4.26 Bulldog clip 82
Figure 4.27 Concepts for integrated clamping 82
Figure 4.28 Preliminary integrated clamp design 83
Figure 4.29 Slot to receive clamps 83
Figure 4.30 Final integrated clamp design 83
Figure 4.31 Early Baseboard concepts 84
Figure 4.32 Complete Baseboard 84
Figure 4.33 Baseboard top casing concept 85
Figure 4.34 Curved Baseboard with aluminium side casings concept 85
Figure 4.35 Complex shape to be procured through Rapid Prototyping 86
Figure 4.36 Final lightweight folding conceptual design of baseboard 86

Figure 5.1 Forces involved in human page separation 88
Figure 5.2 Coefficient of Friction rig 89
Figure 5.3 Free Body Diagram of Friction Sled 89
Figure 5.4 Measuring normal force 90
Figure 5.5 Variables pertaining to finger design 91
Figure 5.6 Finger representation and torque calculation 92
Figure 5.7 Height of centre point of rotation for primary finger 92
Figure 5.8 Primary finger motor [71] 93
Figure 5.9 Transducer Beam deflection 95
Figure 5.10 Transducer beam design parameters [74] 95
Figure 5.11 Final Primary finger casing design 97
Figure 5.12 Fabricated horizontal carriage 98
Figure 5.13 Exploded view of final primary finger assembly 98
Figure 5.14 Examination of aesthetics in 3-D software 99
Figure 5.15 (right) Examination of functionality in 3-D software 99
Figure 5.16 3-D model of complete assembled finger - 99
Figure 5.17 Illustration of the forces involved in the horizontal drive system 100
Figure 5.18 Location of belt clamping on carriage 102
Figure 5.19 Geared horizontal drive motor [75] 102
Figure 5.20 Conceptual Horizontal drive system 103

Figure 5.21 Conceptual sliding tensioning mechanism for
the horizontal drive system 103

Figure 6.1 Lumped Model of the elements involved in
the automation of the page turner 104
Figure 6.2 Right finger assembly Components 105
Figure 6.3 BX-24 Microcontrollers 106
Figure 6.4 Torque-Speed Characteristics for the selected geared dc motor 108
Figure 6.5 Torque-Speed Characteristics for a stepper motor[77] 109
Figure 6.6 Chopper Motor Control [79] 111
Figure 6.7 Stepper Motor Translator and Driver 112
Figure 6.8 a). Reflective photo sensor b). Printed encoder strip 114
Figure 6.9 a). Comparator 'Chatter' b). Output with threshold [82] 114
Figure 6.10 Single-supply non-inverting Schmitt trigger 115
Figure 6.11 Metallic foil Strain Gauges used 115
Figure 6.12 Half Wheatstone Bridge configuration 116
Figure 6.13 Half Wheatstone Bridge and AD 623 Instrument Amplifier Set-up 119
Figure 6.14 System mock-up of finger, used to test
Transducer beam design parameters 120
Figure 6.15 Amplifier output showing noise in the system 121
Figure 6.16 Amplifier output showing play in the system 121

Figure 7.1 Illustration of finger size 123
Figure 7.2 Fingertip and Strain Gauge set-up 123
Figure 7.3 Spliced secondary finger drive belt 125
Figure 7.4 Flexible secondary finger drive belt 125
Figure 7.5 Examining suitability of new belts 125
Figure 7.6 Schematic of carriage board 127
Figure 7.7 Assembled Carriage Board 128
Figure 7.8 Horizontal drive mechanism showing 2:1 step-down gear ratio. 129
Figure 7.9 Fully assembled finger and carriage control board on slide-way 130
Figure 7.10 Graph showing amplifier output voltage Vs. normal force 131
Figure 7.11 Over-torqued response of stepper motor 132
Figure 7.12 Repeatability of step count 133
Figure 7.13Amplifier output illustrating variance in step
response from stepper motor 134
Figure 7.14 Move fingers to required position 137
Figure 7.15 Lower fingers onto page 138
Figure 7.16 Move fingers together 138
Figure 7.17 Move secondary finger into entry position 139
Figure 7.18 Outside finger lifts before inside finger, to allow page to move 139
Figure 7.19 Primary finger moves in a convex motion path 140
Figure 7.20 Page finally flips over before finger moves vertically
off the page and returns to required position 140
Figure 7.21 Final working functional prototype. 142

Abstract

This thesis deals with the effectiveness of automatic page-turners as one form of assistive technology. It examines several of the existing commercially available products with a view to developing a universal system that would have the potential to satisfy both the special needs and musician sectors. It explores the current trends regarding the collection of statistical data on people with a physical disability, which is intended to identify the present and future needs for such assistive technology devices. The project utilizes a user-centric approach to document the requirements of the end users of such a device, before conceptualising a model which would have the potential to satisfy the expanded target market. It explains in detail the development process of the working model, which employs two anthropomorphic finger-like mechanisms, both of which incorporate force feedback. These finger-mimetic components are used to separate and turn the pages of the reading material. A functional prototype was built and a report of the preliminary testing carried out, together with a fully documented illustration of the final working engineering model is included. The test results reveal that the system has shown great potential for the successful development of a more universal Automatic page turner that could satisfy both identified markets.

Chapter 1. Introduction

Turning the pages of a good book or 'page-turner' as they are commonly described today is for most of us a task which is taken for granted and almost never considered. However, in order to accomplish this activity, a person must possess motor output skills of mobility and manipulation. Unfortunately not everybody possesses the fundamental skills required to perform this activity without assistance. Whether congenital, caused through illness, accident or simply part of the aging process, these limitations can often be overcome through the use of Assistive Technology systems.

Automatic electronic page-turners are one such form of Assistive Technology. These products are used by people with a physical limitation, which prevents them from independently turning the pages of a book without such a device. The automatic page-turner is paramount to the education and empowerment of people with a disability by allowing them to independently perform this task using a suitable actuation device. However, research has shown that many such assistive technology devices currently available are less than effective.

The automatic page-turner, as an Assistive Technology device originates from a similar device, which was first designed over a century ago to facilitate uninterrupted playing of an instrument by musicians. However, these devices, although performing the same basic function of automatically turning pages are simpler in their design, and are normally preloaded with a standard size manuscript.

The initial aim of this project was to examine, analyze and improve the performance of a device developed previously at Dublin City University. This performance enhancement was to include both functional and aesthetic elements. However during the course of this initial analysis, it became apparent that there were several concerns surrounding the paper manipulation technique used in this device. This led to a reassessment of the project scope which resulted in the design a more universal system which would have the potential to satisfy both the Assistive Technology sector as well as facilitating the uninterrupted playing of a musical instrument.

A number of design methodologies were examined, in an effort to select the best approach to take for the design of a new device. Universal Design is one such design methodology that aims to develop systems that will be suitable for use by as many people as possible. It is believed that in order to best implement the concept of Universal Design, one should be familiar with some of the more generic product development methodologies, for both the mainstream and the specialist Assistive Technology sectors. By utilising both design approaches, one incorporates the fundamental design characteristics of both styles, resulting in a more holistic approach to the concept of Universal Design.

This combined methodological strategy can be applied to expansive Universal Design challenges, whether approaching from the mainstream or the Assistive Technology sector. It is hoped that by approaching the inclusive initiative of 'Design for All' from the Assistive Technology sector more experience may be gained in the challenge of satisfying all sectors of society.

The project examines several of the automatic page-turners which are available today. It explores the various paper manipulation approaches taken by the designers of these devices, and discusses the effectiveness of each, as well as the appropriation of the paper handling techniques used, with respect to the identified universal product design methodology.

Integrating a user-centred approach, a product design specification was developed, after which several conceptual designs were produced, using a solid modeling software package. Having identified what was believed to be a suitable concept, mimetic of the human approach to page separation, final working drawings of the anthropomorphic design were produced and subsequently fabricated. Having determined the forces involved, much time was dedicated to the sourcing of suitable components, while maintaining a lightweight and low-cost theme.

The project concludes with a working engineering model of a device which has the potential to satisfy both previously identified markets. However, much refinement is needed on the device in order to increase the cycle speed, so as to satisfy the musicians sector.

Chapter two of this document is a literature review which defines several key topics and subsequently addresses many related issues, including an examination of the most pertinent design methodologies as well as the identification of the need for more assistive technology devices. The literature review also introduces the commercially available page-turning devices found during the course of this research. Chapter three discusses the qualitative research methods used and examines the pros and cons of the page-turning devices introduced in chapter two. This chapter carries on to define a set of user requirements which led to the development of a Product Design Specification. Chapter four examines the various concepts that were considered and also the approach taken in developing the concept used in the final design. This is followed in chapter five by illustrating the development of the mechanical aspects of the final concept. Chapter six uncovers the components used in the control of the mechanisms involved in the automatic turning of the pages. Chapter seven discusses some of the problems that were encountered during the fabrication and assembly of the device, as well as illustrating the testing that was performed on both the individual elements as well as the overall device. Finally, chapter eight discusses the findings and conclusions made during the course of this research, before recommending a variety of design changes which could be made to improve the existing working model.

Chapter 2. Literature Review

The project utilized a combination of concurrent design, aided by a user-centered approach and aspired to incorporate a Universal Design theme in an effort to expand the market. This chapter begins with an examination of these methodologies, before highlighting the approach taken by summarising the various aspects of each methodology used at different stages of the project. It subsequently defines disability and presents the identified need for more Assistive Technology devices through the current availability of statistics on disability. After defining Assistive Technology it carries on to discuss categorisation of Assistive devices, before illustrating the sources and standards of such devices. It continues by illustrating the quantitative research performed on automatic page-turners and finally examines the various topics related to the paper handling technique chosen for the design of the new automatic page-turning device.

2.1 Mainstream Design Methodologies

The diversity and ever increasing number of design methodologies, techniques and tools available today relating to product design and development are enormous. As a result of an increasing number of specialists in the area of design, many methodologies are specific to certain industries and technologies. Variables, such as product type, target customers, risk profile, industry, market dynamics, and a multitude of other factors all contribute to determining which specific methodology will be used.

However there are also many methodologies that take a generic approach to product design and development and more often than not these methodologies can be applied to a variety of design projects. It must however be remembered that a methodology is simply a way of describing a set of conceptual approaches that are used to develop the product realisation process. Two of the more common approaches can be seen in figure 2.1. The first of these being the classic 'waterfall approach' sometimes referred to as the 'over the wall' approach. This involves comprehensive definition and control of requirements at the projects front end, so that the development process will run smoothly downstream. This process is sequential, such that, each stage of development is carefully completed and approved by appropriate functions before progression to the next phase [1]. This method can be both time consuming and is susceptible to much reworking due to the lack of information sharing.

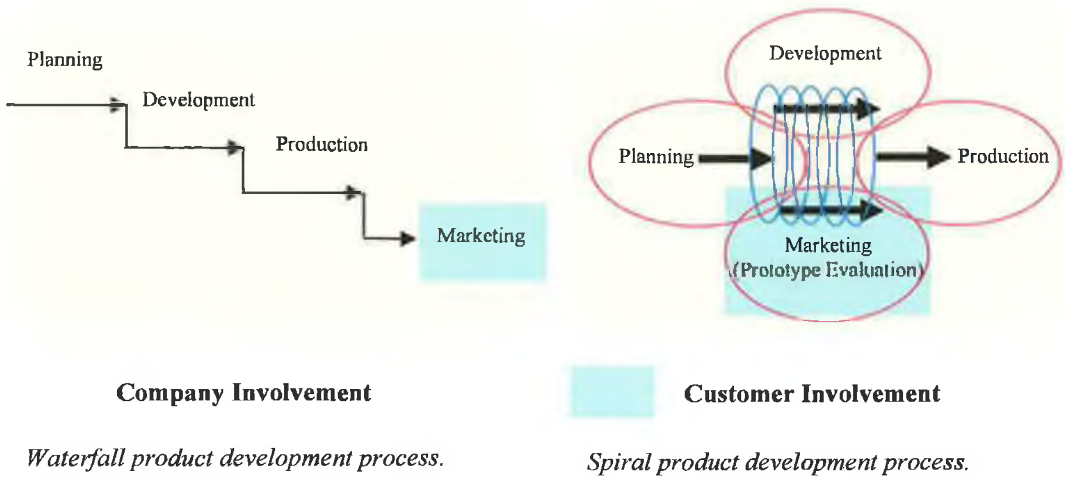


Figure 2.1 Product development process comparisons [1]

On the other hand, the spiral or concurrent engineering (CE) process is iterative, incorporating feedback from customers and internal parties and translating it into the next iteration of the development process. The spiral process allows customer requirements to evolve, recognizing that market requirements often change during the course of development. This is a more harmonised approach to the integrated, concurrent design of products and their related processes, including manufacture and support. CE is "intended to cause the developer, from the outset, to consider all elements of the product lifecycle from concept through disposal, including quality control, cost, scheduling and user requirements" [2] As such, the implementation of the concurrent approach provides early considerations for every aspect of a product's development process. The result of concurrent development is a more customer-centric, higher-quality product that meets with improved customer satisfaction and potentially greater market acceptance. As developers seek to more closely connect their products with customer needs, they may increasingly turn to the spiral method, or some derivative of it, to help their development efforts become more customer-centric.

2.2 Customer-Centric Design

Customer-centric or user-centered design is a very broad term which describes the phenomenon of involving the end user in the process of designing the product. It may be an attempt at determining what exactly the user wants from the finished product or may be used to determine the best solution to a problem that an individual person faces. Although the concept of gaining feedback from the end user is simple, in reality sometimes the user doesn't even know what they want from the product. Bratvia and Hammer report that: "part of the problem is that the disabled consumer is often not aware of their own needs as they relate to assistive devices" [3].

As a result, there are many approaches that can be utilized to facilitate the process of gaining knowledge about the products' end user. Examples of a user-centric approach to data collection methods include questionnaires, opinion polls, focus groups, immersive experience, longitudinal analysis, shadowing and many more [4]. The methods used depend on what is required of the user and what the designer is aiming to achieve by using such an approach. With so many approaches to choose from it is important that the designer is aware of what data collection methods to use at the various stages of the design process in order to gain the most effective, reusable end-user information. [5] This becomes even more critical when limited staff and financial resources must be spread across the whole development cycle. One very common approach to customer-centric design of mainstream products uses the Quality Function Deployment (QFD) methodology, however a more appropriate guide to user involvement in the design of products for people with functional limitations is the USER*fit* methodology.

2.3 The USER*fit* Methodology.

The USER*fit* methodology involves the use of nine summary tools that are used to support the developer in addressing the subject of usability in design [6]. This intuitive approach ensures that the designer considers all aspects of user requirements at the earliest stages of the product development cycle. The tools can be revisited a number of times in an iterative design process until the designer is satisfied that enough knowledge has been gained, both about the end user and the environment in which the product will be used. The USER*fit* development process offers the designer various data collection techniques and explains which methods are most appropriate to their situation. It assists the designer in subsequently condensing the data into an easily assessed, highly visible set of records. The most fundamental description of the design process normally contains the following four phases:

- **Problem definition**
- **Analysis and specification**
- **Build**
- **Testing**

Most designers will intuitively recognise these four headings as phases of the design process, although they may not actually use the same terminology. This is not important, since it is the understanding of the process that is most important. Figure 2.2 illustrates the nine tools incorporated within the USER*fit* methodology. It should be noted that due to the technical nature of the fabrication phase, it is beyond the scope of this methodology and therefore USER*fit* does not offer any assistance here. However, examining the remaining phases of this summarising methodology in more detail, allows for the consideration of how USER*fit* can be embedded within the concurrent design process.

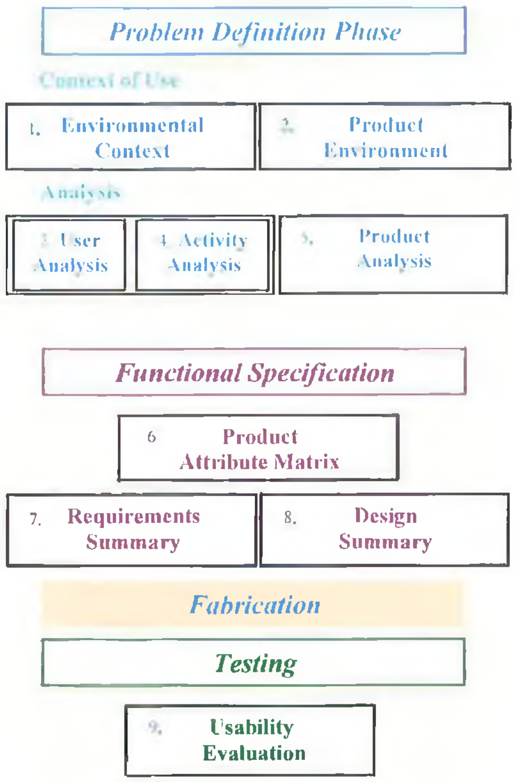


Figure 2.2 Illustration of the nine USERfit summary tools **[6]**

2.3-1 Problem Definition

At the earliest stages of the design process, a designer will define the problem under consideration and begin to conceptualise solutions to solve the problem. It is at this stage that the designer must become familiar with the general context in which the product will be used. The USER*fit* Environmental Context and Product Environment tools allow designers to refine a general understanding of the problem that is to be explored and to examine how a product may fit into the wider environment in which end users live. By using these tools the designer is compelled to consider the wider implications of how the product will be supported and also document some of the likely implications of these factors.

Examples of the methods used while applying these tools are illustrated in figure 2.3, along with a selection of methods which can be used for the more detailed analysis activities that are supported. These cover what is known about the individuality of the end user (User Analysis) and the activities (Activity Analysis) that they need to perform. The User Analysis (UA) develops into a database of design information about user characteristics, and summarises the repercussions that these may have for the product. The Activity Analysis (AA) performs a similar function in describing the activities or tasks that each user will need to perform.

Problem Definition

- **User Mapping**
- **Brainstorming**

Analysis/Specification

- **Task analysis**
- **Direct observation**
- **Diary methods**
- **Questionnaires**
- **Interviews**
- **Group discussion**
- **Empathic modelling**

Figure 2.3 Problem definition and analysis methods **[6]**

2.3-2 Functional Specification

Once some understanding of the user, their environment and their activities has been obtained, the designer can then move to the process of developing a detailed specification for a product to satisfy user's needs. The USER*fit* methodology can be a significant help to the designer during the process of refining a functional specification for products. It does this with the aid of a Product Attribute Matrix (PAM) which assists by cross–referencing the *desired* features of a product (User and Activity Analyses) with its *actual* features (Product Analysis and Environmental Context). This PAM can be compared to the interrelationship matrix used in QFD, and it allows an initial examination of the likely success of a product in meeting the end user's requirements. The results of this comparison are then used to create a Requirements Summary (RS) and Design Summary (DS) which may be taken through into the final Product Design Specification phase. As such the functional specification can greatly assist the designer in compiling a comprehensive user-centred Product Design Specification.

2.3-3 Test.

Having built a prototype of the product, USER*fit* aids the developer in assessing the usability of the product through the use of the Usability Evaluation (UE) tools as seen in figure 2.4. These help in the planning of the test phase, in summarizing the results from the tests and in recording any design modifications that are deemed necessary. During testing, USER*fit* places the emphasis on evaluation of the products' functionality and how well it matches the user requirements.

- **User trials**
- **Direct observation**
- **Questionnaires**
- **Interviews**
- **Group discussion**
- **Laboratory trials**
- **Field trials**
- **Expert opinion**

***Figure 2.4 Usability evaluation and testing methods* [6]**

Combining the mainstream concurrent approach to design with the USER*fit* design methodology which is aimed at Assistive Technology developers, results in a more universal approach to design.

2.4 Design for All (Universal Design)

Universal design methodologies embrace the challenge of designing mainstream products and environments for as large a market as possible, including disabled and elderly users. The past decade has seen the evolution of Universal Design, from being a topic of marginal interest to it shifting nearer to the hub of European policy [7]. Many definitions have been given to the terms "Design for All" and "Universal Design". The Center for Universal Design at the North Carolina State University provides the following definition:

"Universal design is the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design." ***Ron Mace*** [8]

The term 'Design for All' has given rise to much debate surrounding its meaning, since, designing a product or service that everybody could use seems an impossible task. As a consequence, many other terms such as 'barrier free', 'accessible' and 'inclusive design' were introduced. "Inclusive design" is similar to "Design for All", but the definition is less categorical with regard to the potential users:

"inclusive design is the design of mainstream products and/or services that are accessible to, and usable by, as many people as is reasonably possible on a global basis, in a wide variety of situations and to the greatest extent possible without the need for special adaptation or specialised design." [9].

2.4-1 Universal Design as an Evolving Paradigm.

The motivation behind the evolution of Universal Design has been aided by the information age, where information such as global demographics have come to light. This newfound knowledge, combined with the concept of the emerging "grey pound" [10] or 'grey euro' as the case may be, has really helped to highlight the plight of this innovatory Universal Design initiative. This has been fuelled by governmental legislation to help create a more inclusive society with the introduction of two major policy initiatives by the

European Commission – e-Europe and e-Accessibility which impact across the board to all the citizens of Europe. [7]

Although the terms 'Design for All' and 'Universal Design' evoke thoughts of generality and 'one shoe fits all', the application of these design philosophies are for the most part, contextual. It is for this reason that the compilation of a best practice doctrine has yet to be realized. As such, the implementation and practice of these all-embracing ideologies continues to be a challenging area of research and much more work is needed in this area in order to solidify the approach that designers need to take, in order to put Universal Design into practice on a more regular basis. This could take the form of check-lists, work-routines, norms, standards and examples, along with more reliable data on anthropometrics in a form that can be used more effectively [11].

However several suggestions do exist as to the methodological approach that could be taken, including the establishment of seven Universal Design principles (See Appendix A.). A growing number of white papers along with a number of suggestions and checklists that designers can reference as they progress through the process of universal product design are also beginning to emerge. For example, Vanderheiden (2000) who is an authority on Universal Design emphasizes the importance of prioritisation by specifying that designers must ask the question: "What is most important?" [12] What happens all too often is that, designers become overwhelmed with the scope of Universal Design that they become "locked" and end up focusing on what is easy and produce products that may not be usable by anyone.

2.4-2 Fiscal Benefits of Integrating a Universal Design Strategy

Figure 2.5 illustrates the economic advantages that the integration of a Universal Design strategy can bring. It should be evident that more effort is needed during the early stages of the design process, so that the product is designed to be useable by the largest audience possible. This is without doubt one of the principal difficulties in trying to convince industry to realise these revolutionary methodologies. To date, industry has taken the stance that they would be willing to implement Universal Design, providing that it was either easy to do, or that a consultancy would do it for them and providing that it did not increase the cost of the product or service. There does not appear to be widespread acceptance of the need for Universal Design training programs for designers or an appreciation of the potential increased market of more accessible products. “The concept of ‘undue burden’ appears to be anything that would cost more than the able-bodied version”. [13]

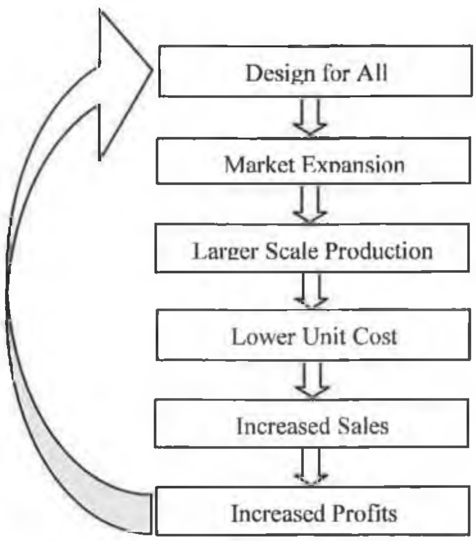


Figure 2.5 Economics of the Universal Design cycle

However, it should be palpable that products incorporating a Universal Design theme are going to be the most cost effective products in the long term. Designing separate products for different customers is expensive and time consuming and leads to higher priced products with a smaller potential market. The ‘design for all’ approach usually pays for itself since a wider population (and market) can be addressed with the basic product, which itself is often more usable and attractive. For example, a Universally Designed product may suit 95% of the population rather than the 80% addressed when not taking wider requirements into account [14]. This is of course dependent on the additional number of people that the universally designed product will accommodate. Before the largest number of potential product users can be targeted, it is necessary to determine the nature of this additional population and the number of people it includes.

2.5 Summarising the Methodological Approach Used

The simultaneous use of a combination of design methodologies encouraged the employment of the concurrent engineering philosophy and allowed for a better understanding of the device and its users. No single methodology could address all the concerns for the successful development of the automatic page turning device. Therefore, during the various phases of the project different aspects of several methodologies were used in an effort to replicate the team approach to concurrent engineering design.

At the early stages of any design project, direct contact with users can provide a valuable resource for designers who often find themselves designing products for use outside their own experience, understanding and expertise. [15] As a result the approach taken was to involve the end-users and other stakeholders of the page-turning device from the outset, which promptly led to the development of the initial design brief, which was to:

"Design a reliable, transportable automatic page turning device, to assist people with a physical disability that prevents them from turning the pages of a book themselves. The device should be versatile in both its functionality and actuation capabilities while comprising discretely pleasing aesthetics and should cost no more than one thousand euro to buy."

Utilising the USER*fit* approach much knowledge was gained through the use of the group discussion, direct observation and task analysis methods. Although the USER*fit* methodology was not strictly followed, it was felt that this approach would be more beneficial than other user-centred approaches such as the Quality Function Deployment methodology [16]. The reason for choosing this approach over others was that the USER*fit* methodology was developed specifically for designers of assistive technology products and as such allowed for a more empathetic approach to be taken, leading to a better understanding of end user requirements.

While the concurrent engineering design methodology encourages examination of many aspects of design from cradle to grave, it does not explicitly examine economies of scale. Therefore other expansive design methodologies were also examined in an effort to reduce unit costs of the device through market expansion. It was initially believed that perhaps by using a generic product structure, a product family could be developed that would satisfy both the assistive technology and musicians sector through development of common modularised product architecture [17]. However further research revealed that perhaps by using the Universal design methodology, a more versatile product that could operate at faster speeds than any of the existing devices could be designed. This led to the conceptualisation of a universally designed, more manipulative device that would have the potential to satisfy both sectors.

An amendment was then made to the design brief to include the more Universal approach that would be taken. The design brief was reassessed to state that "the device under development should also have the potential to turn pages quickly enough to satisfy the musicians sector".

After extensive analysis on the various methods used previously to separate the pages during the automatic page turning process, it became clear that the most appropriate method to perform this task for the new universal design would be to use friction. Having clarified that the friction method of page separation would be employed, a heuristic approach was used during the conceptual development phase of the project, whereby the testing of a variety of force sensors and transducer configurations were carried out to determine the most suitable method of force detection. Having heuristically developed a final conceptual design a preliminary design review which was based on Pugh's method [18] of concept optimisation was performed to determine the potential success of the design

This was followed by an embodiment design approach, whereby, parametric solid models of the various mechanisms were developed and tested for functionality, interference and aesthetics, before the fabrication process took place. The testing of the assembled device took the form of carrying out a number of tests on various book types and subsequently tabulating the results of these tests.

2.6 Defining Disability

Every human being can experience a decrement in health and thereby experience some disability. This is not just something that happens to a minority of people, but rather all of humanity. The National Disability Authority Act (Ireland) defines disability as:

"disability, in relation to a person, means a substantial restriction in the capacity of a person to participate in economic, social or cultural life on account of an enduring physical, sensory, learning, mental health or emotional impairment;" [18]

This broad definition places absolute emphasis on the person and as such does not take account of the surroundings in which the individual functions on a daily basis. Is it not true that any individual who is placed in a less than accommodating environment becomes disabled? For example, someone who uses a wheelchair may be 'disabled' amongst a group of individuals performing an activity such as climbing a mountain but perfectly 'able' amongst that same group of individuals sitting round a table having a discussion. For someone with profound hearing loss the situation may be totally the reverse [19]. It must therefore be said that the initiative of placing all the emphasis on the person is significantly dated and is a somewhat simplistic attempt at an explanation of a much more complex phenomenon.

The United Nations statistical division conceptualises disability as “the result of an interaction between the person with the disability and their particular environment.” And it carries on to say that disability can be conceptualized in many ways, “including at the level of the body, the person, or the society.” [20]

The World Health Organization (WHO) has recently proposed two major conceptual models of disability. The first being the 'medical model', which views disability as "a feature of the person, directly caused by disease, trauma or some other health condition that requires individual medical care provided in the form of treatment by professionals". The second of the conceptual models of disability is the 'social model', which sees disability as a socially created problem and not at all a feature of an individual. In the social model, disability demands a political response, since the problem is created by an unaccommodating physical environment brought about by attitudes and other features of the social environment.

On their own, neither model is adequate, although both are partially valid. Disability is always an interaction between features of the person and features of the overall context in which the person lives. A better model of disability is one that synthesizes what is true in the medical and social models, without making the mistake of reducing the whole complex notion of disability to just one of these aspects. It is very important to be aware that disability, as described above, is not simply an issue in the medical sense, but the complex subject of both the medical and environmental issues. This more useful model of disability might be called the "*biopsychosocial model*" [21]

2.7 'Identifying the Need'

"*Statistics on disability are difficult to compare internationally, since different countries have different definitions of disability and different degrees of political will to publicise such information.*" [22]

When attempting to gather data on the numbers of people with a functional limitation and their level of disability, it becomes apparent that there is a severe lack of reliable information. Before support can be offered in a positive and structured manner, it is necessary to identify the problems faced by people with a disability. In the past, data collection methods on people with disabilities have been somewhat irregular, both in their prevalence and taxonomy. It is important to guarantee that data is collected in a standardised manner, considering that the questions used, their structure and wording, and how they are understood and interpreted by the respondents all affect the identification of persons with disabilities. This lack of standardisation is evident when the two sets of data

***Table 2.1 Statistical table from UN statistical division* [20]**

Country	Percentage
Denmark	10.0 - 12.0
Finland	5.2 - 8.3
France	5.0 - 8.3
Ireland	3.3 - 5.0
Italy	1.7 - 17.1
Luxembourg	10.0 - 11.0
The Netherlands	9.5
Norway	12
Portugal	7.4
Spain	25
Sweden	12
Switzerland	1.6
U.K.	7.3

***Table 2.2 Statistical table from the INCLUDE project* [23]**

Country	Percentage
Denmark	12
Finland	8.3
France	10.2
Ireland	11.6
Italy	12.1
Luxembourg	10.5
The Netherlands	11.9
Norway	12
Portugal	11.4
Spain	14.9
Sweden	12
Switzerland	1.6
U.K.	11.6

in tables 2.1 and 2.2 are compared. Table 2.1 is a publication by the United Nations [20] of data taken from various European countries and Table 2.2 is a comparable set of results taken from the INCLUDE project [23] When comparing both sets of results, particularly the highlighted sections, it becomes clear that this information is quite unreliable.

The variation between the incidence of disabilities in the various countries listed in the two reports may be caused by a number of factors: different criteria for reporting, varying degrees of industrialization, rate of traffic accidents, participation in wars, etc [20].

Several bodies have recently recognized the need for improvements in the collection and compilation of disability statistics, both at a national and international level. New modi operandi have been developed which will allow cross regional and cross cultural comparability.

2.7-1 **Disability Statistics at a National Level.**

In Ireland, the Department of Health and Children established a National Physical and Sensory Disability Database (NPSDD) Development Committee in 1998. This committee comprised of representatives from the Department of Health and Children, the Health Research Board, the health boards and voluntary agencies involved with the disabled and all were involved at each stage of development. The committee produced a final report in 2001 [24] that details proposals and recommendations for the implementation of a National Physical and Sensory Disability Database. It is thought that the implementation of such a database will provide a more complete picture of the needs of people with a physical or sensory disability.

The data collection form for the NPSDD identifies 5 different types of information to be compiled: (1) Administration Details, (2) Client Details, (3) Specialised Health and Personal Social Service Usage and Requirements, (4) Technical Aids and Appliances, and (5) Details of Disability.

Section 4 above is the area that deals primarily with the individual's environment and the tools used to control that environment. It allows the client to indicate up to seven technical aids and appliances that are currently used and seven technical aids and appliances that may be required in the future. This section is of particular relevance to this project and will be an invaluable source of need identification in the area of Assistive Technology product development in the future.

At the end of January 2004 there were 19,961 people registered on the NPSDD [25]. It must be stressed however, that the implementation of this database is still actively underway and is not considered to be complete. Therefore any information currently available through this database is quite limited and would not be an honest reflection of the number of people in Ireland with physical and sensory disabilities.

2.7-2 **Disability Statistics at an International level.**

An international classification has been developed by the World Health Organisation. The International Classification of Functioning, Disability and Health (ICF) 'mainstreams' the experience of disability and recognizes it as a universal human experience [21]. By shifting the focus from cause to impact, it places all health conditions on an equal footing, allowing them to be compared using a common metric – the 'ruler' of health and disability. The ICF utilises domains that help to describe changes in body function and structure: what a person with a health condition *can* do in a standard environment (their level of capacity), as well as what they *actually* do in their usual environment (their level of performance). The new system is not just about people with conventionally acknowledged disabilities but about all people. It assumes there is a continuum of relative degrees of ability and acknowledges that many disabilities are not apparent but are linked to chronic health conditions - like arthritis, heart disease, back problems – all of which impact on a persons ability to function.

ICF offers an international, scientific tool for the paradigm shift from the purely medical model to an integrated 'biopsychosocial' model of human functioning and disability. It is a valuable tool in research into disability, in all its dimensions - impairments at the body and body part level, person level activity limitations and societal level restrictions of participation.

2.7-3 Scope of NPSDD and ICF

Although both the ICF and the NPSDD have some overlapping attributes, one of the fundamental differences is the scope of each. The NPSDD only seeks to register those individuals with physical and sensory disabilities under the age of 65 years, who are using, or within 5 years will need to use, specialised health, personal social services and Assistive Technology equipment. Statistics from this source will therefore never equate to the actual percentage of the population with a disability in this country. On the other hand, the ICF takes a more generic approach to a populations' state of well being, which includes all individuals young and old, disabled and able-bodied. Although both have a different scope it should be clear that the ICF classification allows for the gleaning of information to compare with the NPSDD statistics.

At present, the quality of statistical information available regarding people with disabilities is not of a high quality and therefore much more work is needed in this area. Both the ICF, at an international level and the NPSDD, at a national level will help to fill this void in the future, as long as they are utilized.

2.7-4 United States Survey

In the United States a report was published by the Consumer Electronics Manufacturers Association (CEMA) in conjunction with the Electronic Industries Foundation (EIF) and the Telecommunications Industry Association (TIA) [26]. Data was taken from the National Center for Health Statistics (NCHS) and from the National Institute on Disability and Rehabilitation Research (NIDRR). Each year the NCHS conducts a survey of approximately 50,000 households. The 1994 survey asked questions about functional limitations. About 20,000 individuals of 107,000 queried, reported a disability. The two largest groups of individuals identified both had physical disabilities. First among them were people with mobility limitations, that is, limited ability to get about or limited muscle control. Second in frequency were individuals with limited hand use. Sensory disabilities followed: hearing and vision impairments. The graph shown in figure 2.6 gives some idea of the range and proportion of the various disabilities recorded.

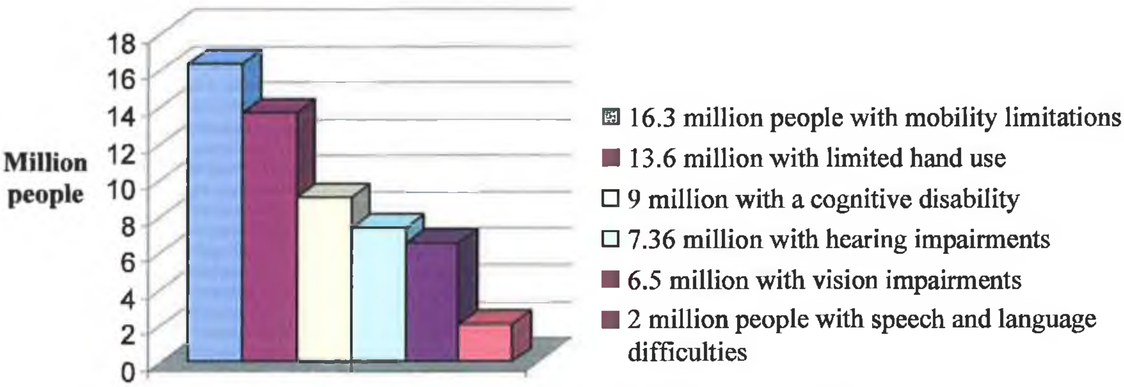


Figure 2.6 Results from NCHS survey 1994 **[26].**

This survey provides usable statistical information about people with functional limitations. It was produced to help manufacturers plan and design products, while promoting features that would enable all individuals, including those with functional limitations, to perform independently and efficiently at home and in the workplace. Figure 2.6 clearly demonstrates that there are a significant number of people with some form of disability. Focusing on the number of people with limited hand use, which includes people with limited movement or range of motion, as well as both gross and fine motor control limitations, gives a clear indication of the potential market for products such as the automatic page turner, that can help alleviate the manipulation problems faced by people who have some difficulty using their hands.

2.7-5 Disability and Age.

Variation in ability however, is not special but ordinary and it affects most of us for some part of our lives. As we get older, our levels of functional limitation increase; hence there is a large overlap between age and disability, with 70% of people with disabilities being aged 60 or over. [14]

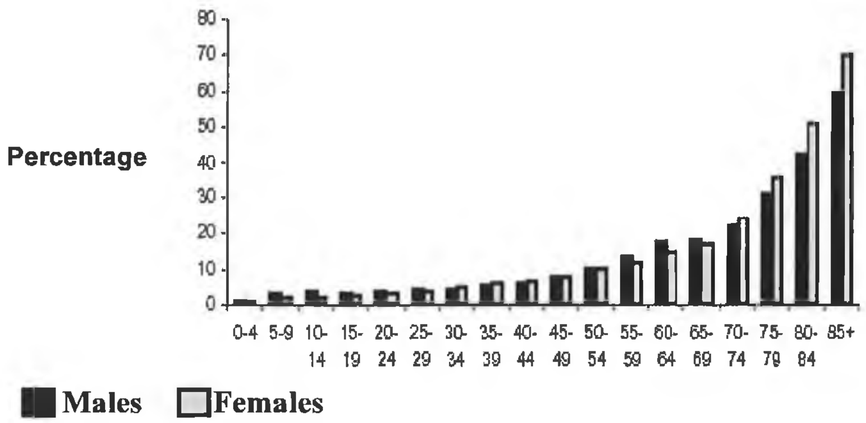


Figure 2.7 Proportion of persons with a disability by age group and sex 2002 **[27]**

Almost 324,000 persons, representing 8.3 per cent of the total Irish population, reported a long lasting health problem or disability in April 2002 (See figure 2.7) [27]. These persons answered "Yes" in response to at least one of the categories distinguished in Questions 14 and 15 of the 2002 census form in relation to disability [28]. The incidence of disability was higher among females than males (8.7% compared with 7.8%). For persons aged 15 years and over, the proportion who indicated that they had a long lasting health problem or disability increased for every five year age group from 15-19 up to 80-84 years for both males and females. Nearly two-thirds of those with a disability were aged 50 years or over. Figure 2.8 is based on data taken from the National Institute on Disability and Rehabilitation Research (NIDRR), National Health Survey 1985 [29].

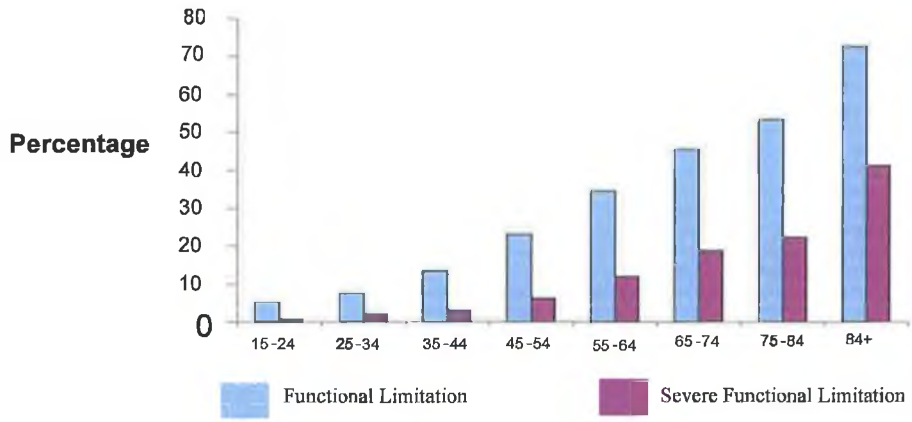


***Figure 2.8 Functional limitations as a function of age* [29]**
(displayed in clustered column form to facilitate comparison)

Comparing these two graphs taken from their relative first world regions would signify that the majority of the industrialized world is following a similar trend, regarding a person's functional limitation during the ageing process. Taken in isolation, this information simply tells us that as we get older, we loose some of our physical ability. However, when one considers these figures combined with the dramatic increase in life expectancy, which has taken place over the last century, it is clear that this will have enormous implications for the future prevalence of disability and the associated demand for more Assistive Technology and Universally Designed products.

It is estimated that by the year 2025 over 25% of the Irish population will be over 50 and this figure increases to over 40% by 2050. (See Appendix A) [29]. Examining a larger population, it is believed within the Member States of the European Union, the number of people who are elderly or disabled can be estimated at between 60 to 80 million The changing European age structure means that by the year 2020, one in four of the population will be aged over 60 and the largest increase is expected in the oldest age groups (75+), where disability is most prevalent [14]. It is a major challenge for the European Union to maintain and improve the quality of life, integration and independence of these citizens, as well as to contain the associated rise in the cost of care. Technology can play an important role in responding to this challenge. This worldwide phenomenon has become so prevalent that the Massachusetts Institute of Technology (MIT), in conjunction with industry, have set up a Lab dedicated to examining various aspects of technology and how it may be aimed at the older generation [31].

2.8 Assistive Technology

Assistive devices stem from mans' enthusiasm through the ages, to help, assist and abet others around him, who were either born with a functional limitation or had one inflicted upon them through accident, war, illness or simply as part of the ageing process. People have been using sticks to support a broken or injured leg for millennia. [32].

Assistive Technology is a very broad term used to describe a range of services, practices, strategies and devices used to help overcome the difficulties faced by people with disabilities. One very widely used definition of Assistive Technology describes it as:

"Any item, piece of equipment or product system whether acquired commercially off the shelf, modified, or customized that is used to increase, maintain or improve functional capabilities of individuals with disabilities"[33]

Due to the complexity and diversity of Assistive Technology currently available, this document will focus on the specifics of products and devices. As such the many services and other facets of Assistive Technology which are beyond the scope of this project will be omitted. This differentiation is sometimes referred to as hard and soft technologies respectively [34].

2.8-1 Categorization

Further distinctions in the area of Assistive Technology products can be made using the terms Assistive Technology 'appliances and tools'. The former "provides benefits to the user, independent of the individual's skill level" [35], where as with the utilization of Assistive Technology 'tools', the user needs to develop a set of skills. For simplification purposes in this text the term product or device may be used to describe both appliances and tools.

Assistive devices can be categorized into many different groupings depending on what is required and who is referring to them. According to Behrmann and Jerome (2002), Assistive Technology devices can be categorized into three categories: No technology, Low technology and High technology [36].

The "No Technology" category refers to Assistive Technology items or adaptations which may be something as simple as putting hot glue gun beads on pages of a book to separate the pages and make them easier to turn. Such modifications are relatively inexpensive and have the added advantage of being developed specially for the needs of an individual user.

The "Low Technology" category refers to items which are electronic but do not include highly sophisticated computer components. Such items might include electric page-turners.

"High Technology" items and equipment refer to those items that are more sophisticated. These items are likely to be the most expensive, but also have capabilities that are multifunctional. "High Technology" devices usually include some type of computer/microprocessor operation which incorporates software.

This categorization is of course subject to change similar to the way in which mainstream technology progresses, last years "High Technology" products are next years "Low Technology" products. The categorization of Assistive Technology products is therefore difficult to solidify, predominantly due to advances in the field. It should also be pointed out that the development of new concepts requires that new classification methods and ways of describing Assistive Technology are also developed.

2.8-2 Commercialization vs. Customization

When an individual with a functional limitation displays a need for an assistive device which is not available through mainstream, commercially available products, then an attempt is made to find a suitable device, which is commercially produced for people with a disability. Due to the individuality of people with disabilities, in many circumstances suitable Assistive Technology devices are a combination of components, taken from standard commercially available products and components that are produced specifically for the special needs market. For example, computers and specially written pieces of software, when combined, could produce an augmentative communication device. These combined products are indicated by the cross hatched area in figure 2.9. [37]

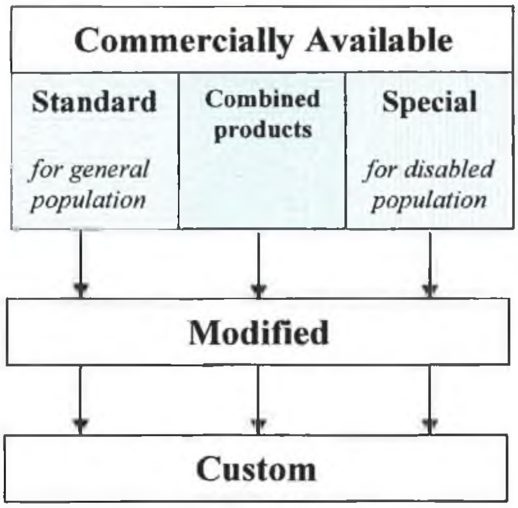


***Figure 2.9 Progression from commercially available products to modified and custom devices*[37]**

However, when an appropriate device cannot be found, a modification will be made to the nearest commercially available device, so that it better suits the individual's needs. Other times this is not possible and the person will need a custom built device. This approach is normally very expensive and may take a considerable amount of time to develop. A point to note is that by using the term 'commercially available product' in this text, it is taken to mean that the products in question are being either mass or batch produced, and as such are not custom built devices.

2.8-3 Availability and Standards of Assistive Technology

There are countless Assistive Technology devices available today, only some of which are available on a commercial basis. There are many reasons for this, the most prominent being the fiscal benefits seen by the manufacturers are not as transparent for certain products as they are for others. Before quality products can be produced cost-effectively, they need to be manufactured using either batch or mass production methods. This requires much investment during the early stages of development. Attaining this initial investment is dependent on identifying an extensive product market, using various market research techniques, which include statistical analysis.

The standard of statistics on disability presently available is less than effective in convincing manufacturers, developers and investors of the need for more assistive devices. As a result many Assistive Technology devices available today are not of a reasonable quality and user expectations are not being met [38]. This notion is compounded by the following two quotes; the first is from the Centre for Assistive Technology (CAT) University of Buffalo, New York, and the second from 'Enable Ireland':

"Centre for Assistive Technology staff have yet to find a Page-Turner that wouldn't be a source of frustration for most people" [39]

"If you are dependant on technology for many of your basic rights, communication, mobility and education. The consequences of a piece of equipment mal-functioning or breaking down can be catastrophic!" [40]

In this sea of mediocrity, a legacy of techno phobia remains, caused by a lack of resources, and limited awareness on the Assistive Technology developer's behalf. The latter is slowly being rectified through the use of multimedia systems such as the internet, combined with the current design trend of user centered design. Today a plethora of websites exist which should help developers decide on a better approach to Assistive Technology product design.

2.8-4 Advancement of Assistive Technology

Some of the factors relating to the advance of Assistive Technology are disability awareness campaigns, the pace of mainstream technological change and the highlighting of the demographic changes currently taking place worldwide. The many recent legislative equality policies that have been implemented throughout the industrialized world, highlighting the plight of people with a functional limitation, have also added to the progression of Assistive Technology.

2.9 Automatic Page-turners as Assistive Technology

Early in the project, quantitative background research was performed to examine the automatic page-turner as an Assistive Technology device. This included sourcing what was commercially available in the area of automatic page-turning devices as well as uncovering any other similar projects or related research topics. During the preliminary stages of the research, much time was dedicated to internet searches which were used to examine the global competition. This initial research revealed that several devices existed and furthermore several related projects had been carried out in the past.

One of the projects of particular interest was carried out at the Applied Science & Engineering Laboratories of duPont Hospital for Children and the University of Delaware. This project involved a fifteen person strong team of researchers developing an automatic page-turner in conjunction with Maddack Inc. (In the United States Maddack Inc. is the largest single manufacturer of rehabilitation equipment.) [41].The team was comprised of people with and without a physical limitation. Together with Maddack, they had made a commitment "to share resources where appropriate, to create the best page-turning device possible".

This project started with the evaluation of several commercial page-turners and a patent investigation. A questionnaire was created and sent out to the mailing list of the Consumer Innovation Laboratory. The results of the study revealed many interesting aspects including the fact that 86% of respondents preferred reading from a traditional paper medium rather than from a computer screen. (See Appendix A) [42].

Utilising personal experiences combined with those of the manufacturer, a product design specification was compiled (See Appendix A). This PDS seemed to be overly ambitious and indeed had the product been produced, it would have been more akin to a robotic manipulator. Such high aspiration eventually led to the break up of the design team. The project had run for three years approximately but failed to meet the PDS requirements.

2.9-1 'DUNE' Project

Several of the devices found, appeared very promising but any attempt at gaining further information about them was met with either no response or a redundant internet hyperlink. One such device was developed by two product designers, at the request of St.Thys centre in Marseilles, France. (Pigasse and Sauvage 1995). [43] The DUNE project appears to have produced a prototype after extensive work had been carried out as can be seen in figure 2.10. No further information could be found for this device, despite extensive searches and attempts to contact the designers.

***Figure 2.10 Roughs from the Dune page turner and DUNE prototype* [43]**

2.9-2 MIT Page-turner development (Professor E. Blanco)

***Figure 2.11 Ernesto Blanco stands by a page turner he invented* [44]**

Further research revealed a device that had been developed at MIT [44]. Blanco (1999) had developed a device which he hoped would benefit musicians by automatically turning the pages of their music scripts without them having to pause from playing their music (See figure 2.11). The device utilizes a mechanical arm with a small spool of sticky tape that adheres to the top page and subsequently lifts it in a semi-circular motion to turn it over. On releasing the pages "the sticky spool rolls a bit and strips off easily".

Blanco states "There are a few page turners on the market already, but they're very expensive and very unreliable. This one cost only about $150 to make. And it works". However he has not marketed any of his page turners yet because a market study done at Sloan business school (MIT) revealed discouraging prospects.

2.9-3 'Compagnie' Page-turner

Developed in France by LEEntreprise (See figure 2.12) this was another product which was found to be difficult to gain more information on. However, on their website [45] the manufacturer claims "The standard model applies to reading books of any format up to 5cm thickness and usual magazines sizes." However they discourage the use of heavy weights of paper such as "thick art books". The product works "through a transparency and is set in motion by touch control or breathing into a microphone." It is made clear however that "Should two pages be turned together, (which can even happen when turning by hand), reversing the action will correct the procedure." And finally "the price quoted includes the turner with controls, the lamp above and an alarm."

Figure 2.12 'Compagnie' Automatic page-turner **[45]**

2.9-4 'Quest Enabling Designs' (QED) Page-turner.

The first commercially available product to be reviewed (See section 3.2) was developed by Quest Enabling Design (QED) in the UK [46]. This unit can turn pages of tabloid newspapers, paperbacks and hard backed books. This well proven paper manipulation method uses a vacuum

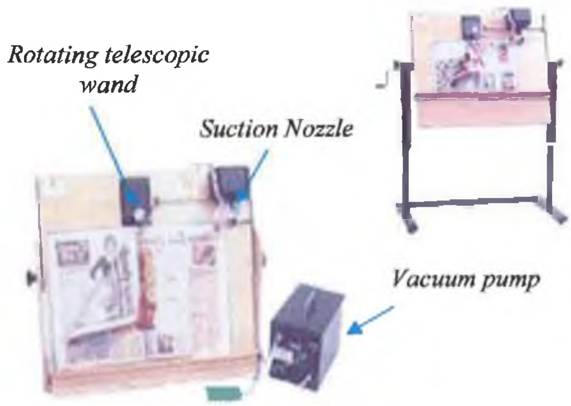


Figure 2. 13 QED page-turner **[46]**

pump connected to a patented nozzle system to suck up and slightly bend the corner of the top page - thus forcing the other pages away, resulting in successful page separation. A central wand then rotates and turns the page, flattening it ready for reading (See figure 2.13). The page-turner comes with a table top stand, fitted with heavy duty clamps for securing it near the edge of a table or trolley.

2.9-5 'GEWA' Page-turner

The GEWA page-turner was developed in the United States by ZYGO industries [47]. The page-turner is designed to be used with either a multiple switch with four functions, or a scanning controller with a single switch. It allows the user to manipulate a mechanically driven, rubber roller, through four simple manoeuvres, to complete independent page turning of books and magazines.

Figure 2.14 GEWA Page Turner BLV-6 [47]

This device uses mains power to move the roller from side to side across the book to turn the pages forwards and backwards, while two transparent sheets hold the pages in position. The device can accommodate both hard and soft backed books and can be operated by a range of switches, including sip and puff, plate and independent joystick control. The device can be angled to 45° and can be used in conjunction with the Possum range of Environmental Control Systems [48].

2.9-6 'TURNY' Page-turner

Figure 2.15 The basic TURNY unit **[49]**

This next product very closely resembles the page turner developed at MIT, as discussed in section 2.8-2. This device uses the same sticky tape principle to turn the pages of the reading material and is now commercially available. This electronic page-turner is designed for books, magazines, and pocketbooks. The device uses an oscillating arm with an adhesive roll, which adheres to the page and subsequently lifts the page (See figure 2.15) [49]. The device can be actuated by a variety of methods, including; a light touch or blow signal, an infrared remote control or using speech recognition. "The basic model is the Table Unit,which can be used with various stands to create the other models" seen below in figure 2.16. The supplier of this device claims "This new model has been specially developed for bed-ridden patients in order to allow them to read above their heads while lying prone on the bed."

TURNY Mobile **TURNY Secustand** **TURNY Switch**

***Figure 2.16 Variety of stands for TURNY*[49]**

2.9-7 'Touch Turner' Page-turner

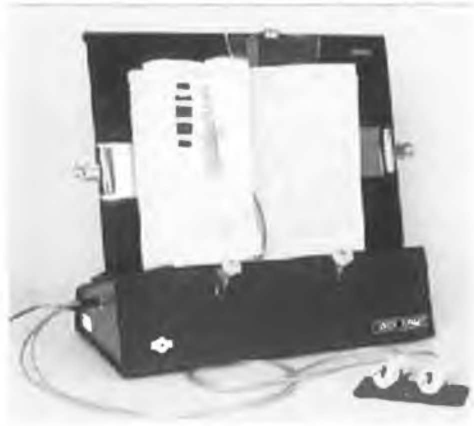
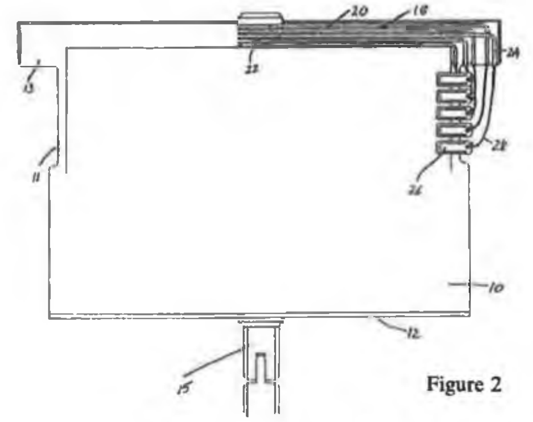


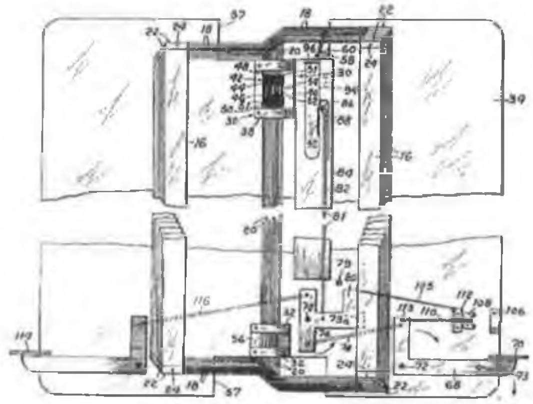
Figure 2.17 Touch Turner- Model CR **[50]**

There are two models of the 'Touch Turner' available [50]. Model C allows for pages to be turned forward only, while model CR allows pages to also be turned in reverse. The device uses a pair of friction-roller page separators combined with a rotating arm, which is used to flip over the pages (See figure 2.17). The website claims that "Both models are available with an interface which allows various types of switches to be used on the same unit. Switches by other manufacturers that use a mini-phone jack may be compatible with this interface. Also available is a 110-volt AC wall adapter which is also installed at the factory."

2.10 Patent Searches

In an effort to reduce the likelihood of patent infringement a patent search was performed. Although somewhat limited this search revealed that many of the patents for automatic page-turners were focused on the musician's page-turner, which is designed to turn the pages of standard size music scripts. The majority of these patents have involved the use of a plethora of finger-like components, which meant that the device would be set up with one such component between each of the pages that were required to turn automatically during a playing period. Figure 2.18 illustrates some of the devices found.





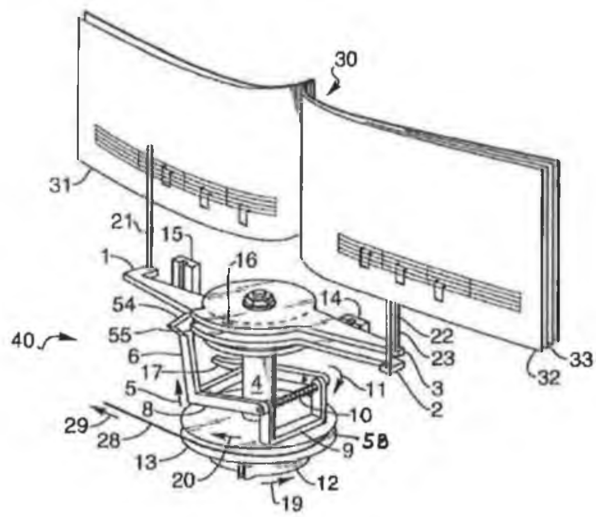


Figure 2.18 Examples of page-turner patents for musicians

However, there were also several patents that related to the automatic page turner as an assistive technology device. One of the patented designs that was of particular interest would have almost certainly have caused an issue with further development of the previous design at Dublin City University can be seen in figure 2.19. Although no devices were found that resembled the two fingered approach to automatic page turning, it would be necessary to carry out a further investigation should this concept prove successful. The sources of these preliminary patent searches were the United States Patent and Trademark Office (USPTO), and the European Patent Office (EPO).

U.S. Patent **Feb. 24, 1987** **4,644,675**

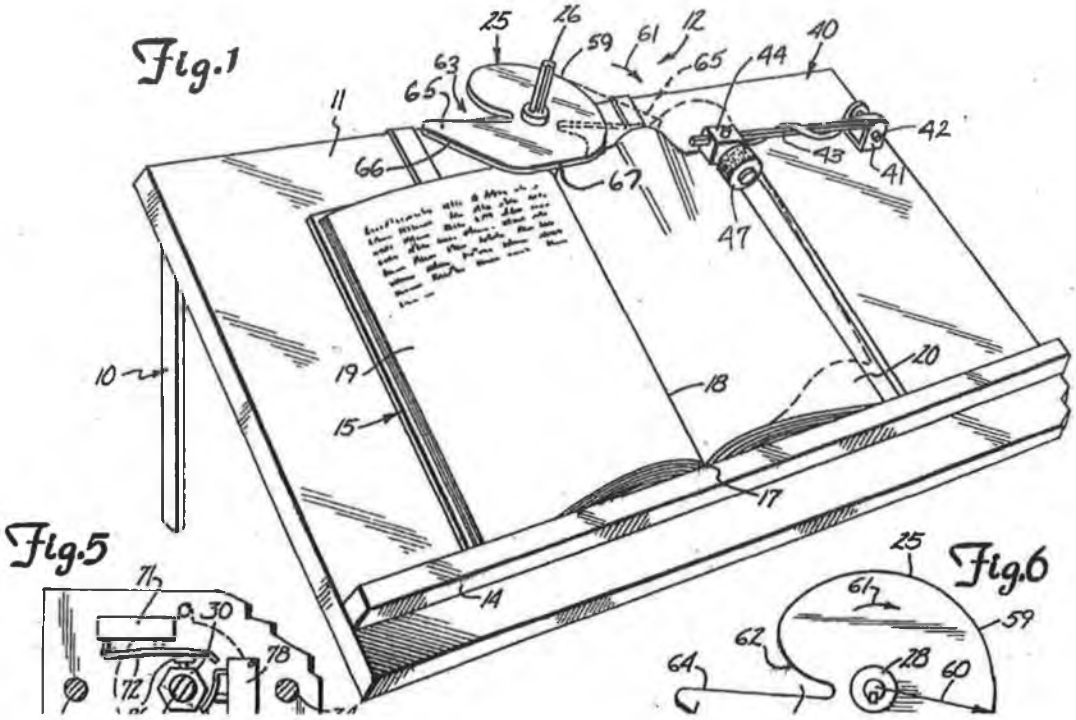


Figure 2.19 *Example of page-turner patent as Assistive device*

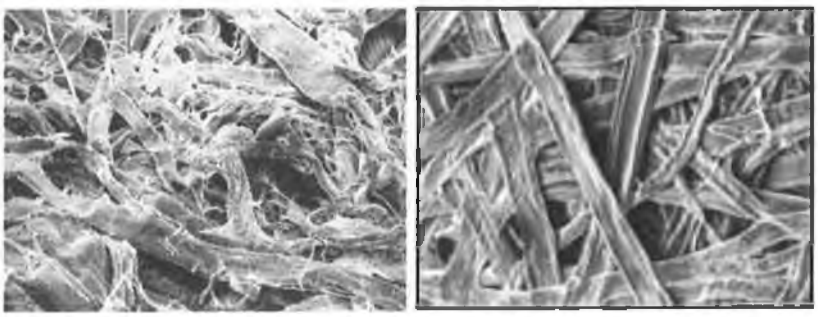
Having gained a broad knowledge from the published work on automatic page-turners, it was subsequently felt that a 'hands on' approach was needed, to find out what was available on the ground and to examine the tangible nature of these products. Several sources of Assistive Technology in Ireland were contacted to determine if it was possible to set up a working demonstration of the products that were available. It was also believed that other devices may have existed that had been overlooked in the research thus far, but this turned out not to be the case as is discussed in the product review section of chapter 3.

2.11 Further Reading

In an attempt to understand the mechanics of frictional page separation as performed by humans, further research was carried out. This began with an examination of paper frictional forces followed by a look at human haptics and human slip detection. This was followed by an examination of machine haptics and slip detection methods used in a variety of applications, with a view to exploring the feasibility of incorporating these techniques into the automatic page turning device.

2.11-1 Paper Frictional Analysis.

It is well known within the paper industry that the understanding and control of friction is a key parameter, which is vital to measure in paper manufacturing, development, quality assurance testing as well as paper manipulation techniques [51]. Paper is made up of bundles of individual fibers laid down into a thin even layer [52]. Magnification visually confirms the individual-fiber make-up (see figure 2.20). When examined at this magnification level, it can be seen that it is the variance in the roughness of this surface which dictates the variety of frictional coefficients between various paper types.



Poor quality of paper *Higher quality of paper*

Figure 2.20 Highly magnified pictures of paper [52]

Figure 2.21 Advanced Paper Tribometer **[51]**

The science of friction, wear and lubrication is called tribology. The methodology of precision, repeatable and reproducible measurements of friction and wear is called tribometrology. The 'Advanced Paper Tribometer' seen in figure 2.21 was developed to study paper in moving interfaces [51]. Using this tribometer, an experiment was performed whereby load was decreased from 500 mN to 50 mN. Measurements were taken during unidirectional linear sliding at a speed of 1 mm/s for a total of 60 seconds at each load. The envelope of dynamic Coefficient of Friction (COF) performance was quickly characterized. From the graph seen in figure 2.22, it is evident that the dynamic COF increases with decreasing normal force, indicating involvement of both elastic and plastic deformation at the paper interface as well as a creeping mechanism. However since the dynamic Coefficient of Friction is lower than the static case, experiments were carried out to determine the static COF for several paper types (See Section 5.2)

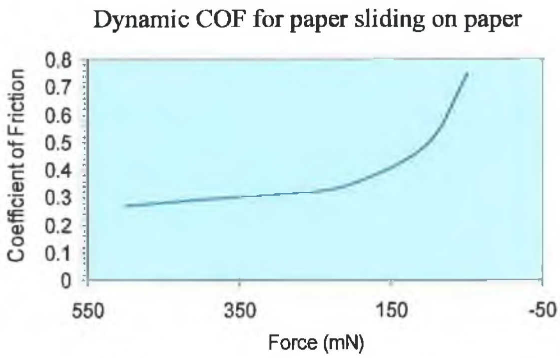


Figure 2.22 Dynamic COF for paper on paper with decreasing force **[49]**

2.12 Human Haptics

The complex feedback systems that humans use for page separation involve both sight and touch. Although machine vision is a rapidly expanding area of research, suitable systems have not yet been developed that would be appropriate to incorporate into a device such as a page-turner. It was therefore decided to focus on the touch element of the human approach to page turning. Human haptics is the study of how people sense and manipulate the world through touch [53]. The mechanics of the skin and subcutaneous tissues is as central to the sense of touch, as optics of the eye are to vision and acoustics of the ear are to hearing. In spite of the fundamental importance of the sense of touch in our lives, very little is known about the mechanics and the mechanisms of touch. Through our haptic senses, humans can determine various physical attributes about the objects we touch. For example our sense of touch helps us determine not only if an object is rough, wet, slippery or warm, but also the level of force, which is being applied [54]. Only some of these attributes play a key role in the manipulation of pages, namely, slip detection and the application of force.

2.12-1 Human slip detection

The sensors used by humans to detect slip are our mechanoreceptive nerve terminals, which produce complex incipient slip feedback signals. These signals are caused by lightly loaded protrusions in the skin near the periphery of the contact interface, which break loose just before gross sliding occurs [55]. This is an important aspect to page separation since this feedback determines the amount of force that is applied to the page. For example if we feel that our fingers are beginning to slide over the page then more pressure is applied until slipping stops and the pages begin to separate. The palms of the hands and fingers have a pattern of ridges and furrows (see fig

***Figure 2.23 Human fingertip showing friction ridges* [56]**

2.23) [56], which help in gripping and traction. Small pore openings on the hands discharge perspiration which is approximately 99% water and 1% salts and organic matter. Research has shown that the Coefficient of Friction for human skin in contact with paper is approximately 0.27 when dry and increases when wet to 0.42. [57] Everybody is familiar with the action of licking ones fingers to separate the pages of a book.

2.13 Machine Tactile Sensing 'Haptics'

Much work is presently underway in the area of machine haptics and tactile sensing. This is primarily aimed at improving the sensitivity of robotic manipulators as well as developing systems for better human-machine interaction. Machine haptic sensing can involve the various aspects of touch previously mentioned. This requires the development of complex haptic sensors combined with advanced algorithms which mimic human tactile neural coding. Haptic research has been carried out at this generic level by modeling the dynamics of a Primate Finger-pad in the 'touch lab' at MIT [53]. However, although this level of touch sensing may be essential for some applications, it would not be necessary for page manipulation. Therefore the research for this project focused on more specific aspects of machine tactile sensing, namely, force feedback and slip detection using relatively small sensors. Many approaches have been taken in an effort to realise machine slip detection, some more complex than others.

One such approach used two accelerometers, embedded within a synthetic finger-tip as seen in figure 2.24 [55]. This method uses silicone rubber projections that form local contact regions that can slip independently from one another and produce small vibrations.

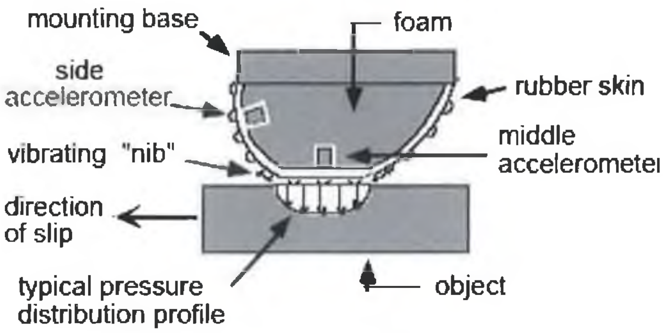


Figure 2.24 Design of fingertip using accelerometers **[55]**

The vibrations occur as these 'nibs' break free just before gross slipping occurs and subsequently propagate through the skin before being measured using the two accelerometers that are bonded to the skin.

Another approach to establishing slip is to use optical mouse technology, whereby a light-emitting diode (LED) illuminates the surface underneath the detector which reflects off microscopic textural features in the area. A plastic lens collects the reflected light and forms an image on a CCD sensor which continuously takes pictures normally at a rate of 1500Hz or higher. These images are then sent to an optical navigation microprocessor for signal processing. (See figure 2.25) [58].

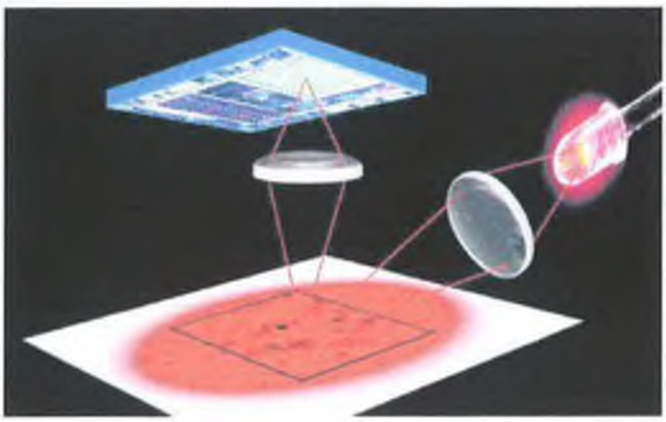


Figure 2.25 Optical Mouse sensor technology **[58]**

This approach was used to detect foot slippage by installing the required sensor on the soles of the feet of a quadruped robot. (See figure 2.26) [59].

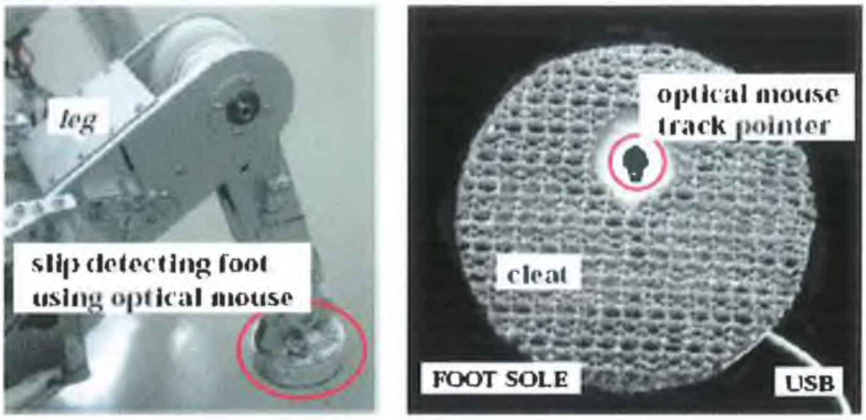


Figure 2.26 Optical mouse sensor on sole of quadruped foot [59]

Researchers at the University of Tokyo have used an Acoustic Resonance Tensor Cell, (ARTC) sensor to determine the coefficient of friction on initial contact with an object (See figure 2.27) [60].

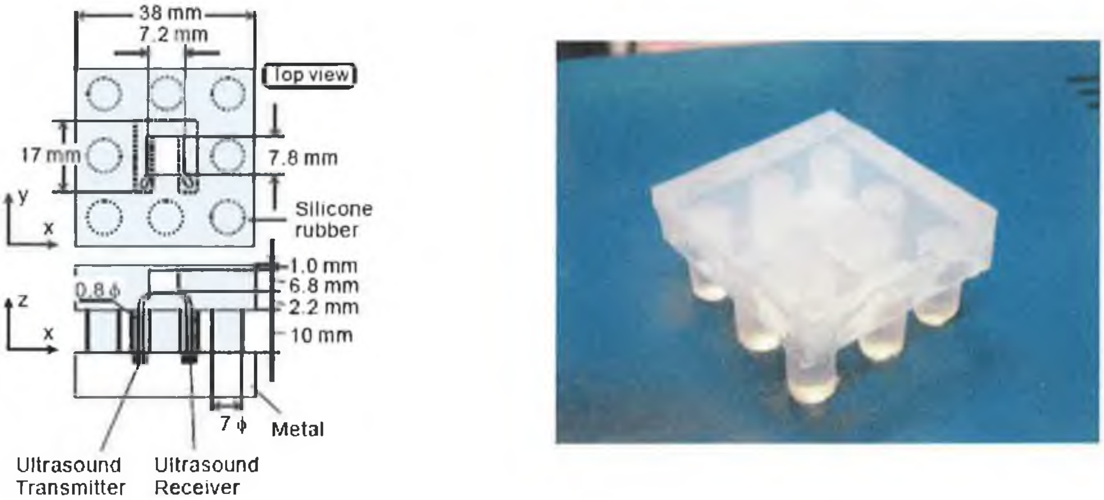


***Figure 2.27 Structure of Acoustic Resonance Tensor Cell (ARTC) Sensor* [60]**

Other methods used in determining slip detection and force sensing have included embedding several strain gauges and PVDF (polyvinylidene fluoride) films distributed randomly as force detectors. (See figure 2.28) [61]

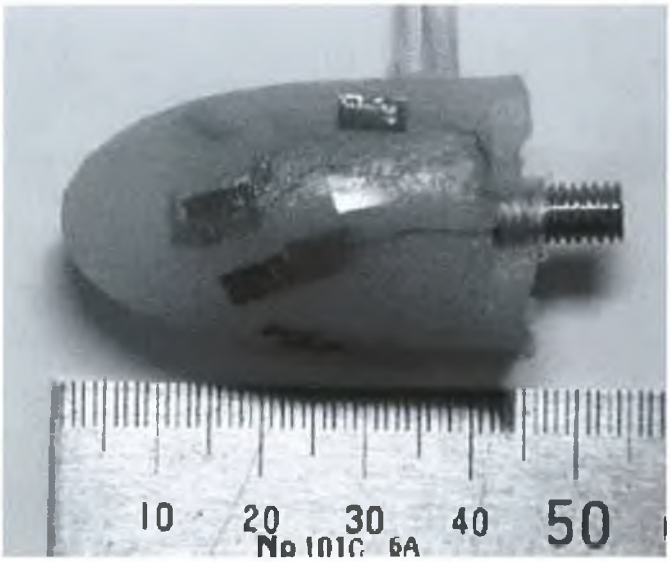


***Figure 2.28 Randomly distributed sensors in a soft fingertip* [61]**

The finger-tip shown in figure 2.29 uses a six axis force/torque sensor to detect both applied force and slip. [62]

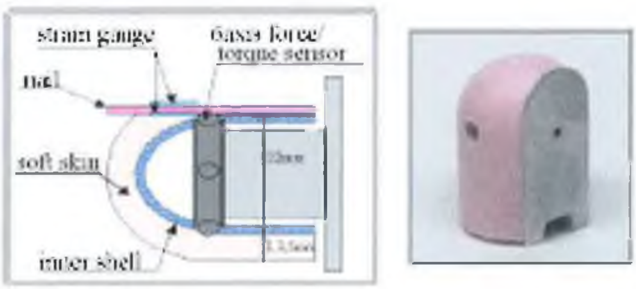


***Figure 2.29 Soft haptic robotic fingertip complete with fingernail* [62]**

These different types of tactile detectors have had varying success during testing. There have been many approaches investigated to develop tactile sensing devices, however most of them require substantial computer processing power which enables them to function correctly. It was therefore decided that before these somewhat complicated methods of slip detection and force feedback could be incorporated into an automatic page-turning device, a system would have to be developed which would comply with the use of such sensors.

Following extensive secondary research carried out on the concepts and theories behind the design of an automatic page-turner and a study of existing products, the focus now turns to a detailed product review and the development of a Product Design Specification.

Chapter 3. Product Review and PDS Development

Prior to the initiation of this particular project, a final year undergraduate student at Dublin City University had designed and built a prototype automatic page-turner [63]. This device was subsequently delivered to a facility run by the 'Enable Ireland' group to allow unsupervised testing of the device. Shortly after the commencement of this project, an appointment was made to meet and discuss the outcome of this informal trial.

This initial feedback revealed invaluable information, not only about the device under test, but it also uncovered many aspects that were subsequently found to be very helpful when compiling a set of user requirements, which formed the basis of the Product Design Specification (PDS). During this initial meeting, a further appointment was scheduled, to have a group discussion, which would include the end-user, her parents, two occupational therapists, a carer (personal assistant) and two engineers. This group discussion was scheduled to take place at the 'Enable Ireland' facility in Bray (Co. Wicklow) several months after this initial meeting. This allowed more time to organize and develop a structure for this meeting including a list of questions which would need to be answered, in order to become more familiar with the end user, the specific area of Assistive Technology and what was expected from the device under development.

Using the knowledge gained from the staff at 'Enable Ireland' a review of the previously designed device was undertaken in order to examine the problems experienced during the trial and to evaluate the feasibility of using a similar method of page-turning in the new device. This was followed by a review of the existing commercially products.

3.1 Review of Previously Designed Device

The device incorporated a single rotating friction wheel to separate the pages of the reading material (See figure 3.1). This action created a buckle in the top page which would allow a secondary mechanism to enter as it rotated and continue to flip-over the page. (See figure 3.2)

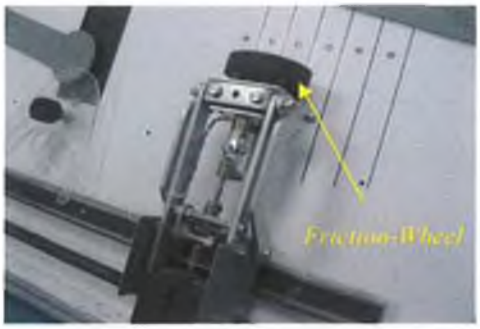


Figure 3.1 Single friction wheel

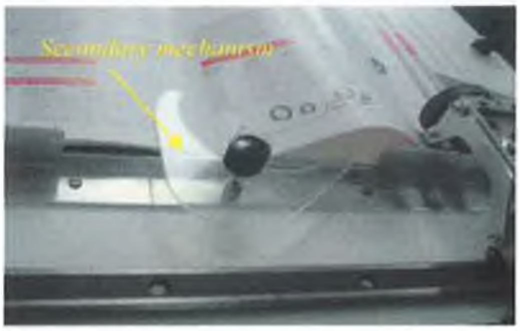


Figure 3.2 Secondary page flipping mechanism

While it was evident that a lot of work had gone into the design of this device, the method used to separate the pages of the book was not successful; the friction wheel would fail to adhere to the page resulting in failure to create the buckle. The device did incorporate a facility whereby the user could increase the pressure on the page using the joystick actuator in order to overcome this problem. However, when this extra pressure was applied, the friction wheel frequently caused a fanning effect (see chapter 4) resulting in the secondary flipping device having difficulty entering between the top and subsequent pages. When it did manage to enter the buckle the added pressure caused the wheel to exert such force that the secondary device either had

Figure 3.3 Excessive pressure from friction wheel.

difficulty in pulling the page from under the friction wheel, (see figure 3.3) or would tear through the page of the book. This was dependent on the paper thickness.

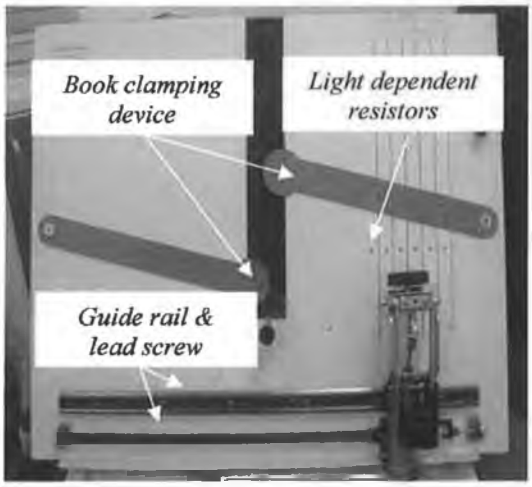


Figure 3.4 Complete previously designed device

The clamping mechanism had also proven unsuccessful in holding the reading material fast. This allowed the friction wheel to move the whole book instead of simply moving the top page, resulting in a malfunction of the device. Because of development time limitations the weight and transportability of the device were less than ideal. This was partly due to the incorporation of a mild steel lead screw and a hardened steel guide rail used to move the friction wheel carriage back and forth, to facilitate turning pages both forwards and backwards. These were mounted on an 18mm thick MDF (Medium Density Fibre) baseboard, all of which were contributing factors to the weight issue. (See figure 3.4)

3.2 Review of Commercially Available Products

Following this review, in an effort to closely examine any other page-turning devices which may have been available, contact was made with several sources of Assistive Technology. This eventually led to an appointment being made with a member of staff at the Assistive Technology department of the Central Remedial Clinic (CRC) in Clontarf, Dublin [64]. Having met two of the staff, who both had vast experience in the area of Assistive Technology, much knowledge was gained regarding the automatic page-turning products that they were aware of, including some of the problems that people had encountered while using them. At this point an arrangement was made to view and digitally record three of the four commercially available products which had been found through previous research. The QED, GEWA and TURNY page-turners, were the three devices available, however the staff at CRC did not have access to the 'Touch Turner' device. The footage taken was used for a comparative product analysis and also during the previously scheduled group discussion (See section 3.4).

The product analysis revealed the relative merits and demerits of each of the commercially available page-turners recorded. Below is a succinct description of the results of this product analysis, which is followed by a summary table of the various attributes of these three products, as well as the other two commercially available products identified in chapter 2.

3.2-1-Product 1. QED Page-turner.

Positive aspects:

- Suitable for turning large documents such as tabloid newspapers.
- Requires substantial set-up and adjustment.

Negative aspects:

- Cumbersome device which is inherently rather heavy.
- Forward turning only.
- Use of Vacuum pump.
  - Not easily transported.
  - Rather noisy.

3.2-1-Product 2. GEWA Page-turner

Positive aspects:

- Little or no adjustment required to set up.
- Very successful page-turning operation
- A rubber roller manipulates the pages forward and backward, singly or continuously.
- Can be used at an angle suitable for use by individuals who are restricted to lying in bed.

Negative aspects:

- Page turning sequence not automated – The user must maneuver the centre roller through four separate actions to complete one page turning operation.
- Inner and outer plastic panels secure and flatten the document being read. This makes the product susceptible to reflections and glare while reading.
- Very expensive.

3.2-1-Product 3. TURNY Page-turner

Positive aspects:

- Small, neat and relatively lightweight with a modern appearance.
- Very little adjustment required (adjust length of oscillating arm)

Negative aspects:

- Residue from adhesive roller remains on the pages of the reading material. (This results in only one read of the book being possible, using the device. Also makes it difficult for anybody to separate the pages after the device has been used)
- Frequent changes to the position of the adhesive roller are necessary to improve reliability.
- Requires replacement adhesive roller cartridges.

Table 3.1 Commercially available product characteristics summary table

Product	Width (CM)	Height (CM)	Weight (Kg)	Turns both directions	Max page size	Max thickness (mm)	Price Guide
QED	50	60	7	MD	Newspaper MD	50	STG £1,880
GEWA	60	50	2.3	Yes	A4	50	STG £1,868
TURNY	45	40	2.5	Yes	A4	40	USD $3400
Touch Turner	50	45	NA	MD	A4	NA	USD $1300
Compagnie	40	60	9	NA	A4	50	STG £1,558.4

This table summarises the various aspects of the devices reviewed. It should be noted that the prices may vary depending on the source examined. Note: **MD** (Model Dependent) **NA** (Not Available)

3.3 Identified Paper handling methods

The process of automatically turning a page of a book can be broken down into three fundamental actions, namely, page separation, turning of the page, and finally holding the pages open. The following elucidation of the relative merits and demerits of the various page-turning techniques used in the existing products was employed to examine their suitability for incorporation into a universally designed product, having the potential to satisfy both identified markets.

3.3-1 Pneumatic Approach

The first method incorporates the use of a pneumatic suction cup to separate the pages of the reading material (See Figure 3.5-A). Although this tried and tested technology is very successful when set up precisely, it is more suited to its application in larger paper handling machines, like large printing machines. Using this approach in the automatic page-turner, the initial set-up and adjustment has proved to be time consuming. A compressor is required to apply the vacuum to the suction cup and must be transported with the device. Compressors tend to be quite heavy and cumbersome. They are also inherently noisy, which rendered this method highly unsuitable for incorporation into an easily-transported product, which was required to operate quietly. Gas cartridges were considered as a method of creating the vacuum needed, but the minimization of service required on the product deemed this as unsuitable.

3.3-2 Friction Approach

Method B uses a full length neoprene coated friction-roller, which rests on the reading material, before rotating to perform the separation process (see Figure 4.8-B). This is very similar to the approach that is used in many photocopying and small printing machines. The friction roller approach is essentially too slow in turning pages, for the musicians market, where speed is vital. While the approach of using a large friction-roller is favourable in terms of functionality, it is also inherently quite ungainly and rather clumsy for an automatic page-turning device. However a simpler friction approach was considered to have potential for further development.

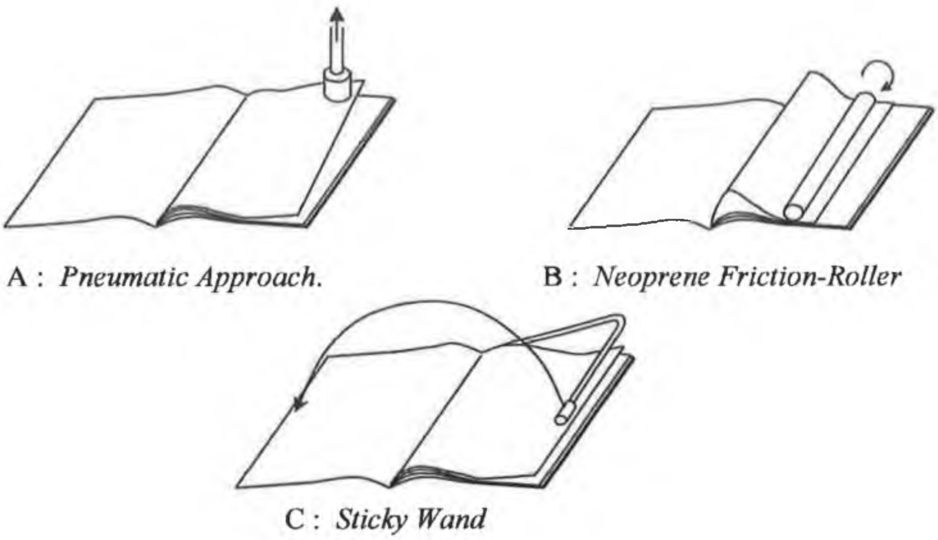


Figure 3.5 Three identified approaches to page turning

3.3-3 Adhesive Approach

The third method employs a sticky wand, which makes contact with the pages of the reading material and subsequently performs both the separation and turning operations using the same device (See Figure 4.8-C). However its downfall lies in the fact that paper is a fibrous material and as such, there is a transfer of materials at the contact interface to and from the sticky roller. This results in a gradual decrease in the reliability of this method due to a diminution of the stickiness as well as a residue being left on the page that has just been turned, leaving the pages with a tendency to adhere to each other. It was felt that this fundamental flaw, calls for high level research into adhesive materials, to examine if this method could be in any way usable. The adhesive process of joining two materials demonstrates that the bonds which are created at the interface, are often stronger than the parent material, resulting in the weaker material breaking away on separation. Perhaps future developments in the area of adhesive materials may potentially render this method more appropriate

3.4 Group Discussion

Having gained firsthand experience of the various products available and having recorded these devices while operating, the footage taken was brought to the group discussion, which had been previously arranged with 'Enable Ireland', in order to assist in qualitative data collection. The general idea of a group discussion is that the involved parties e.g. consumers, care providers, parents and product developers, can be brought together to help refine the requirements for a particular product and can collectively generate ideas that could otherwise be overlooked. Group discussions and focus groups are suitable methods of retrieving data that is not readily available, or to acknowledge experiences not previously recorded. The focus group method relies upon the interaction between the individuals - encouraging synergy within the group [65]. It must therefore be recognized that, often, group participants may need some encouragement to get involved and have an input into the product's design. It is important to be clear as to the aims of the meeting before it begins, for example what areas of the products development need to be addressed. Time should be carefully planned so that the participants do not become uninterested or exhausted by the somewhat technical speak that can ensue [66].

The focus group started with an introduction and a brief explanation of the agenda of the meeting, which included an emphasis on the informal nature of the discussion and the fact that the primary reason for the meeting was feedback. This approach was taken to encourage all participants to speak and ask questions at any time during the meeting, which made for a very relaxed atmosphere.

The video presentation of the existing devices was paused several times to discuss the different aspects of the products that had been uncovered, as well as some of the potential problems, which could be encountered while using these existing products. Much feedback was gained from this group discussion, including the reiteration of the importance of transportability, as well as wheelchair joystick actuation. However, it was felt that direct observation while using a page turning device may assist further in identifying any obvious problems or difficulties faced by the two principal user groups, namely, the end users and the care givers/occupational therapists.

3.5 Task Analysis / Direct Observation.

Following the preliminary group discussion, an arrangement was made to obtain an existing product and perform a user trial. The product in question was the TURNY, which is the most recently developed of the available automatic page-turners. Once again, digital records were made, (with the consent of all parties) during these user trials, which were subsequently used for the purposes of both user and product analysis. Direct observation is an invaluable data collection technique, which is used when attempting to gather information relating to any difficulties encountered by both the end users and their assistants.

In order to gain as much feedback as possible, in a relatively short period of time, the approach taken was to allow the Occupational Therapist to remove the product from the box and record the course of action that ensued, with as little interference as possible. This technique was used to make a record of the Occupational Therapist's approach to setting up an Automatic Page-Turner. This initial task confirmed the importance of unambiguous step-by-step instructions and illustrations to describe the set-up and subsequent operation of such a device.

The actuation of this page-turner can take the form of sip and puff, infra-red or a single switch mechanism, the latter was the choice of the end user for this trial. Having set up the device, the user was asked to operate the device in both directions. The first problem that was encountered was the difficulty in placing the switch in a suitable position that would be comfortable for the user. Another issue was that the method used to turn the pages in the opposite direction was for the user to hold their hand on the actuation device for a five second period. This was found to be particularly difficult for the user to perform and involved thrashing of the switch, which delivered mixed messages to the page-turner, resulting in device malfunction.

Following this task analysis, both the end user and the Occupational Therapist were asked a series of questions about their experiences. This revealed several further concerns regarding difficulties that were experienced while setting up and subsequently using the device. These difficulties were noted and later documented using the USER*fit* summary tools appropriate to these data retrieval methods, in an attempt to solidify a set of user requirements.

3.6 User Requirements

The following list of user requirements was compiled through the various methods of gaining feedback that were used thus far. This was performed by examining the existing commercially available products, talking to Assistive Technology specialists and occupational therapists, organising group discussions and finally carrying out a user trial and task analysis.

List of User Requirements.

Stakeholder (End User)

- Turns pages both forwards and backwards
- Is very easy to operate and understand
- Can handle various types of switching (actuation) mechanism
- Can handle various types of book
- Will turn pages relatively quickly
- Aesthetically pleasing

Stakeholder (Carer & Parents)

- Is easily set-up
- Lightweight
- Easily Cleaned
- Easily maintained
- Foldable, easily stored

- Easily transported
- Fits onto wheelchair easily
- Quick to attach/detach to/from chair
- Easily rectified if jamming occurs
- Well priced unit

This User Requirements list helped produce a Product Design Specification which was developed using the combined feedback from the various sources described previously as well as feedback from a brief discussion with a professional musician. This discussion highlighted two fundamental requirements that were necessary in order to satisfy the musicians sector. Besides the reliable functionality of the device, speed of operation was vital so that a musician was not left without their successive music script, and the second was that an over-ride facility should be built into the device which would allow human intervention. While these functional requirements were paramount to the successful operation of the device as an automatic page turner for the musicians sector, they were not given high priority during the first iteration of prototype development. Using this additional information the PDS was produced.

3.7 Preliminary Product Design Specification (Proof of concept phase)

1. Customer requirements (The following design requirements need to be met :)

1.1 Functional Performance:

- ❖ The product should be capable of turning pages both forwards and backwards.
- ❖ The product should be able to operate successfully using the following types of reading material.

- hardback books
- Paperback books
- Magazines
- Bound journals and white papers
- loose-leaf notebooks

1.2 Speed of operation:

- ❖ Cycle speed should be kept below eight seconds (Proof of concept) The paper handling technique used in the design should have the potential to be reduced to a cycle time of three seconds or less.

1.3 Compatibility:

- ❖ The product should be compatible with the following types of actuation device.

- Wheelchair joystick
- Single switch input
- Sip & puff
- Infra Red remote control

1.4 Transportability:

- ❖ The device should be foldable and contain all components as integral parts of the overall product (excluding cables and actuation devices).

1.5 Durability:

- ❖ All elements should be capable of withstanding wear and tear under normal operating conditions*.
- ❖ Where any delicate elements are necessary, appropriate action should be taken to ensure these elements will not be damaged under normal operating conditions*

(****Normal operating conditions*** – Operating in a Normal Environment – see section 3.2, while performing remote actuation of automatic page-turning operation to comply with supplied set-up and operational documentation)

1.6 Target costs:

The production cost for each unit should be less than 500 euro. (Min 1000 Units)

1.7 Documentation:

- ❖ All documentation supplied with the device should be clear and unambiguous. It should include extensive use of pictures, sketches and pictorial semiotics where possible.
- ❖ Documentation should include
    - Step by step set-up and operation.
    - Actuation options.
    - Maintenance recommendations.
    - Troubleshooting.

2. Physical Product features

2.1 Size of product:

- ❖ The overall size of the product should be kept to a minimum, so as not to be intrusive for the end user or other parties in the immediate vicinity of use.
- ❖ The product should be capable of operating with an A4 sized book
- ❖ The product footprint should be no larger than a 600mm square
- ❖ The depth of the product should not exceed 100mm (when closed)

2.2 Weight of product:

- ❖ The product should be as light as possible to allow for easy transportation and moving and should not exceed 4Kg or 9Lbs.

2.3 Materials selection:

- ❖ The criteria for choosing materials will be based on the following:

- Cost
- Weight
- Appearance
- Environmentally-friendly / recyclable

- ❖ The materials chosen should be used in their raw state where possible; as such they should not require extensive finishing processes.

2.4 Power source:

- ❖ The product should be capable of working from the wheelchair batteries or a mains 12V dc adapter

2.5 Aesthetics, Appearance and finish:

- The device should be minimalist and no clumsy mechanisms should be visible
- It should be pleasing to the eye when both open and closed
- All components should be designed to continue the lines of the product where possible
- Color and shape should be used to highlight any control buttons and interface connections that are used

2.6 Ergonomics and anthropometrics:

Ergonomics.

- The product is to be designed with suitable features that will assist the person setting up the device to do so easily.
- The product should not contain any small knobs or switches where unnecessary.
- All connections and control switches should be clearly marked and easily adjusted or turned on and off where necessary.

Anthropometrics.

- Due to the fact that this device will be stand alone, and as such will be interacted with through an actuation device, the need for extensive anthropometric considerations in the design is limited.

3. Technical Requirements.

3.1 Component selection:

- Off the shelf components should be selected and integrated where possible.
- Standard parts should be used where replacement will not cause the product to become obsolete.
- Forward compatibility issues should be examined when selecting components. I.e. check with the manufacturer for how long the component has been in production and for how long more is the component predicted to run.
- Standard footprint for components where possible.

3.2 Operating Environment :

- ❖ The environment in which the device will be used should be a clean and dry indoor setting; such as the home of the end user, a school, library or a special need center.
- ❖ As such the environment in which the product will be used should be free from moisture and excessive quantities of foreign bodies such as dust and insects which may cause the device to malfunction.

3.3 Safety :

- ❖ The product should not contain any sharp corners; protrusions or contain any obvious hazards.

3.4 Testing:

- ❖ The testing of the engineering model will be carried out at Dublin City University (proof of concept).
- ❖ Further preliminary testing of the finished prototype should be carried out with the end user to determine the level of user satisfaction

4. Manufacturing facility

4.1 Quantity:

- ❖ *The number of units to be produced will be evaluated on successful completion of the proof of concept phase. A batch of ten units should be fabricated after successful completion of this phase to allow beta testing to be performed.*

4.2 Maintenance:

- ❖ Routine service and cleaning procedures should be clearly documented and supplied with the product documentation.
- ❖ The need for maintenance of the product should be kept to a minimum.
- ❖ Replacement parts if needed should be readily available.

4.3 Disposal /decommission :

- ❖ Environmentally friendly materials should be used where possible.
- ❖ The product should be designed for disassembly to facilitate recycling of materials and components.

Chapter 4. Concept Development

As discussed in chapters 2 & 3, a device had been developed previously at Dublin City University by an undergraduate student and had been delivered to 'Enable Ireland'. Having obtained feedback from the staff at 'Enable Ireland', it was believed that perhaps a revisit to this device would uncover certain aspects that could be used in the development of a new device. This led on to an examination of the human approach to page-turning which is followed by an examination of several conceptual approaches to developing a system mimetic of this approach. This chapter describs the various steps taken during the conceptual development stage of the project, rather than simply providing several conceptual illustrations and subsequently applying a method of concept optimisation. It concludes with a tabulated comparison between the new conceptual design and the previously examined commercially available devices

4.1 Pre-existing DCU page turning device

Much time had been spent on the development of the centre rotating component (see figure 4.1) which acted as a page-flipping device, and also held any subsequent pages open and flat. This dual operation suggested that perhaps this aspect of the original product could be used in the new design, since it was believed that it could perform well with a successful page separation mechanism.

Figure 4.1 Previous page flipping component

Figure 4.2 Test piece for new page flipping component

One of the problems envisaged was that the size of this component would need to be reduced in order to allow the back and forth movement of whatever primary page separating device would eventually be developed. Initially some smaller test pieces were fabricated and tested (See figure 4.2) but these were soon abandoned because it was realised that this component needed to reach further toward the centre of the book so as to overcome the issue of page weight.

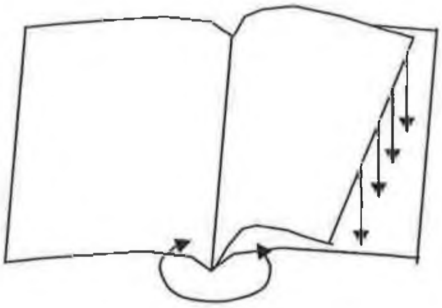


Figure 4.3 Page weight as an obstacle to page flipping

More often than not people tilt the book or magazine they are reading at some angle close to 45° from horizontal. Therefore, when designing an automatic page-turner, it is paramount that the device has a facility to perform this tilting operation. However, when the page-turning mechanism is located at the lower edge of the reading material, this tilting operation causes the weight of the page being turned to hinder the flipping over of the page (See figure 4.3).

Figure 4.4 Touch Turner illustrating the extended page flipping arm

A device that incorporates a similar principle is the Touch Turner (See figure 4.4). However, this product overcomes this problem by utilising a component that extends further up toward the center of the book, resulting in a more balanced application of force to flip over the page, therefore lessening the negative effect of the weight of the page.

Figure 4.5 Redesigned page flipping mechanism

In an attempt to redesign a similar small mechanism that would reach as far as possible toward the middle of the page, while still incorporating the dual action previously discussed, a concept was created whereby the overall shape of the page-flipping device was changed and two spring loaded passively extending arms were added. This meant that the turning mechanism would reach further into the page, resulting in an alleviation of the original problem (See figure 4.5). The altered geometry of this new design meant that the arms would perform the lifting of the page as the mechanism turned, helping to clear the binding of the book as well as improving the page-flipping process. Figure 4.6 A-F indicates the action that one complete revolution (in an anticlockwise

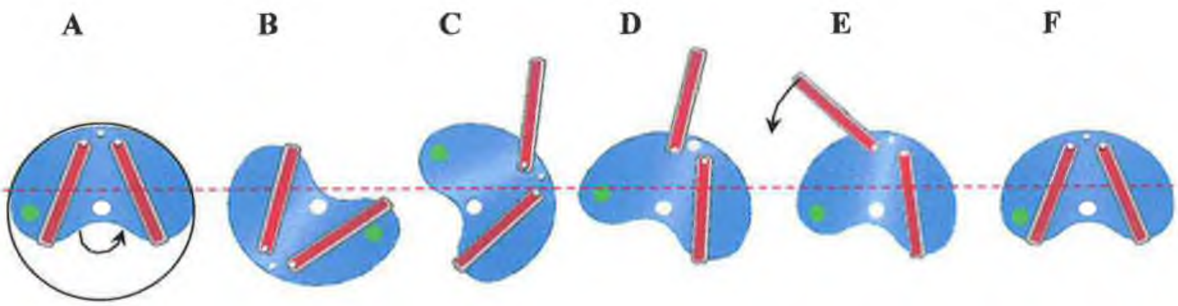


Figure 4.6 Rotation sequence for new page-flipping design located at the bottom edge of the reading material (represented by the red line)

direction) of the mechanism should perform. The green dot is used for illustration purposes only, to help the reader keep track of the mechanisms rotation.

Having concluded that this new mechanism had the potential to provide a better solution to the problem of flipping over the page, an emphasis was put on the development of a reliable page separation concept.

4.2 Further Page Separation

Based on the paper manipulation techniques illustrated in chapter 3, it was decided that the only method previously used that would be considered for further development was the use of friction. Four of the page-turners examined use this form of page separation (see figure 4.7). As pointed out previously, photocopiers and small printers incorporate the same principles of friction to separate pages. However, it should be noted that although vast financial backing and resources were used in the development of these devices, they can still jam or fail to correctly pick up sheets of paper.

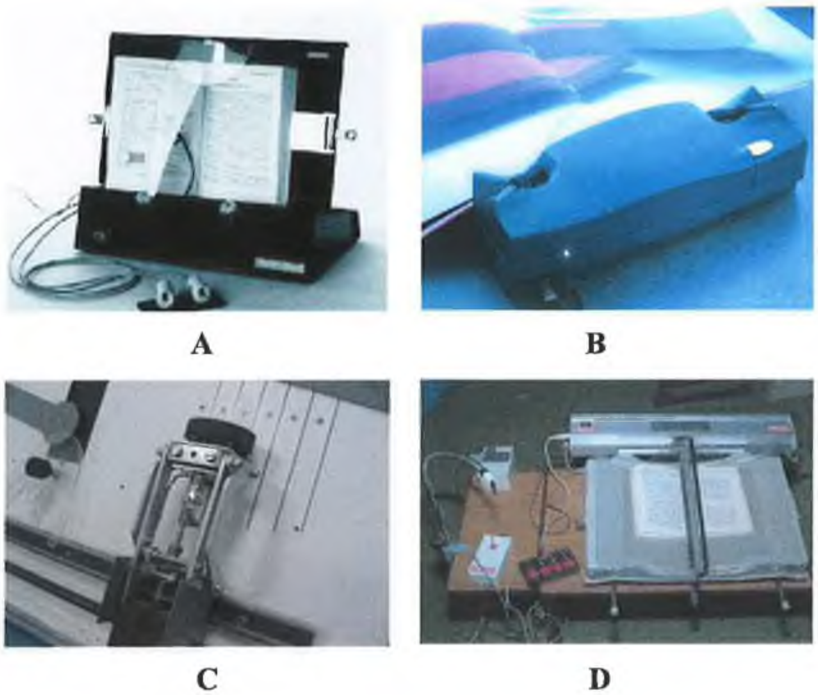


Figure 4.7 Four devices that use friction as their method of page separation

The GEWA page-turner shown in figure 4.7-D is the only device that uses a full length roller and although somewhat intrusive, this device seems to work very well. It was this concept that led to the development of the device designed previously at Dublin City University, which actually utilised a friction-wheel taken from a dismantled printer (See figure 4.7-C). It was hoped that this single wheel would perform in the same way as the GEWA product, but would be much less intrusive. However, the utilisation of a single

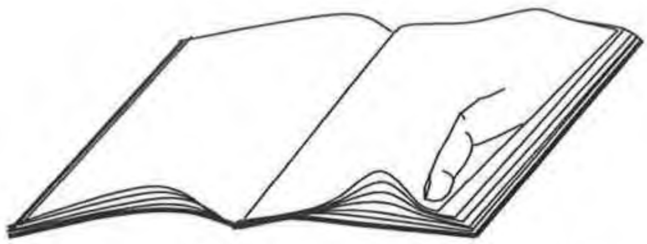


Figure 4.8 Single point of force causing a fanning effect

friction wheel to apply a single point of force causes an inconsistency in the separation of pages, whereby regular fanning effects between the top page and the subsequent pages of the reading material takes place (See Figure 4.8).

4.3 'What Humans Do'

At this point, it was decided to revert back to basics and examine what methods humans use to separate pages. It was clear that one of the methods used by humans takes the form of applying varying pressure using two fingers or a finger and thumb. The pressure is applied to the top page and the two fingers are subsequently drawn closer together causing a buckling effect on the top page.

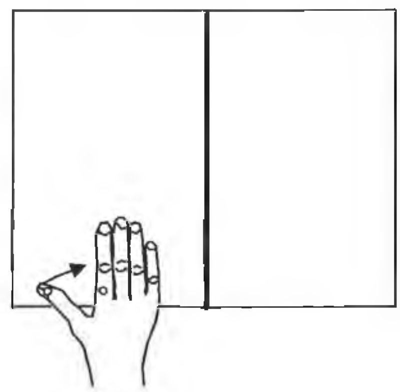


Figure 4.9 Human approach to page separation

(See figure 4.9). Most times the top page will separate from the underlying pages because the coefficient of friction between the skin and the page is greater than that between the pages. When examined more closely, it can be seen that due to the compressibility of the paper and the small air gap between the pages, a buckle begins to form. This occurs simply by applying pressure at two points. Furthermore the buckle created in the top page is substantially greater than that of the underlying pages. (See figure 4.10) Paper sheets like so many other sheet materials have an inherent resistance to buckling; therefore the second page, which has less deformation, will resist the horizontal forces being applied, by the drawing together of the fingers on the top page, resulting in only the top page being buckled.

This analysis led to the conclusion that the development of two human-like fingers, that could apply just enough force and which would incorporate synthetically produced fingertips, mimetic of the attributes of human skin, could almost guarantee single page separation.

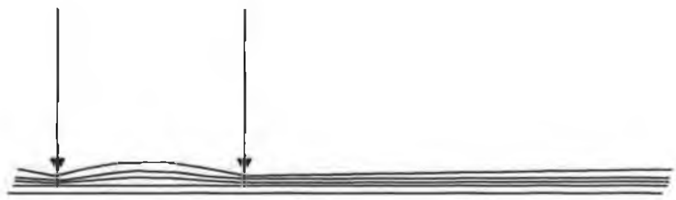


Figure 4.10 Two point force on page causes buckling

It was clear that the development of two such haptic-like devices would require a lot of time and resources, which may have compromised the initial concurrent product development approach that was to be taken, resulting in less emphasis being put on the finished prototype. Nevertheless it was decided that this concept should be investigated further, despite the possible complexity and delicacy that could be involved in developing the force feedback system that would be needed to measure the small forces involved. Initially several ideas containing a current controlled long-stroke solenoid were considered as it was thought perhaps this approach could offer a method of applying pressure to the page, but these soon gave way to the development of a more controllable finger, using motors.

4.4 Concepts for Fingers

There were several aspects that had to be considered for the development of these fingers. A preliminary list of attributes was compiled, which included the following:

- **What type of force detection sensor would be used?**
- **What would be the overall geometry of the finger?**
- **How would the finger to be moved in the vertical and horizontal directions?**
- **From which materials would it be produced?**

This led at first to the relatively simple cantilever design shown in figure 4.12, which was to incorporate a two Newton specific load micro-switch. These more crude concepts soon gave way to a more refined shape using the same simple adjustable micro-switch and leverage mechanism, to determine the applied force (See Figure 4.13).

Figure 4.11 Initial concept for finger mechanism wire-frame

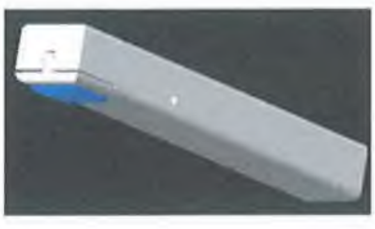


Figure 4.12 Initial concept for finger mechanism rendered solid model

However, this idea called for the design of an arrangement of components that would require either manual calibration, resulting in a fixed pressure being applied to the page, or the fitting of a motor to allow variable pressures to be applied, using the microcontroller. It was therefore decided that this approach was unsatisfactory.

Figure 4.13 Early finger concepts

It was believed that the design of a more versatile finger would offer the best chance of successfully separating pages of varying weight and thickness. This resulted in further investigation into several other suitable methods that could be used to measure force. This investigation revealed several possible approaches that could be taken.

4.4-1 Force Sensor Options

A number of options were examined, many of which were too expensive to incorporate into the product, for example low force miniature button load cells which can cost between $100 and $400 (see Figure 4.14) [67]. Due to the high cost of these devices, a proposal was then considered, which involved building a load cell. Although not completely ruled out, it was believed that a less complex solution was required at this point, which led to an investigation of Force Sensing Resistors.

Figure 4.14 Miniature button load cells **[67]**

4.4-2 Force Sensing Resistors

A preliminary examination of the Force Sensing Resistor (FSR) revealed that although they are similar in appearance to a metallic foil strain gauge (see figure 4.15-A) and they respond to external force disturbances when a current is passed through them, the similarities stop there. Due to its construction, the FSR operates differently from the strain gauge. The FSR is made using a polymer ink which acts as an insulator between the conductors (see figure 4.15-B) [68]. Therefore by applying pressure to the surface of the FSR, its conductance increases causing the output to vary in the opposite way to that of a metallic foil strain gauge (See figure 4.16).

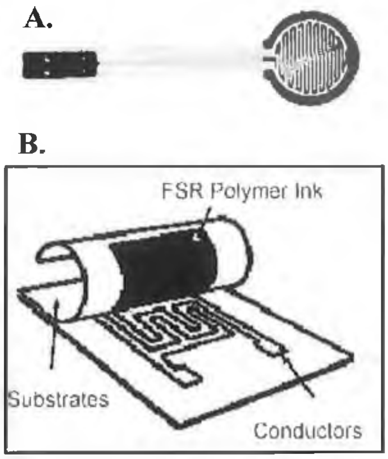


***Figure 4.15 Force Sensing Resistor* [68]**

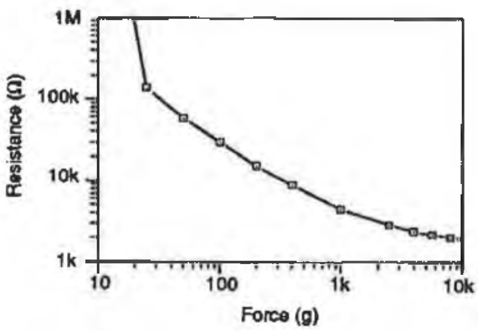


Figure 4.16 FSR output response (For interpretational convenience, a log/log format is used)

Initially it was believed that the FSR would perform well enough to incorporate it into the finger design, however further investigation into the application of the FSR, combined with experimental analysis, uncovered several problems with the suitability of these devices. Although the idea of using an FSR is relatively simple, the manufacturers recommend that the actuator's footprint should be applied at 90° to the centre of the sensor's active area and stay well within the conductive area, to avoid edges where the device's spacer material prevents proper shunting (see figure 4.17).

Figure 4.17 Fingertip concept using an FSR

To facilitate the thicker books this would require the development of an intricate (considering the length of the finger would be approximately 100mm) belt-driven linkage system, which would maintain the actuator at an angle normal to the page (See figure 4.18).

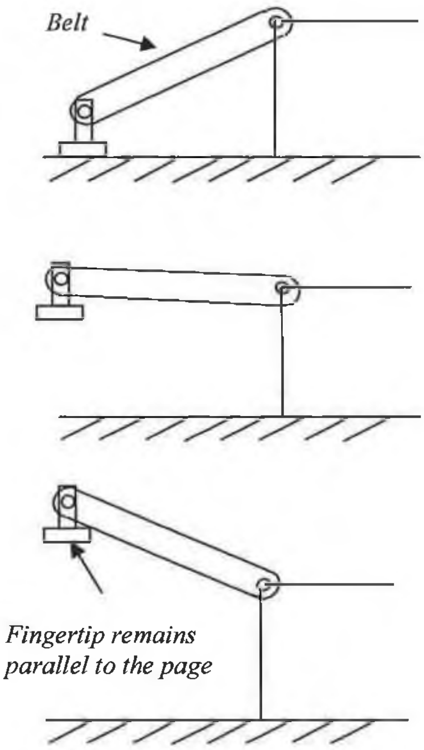


Figure 4.18 Fingertip positional correction mechanism

Furthermore an estimation of approximately 100g was made for the relatively small force required at the finger-page interface. This makes the FSR difficult to use, since the response at the lower end of its range is switch or step-like as is clear from the output response graph shown previously. This would be comparable to the on/off-like response of the specific load switch discussed previously.

Another problem with the use of the FSR is that the output repeatability is load dependent. Light loads up to 100g can exhibit repeatability tolerances of around -

35% to +90%, which improves with higher forces where typical tolerances are around ± 5%. Device to device variation can also be as much as ± 15%. [69] These sensors also suffer to some extent from the following problems:

- **Non-linearity**
- **Hysteresis**
- **Drift**

Additional research performed on these sensors revealed that several other researchers had experienced a delay in the settling time of the sensors [70]. It is believed that the use of polymer ink and the associated air hole, which allows movement of the ink in the design of these devices, results in a dynamic charge distribution, which causes this slow rise and settling time. Finally, after much analysis on this simple approach to measuring the pressure being applied to the page, it was decided that the FSR was not suitable for this application, due to its delayed reaction time, poor repeatability and step-like response at low force.

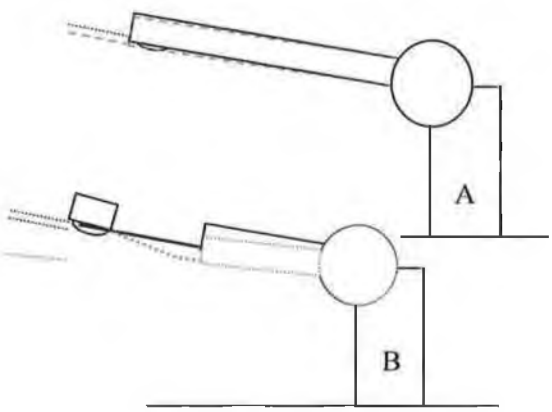


Figure 4.19 Benefits of bending beam over FSR force transducer concept

However an important factor which had been overlooked while focusing on the analysis of these devices, was that the physical distance travelled from a low to a high force for an FSR attached to a rigid beam, is very small (See Figure 4.19-A). Therefore, the sensor would need to be placed at the end of a flexible beam which would absorb some of the energy being supplied by the motion control system and by so doing, increase the resolution of the finger control system (See Figure 4.19-B). This is paramount when one considers that the pressure being applied to the page through the finger, whether moving in a vertical path or rotating around an axis as seen in figure 4.19 will be controlled by a motor. The resolution of the motor control system is fundamental to varying the applied pressure to suit as many weights of paper as possible. Therefore, in an effort to prevent the requirement of a sophisticated motion control system, it was decided to develop a system using the flexible beam approach. With this in mind, it became clear that the application of a strain gauge based transducer would be more appropriate, because beam design would be necessary whether using an FSR or a strain gauge set-up

4.5 Secondary Finger Concept

In conjunction with performing research on force sensor selection, further work had been carried out on the various other aspects of the finger design. During this analysis, it was realised that perhaps the secondary process of turning over the page could be performed using the fingers themselves. It was envisaged that the primary finger could include a secondary device or finger which would enter the buckle that had been created by the primary fingers (See Figure 4.20). It was believed though, that the size and shape of the buckle created may vary as a result of the type of paper being used.

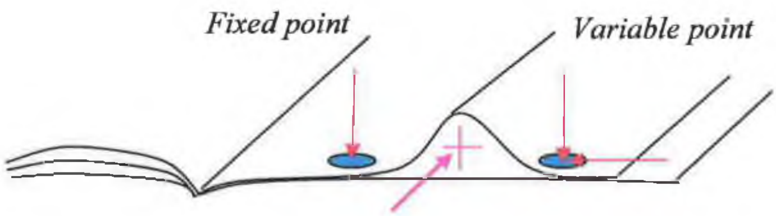


Figure 4.20 Entry point for secondary finger.

However, this variance was not seen as a problem since the distance between the two fingers as they created the buckle could be controlled, resulting in a larger or smaller opening as required. A variety of solid models were produced in order to visualize this concept of the secondary finger device (See Figure 4.21). This preliminary design was to incorporate a motor attached to the rear end of the primary finger which would control the secondary finger motion.

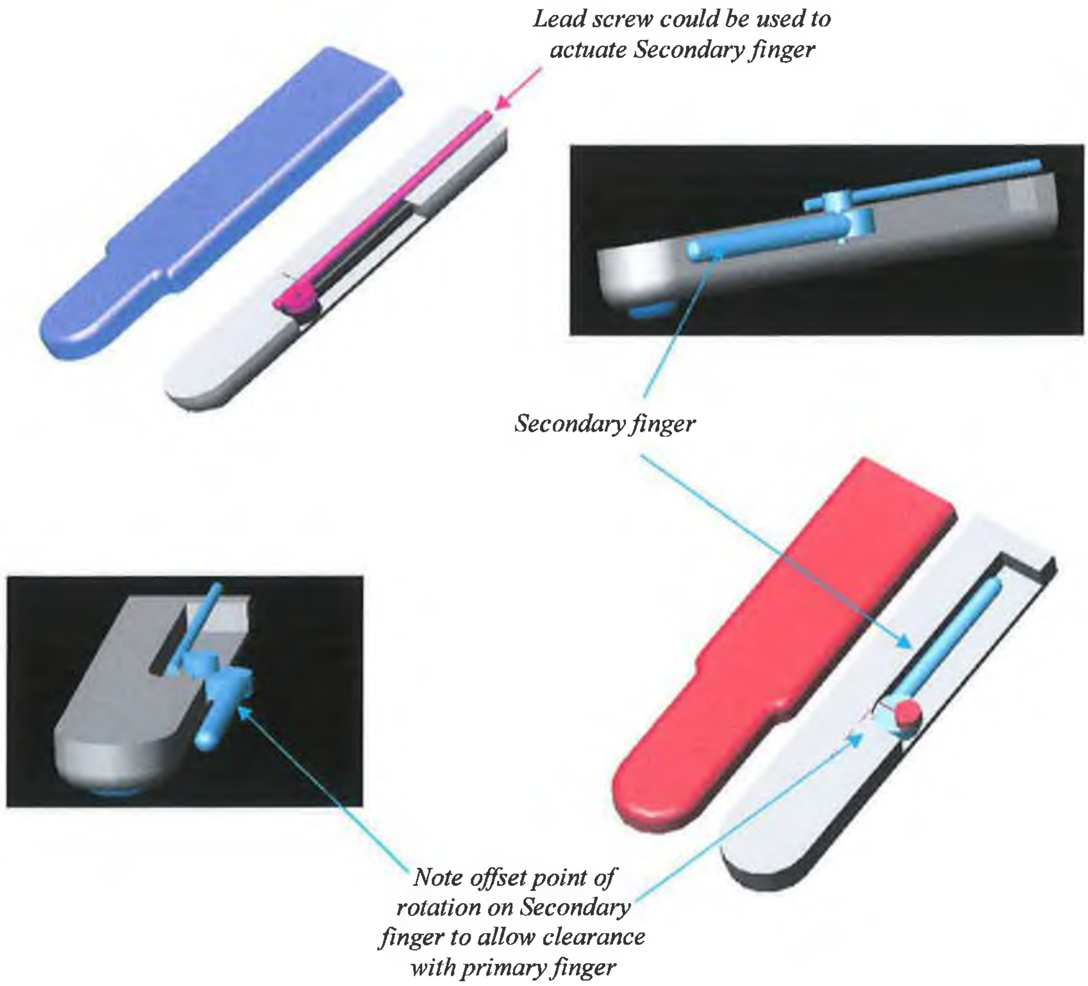
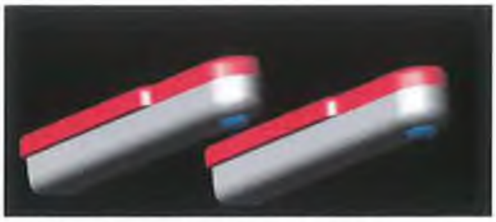


Figure 4.21 Secondary finger concepts

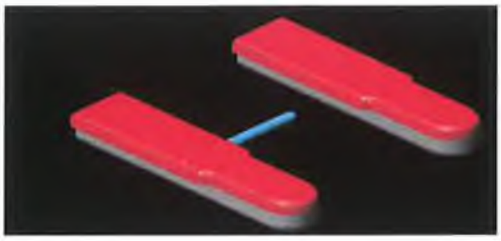
The illustrations below numbered 4.22. (A-G) indicate the sequence which the fingers should follow when turning a page.

Figure 4.22 Conceptual finger sequence during page turning operation



A. *Move fingers to required position.*

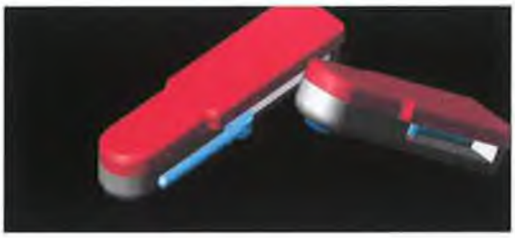
B. *Lower fingers onto page.*



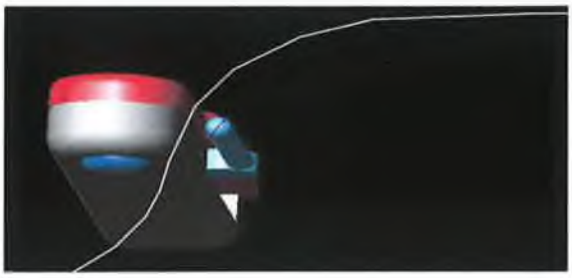
C. *Move fingers together (perhaps swing secondary fingers into position mechanically.)*

D. *move secondary finger into entry position*

E. *Notice motion of secondary finger (centre of rotation offset to allow clearance for page.)*



F. *Outside finger lifts before inside finger, to allow page to move*



G. *Primary finger moves to required position while holding the page (page represented by thin white line).*

Using this secondary finger concept, further work was carried out to bring the design forward while incorporating the bending beam force transducer (See Figure 4.23). The benefit of using the strain gauge was that a more precise measurement could be achieved with the small forces involved. It should be noted that the initial set-up and subsequent amplification of the signal from the Wheatstone Bridge required considerably more development time than when using the simpler FSR approach. Nevertheless, taking all factors into consideration, it was believed that the strain gauge method would offer a far superior, high-resolution system at a relatively low cost. This led to the design and development of the bending beam and the associated bridge and amplification circuit (this is discussed in chapters 5 & 6).

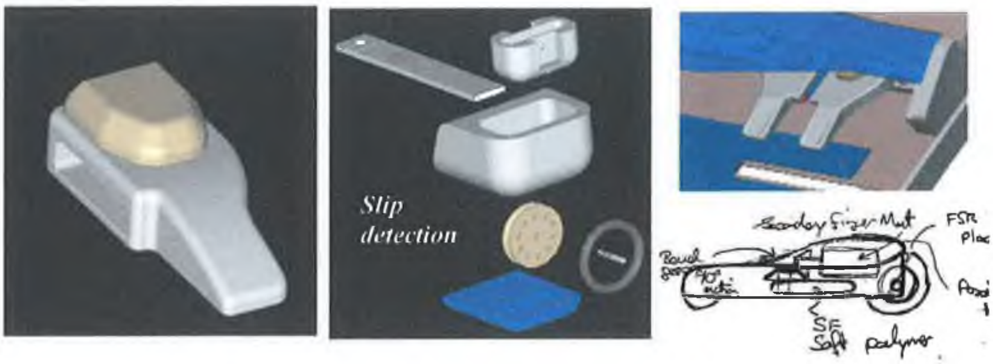


Figure 4.23 Finger concepts

4.6 Finger Movement

While further work on the secondary finger device and the motor used to drive it, was ongoing, the development of a carriage system to move the fingers vertically onto and away from the page, was also being conceptualised. This carriage would also be used to move the fingers to a specified horizontal position, which would depend on the width of the book.

Figure 4.24 Lightweight guide-rail and carriage

It was thought that perhaps the horizontal slide-way or guide could be incorporated into the baseboard, which would reduce the component numbers and the overall weight, but this required the development of a purpose-built carriage, that would run in a slotted baseboard. It was therefore decided that a lightweight aluminium guide-rail and polymer covered carriage, which was available off the shelf would be more suitable at this stage of development (See figure 4.24). Timing belts were to be used to move the primary finger motion carriage back and forth along the guide rail. Figure 4.25 illustrates a conceptual design using two timing pulleys and two encoder mechanisms which would determine the horizontal position of the carriage.

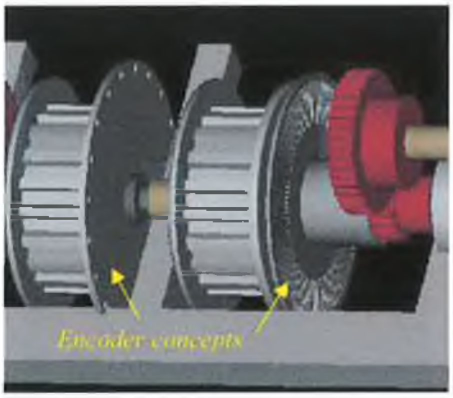


Figure 4.25 Timing pulleys and encoder concepts

4.7 Book Clamping

Fundamental to the page separation process, is the clamping of the book. If the reading material is not securely clamped to the baseboard, movement of the book will occur. This can cause the device to malfunction during the page-separation or turning process, as previously discussed. The significance of the clamping method used, is related to the page separation and turning technique, since the magnitude, direction and application of forces involved can differ greatly. The consistency of the frictional separation methods that will be used in this device rely heavily on a firm method of clamping.

Examination of previously used methods of clamping revealed that the majority of the page-turners utilize some form of spring steel 'bulldog clip' to hold the books in position (See Figure 4.26). This simple approach works well but is susceptible to loss or damage of the clamps, since they are not an integral part of the device. As such, it was felt that an important feature of the clamping mechanism was to integrate it into the overall product.

Figure 4.26 Bulldog clip

Another important aspect of the clamping mechanism was to ensure that it did not interfere with the page separation or turning process. Having selected the method of page separation and turning that would be developed further, it was clear that certain clamping options were not applicable, since they would interfere with the independently moving fingers. Initially it was thought that a spring-loaded leverage mechanism could be used (See Figure 4.27) but further development of the baseboard led to this approach being abandoned.

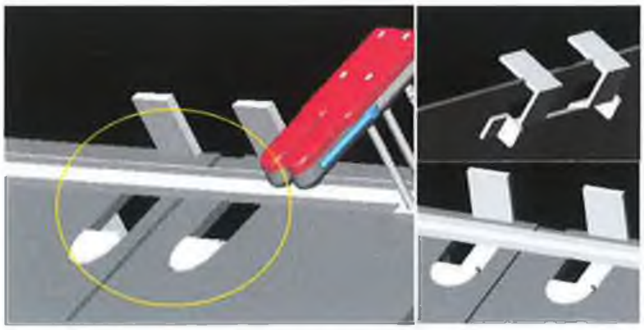
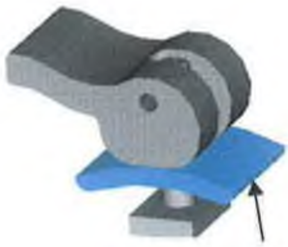


Figure 4.27 Concepts for integrated clamping



Thin layer of Dycem attached to underside

Figure 4.28 Preliminary integrated clamp design

To increase the effectiveness of the clamp, it was decided that the non-slip material: Dycem [71] should be incorporated into the clamping mechanism, since it has a very high coefficient of friction. This led initially to the design of a cam-like mechanism, which utilized a polycarbonate pre-stressed base, coated with a thin layer of Dycem (See Figure 4.28). This mechanism was to slide back and forth in a slot, cut in the baseboard, to accommodate various book widths (See Figure 4.29). This first cam-like model soon gave way to a more refined design, which continued the lines of the product (See Figure 4.30)

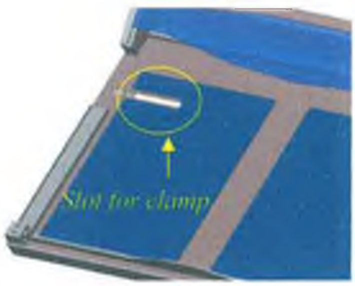


Figure 4.29 Slot to receive clamps

It was believed that the clamp could not only secure the book, but could also be used to determine the width of the book. This was to be done by connecting the lower section of one of the clamps to one end of a linkage mechanism, and the other end to a slide potentiometer. This linkage mechanism and potentiometer would be located on the under side of the baseboard.

Figure 4.30 Final integrated clamp design

4.8 Frame and Baseboard

Since the device should be as lightweight and as transportable as possible, the frame and baseboard, being the largest components, should be made from a carefully selected lightweight material. Several sheet materials were considered for their suitability. Initially it was thought that perhaps a sheet of carbon reinforced thermosetting plastic, set into an aluminium frame would be a good choice, considering its strength to weight ratio. This option proved rather expensive however and would be susceptible to fracture if dropped. Other materials examined were balsa wood, dural sheeting, bamboo board, foam backed plastics. All of these materials had some failings, whether they were too soft like balsa or too expensive like the dural sheeting. Several conceptual models of the baseboards were developed, which incorporated a variety of materials (see figure 4.32). It was finally decided that a 3mm aluminium frame could be used with a 4mm maple-finished sheet of plywood (see figure 4.33).

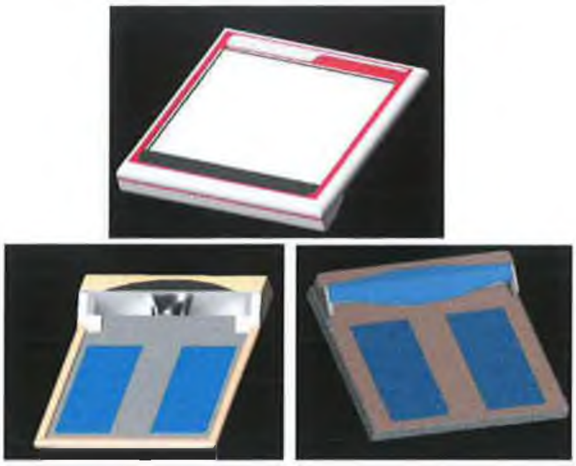


Figure 4.31 Early Baseboard concepts

Using this approach, it was estimated that the weight of the baseboard should be approximately 500g which would help to comply with the reduced weight aspect of the product design brief.

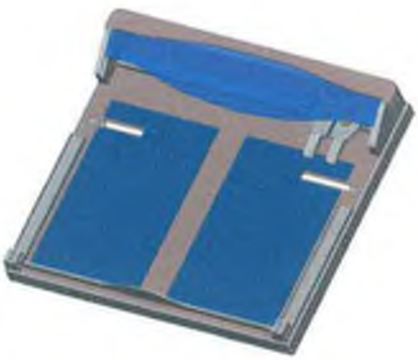


Figure 4.32 Complete Baseboard

Plywood is made from thin cross-banded veneers glued together with phenolic resin adhesive. The strength properties of plywood are dependent on the number and thickness of veneers, wood species and grain direction [72]. The board can be laser cut to any required shape very quickly, leaving only a slightly blackened edge due to the vaporisation process, which would not adversely affect the overall appearance of the product. It was envisaged that each finished board could cost as little as €10. The classic appearance of the maple-finished plywood, combined with the modern aluminium frame would blend easily into most environments and is very pleasing to the eye.

Figure 4.33 Baseboard top casing concept

In an effort to improve the shape of the baseboard, further work was performed on the frame and casings (see figure 4.33). After much refinement, the overall design involved the inclusion of more curves, rather than simply maintaining the easily manufactured straight line components that were previously conceived. The basic idea of using an integral frame and 4mm plywood platform was still maintained but the shape was different as can be seen in figure 4.34.

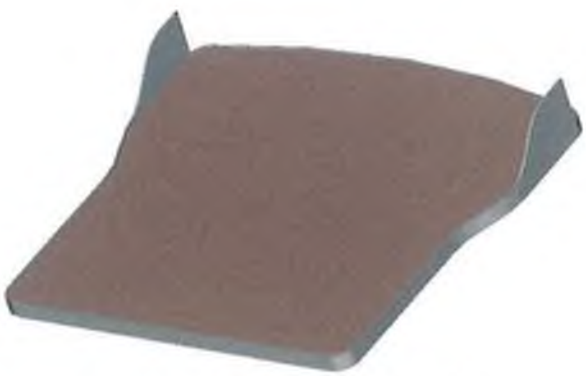


Figure 4.34 Curved Baseboard with aluminium side casings concept

The side casings posed a real challenge and it was eventually decided that 3-D printing should be used for their development. This added flexibility to the design, which could incorporate complex

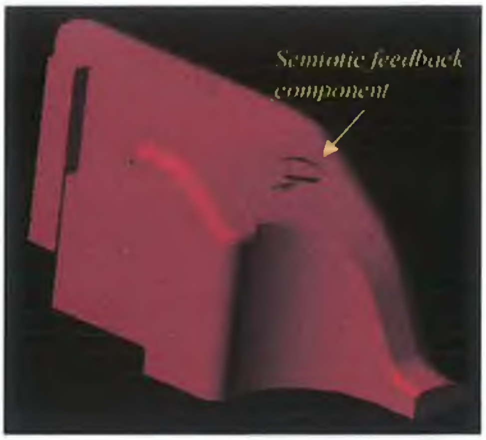


Figure 4.35 Complex shape to be procured through Rapid Prototyping

shaped components that could be produced through rapid prototyping. Using rapid prototyping, semiotic feedback could easily be incorporated into these components (see figure 4.35). The overall look of the baseboard could now take on a more professional appearance in the form of smooth lines and curves (see figure 4.36).

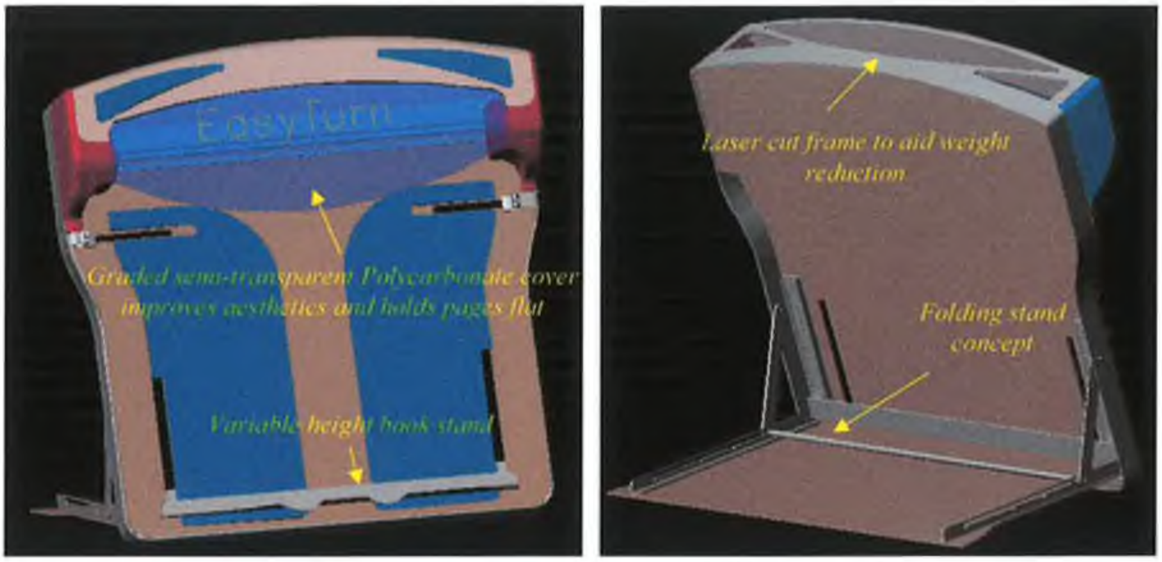


Figure 4.36 Final lightweight conceptual designs

At this point a preliminary design review (PDR) was carried out to establish how well this conceptual design fulfilled the user requirements as well as the level of compliance with the Product Design Specification (PDS). This was carried out using a weighted table (scaled 1 to 5 in increasing order of achievement) that incorporated selected headings from the PDS that were deemed appropriate to compare with the conceptual design at this stage

(See Table 4.1). This process was repeated for the three commercially available products examined previously and the results compared. (See table 4.2)

Table 4.1 Weighted performance analysis potential for new conceptual design

Specification Category	1	2	3	4	5
Functional Performance:				√	
Speed of operation:					√
Durability:		√			
Target costs:				√	
Size of product:			√		
Weight of product:				√	
Transportability:				√	
Aesthetics, Appearance and finish:					√

Table 4.2 Comparison between new conceptual design and three commercially available devices

Specification Category	New Concept	Turny	QED	GEWA
Functional Performance:	4	3	2	5
Speed of operation:	5	3	4	2
Durability:	2	4	4	3
Cost:	4	1	2	2
Size of product:	3	4	1	2
Weight of product:	4	3	1	3
Transportability:	4	3	1	2
Aesthetics, Appearance and finish:	5	4	2	2
TOTAL	35	28	20	23

The above tables indicate that the new conceptual design has the potential to outclass the available products on many of the specification categories. They also help to indicate areas of improvement, for example, the durability of the device which requires further examination and improvement. This work is explained in chapter 5.

Chapter 5. Refining Concepts - Mechanical Analysis

Examination of the identified human page-separation process revealed several fundamental aspects that needed further analysis and quantification. These elements included the nature of the feedback system used, as well as the application of the forces involved. Figure 5.1 indicates the forces involved:

- Downward applied force
- Horizontal applied force
- Coefficient of friction between the pages (paper COF)
- Coefficient of friction between the finger and the page (skin COF)

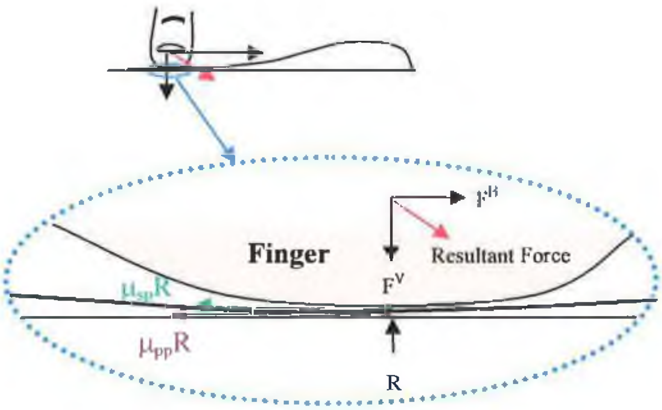


Figure 5-1Forces involved in human page-separation

By examining the system more closely, it can be seen that during a successful page separation process, the frictional force at the skin-paper interface $\mu_{sp}R$ must remain substantially higher than the same force at the paper-paper interface $\mu_{pp}R$. In order to develop an anthropomorphic system capable of mimicking this operation, primary research was carried out on the various human aspects related to this procedure, as discussed in chapter 2. The following is a description of how the forces involved were measured or approximated.

5.1 Frictional Analysis

Approximations of the frictional coefficients involved in the page separation process were made using a rig similar to that shown in figure 5.2. This apparatus is used to evaluate the static and dynamic frictional properties of sheet materials. This was performed by attaching a sheet of paper to the table and likewise applying a sheet of paper or dycem to the underside of the sled. Weights were then added to the sled and subsequently applied to the hanger which was attached to the sled by a string, which ran over a low friction pulley. As the weight on the hanger was increased and the sled just began to move, the coefficient of static friction was calculated. The Free Body Diagram in figure 5.3 shows the forces acting upon the sled used for the evaluation of the coefficient of static friction.

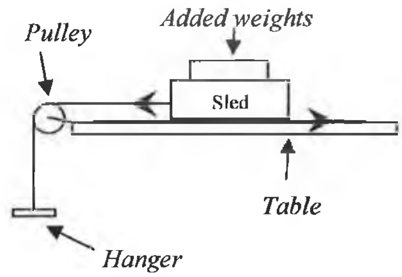
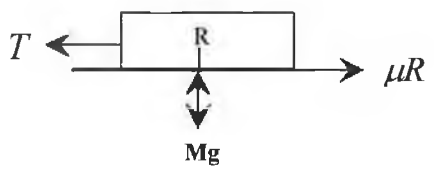


Figure 5.2 Coefficient of friction rig



Static Case

$T = \mu R \quad R = Mg$

$$\therefore \mu = T/R$$

Figure 5.3 Free body diagram of friction sled

Each friction experiment was carried out five times using a variety of paper types, which resulted in a calculated Static Coefficient of Friction ranging between 0.3 and 0.5 for the various paper types.

Performing the same experiment on dycem, with the aim of determining a suitable material to incorporate into the fingertip resulted in a Static Coefficient of Friction ranging between 1.02 and 1.25.

5.2 Vertical Force

To establish an approximation of the downward force involved in successful page separation, a simple experiment was performed using digital weighing scales. This was carried out by placing two sheets of paper onto a weighing scales and applying enough pressure to separate the pages, using one finger as a single point of contact. (See fig 5.4). This experiment was carried out on various types and thickness of paper using both dry and moist skin and a rubber thimble (see table 5.1). It can be seen from the table that the use of a rubber thimble reduced the amount of force required to separate the sheets of paper. This resulted in a downward force approximation, which was used to help specify a suitable motor, which could apply the force range attained by this experiment.

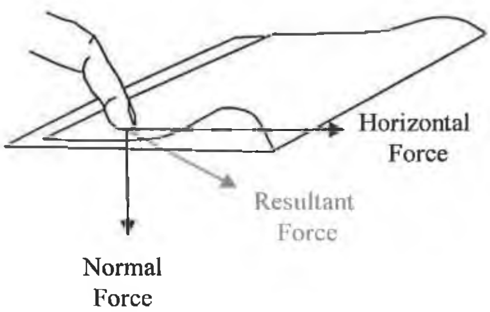


Figure 5.4 Measuring normal force

Table 5.1 Results of normal force needed to overcome static friction

Paper type	***Dry Skin***	***Moist Skin***	***Rubber thimble***
A4 sheet	1.0N	0.85N	0.8N
Light text book	0.95N	0.85N	0.8N
Heavy text book	1.25N	1.1N	1.0N
Magazine	0.95N	0.78N	0.75N

5.3 Finger Development

Since the finger dimensions would be required before the motor torque could be specified further development of the primary finger was necessary at this stage. Considering that the primary finger had to be designed to 'house' the secondary finger and the force transducer, it was necessary to examine the various aspects directly associated with these system components.

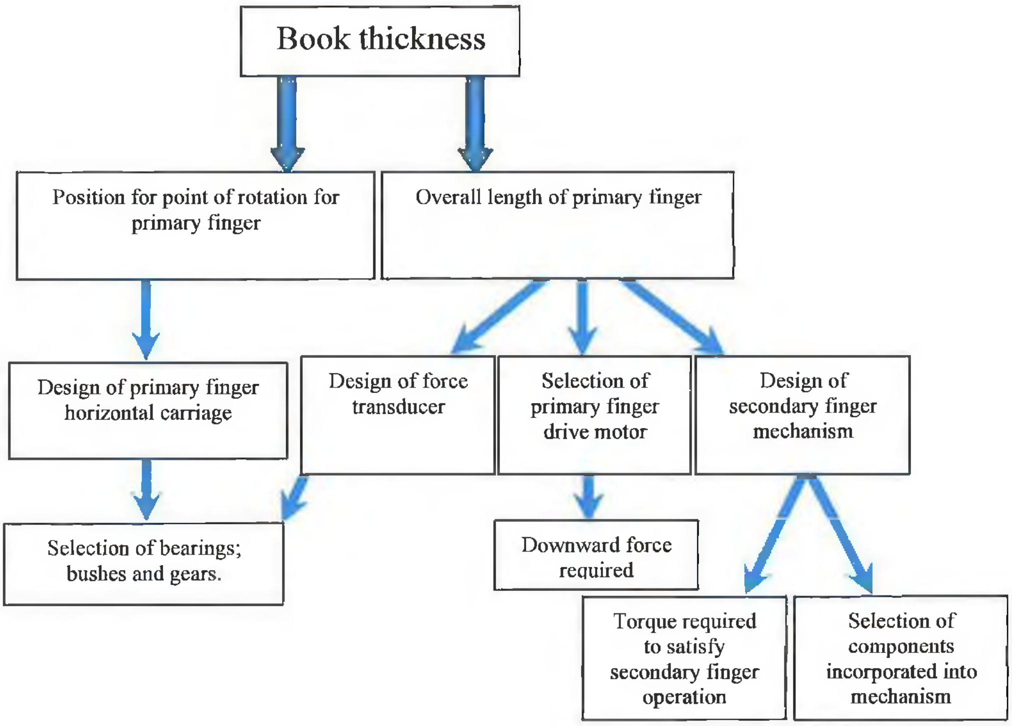
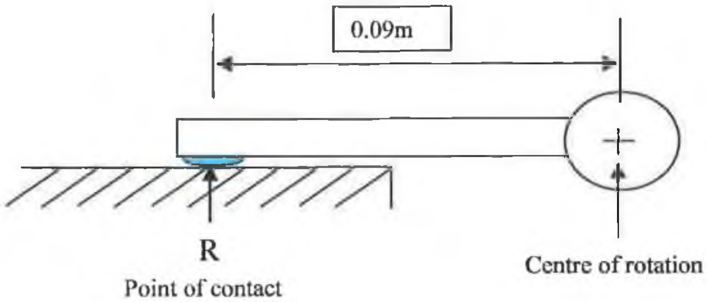


Figure 5.5 Variables pertaining to finger design

Outlined in figure 5.5 are some of the dependent variables pertaining to the system. As a starting point, an estimate of the overall length of the primary finger was made, which was based on research carried out on various dependent parameters, such as maximum book thickness, required downward force using the thimble rubber, cost and availability of different types and sizes of motors and transducer beam design. Having decided that the overall length from point of rotation to point of contact would be 90mm, a simple moments calculation determined the approximate working torque required by the primary finger motor to be approximately 90mNm. (See figure 5.6)



R = (1N) *from table 5.1*

d = 0.09m

$\Rightarrow$ **Tmax ≈ 90 mNm.**

Figure 5.6 Finger representation and torque calculation

Having decided that the device should be capable of operating with a book thickness range of 2.5 - 45mm, meant that the vertical point of rotation had to be at least 50 mm above the base board, so as to ensure proper force detection. (See figure 5.7)

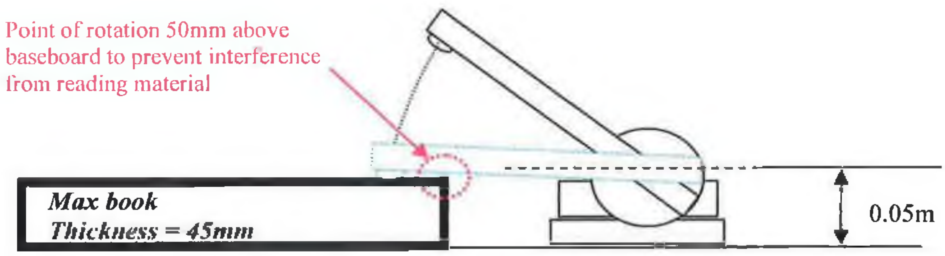


Figure 5.7 Height of centre point of rotation for primary finger

As introduced in the last chapter, the primary finger needed to operate with relatively high resolution in order to apply small increments of force, until a specified level was reached. At which point, the applied force needed to be maintained while the finger carriage moved in the horizontal direction to create the buckle in the page. In order to accomplish this, the motor needed a holding torque. Sourcing a motor which fulfilled this criterion proved more difficult than expected, however, a suitable motor was eventually sourced (see figure 5.8). The result was a 12V Stepper motor and gearbox combination, which had post gearing characteristics of 4096 steps per revolution and a pull-in torque of 49mNm [73]. This meant a further reduction in gearing was necessary to comply with the torque required by the finger (See section 5.4-1). Obtaining this motor meant, that the design of the carriage assembly, which would carry the primary finger could be finalised. It also meant that detailed analysis could be carried out on the force transducer. (The types of motor chosen, their characteristics, and associated control systems will be discussed in more detail in chapter 6.)

***Figure 5.8 Primary finger motor* [73]**

5.4 Force Transducer Design.

Cantilever beams subject to bending moments about the point of clamping are frequently used in transducer design. Using a bending beam transducer meant that some relatively straightforward analysis would suffice for beam design. The simple geometry of a beam facilitates the mounting of the strain gauges. There are many references that explain the fitting of strain gauges, which vary in their detail and appropriation to this device [74]. A thin beam results in good temperature compensation because the temperature difference between the gauges is kept to a minimum [75]. The strain in the beam was measured by fixing the strain gauges at the appropriate location on the beam and reading the difference in resistance between the gauges, as the beam began to bend (See figure 5.9). The details of the Wheatstone bridge circuit used and the amplification of the signal from the bridge will be discussed in more detail in the next chapter.

The low capacity transducer beam required the selection of a suitable material, from which it would be fabricated to allow just enough force to be applied to the page. It also required that the dimensions of the beam harmonize with the overall finger dimensions and system resolution, while operating within the limits of the strain gauges and amplification circuit. Low capacity transducers tend to use an aluminium alloy such as 2024-T8 [76]. However, the aluminium alloy used was 6060-T66, which is a more widely available alloy, which still maintains the following properties required in transducer material selection:

- Elastic material.
- Isotropic.
- Low hysteresis.
- Minimized creep under sustained load.
- High linear stress/strain characteristics.

5.4-1 Force Transducer Resolution

Since the selected motor had a resolution of approximately 4000 steps per revolution, and allowing that the overall finger length was 90mm, meant that for each step of the motor, the end of the finger moved by 0.14mm per step. The fact that the transducer beam was half the length of the primary finger (See figure 5.9) meant that the distance covered by the end of the beam was half that of the finger, which increased the resolution to 0.14 / 2 = 0.07mm per step. Furthermore, because the torque from the motor was not sufficient to drive the finger onto the page at a force of 1.0N, it was necessary to gear the finger down by a ratio of 2:1. This of course reduced the speed at which the finger operates, but also increased the resolution by an order of magnitude. It was therefore calculated that the beam would deflect by approximately 0.035mm for each step of the motor. From this analysis, the beam was designed using a maximum deflection of approximately 1.25mm, which equated to around 35 steps to apply the full force of 1.0N.

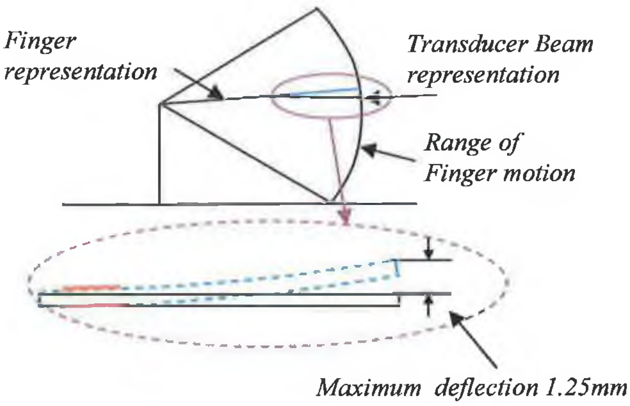


Figure 5.9 Transducer Beam deflection

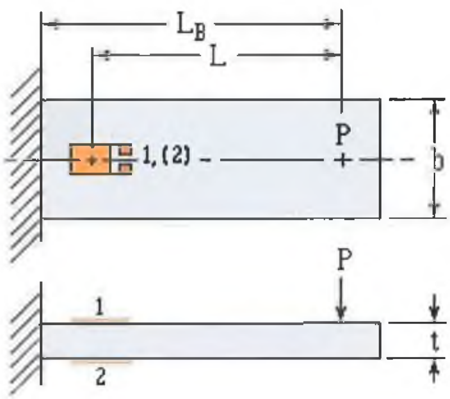


Figure 5.10 Transducer beam design parameters [77]

The beam was designed using the equations below which correspond to figure 5.10. Equation **1** represents the amount of deflection experienced by the beam and equation **2** represents the amount of bending strain. [77]

$$D = \frac{4PL_B^3}{Ebt^2}$$ **E^qn. 5.1**

$$\mu\varepsilon = \frac{6PL*10^6}{Ebt^2}$$ **E^qn. 5.2**

Where

D	=	Beam deflection	m
E	=	Young's Modulus for the elastic material	N/m^2
P	=	Magnitude of applied force	N
L_B	=	Overall length of the beam from point of force to clamped edge.	m
L	=	Distance from clamped edge to centerline of gauge	m
b	=	Width of the beam	m
t	=	Thickness of the beam	m

A spreadsheet was used to input these parameters, using the same units as above, (see table 5.2) which allowed theoretical changes to be made to the beam dimensions, while maintaining the same or similar amounts of deflection. This meant that the design of the beam could be easily altered to comply with the overall dimensions of the primary finger.

Table 5.2 Tabulated Transducer beam design parameters

L_B	0.045	**Deflection**	0.001215
t	0.00095		
E	$70*10^9$		
P	1		
b	0.005		
L	0.035	**µStrain**	664.8199

5.5 Finalising the Finger Assembly

Satisfied that the design of the force transducer could be altered to accommodate the secondary finger mechanism, when incorporated into the primary finger, it was necessary to concentrate on further development of the primary finger as a complete system. This involved firstly finalising the design of the secondary finger mechanism and the horizontal carriage which would be used to move the individual fingers back and forth across the guide rail.

Determining the torque required by the secondary finger mechanism proved rather difficult. It was not only the weight of the page, but also a page pulling action was required to reshape the buckle in the page, which would ensure correct secondary finger function. Many motors were examined in an effort to obtain a suitable motor for the task of secondary finger actuation, which eventually led to another stepper motor being selected. Parametric solid modelling was used to develop the finger, which facilitated changes being made without altering all the drawings. Many iterations of the primary finger were made in an effort to integrate the secondary finger mechanism and force transducer, while keeping the overall design as small, unobtrusive and light-weight as possible, (See figure 5.11). The finger was divided into two sections to facilitate component assembly.

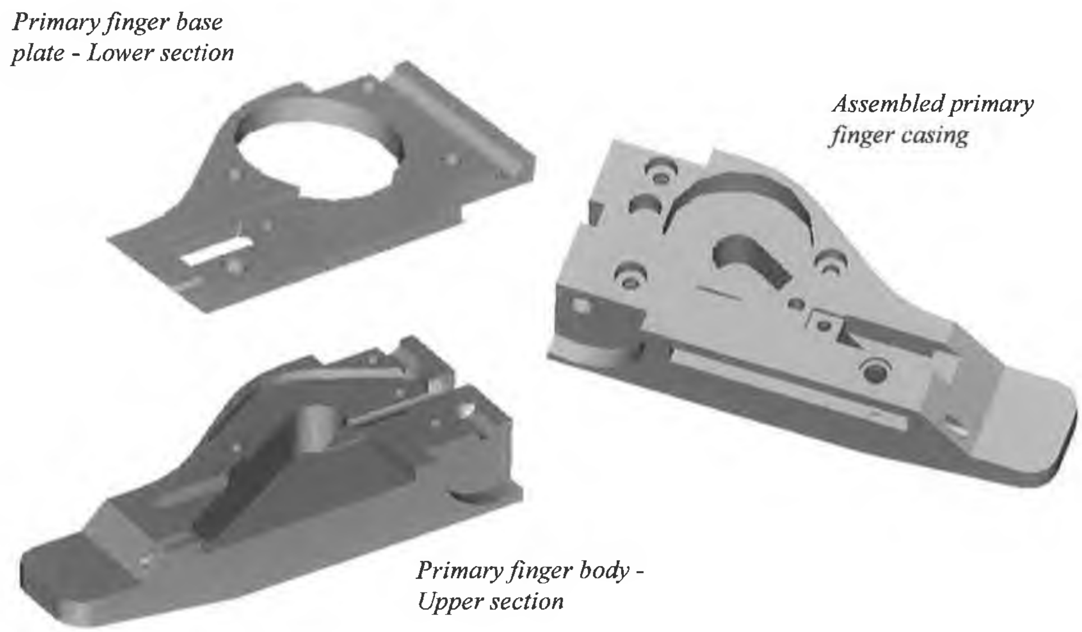


Figure 5.11 Final primary finger casing design

The procurement of many components was necessary before the final finger casing design could be completed. Eventually the secondary finger motor was incorporated into the design using a pair of timing pulleys and a timing belt. (See figure 5.13) Polymer gears and polymer push-in bushes were used in both the primary finger and the horizontal carriage, to reduce cost and weight. (See figure 5.12) Figure 5.13 illustrates an exploded view of the final finger assembly along with a table annotating the main components of the assembly.

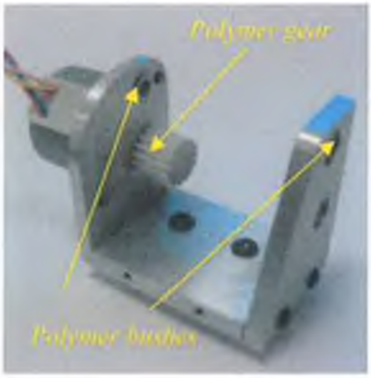
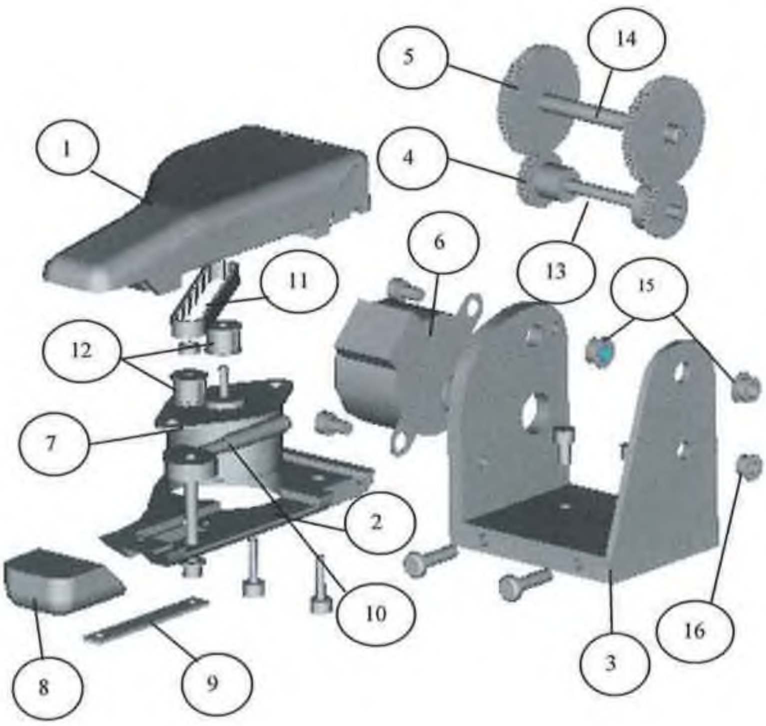


Figure 5.12 Fabricated horizontal carriage



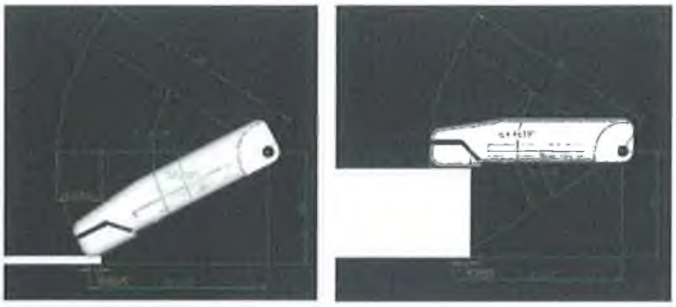
1	Primary Finger body
2	Primary Finger base plate
3	Horizontal carriage
4	Primary Finger Drive gears
5	Primary Finger Driven gears
6	Primary Finger Stepper motor
7	Secondary finger Stepper motor
8	Finger tip
9	Bending element of transducer
10	Secondary finger assembly
11	Secondary finger timing belt
12	Secondary finger timing pulleys
13	Drive shaft
14	Driven shaft
15	Driven shaft polymer bush
16	Drive shaft polymer bush

Figure 5.13 Exploded view of final primary finger assembly

As well as facilitating the iterative design process and examining the aesthetics of the device under development (See figure 5.14), the use of solid modelling software was essential for checking device functionality before the final casing drawings were sent for fabrication. This involved using the three dimensional models produced in Mechanical Desktop to examine the proposed finger positions while operating on books of varying thickness (See figure 5.15) as well as checking for any interference issues (See figure 5.16) Having examined this design in great detail, the final drawings for the main body and the base plate were submitted for fabrication.

Figure 5.14 Examination of aesthetics in 3-D software

Figure 5.15 (right) Examination of functionality in 3-D software



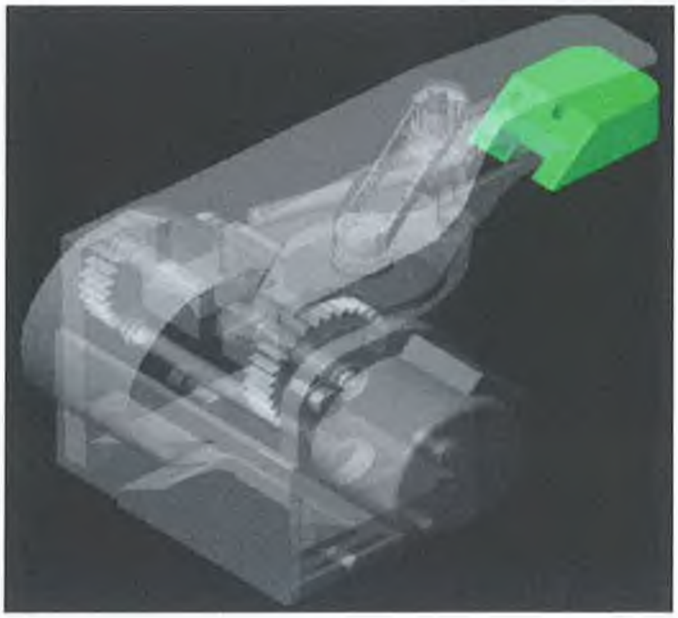


Figure 5.16 (left) 3-D model of complete assembled finger - used to check for functionality and clearance problems

5.6 Horizontal Drive System

The horizontal drive system, which included two motors, four pulleys, two timing belts and a belt tensioning system, was specified by using a combination of theoretical and empirical data. In order to approximate the torque required by the horizontal drive motors, the pulling force required by the timing belts needed to be established. A front elevation of the carriage system, which includes the forces involved, can be seen in figure 5.17. Experimental analysis was carried out to attain the frictional coefficient between the guide rail and the polymer slide, which resulted in a static coefficient of friction of 0.35. Although not yet complete, the weight of the carriage assembly was estimated at approximately 250g.

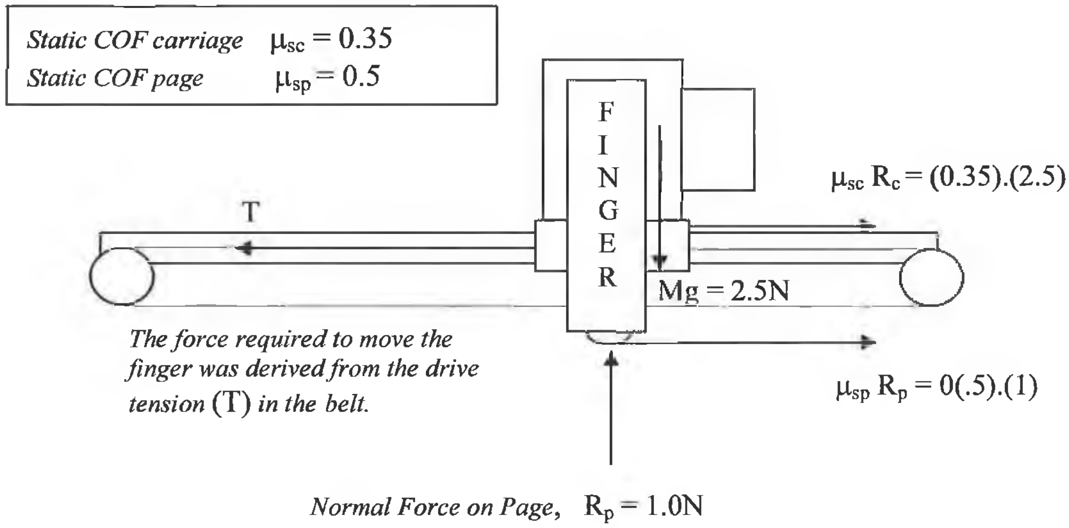


Figure 5.17 Illustration of the forces involved in the horizontal drive system

In order to estimate the tension (T) needed, to overcome the two static frictional forces $\mu_{sc}R_c$ (***the frictional force on the rail***) and $\mu_{sp}R_p$ (***the frictional force at the page***), the following calculations were performed:

$$\mathbf{T = \mu_{sp}\, R_p + \mu_{sc}\, R_c}$$

$$\mathbf{T = 0.5 * 1.0 + 0.35 * 2.5}$$

$$\mathbf{T = 1.375N} \text{ (Static case)} \qquad \mathbf{E^{qn}.\ 5.3}$$

An approximation of 1.4 Newtons was therefore considered to be the minimum force required to initiate movement of the assembly, while separating two sheets of paper. Allowing that the pitch circle diameter of the timing pulleys chosen, was 22mm, the torque required by the motor was estimated as follows:

$$\mathbf{Distance = 0.011m}$$

$$\mathbf{Force = 1.\ 375N}$$

$$\mathbf{Torque \approx 15.13\ mNm.} \qquad \mathbf{E^{qn}.\ 5.4}$$

However, this estimation omitted other forces involved, namely, the rate of acceleration at which the finger would be moved and the frictional forces in the pulley and motor shaft bearings, caused by the tensioning of the timing belt. It also failed to take account of the location of the applied force on the carriage, which, it was felt could increase the required torque considerably. It was therefore necessary to set up an assembly of several components to gain some experimental feedback. As the finished assembly was not used for this analysis, weights had to be added to a mock assembly to replicate some components not yet produced. The feedback gained through this experimental analysis, proved that the calculated values were very close to the actual required forces. However as envisaged, it was noted that due to a twisting of the carriage slide, when trying to move the carriage assembly via the end of the finger, it would not move without applying

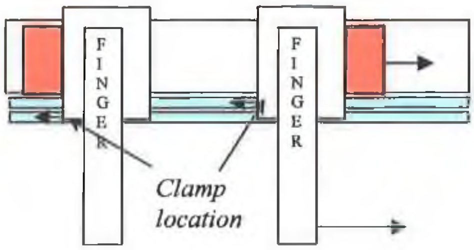


Figure 5.18 Location of belt clamping on carriage

considerable force. It was therefore imperative that the belt was located in the best position possible, which was considered to be between the two opposing forces (See figure 5.18). Although the frictional force between the pages and the frictional force experienced by the carriage, due to the weight of the assembly, were not equal, it was felt that this was the best location from which to pull the carriage so as to minimize the risk of twisting. On this basis, a 12V dc motor was selected, which was geared at a ratio of 100:1, resulting in a no-load speed of 84rpm and supplying approximately 230mNm of torque (see fig 5.19) [78]. Though difficult to precisely analyse the system without having the completed carriage assemblies, it was believed that these motors would supply more than enough torque to perform the required task sucessfully. For this reason, combined with their relatively low operational speed, it was decided that polymer gears would be used at a ratio of 2:1, to step up the motor speed. Using this information, combined with the fact that the pulley wheels used, had a PCD of 22mm, as previously stated, the following calculation was used to determine the horizontal speed of the finger carriages:

***Figure 5.19 Geared horizontal drive motor* [78]**

$$\frac{(0.022 \times \pi)(84 \times 2)}{60} = 0.195ms^{-1} \qquad \textbf{E}^{\textbf{qn}}\ \textbf{5.5}$$

Independent finger operation was one of the horizontal drive requirements, combined with correct location of the drive belt to the carriage. Therefore many concepts for motor placement were developed using the dimensions from the motor itself (See figure 5.20). The timing belt system also required some form of tensioner which led to further conceptual designs being developed (See figure 5.21)

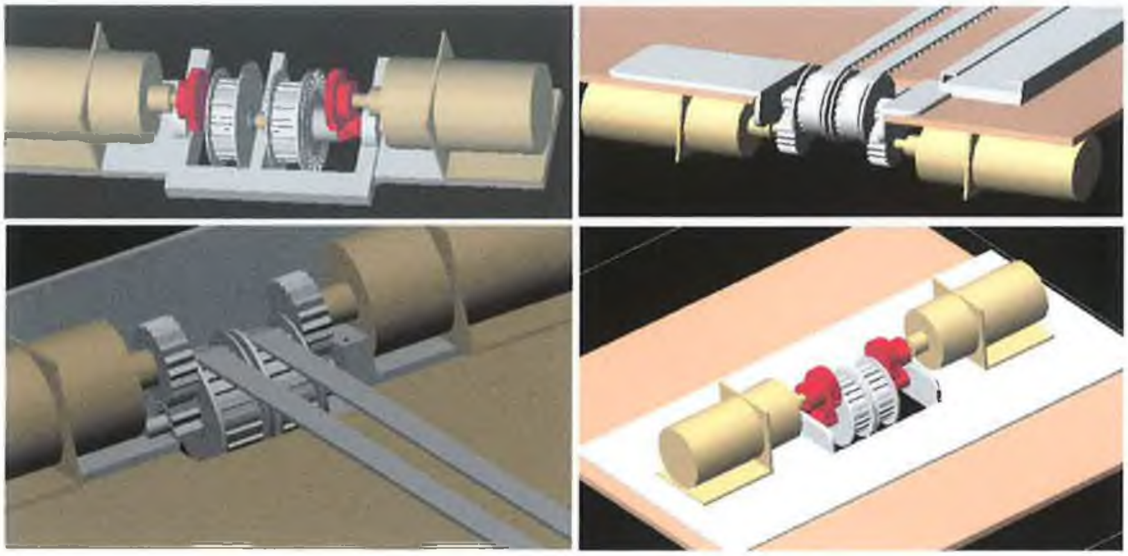


Figure 5.20 Conceptual horizontal drive system

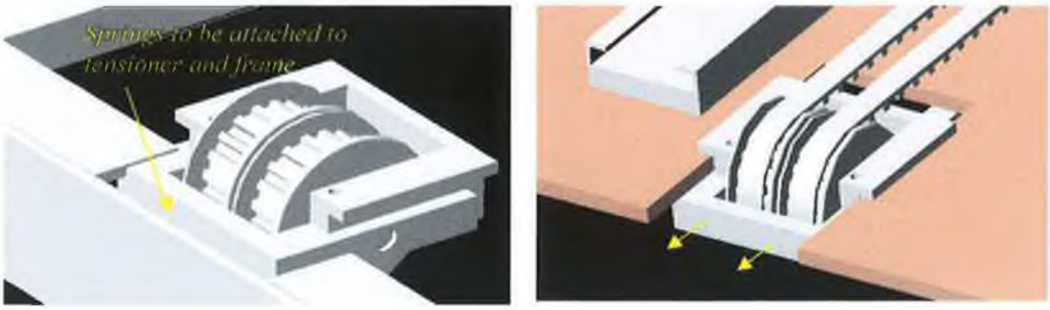


Figure 5.21 Conceptual sliding tensioning mechanism for the horizontal drive system

Having completed the fundamental mechanical design analysis and working drawings, work began on the fabrication of the various components required. While component fabriction was on going, the focus of the project turned to the control of the various assemblies that need to be automated.

Chapter 6. Electronics and Control

The fundamental initiative of an automatic page turner is that the user should be able to almost effortlessly perform the task of turning the pages of a book. Because of the many variations in book size, paper weight and finish, the two fingered approach was used to increase the flexibility of the device. This chapter illustrates the methods used in the selection and implementation of the various control components involved. Modular testing of the various elements was initially carried out using breadboards, while a number of parts were being fabricated, as discussed in Chapter 5.

6.1 Overview of Control

An integral part of the flexibility of the device involves the use of a suitable programmable microcontroller, which allows changing of variables to best fit the automated functions to be performed on a variety of book types. Figure 6.1 depicts the various elements of the page turner used to automate these functions.

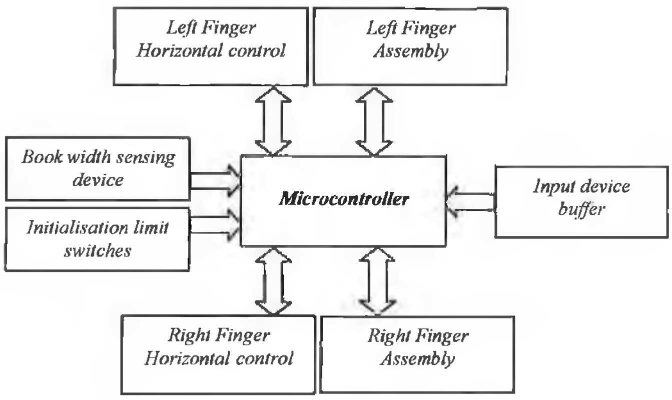


Figure 6.1 Lumped model of the elements involved in the automation of the page turner

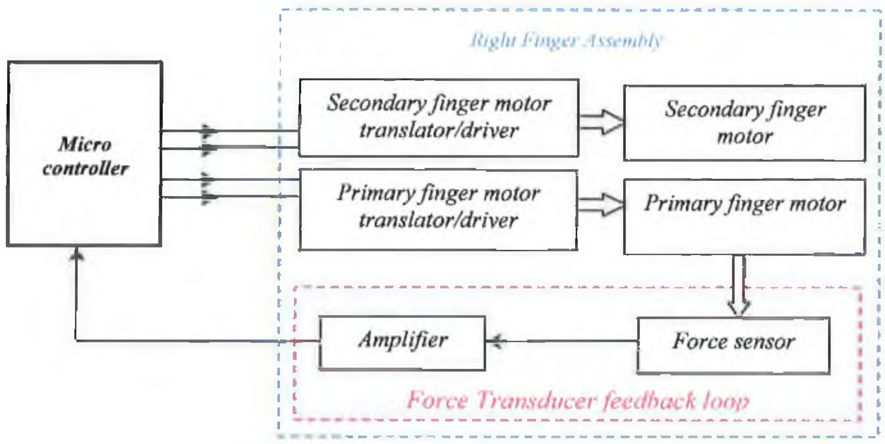


Figure 6.2 Right finger assembly components

Figure 6.2 uses the right finger assembly block taken from the lumped model above, to illustrate in greater detail, some of the components involved. Since most microcontrollers are digital devices and the output from the force transducer is analogue, some form of analogue to digital conversion was required.

6.2 Selecting a Microcontroller

The approach used in selecting a microcontroller was to source a device which incorporated on-board analogue inputs. Choosing a microcontroller without analogue inputs would have involved external circuitry, increasing the number of components needed and adding to the risk of connection failure. This led to an examination of the characteristics of several microcontrollers, with a view to controlling the various elements. Below is a list of some of the factors which were considered during the microcontroller selection process.

- Number of I/O pins
- Analogue inputs (resolution of A/D converter)
- Program storage (Volatile or not)

- Amount of RAM
- Programming language
- External interface compatibility (TTL,CMOS)
- Processor speed
- Multitasking capabilities
- Cost

Numerous documents were sourced which made comparisons between several of the currently available microcontrollers. After examining these comparison tables (See Appendix B) and reading the associated literature, a decision was made to use the BX24 microcontroller from Netmedia (see figure 6.3) [79] This microcontroller comes with 32kb EEPROM for program storage (8000 lines of code), 400 Bytes of Ram for Variable storage, 21 I/O lines, 8 of which can be used as 10 bit A/D or D/A inputs. All outputs are TTL and CMOS compatible. The programming language used is Basic, which was easily acquired. 65,000 lines of code a second can be processed. A powerful feature of BX-24 is its ability to multitask, which allows complex programs to be simplified by dividing them into smaller, more manageable pieces. Obviously there are some limitations; timesharing the processor adds a certain amount of overhead that can slow down a program. However, at a cost of $40, this was considered to be the most suitable microcontroller for the page-turner.

Figure 6.3 BX-24 Microcontroller **[79]**

6.3 Motor Selection

Since the page-turner would be powered either from wheelchair batteries or from a mains dc adapter, the types of motors that were chosen were limited to dc motors. The three motors selected were two stepper motors for the primary and secondary finger operations and a dc motor for the horizontal drive. These motors were chosen, based on size, weight and their ability to fulfill the fundamental characteristic requirements of their operation, as discussed in Chapter 5. However, before the appropriate motors were selected, other motor types were examined, with a view to sourcing the least expensive configuration, which would fulfill the outlined requirements. These were dc motors, dc Servo motors and Stepper motors. Initial research revealed that the cheapest of the three types, were the dc motors, followed by the stepper motors. It also became clear that sourcing small, inexpensive motors which possessed the required torque would be a considerable challenge. It was soon realized that that to develop the levels of torque required, some form of gearing would be essential in an effort to keep the motors as small as possible. This led to the examination of many separate motor and gearbox configurations, as well as several combined motor/gearbox drives. The separate gearbox option proved to be a more expensive solution, which resulted in two of the three selected motors being integrated motor/gearbox combinations.

Before these motors were selected some additional analysis was carried out, which included examination of the fundamental motor characteristics and a review of their respective motor control techniques.

6.3-1 DC Motor Characteristics

DC motors are best characterized by their smooth motion and ability to operate at relatively high speeds. They are suitable for precise motion applications; however this requires the use of a closed loop control system, which involves feedback from a motor shaft or positional encoder. The torque–speed characteristics of dc motors are primarily dependent on how the motor is wound. Figure 6.4 illustrates the torque-speed characteristics for the selected horizontal drive motor. Because a dc motor is self commutating, once its windings are energized the motor begins to rotate, quickly picking up momentum. After the windings are de-energized the momentum will gradually wear off due to friction, resulting in a gradual reduction in speed, until eventually the motor stops.

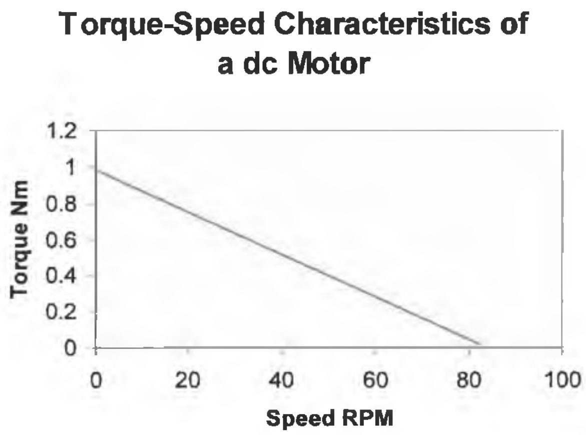


Figure 6.4 Torque-Speed characteristics for the selected geared dc motor

However, the horizontal drive dc motors that were selected to drive the finger carriage back and forth, needed to be capable of an abrupt stop, whereby, the motor could turn a specified amount and then stop very quickly at a predetermined point. This was achieved by electrical braking, which is carried out by reversing the direction of the motor. This is discussed in more detail in section 6.3-6.

6.3-2 Stepper Motor Characteristics

There are two fundamental differences between dc and stepper motors. The first is that, stepper motors have no brushes and as such are categorised as multi-pole brushless dc motors, which require external commutation. The second difference is that rotation speed of a stepper motor is independent of load, provided it has sufficient torque to overcome slipping and the speed remains below the maximum slew rate (see figure 6.5) [80]. The maximum start rate for a stepper motor is normally 600-700 pulses per second, which limits the speed of rotation. If the sequencing is faster than the rotor can move, the rotor will slip until sequencing is slowed enough for the rotor to again lock-in to the sequence. Stepper motors also have another characteristic, holding torque, which is not present in dc motors.

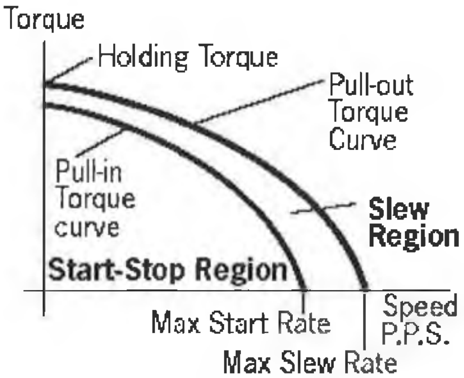


Figure 6.5 Torque-Speed characteristics for a stepper motor **[80]**

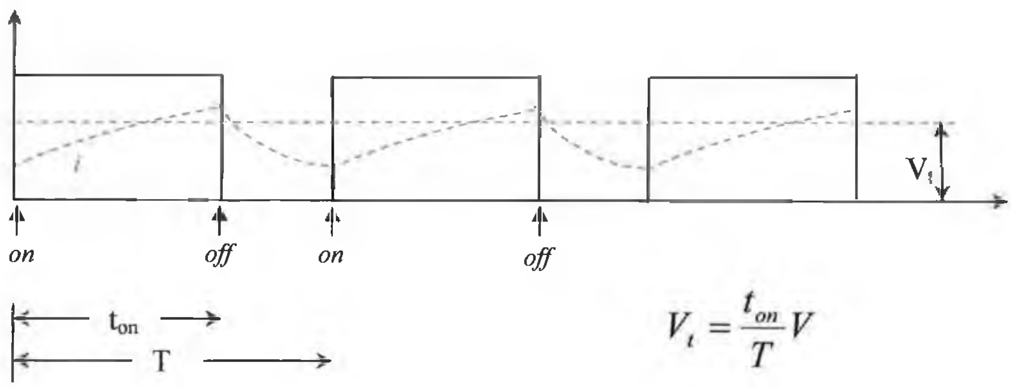
This allows a stepper motor to hold its position firmly when not turning, which can be useful for applications where the motor may be starting and stopping, while the force acting against the motor remains present. Because stepper motors rotate a specific number of degrees in response to an input electrical pulse, they are well suited to digital control. Stepper motors can be driven using open loop control systems, however if a stepper motor in an open-loop control system is over-torqued, all knowledge of rotor position is lost and the system must be reinitialized. For this reason, stepper motors are usually selected to run with a torque safety margin.

6.4 Motor Drivers & Control

The current that drives a dc or stepper motor typically comes from a power device, known as an amplifier or driver. Power drivers are normally located between the motion controller and the motor. The power driver takes the control signals generated by the motion controller, which are normally only a few milliamps and converts them into larger current power signals sufficient to drive the motors. Initially, some experimental analysis was performed, whereby each motor type was driven using a combination of discrete components and a series of Darlington transistors. However, further research carried out on methods of motion control revealed more specific drivers were available for each motor type.

6.4-1 DC Motor Drivers & Control

Several experiments were performed using discrete components to form a full H-Bridge driver, which required the use of four control lines from the microcontroller. This approach meant the motor could be driven in both directions and could also be stopped suddenly, using electrical braking. This led to the acquisition of a dedicated 16 pin quadruple high-current half-H driver, which is designed to provide bidirectional drive currents of up to 600-mA at voltages from 4.5 V to 36 V. The L293D from Texas Instruments [81] formed the basis of the horizontal drive for both dc motors. Each output is a complete totem-pole drive circuit, with a Darlington transistor sink and a pseudo-Darlington source. Using this driver meant that only two control lines were required from the microcontroller, for each of the dc motors, instead of the four lines previously used. Since a DC motor acts like an inductor, a large back emf is generated during switching. Therefore high-speed output clamp (flyback) diodes were used for inductive transient suppression. This was very important considering that the speed of the dc motors was controlled using a chopper (buck converter) technique, as seen in figure 6.7. This technique converts a fixed voltage dc supply to a variable voltage dc supply [82].



$$V_t = \frac{t_{on}}{T} V$$

Figure 6.6 Chopper motor control **[82]**

As the steps and the intervals between them become smaller, the average current demand of the motor increases. This is because the motor is operated at its maximum torque condition every time it starts to rotate and every time it is reversed for electrical braking. At low frequencies the motor speed tends to be jerky and the 12v "kicks" are audible, at high frequencies the motor's inductance becomes significant and power is lost, as a result the motors were run between frequencies of 30-200Hz.

6.4-2 Stepper Motor Translator/Drivers & Directional Control

Both of the selected stepper motors were pressed case (tin can), permanent magnet unipolar driven motors. Because stepper motors require external commutation an additional component called a translator was needed (See figure 6.7). The translator is a sequential logic device, used to energize the windings in the correct sequence, before the motor's shaft will rotate. Reversing the order of the sequence causes the motor to rotate in the opposite direction.

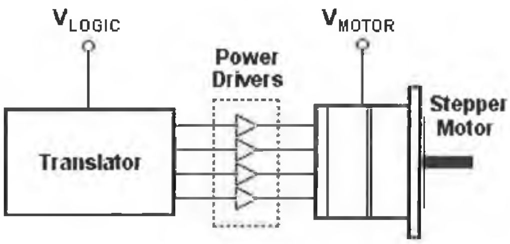


Figure 6.7 Stepper motor translator and driver

If the motor windings are not energized in the correct order, the motor will not turn, but instead it may simply buzz and not move, or it may actually turn, but in a rough or jerky manner. Once again, several experiments were performed using a variety of discrete components, before sourcing an integrated translator/driver. The UCN5804B from Allegro [83] is a dedicated translator/driver which combines low-power CMOS logic with high-current and high-voltage bipolar outputs. This device provides complete control and drive for a four-phase unipolar stepper-motor with continuous output current ratings of up to

1.25A per phase (1.5A start-up) and 35V. The Two-phase drive format was used for both motor applications since this method energizes two adjacent phases in each position, which offers an improved torque-speed product, greater pull-in torque, and is less susceptible to motor resonance.

Both of the stepper motors were driven using open loop control, however the dc motors required positional feedback from an encoder. This led to the examination of a number of encoder options in an effort to obtain a suitable device for the horizontal drive system.

6.4-3 Positional Encoder Development

Purchasing encoders off the shelf can be expensive, combined with size limitations and mechanical design implementation as illustrated in Chapter 4, this approach was considered inappropriate for the page-turner. Therefore it was necessary to develop a suitable positional encoder in order to achieve the various desired horizontal positions of the finger carriage. The positions would be defined by the width of the book being read, which in turn was to be determined by a slide potentiometer, as discussed in Chapter 4.

A positional incremental encoding system was developed using a reflective object sensor, which consisted of an infrared emitting diode and a phototransistor mounted side by side on converging optical axes in a plastic housing (see figure 6.8a). The model chosen also contained a visible-light filter to eliminate spurious signals caused by ambient lighting conditions. The reflective surface was a strip of printed lines which were attached to the slide way (see figure 6.8b).

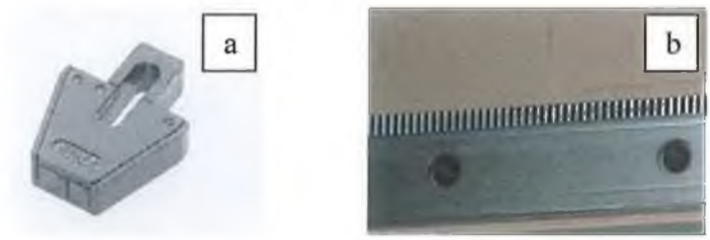


Figure 6.8 a).Reflective photo sensor b). Printed encoder strip

The signal from this sensor could have been input directly to the microcontroller and subsequently processed using a software comparator to define the counting sequence. However, this would have involved an increase in the number of variables already being stored in the limited RAM of the microcontroller, in addition to putting further demand on the processor. The alternative approach was to implement a hardware comparator, which transmitted a square wave digital signal to the microcontroller which speeded up the counting process. The analog signal from the phototransistor can however contain noise from many sources, which is invariably superimposed on the otherwise clean signal. This has the effect of producing multiple output transitions, or bounces, as the input signal crosses the threshold region. (See figure 6.9a).

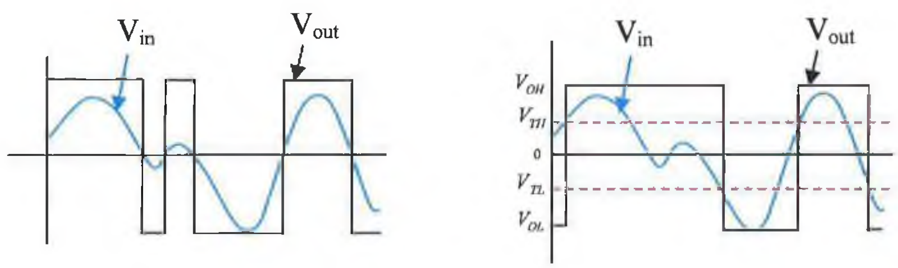


***Figure 6.9 a). Comparator 'Chatter' b). Output with threshold* [84]**

This output 'bounce' is referred to as comparator chatter which is undesirable in counter based applications. However this bounce can for the most part be eliminated through the use of a threshold detector with hysteresis (see figure 6.9b) [84]. The following single-supply non-inverting Schmitt trigger circuit can be used to diminish this phenomenon. (See figure 6.9).

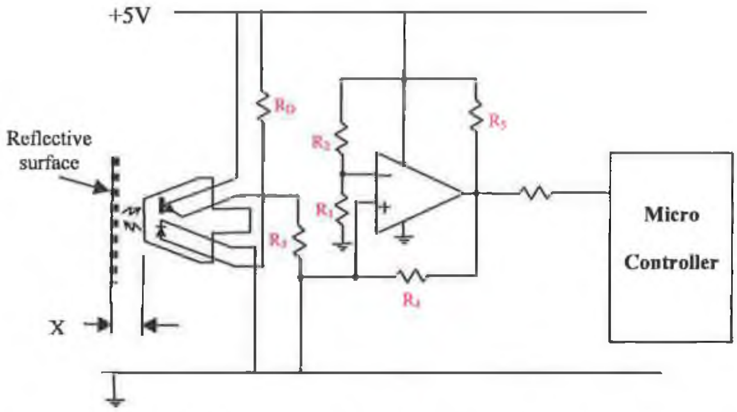


Figure 6.10 Single-supply non-inverting Schmitt trigger

6.5 Strain Gauges and the Wheatstone Bridge

Having designed the force transducer beam, the resistive strain gauges were attached using cyanoacrylate adhesive [85]. The strain gauges used were the bonded metallic type and had a nominal resistance of 120Ω (See figure 6.11) [83]. Resistive strain gauges measure the strain in the bending element (in this case a beam) as discussed in chapter 5. Strain is defined as the ratio between the change in length to the original length of a body.

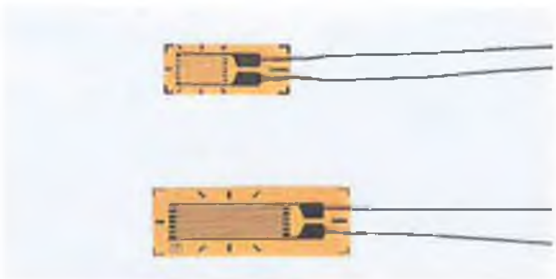


***Figure 6.11 Metallic foil strain gauges used* [85]**

$$\varepsilon = \frac{\Delta L}{L} \qquad \textbf{E}^{\textbf{qn}}\ \textbf{6.1}$$

In a strain gauge based transducer the strain gauges will undergo a small change in gauge length, which is directly proportional to the change in length of the parent material. This results in a very small change in cross sectional area of the gauge which in turn results in a minute change in gauge resistance.

A fundamental parameter of the strain gauge is its sensitivity to strain, expressed quantitatively as the gauge factor (GF). This is the ratio of fractional change in resistance to the fractional change in length (strain).

$$GF = \frac{\Delta R / R}{\Delta L / L} \quad \text{or} \quad GF = \frac{\Delta R / R}{\varepsilon} \qquad \text{E}^{\text{qn}}\ 6.2$$

The gauge factor for the gauges used in the finger transducer was 2, which is a common value for metallic strain gauges. Because the measured strain in metallic transducers is very rarely larger than a few millstrain ($m\varepsilon$), strain is often expressed as microstrain $\mu\varepsilon$ ($\varepsilon \times 10^{-6}$). This relates to changes in resistance that are so small that strain gauges are commonly wired using a Wheatstone Bridge.

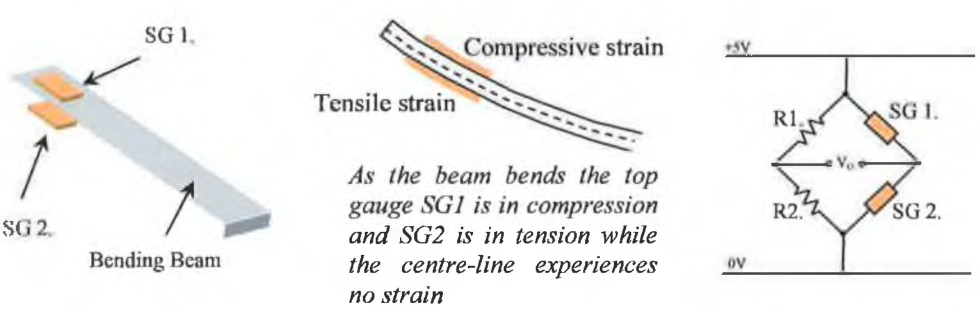


Figure 6.12 Half Wheatstone Bridge configuration

The half bridge configuration which was implemented for the finger transducer uses two gauges in adjacent arms of the bridge. One gauge is secured on top of the beam and the other is placed directly opposing it on the underside of the beam as seen in Figure 6.12. Using this approach, the two gauges measure bending strains that are of equal magnitudes but of opposite signs, since one gauge will be in tension while the other is in compression. The half bridge configuration results in a differential voltage which is double that of a quarter bridge set-up, which uses a single gauge. Furthermore, any resistance changes in the gauges resulting from strains produced by axial loads will be cancelled because the two active gauges are in adjacent arms of the Wheatstone bridge. Likewise, resistance changes of thermal origins can be negated, since both gauges experience the same changes in temperature.

The output voltage from the bridge (V_o) is directly related to the imbalance between resistances in each arm of the bridge and the bridge excitation voltage. This is referred to as bridge sensitivity and is normally expressed as millivolts of output voltage per volt of applied excitation (mV/V). Using the beam design parameters from table 5.2, it can be seen that at full scale deflection of 1.2mm, a strain of approximately $670\,\mu\varepsilon$ should be produced. Putting this value and the gauge factor into the equation below, the bridge sensitivity was calculated to be 0.67mV/V.

$$\frac{V_o}{V} = \frac{F\varepsilon \times 10^{-3}}{2} = \frac{3FPL \times 10^{3}}{Ebt^{2}} \qquad \textbf{E}^{\textbf{qn}}\ \textbf{6.2}$$

Where,

ε	= strain, in $\mu\varepsilon$ units
E	= elastic modulus of the spring material
F	= gage factor of the strain gages
V_o / V	= bridge output, mV/V

Considering that the bridge was excited by a +5V supply, this resulted in a full scale bridge output voltage of ± 3.4 mV. However, because the beam will only be deflected in one direction, the ideal output range, disregarding external disturbances should be 0 to 3.4 mV, which should ideally be linearly proportional to a load of 0 – 1.0N.

As discussed earlier the BX24 microcontroller contains 8 pins which can be used as 10 bit Analogue to Digital Converters (ADC). Therefore when operating within the microcontrollers 0 – 5V range, these 10 bit ADC inputs have a resolution of approximately 5mV. Due to the very small differential voltage signal from the bridge, it needed to be amplified before being input to the microcontroller.

6.6 Bridge Amplification

A preliminary search for strain gauge amplifiers revealed that several specific devices were readily available, the least expensive of which costing approximately seventy euro. In an effort to reduce costs, an instrumentation amplifier could have been built using operational amplifiers. However it was soon realized that there were a number of instrument amplifiers (in-amps) available, of monolithic construction, which delivered twice the accuracy of a two op-amp in-amp. One such device is the AD623 from Analog

Devices, which costs less than buying two op amps, performs better and is a smaller package [87]. It was therefore decided that building an amplifier was totally impractical, considering the availability and cost of these instrument amplifiers, which are specifically produced for the purpose of amplifying differential signals.

Differential measurements are the difference between two test points. However when each of the bridge outputs was referred to ground, the two voltages were equal to approximately 2.5 V as seen in figure 6.13. This voltage, which is common to both inputs, is called the common mode voltage of the differential signal and contains no useful information about the required measurement. The ability of the in-amp to reject these common mode signals is related to the frequency at which the signal is sampled and is referred to as the Common Mode Rejection Ratio (CMRR) [88]. In practice however, common mode signals will never be completely rejected by an in-amp, therefore some remnant of the common mode signal always appears at the output.

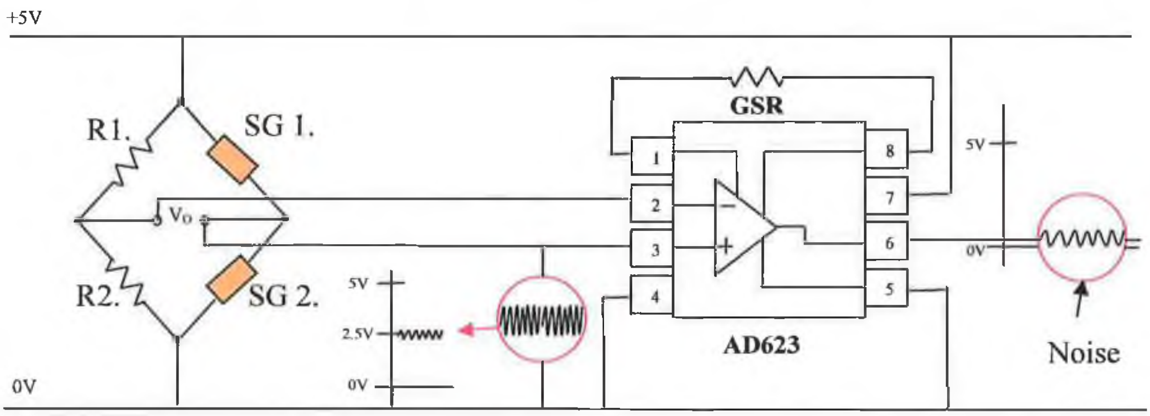


Figure 6.13 Half Wheatstone Bridge and AD 623 instrument amplifier configuration

Because of the small amount of deflection resulting in a rather small strain measurement, the system was setup as shown in figure 6.13 using a 100Ω gain setting resistor (GSR) which equates to a gain of 1000 and therefore 3.4V output from equation 6.2.

Verification of these theoretical values was made by assembling a number of components to replicate the final finger design. After attaching the strain gauges, a beam was secured to a piece of aluminium which represented the finger body as seen in figure 6.14. The stepper motor was used to drive the finger directly and the data signal from the amplifier was captured to a file on the PC through the microcontroller. Since the mock finger was driven without the 2:1 step down gears, the output from this set-up was not the same as the finished finger. Several tests were carried out to examine how well this imitation of the real system matched the theoretical calculations made previously.

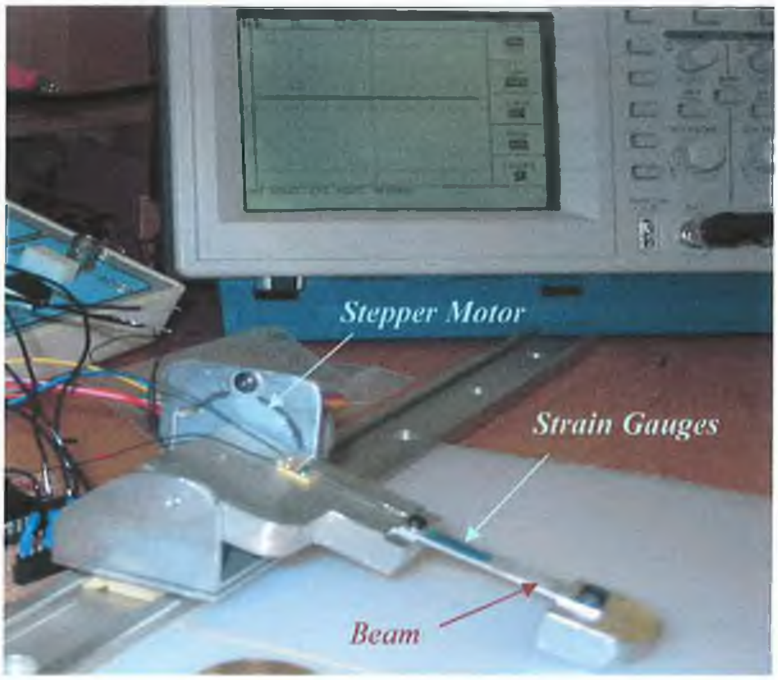


Figure 6.14 System mock-up of finger, used to test transducer beam design parameters

Initially there were some problems with noise in the system, which was caused by the use of a common ground (See figure 6.15), but this was later corrected by using a ground reference pin from the microcontroller, which reduced the noise considerably.

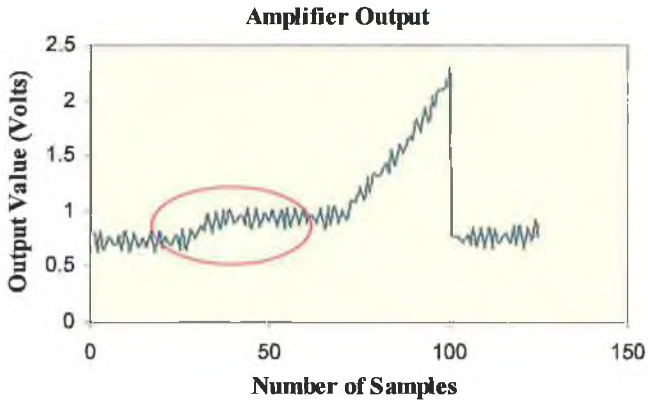


Figure 6.15 Amplifier output showing noise in the system

The highlighted bumps in both figure 6.15 and figure 6.16 were caused by play in the system, which resulted in a number of steps being required to take up the slack, while there was no change in the amplifiers output.

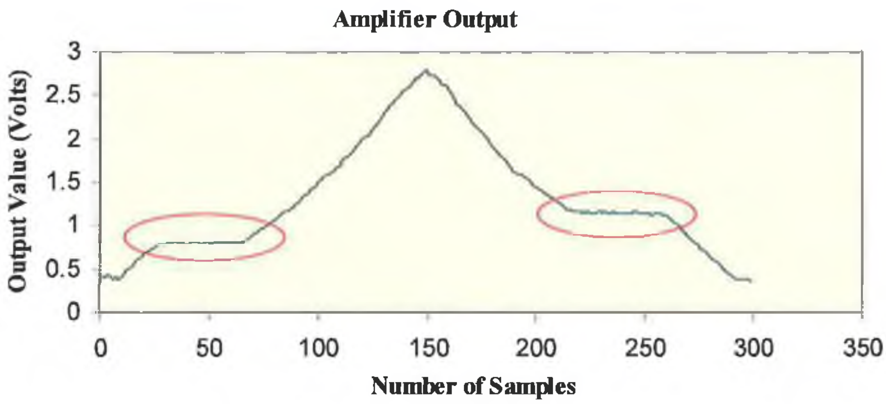


Figure 6.16 Amplifier output showing play in the system

This testing proved that the system worked well, but further testing and analysis would be required on the real finger after it was assembled, as discussed in Chapter 7.

Chapter 7. Assembly and Testing

Having obtained most of the required components and performed modular testing of the different control circuits and mechanisms, the process of assembly began. This chapter gives an account (primarily through illustration), of some of the problems that were encountered during the assembly of several elements of the device. It emphasises the iterative nature of design through a variety of tests and design alterations, which were performed during the assembly process. This is followed by an explanation of the final testing which was carried out on the functioning engineering model which also includes a series of illustrations.

7.1 Finger Assembly

Initially a focus was put on the assembly of the mechanical aspects of the two fingers. This started with the drilling and tapping of the driven gears, which were fixed to small aluminium shafts. These shafts would eventually be clamped between the finger body and base-plate. A focus was then put on the fixing of the bending beam transducer element and associated wiring connections. Because of the small size of the fingers, as is clear by comparing the fifty cent coin seen in figure 7.1, organising the Strain Gauge Bridge and soldering on the leads was quite tedious, due to the intricate nature of this aspect of the device (See figure 7.2). Gradually the various other elements of the fingers were installed, while carefully checking for smooth motion and accurate fit where necessary.

Figure 7.1 Illustration of finger size

The use of polymer push-in bushes facilitated the assembly process, however, after installing the secondary finger mechanism, it was noticed that the finger was not turning as freely as expected.

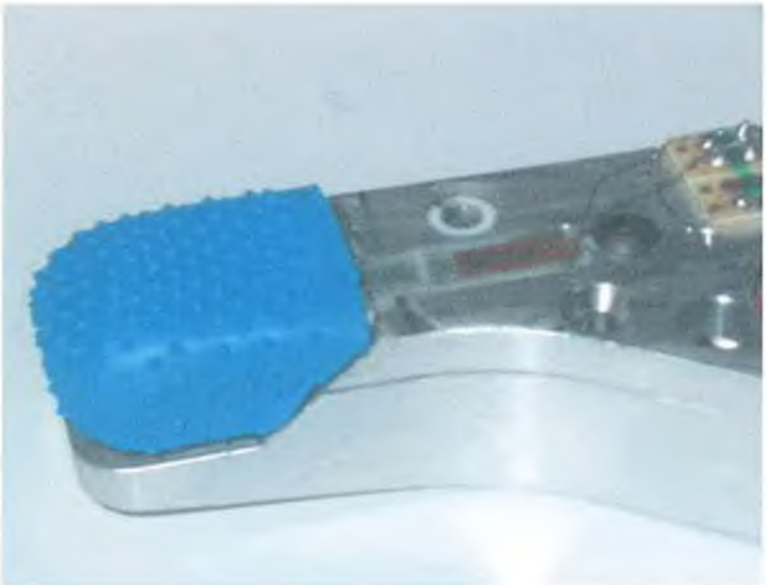


Figure 7.2 Fingertip and Strain Gauge set-up

Testing of the secondary finger operation by driving the stepper motor, verified that the mechanism was not operating sufficiently freely to allow proper actuation of the finger. This meant that there was a possibility that the motor was not strong enough to actuate the finger, however, there was something restricting motion which could be felt by hand.

This led to the dismantling of the finger in order to find the source of this binding. Initially the cause of the problem was not clear, therefore in an effort to facilitate uninhibited rotational motion, the diameter of the secondary finger shaft was reduced slightly. This did help, but did not completely eradicate the problem. Further investigation of this problem led to an examination of the belt used to drive the secondary finger.

During the design of the secondary finger mechanism, a timing belt supplier had been contacted to enquire about the possibility of procuring any size of belt. It was indicated that this was possible, which subsequently led to the finished finger body design. But this was not the case and a longer belt had to be spliced to acquire the correct length of belt (See figure 7.3). This was not a critical problem, since the finger only needed to rotate through less than half of one revolution. However, it was found that the spliced belt which had a polyurethane body with steel tension members, was not flexing sufficiently to run smoothly within the slot made for it, in the finger body. Because of the steel members, the belt was not supple enough to flex around the pulleys, which resulted in the belt rubbing against the side wall of the slot in the finger body. This of course increased the torque required by the secondary finger motor to pull the belt around.

Figure 7-3 Spliced secondary finger drive belt

Figure 7.4 Flexible secondary finger drive belt

This was corrected by selecting another type of belt that had a polyurethane belt body which incorporated polyester tension members (See figure 7.4). However, the fact that these belts had a different pitch, meant that it was also necessary to change the pulleys to suit. However, shorter belts were available in this new pitch, several of which were examined for their suitability (See figure 7.5). Through minor adjustment to the motor's mounting holes, it was found that one of these shorter belts was suitable and subsequently fitted.

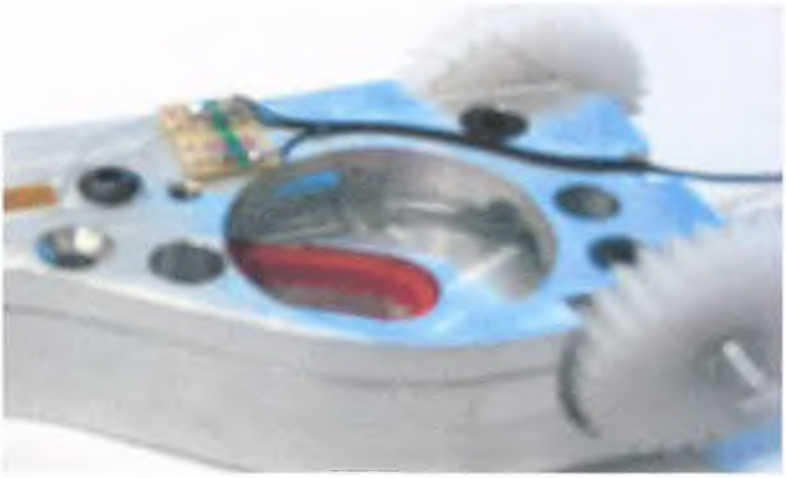


Figure 7.5 Examining suitability of new belts

After reassembling the secondary finger mechanism, a further test revealed that the power supplied by the motor driving the belt remained an issue, whereby finger actuation was performed but was not sufficiently powerful to reshape the buckle in the page (See section 5.5). As a result, the motors were subsequently driven in L/2R mode [89] using a 12V supply. Using this approach did improve the effectiveness of the secondary finger operation to the level expected, where by, the page would slide between the primary and secondary fingers to facilitate page turning. However, it was realised during testing that perhaps a more powerful motor would perform better, since it would then be possible to clamp the page between the primary and secondary finger, resulting in a more definite approach to turning over the page.

7.2 Carriage Control Board Development

While the fingers were being assembled, other work was also being carried out on the development of two finger control boards, which incorporated both the primary and secondary finger stepper motor drivers, the Wheatstone bridge amplifier and were also to contain the comparator for the horizontal encoder. This circuit was not completed however (See figure 7.6). It was considered a better option to have as many of the control components local to the fingers as possible, thus saving on the number of control and power lines needed to link the microcontroller and the finger carriages. This also reduced the likelihood of noise disturbances between the drivers and their relative motors.

The power and control lines to the various components were delivered to the boards via two Flat Flexible Cables (FFC) (See Figure 7.7). These were necessary to allow the independent movement of the two carriages. There are many types of FFC and manufacturers can fabricate these cables to the designer's requirements. However, a minimum order of 200 cables was required before a cable could be made specially.

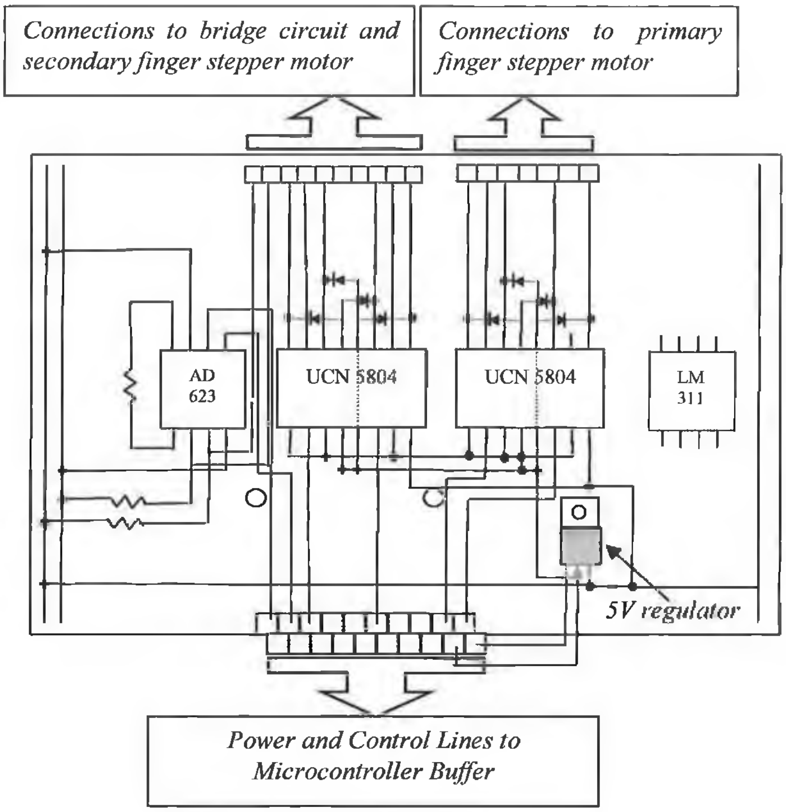


Figure 7.6 Schematic of carriage board

For this reason, the cables used were kindly donated by AXON cables in the UK. The cables used were selected as a best fit to the requirements of the page-turner. Compatible FFC connectors were obtained and soldered to the carriage boards. The cables had to be cut to suit the number of conductors required and were subsequently inserted into the connectors before the outputs were tested. This resulted in a less than perfect solution because the cable assembly and the connectors were not a perfect match. Therefore, great care was taken in order to prevent component damage caused by connector mismatch

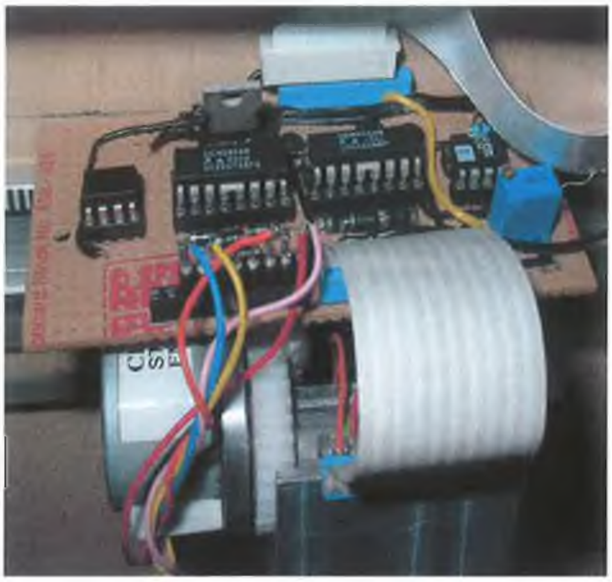


Figure 7.7Assembled Carriage Board

It was hoped that two prototype PCB's would be produced, which would have helped to overcome some of the interconnection issues, particularly relating to the FFC interconnects. However, because of resource limitations this was not completed. Instead the various components were soldered onto a copper tracked prototyping board. This proved rather untidy, but it served the purpose of attaining a working model of the device. The connections to the finger body were made using flexible jumper cables, which allowed movement of the finger, while minimising the risk of connection failure, as seen in figure 7.7. Having completed numerous functionality tests on the circuits involved, the boards were then mounted to the rear of carriages, making sure that soldered side of the boards did not come into contact with the aluminium carriage which would have caused a short circuit.

Before the fingers were located on the baseboard to allow final testing of the force transducers, the horizontal drive mechanism was assembled and tested.

7.3 Horizontal Drive Mechanism

Having assembled the horizontal drive mechanism and associated control circuits, preliminary tests proved that the motors were experiencing some difficulty while moving the finger carriages. The motors were then tested using an independent 12V power supply which had no difficulty moving the carriages. This indicated that the there was a problem with the LD293 motor driver, which had a maximum output current of 600mA. As discussed in the previous chapter, a dc motor pulls its largest current during start-up and direction change. It was therefore believed that the starting current demanded by the motor to move the carriage, exceeded the 600mA limit of the LD293, resulting in sporadic movement of the carriages.

This problem led to a further investigation to examine the possibility of incorporating a different model of motor, which eventually revealed a more suitable servo motor, which could deliver greater torque at roughly the same size and price as the existing motors [90]. However due to time restrictions these more suitable motors were not obtained and tested.

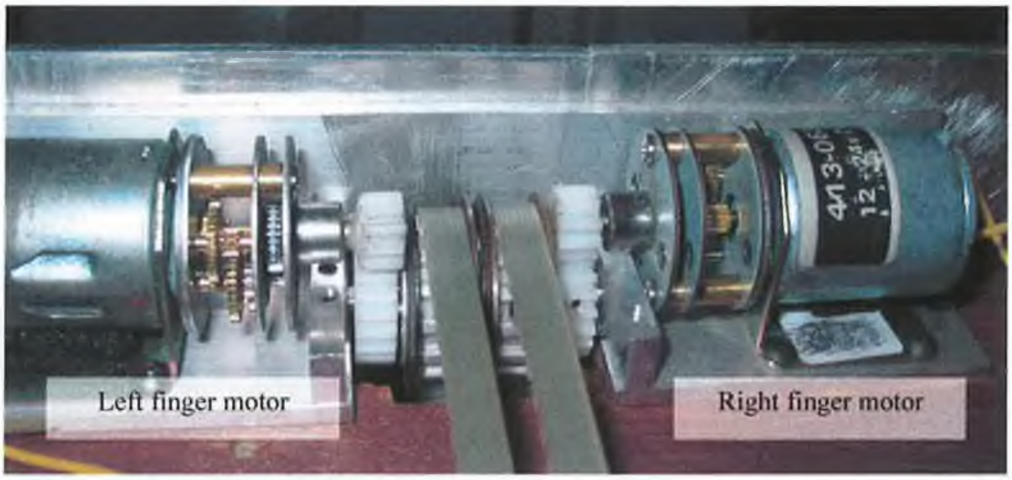


Figure 7.8Horizontal drive mechanism showing 2:1 step-down gear ratio.

The problem of the high current demand from the existing motors was overcome by reversing the 2:1 step-up gear ratio to a 2:1 step-down ratio as seen in figure 7.8, which also illustrates the position of the motors on the underside of the baseboard. This stepping down of the gears reduced the current demand sufficiently, to allow the driver to perform correctly. However, it also reduced the horizontal drive speed at which the carriages could operate, but was necessary to test the two finger approach to page turning.

7.4 Force Transducer Testing

Having developed the carriage boards and assembled the two fingers and the horizontal drive mechanism, the fingers were located on the slide-way in order to verify correct operation of the force transducers (See figure7.9). The output signal from the amplifier was processed through one of the analogue inputs on the microcontroller, to control the amount of force being applied to the page.

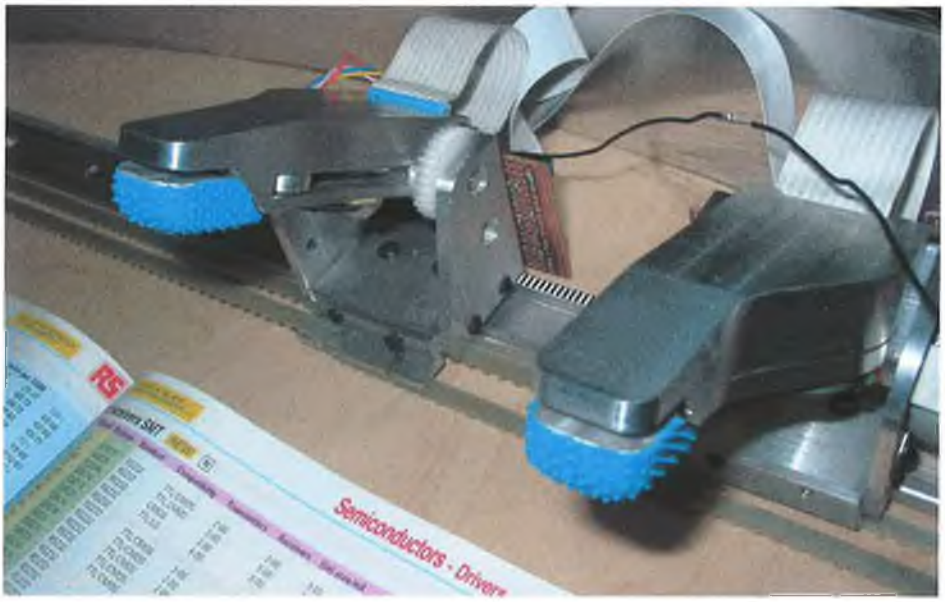


Figure 7.9 Fully assembled finger and carriage control board on slide-way

7.4-1 Measuring the applied force

The force applied by the fingers was measured using digital weighing scales. This was performed by increasing the value of the amplifier output variable in the control algorithm and plotting the corresponding force displayed on the weighing scales (See figure 7.10).

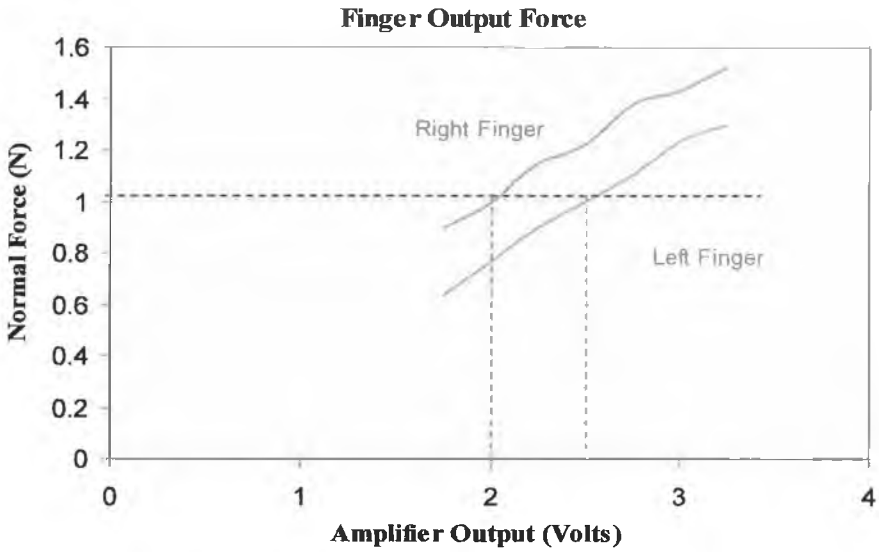


Figure 7.10 Graph showing amplifier output voltage Vs. normal force

There are a number of reasons for the variance between the outputs from the transducers on each finger. Firstly, slight variations in resistance among the bridge arms and lead resistance, can generate some non-zero initial offset voltage, when the bridge is unstrained. Secondly, the bending elements of the two force transducers were fabricated by hand and the placement of the strain gauges was also performed manually. Nevertheless, despite these variations and relatively small offsets, it was felt that the fingers were operating well enough to test the two finger page-turning concept. As a result no offset nulling circuit or software compensator was used, but instead, the threshold value of each finger was set according to its force output value.

It can also be seen from figure 7.8 that the full scale output from the amplifier was quite close to the theoretical output approximation of 3.4 V discussed in section 6.5. However, the force at this output value did not correspond to the calculated value of 1 Newton, but rather 1.4 and 1.5 Newtons for the left and right finger force transducers respectively. The most likely cause of this was the lack of precision used to fabricate the beams and the location of the measuring surface, which was slightly higher than the point of rotation of the fingers. While performing this test it was noted that even a slight change in the position of the weighing scales relative to the fingertip, caused a considerable change in the measured force.

An example of this can be seen in figure 7.11, whereby, while performing a repeatability test, the scales were moved slightly closer to the finger, which resulted in a change in measured force and also step slipping of the stepper motor, as a result of the motor being over-torqued. The repeatability of the applied finger force was found to be within 0.05N over a limited number of tests.

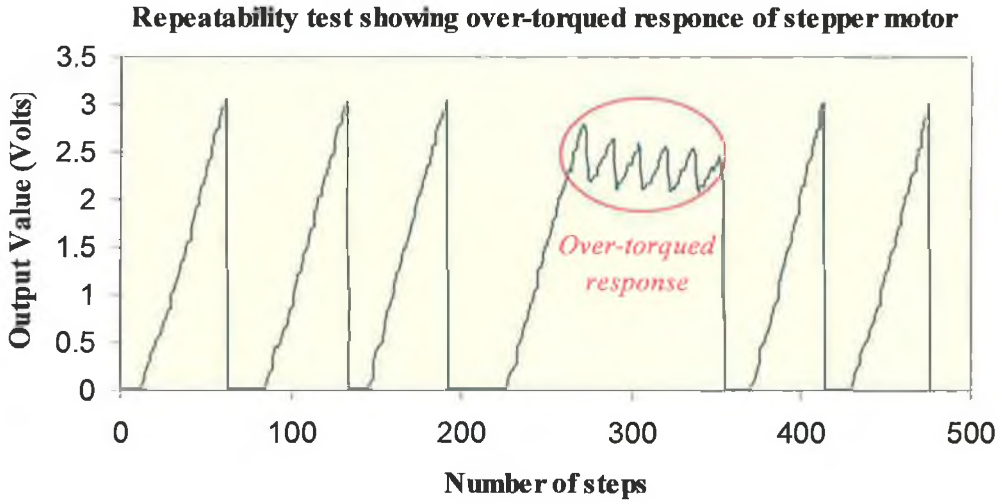


Figure 7.11 Over-torqued response of stepper motor

7.4-2 Force transducer resolution

It was estimated in section 5.4-1 that the resolution of the fingers was 35 steps from 0 to 1.0N. Performing a test to examine this theory revealed that the actual number of steps required to reach the 2V threshold, which equated to 1N of normal force (See figure 7.10) varied considerably. It was clear that the amount of deflection required to reach this threshold differed from the calculated value of 1.25mm, however it was expected that the number of steps would be much reduced from the calculated value of 35 steps. As can be seen for figure 7.12 this was not the case.

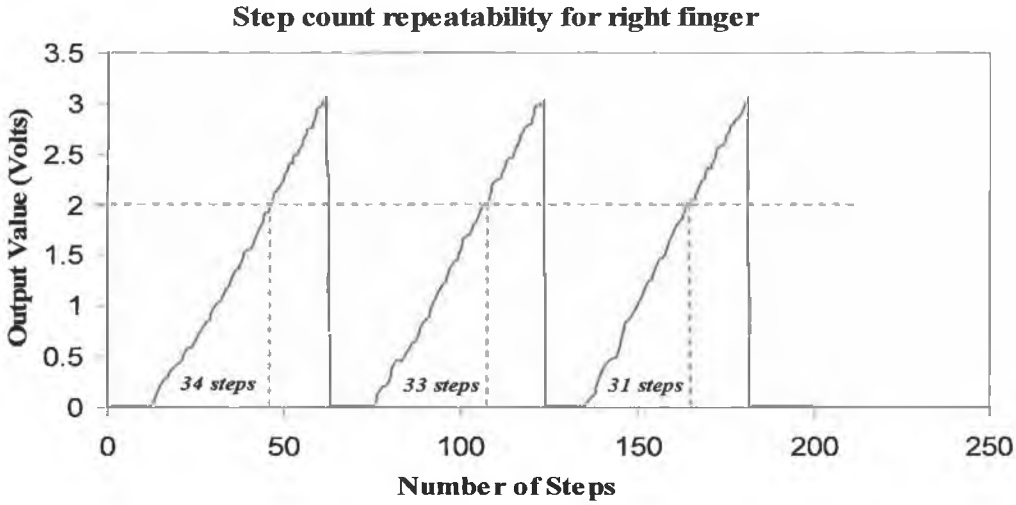


Figure 7.12

In an effort to examine the step response of the transducer more closely, the number of samples taken during the stepping action was increased to 25 samples per step. This clearly indicated that there was actually quite a substantial difference in the output response between each step. It was believed that this step variance (See figure 7.13) was possibly due to imprecise motor construction and the use of poor quality materials, resulting in a variance in torque between the steps of the motor.

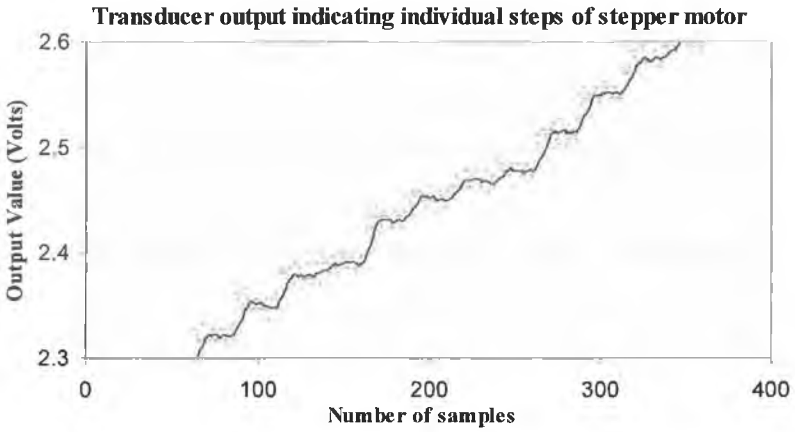


Figure 7.13 Amplifier output illustrating variance in step response from stepper motor

Although this issue remained unresolved, it was felt that there were a sufficient number of steps to facilitate a number of different thresholds which were required to best suit a variety of paper types. What was considered most important was that the fingers could apply a specific force on the page, which had proven to be quite precise and very consistent.

7.5 Device Testing

At this point, the overall device was ready to accept a number of book types for preliminary testing. Several books were tested using a variety of paper types, finishes and weights and the results were tabulated (See Table 7.1). Each paper type was tested at a thickness of approximately 30mm and 5mm to examine the effectiveness of device performance on varying book thicknesses. It can be seen from these initial test results that the method of page separation was very successful, failing only three times in fifty to successfully separate a single sheet from subsequent pages. On each of these occasions, failure to separate the pages was caused by the inflexibility of the heavy paper, which had a much greater resistance to buckling than the lighter paper types. This paper type was found to be very difficult to separate by hand using this method of page separation and required the application of considerable pressure in both the downward and horizontal directions.

Table 7.1 also indicates that the effectiveness of the page flipping was not as successful as the separation process. This was primarily caused by the lack of power in the secondary finger motor, as discussed in section 7.1.

Table 7.1 Test results using five paper types

Paper Type	***Book type***	**Test 1**		**Test 2**		**Test 3**		**Test 4**		**Test 5**		**Book thickness mm**
		S	**T**	**S**	**T**	**S**	**T**	**S**	**T**	**S**	**T**	
Thin leaf ***satin finish***	*Catalogue reference*	√	√	√	X	√	√	√	√	√	X	30
		√	X	√	√	√	X	√	√	√	X	5
Medium leaf ***semi-satin finish***	*Text book*	√	√	√	X	√	X	√	√	√	√	30
		√	X	√	√	√	X	√	X	√	√	5
Medium leaf ***Fibrous finish***	*Novel*	√	√	√	X	√	√	√	X	√	√	30
		√	X	√	X	√	X	√	√	√	X	5
Medium leaf ***Glossy finish***	*Magazine*	√	√	√	X	√	√	√	√	√	X	30
		√	X	√	√	√	X	√	X	√	√	5
Heavy leaf ***Glossy finish***	*Illustration reference*	X	X	√	X	√	√	√	X	X	X	30
		X	X	√	X	√	X	√	X	√	√	5

S – Single page separation
T – Successful Turn

7.5-1 Findings

It was noted that the two most significant variants were the amount of force applied to the page and the distance between the fingers when creating the buckle. These parameters were repeatedly changed to best suit the paper weight and finish. More testing would be required to determine the most effective settings in relation to paper type, book size and thickness. The implementation of the clamping mechanism which would determine the book width, as well as further development of the horizontal encoder, would assist the automatic changing of these parameters in the control algorithm by using a look-up table.

The test results in table 7.1 were performed using standard A4 sized books. While performing similar tests on books smaller than size A3, it was noted that because of the inherent closing behavior of the smaller books, the implementation of the transparent polycarbonate holding device would be required to temporarily hold the book in the open position, while the fingers moved to the turning position.

No significant damage in the form of page tearing occurred during any of the performed tests. However a slight folding of the pages took place adjacent to the books' binding on three occasions. It is felt that this was caused by inappropriate finger movement and a lack of material clamping. This could be corrected by higher movement of the appropriate page turning finger to better clear the binding as well as the implementation of the noninvasive clamping device

As discussed previously the secondary finger did not have sufficient power to grip the page. Since all of the tests were carried out while the device was at 45° to the horizontal, it was also found that the position of the fingers at the top of the page could possibly hinder the page turning operation, since the weight of the page had a tendency to pull the page out from between the primary and secondary finger. Further examination of this problem is necessary and could take the form of increasing the power of the secondary finger mechanism and also possibly relocating the fingers to the bottom of the page. Both of these measures should prevent the pages from slipping out from between the fingers.

The time for each page turning cycle using the two fingered approach was dependent on the book width. The time recorded for an A4 sized book was approximately twenty five seconds, which did not meet the requirements set in the Product Design Specification. However this cycle time could be significantly improved by increasing the power of the motors which in turn would allow a different gearing mechanism to be used.

The following sequence of illustrations indicates the sequence taken by the fingers as conceptualised in figure 4.22.

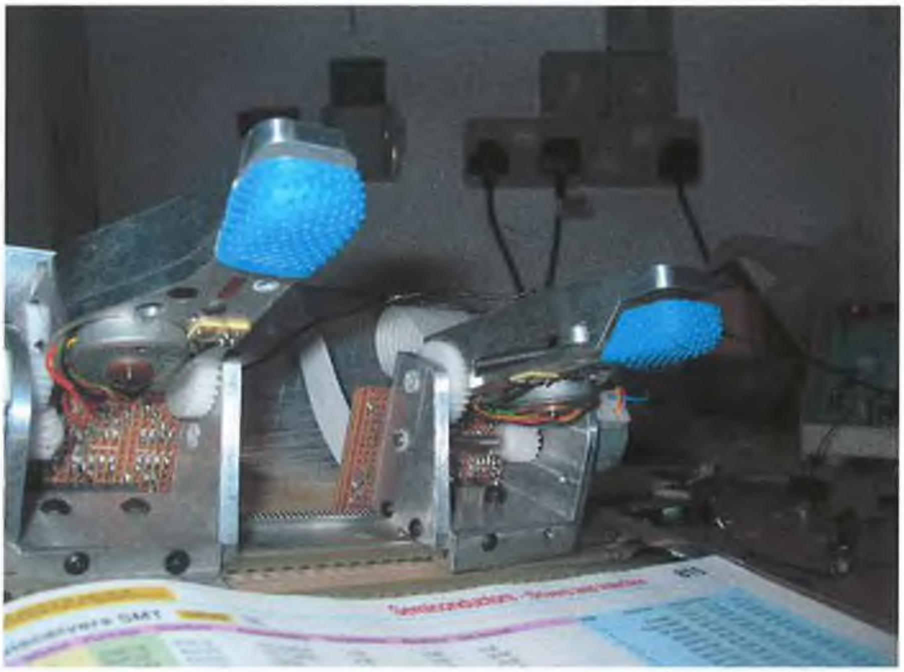


Figure 7.14 Move fingers to required position.

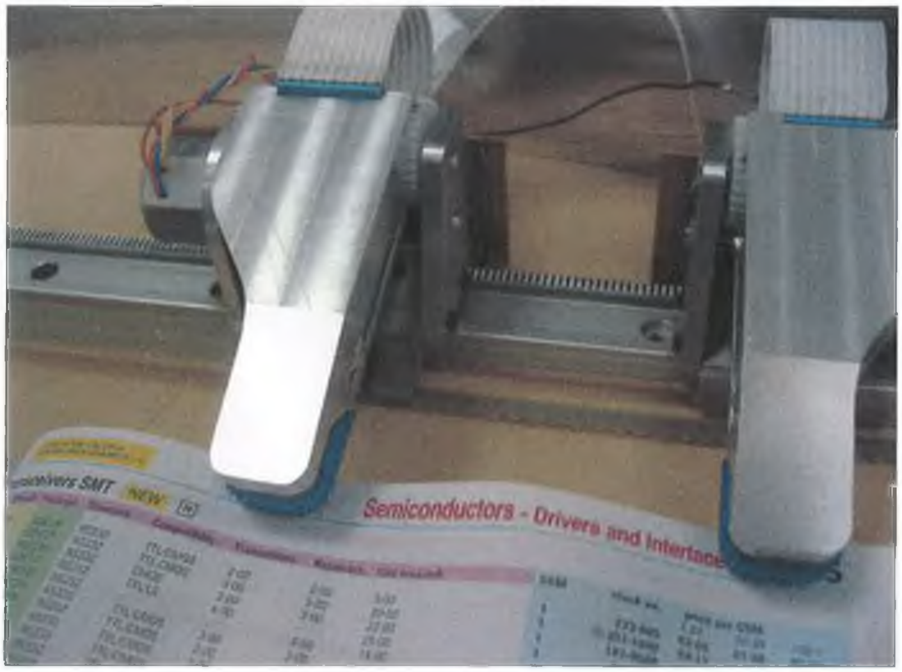


Figure 7.15 Lower fingers onto page.

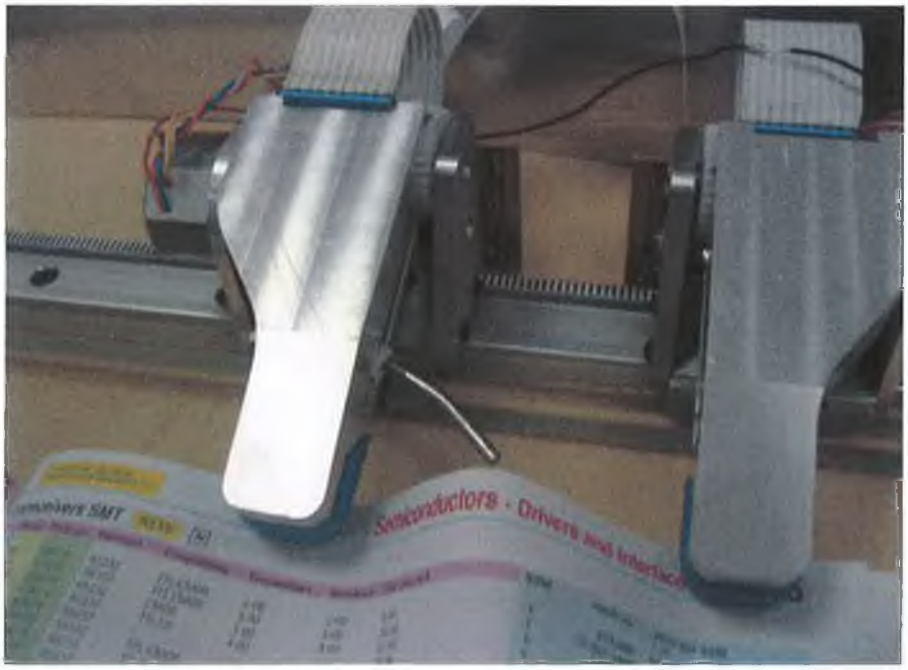


Figure 7.16 Move fingers together

Figure 7.17 Move secondary finger into entry position

Notice motion of secondary finger (centre of rotation offset to allow clearance for page.)

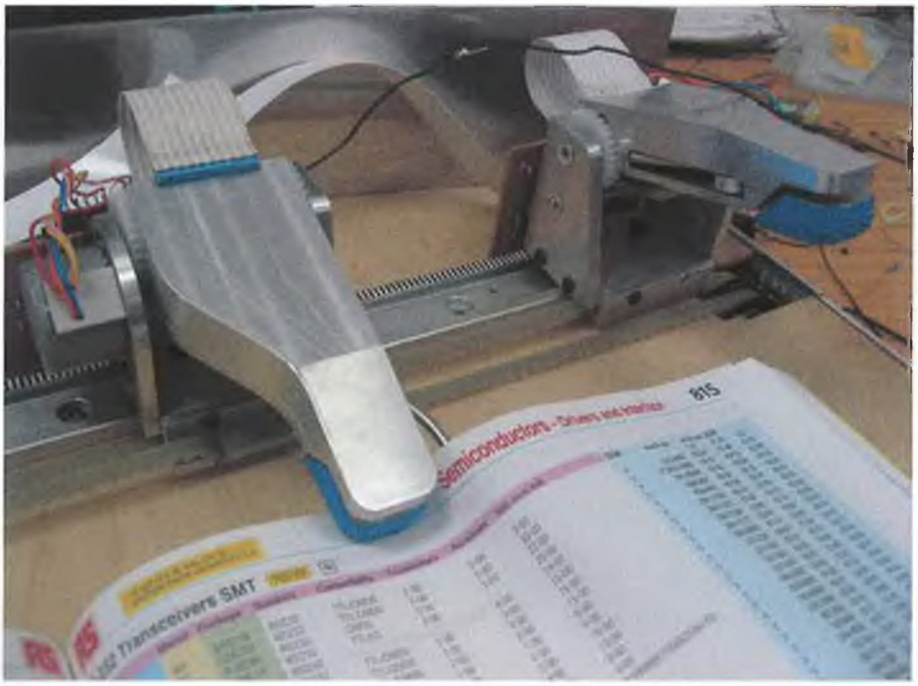


Figure 7.18 Outside finger lifts before inside finger, to allow page to move

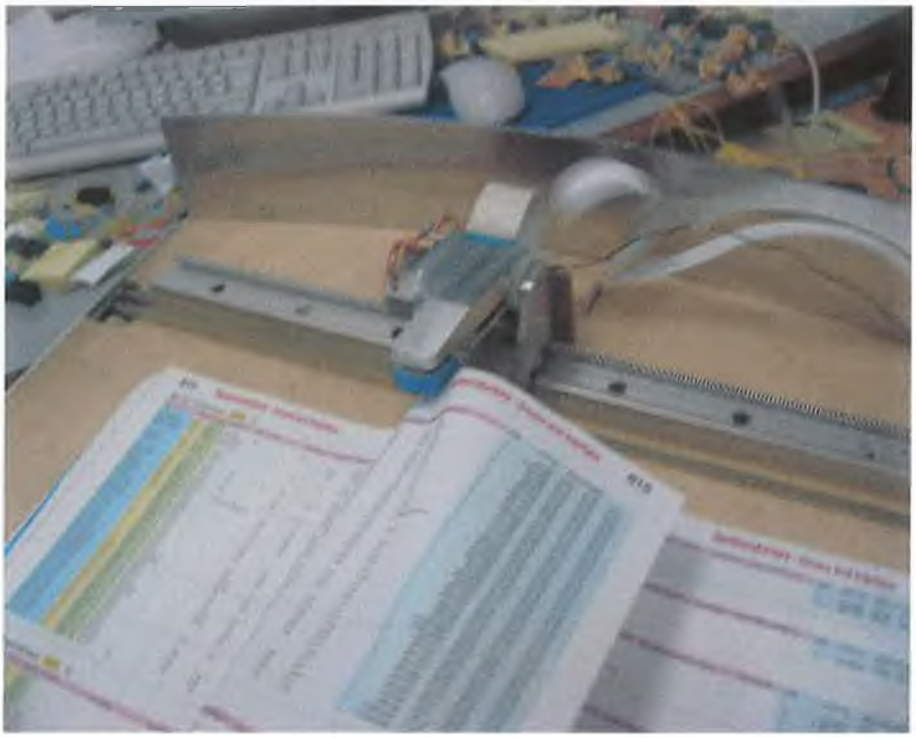


Figure 7.19 Primary finger moves in a convex motion path to allow binding clearance while holding the page

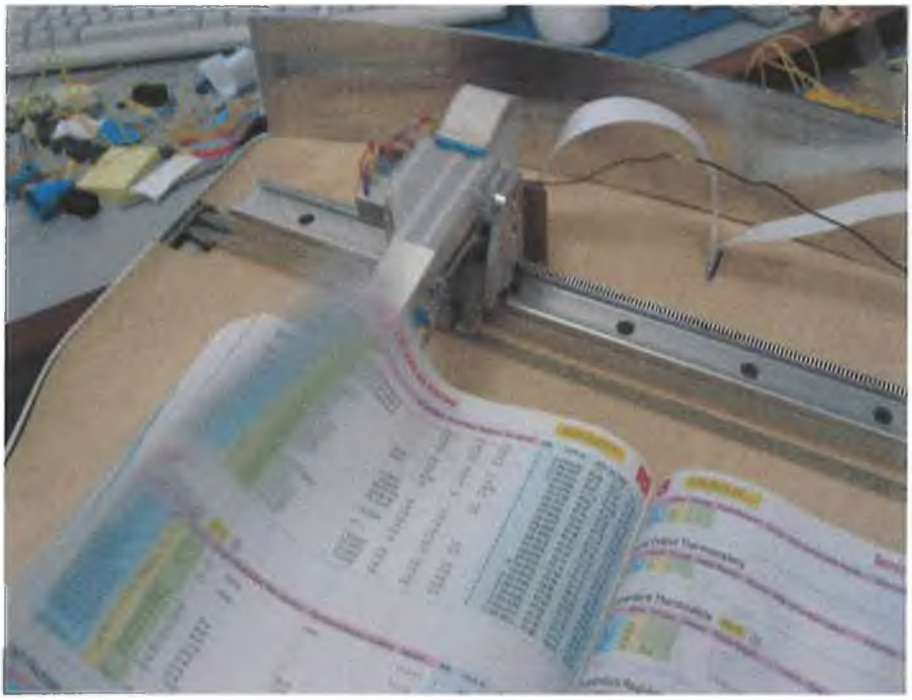


Figure 7.20 Page finally flips over before finger moves vertically off the page and returns to the required position

Having completed the tests and examined the fabricated device at this intermediate stage of prototype development, a critical design review was carried out using the same weighted table as was used in the preliminary design review at the end of chapter four. This was performed to examine how well the unrefined prototype matched the product design specifications and the conceptual preliminary design review. As can be seen from table 7.2 while progress was made with the universally designed page turner, this review scored a total of 27 and as such did not achieve that same level of compliance with the product design specification as did the preliminary design review. However, it is believed that in spite of not achieving the same score as the preliminary design review, this device has great potential for improvement as is discussed in the final chapter.

Table 7.2 Test results using five paper types

Specification Category	1	2	3	4	5
Functional Performance:		√			
Speed of operation:			√		
Durability:			√		
Target costs:				√	
Size of product:			√		
Weight of product:				√	
Transportability:				√	
Aesthetics, Appearance and finish:				√	

Figure 7.21 on the following page is an illustration of the overall final functional prototype.

Figure 7.21 Final working prototype.

Chapter 8. Conclusions and Recommendations

The aim of this project, which was to design and build an automatic page-turner that had the potential to satisfy an expanded market has been realised. The two finger-like mechanisms used in the device, have been proven to be a very reliable method of single page separation. It is believed that by using this two fingered approach which is similar to that employed by humans, that a similar level of consistency can be achieved for the page turning operation. This chapter briefly discusses some of the findings from the preliminary research carried out on need identification, before revealing the achieved level of compliance with the design brief and Product design specification. The chapter concludes with several recommendations that have been identified to help achieve a higher level of page turning reliability from the paper manipulation technique used in the device.

The project used a holistic approach, which involved various aspects of both the assistive technology device and mainstream concurrent design methodologies, with a view to developing a more universal page-turning device. This all encompassing approach, first led to an evaluation of need identification through the use of statistics on people with physical disabilities. This statistical research has shown that there is a more positive approach currently being taken in developing credible statistics about individuals with a functional limitation. This is being driven by demographic change and the emergence of universal design strategies and should give a clearer picture in the future of the size of the market for assistive technology devices such as the automatic page turner.

Further research in the area of automatic page-turners as assistive technology products led to the identification of customer dissatisfaction with many such devices. The two key reasons for this are firstly, the extremely difficult challenge of designing a versatile device that can reliably turn the pages of many different book and paper types. The second is unreliable statistics on people with disabilities and the consequential lack of funding in the assistive technology design sector, which results in the development of dissatisfactory products leading to high unit costs and limited sales. It was for this reason, every effort was made to develop a prototype that could be used not only by the end user, but could also be used to attract funding, to allow further development of the device.

Although much effort was made to develop all aspects of the device, this was found to be too great a challenge to complete as an individual designer. Moreover, while endeavoring to comply with the design brief, much time was dedicated to sourcing suitable components to maintain the low cost, small size theme required to produce an affordable, lightweight and aesthetically pleasing prototype. This had the effect of compromising the level of device completion and compliance with the product design specification. Although most of the physical product feature specifications were met, including the size, weight and materials selected, the functionality, speed of operation and compatibility aspects of the product design specification were not entirely addressed.

By selecting the smallest and cheapest motors and associated drivers, which only just satisfied the torque/speed requirements specified through experimental analysis, no margin for error was made. This allowed unforeseen forces to compromise the functionality and cycle speed of the device through motor power deficiencies which resulted in failure to remain within the parameters specified in the product design specification. While the cycle speed of the device was specified to remain below ten seconds the actual cycle speed was nearer to thirty seconds. This was due to the increased current demand from the horizontal motors which necessitated the alteration of the gearing ratio as discussed in chapter seven, and the high resolution required by the primary finger stepper motor. These issues are discussed further in the recommendations.

Other facets of the device that remained noncompliant with the product design specification included the design and development of a versatile actuation input buffer compatible with the specified actuation devices as well as the fabrication of the folding mechanism, the clamping components and some of the more aesthetic elements of the device. Further work is also required in areas such as design for X and process selection to include, basic processing costs, relative costs and material wastage coefficients, before a realistic manufacturing cost evaluation could be made.

However, having built a device, which incorporates two finger-like components that have been used to successfully turn pages at the first attempt; it is felt that the design has great potential for further development. It is therefore recommended that more time should be spent on testing and finalising some of the more aesthetic aspects of the device before compiling a proposal to attain funding, which would allow the device to be taken to the next stage of development. With this in mind it is recommended that the designer of the next prototype should carefully examine the following issues, before considering the possibility of incorporating some of the recommended changes:

- **Horizontal drive mechanism and slide-way**

A redesign of the finger carriages using a slot in the board, would allow the use of a slide-way, which could be placed on the underside of the baseboard. This would eliminate the problems associated with having to run the drive belt on the front and rear of the baseboard. Using the motor recommended in chapter 7, this approach would allow a quieter, more powerful drive mechanism to be implemented, which would eliminate the interference problems associated with user access to the drive belts and increase speed of operation substantially.

- **Primary finger resolution**

High resolution was required after the fingers came into contact with the page, however, before contact was made, higher speed was required to move the fingers down onto the page. The selected stepper motors had high enough resolution, but when using inexpensive drivers, speed of operation remains a problem, which would need further examination. Ramping of the speed controller may help to reduce this problem, or alternatively the use of a suitable dc servo system may help to speed up this process.

The resolution problems associated with the variance in the steps could have been caused by several factors, such as the flexibility in the polymer gears and the hysteretic effects of the rubber tipped finger. Nevertheless the closed loop force feedback system played a key role in the success of the page separation technique.

- **Secondary finger operation**

During examination of the secondary finger operation it was noticed that a more reliable approach would have been to ensure that the secondary finger motor had the capability to clamp the page between the primary and secondary fingers. This would allow greater horizontal speed of the fingers without the concern of the page slipping from the fingers. The selection of a different motor with a slightly more powerful pull-in torque would be required for this operation.

Finally, it was felt that although the two fingered approach used, offers a much improved solution to the deceptively difficult challenge of automatically turning pages, more advanced technology could comprise of a slip detection sensor, similar to the slip sensing mechanisms examined in the literature review. The combination of force feedback and slip detection would further guarantee single page separation.

Bibliography.

1. Accenture research and Nonaka, Ibujiro and Hirotaka Takeuchi. (1995) 'The Knowledge Creating Company' Oxfored University Press, New York NY, USA.

2. Pennell, J. P.; Winner, R. I. (1989): Concurrent Engineering: Practices and Prospects. In: GLOBECOM' 89 IEEE Global Telecommunications Conference and Exhibition for the 1990s and Beyond. November 27-30, Dallas, 647-655.

3. Bratvia and Hammer (1990) *Focus Groups and user panels* INCLUDE project. CSC-EC-EAEC, Brussels-Luxembourg. [Internet] Available from: http://www.stakes.fi/include/inca002.html[Accessed 8 March, 2003]

4. Methodslab *Methods of customer data collection overview* [Internet] Available from: http://www.presenceweb.i3net.org/methodslab/body.php3 [Accessed 8 March, 2003]

5. Rosenbaum, S. Humburg, J.Ramey, J. Seeley, A. (1995) *Tools and Trade-Offs: Making Wise Choices for User-Centered Design.* CHI proceedings. USA.

6. USER*fit* methodology [Internet] Available from: http://scsx01.sc.ehu.es/acwusfit/ [Accessed 18 June, 2002]

7. Sandhu, S. (2003) *A brief overview of ten years of Universal Design in Europe*. European Institute for Design and Disability [Internet] Available from: http://www.design-for-all.org/artikel.php?ac=direct&id=2443 [Accessed 10 May, 2003].

8. Mace, R. *Center for Universal Design. North Carolina state University* [Internet] Available from: http://www.design.ncsu.edu/cud/univ_design/ud.htm [Accessed 28 July, 2002]

9. Gill, J. (2003). Inclusive Design. [Internet] Available from: http://www.tiresias.org/guidelines/inclusive.htm. [Accessed 28 July, 2002]

10. Marra, J (2002). Press and publications. University of Dundee *Spending all my cash* 8 November 2002.

11. Aslaksen, F. Bergh, S. Bringa, O. R. Heggem, E.K. (1997) *Universal Design – Planning and design for all.* THE NORWEGIAN STATE COUNCIL ON DISABILITY Oslo, [Internet] http://www.srff.no/english/publications.htm [Accessed 20th September 2002]

12. Vanderheiden, G. (2000) p.32-p37. *Priority setting for the development of universal design.* Proceedings from ACM conference on Universal Usability. Arlington, VA, USA.

13. Keates, S. Lebbon, C. Clarkson, J. (2000). *To Universal Design.* Engineering Design Centre, University of Cambridge, Cambridge, CB2 1PZ, UK.

14. EUROPEAN COMMISSION DIRECTORATE-GENERAL III INDUSTRY Legislation and standardization; telematics networks **Standardisation, including industrial aspects of electronic trading** Brussels, 6 29 September,May1998 [Internet] Available from: http://www.etsi.org/public-interest/mandate/M273.pdf [Accessed 15th September 2003].

15. Bruseberg, A. McDonagh-Philp, D. (2000). User-Centred Design Research Methods: The Designer's Perspective. In: Childs P R N and Brodhurst E (eds.) *Integrating Design Education Beyond 2000 Conference*, University of Sussex, September 4-6, pp 179-184. ISBN 1 86058 265 6.

16. Yoji-Akao, (1990), Quality Function Deployment: Integrating Customer Requirements into Product Design, Productivity Press, Cambridge, MA.

17. Xuehong, D. et al (2003). Understanding the Architecture of Product family for Mass Customization. The Customer Centric Enterprise: Advances in Mass Customization and Personalization. Tseng, M.M. and Piller, F.T. (Eds), Springer, New York/Berlin, Chapter 8, pp 138-161.

18. National Disability Authority Act (1999) [Internet] Available from: http://www.nda.ie/cntmgmt.nsf/Category/AF18F1F50122482B80256C7B005A6BD1?OpenDocument [Accessed 13th August 2003].

19. Poulson, D. Waddell, N. (2001). "USERfit: User Centred Design in Assistive Technology." Inclusive Design Guidelines for HCI. Ed. Colette Nicolle & Julio Abascal. London: Taylor & Francis, 143-150.

20. United Nations Statistical Division (2002) [Internet] Available from: http://unstats.un.org/unsd/disability/introduction.asp[Accessed 9th May, 2002]

21. World Health Organisation. (2001) International Classification of Functioning Disability and Health-ICF WHO, Geneva, Switzerland. [Internet] Available from: http://www3.who.int/icf/beginners/bg.pdf [Accessed 23rd July 2002]

22. Statistics CSR Europe (2000) corporate social responsibility in the mainstream of business practice. [Internet] Available from: http://www.csreurope.org/csrinfo/csrdisability/DisabilityFactsandfigures/ [Accessed on 16th May, 2002]

23. INCLUDE project. CSC-EC-EAEC, Brussels-Luxembourg. [Internet] Available from: http://www.stakes.fi/include/incc310.htm [Accessed 23th May, 2002]

24. NPSDD final report (2001) National Physical and Sensory Disability Database [Internet] Available from: http://www.nehb.ie/nehb/publications/reports/Info.%20pack%20Nat%20Dis%20DB.pdf [Accessed on 17th April, 2003]

25. Mulvany, F. (2004) Head of Disability Databases Division, Health Research Board. Holbrook House, Holles Street, Dublin 2, Ireland [Personal communication]

26. TIA report (1998) *Extend Their Reach* Marketing to Consumers with Disabilities: Interpreting the Numbers [Internet] Available from: http://www.tiaonline.org/access/etr_brochure.html. [Accessed 3rd June 2003]

27. Census of Population of Ireland (2002) [Internet] Available from: http://www.cso.ie/census/vol_pserindex.htm. [Accessed 3rd February 2004]

28. Census of Population of Ireland (2002) questionnaire [Internet] Available from: http://www.cso.ie/census/pdfs/censussampleform2002.pdf [Accessed 3rd May 2004]

29. Vanderheiden, G. (2000) p.32-p37. *Priority setting for the development of universal design.* Proceedings from ACM conference on Universal Usability. Arlington, VA, USA.

30. U.S. Census Bureau, International Data Base Population Pyramid Summary for Ireland [Internet] Available from: http://www.census.gov/cgi-bin/ipc/idbpyrs.pl?cty=EI&out=s&ymax=250 [Accessed 3rd Jan 2003]

31. MIT 'Age Lab' [Internet] Available from: http://web.mit.edu/agelab/ [Accessed 23rd July 2003]

32. Cook, A. M. and Hussey, S. M. (2002). **Assistive Technology** *Principles and practice.* 2nd ed. USA, Mosby.

33. Ibid. p.5. Public Law (PL) 100-407. USA.

34. Ibid.p.6 Oder. P (1984). *Hard and soft technology for education and Communication for disabled people,* **Proceedings of International Computation Conference**, Perth, Austrailia.

35. Vanderheiden G.C. (1987) *Service delivery mechanisms in rehabilitation technology.* **American Journal of Occupational Therapy**: 41. p. 705. USA.

36. IST– 38786 IDCnet. Public report (2003). D2.1 - *The needs of industry and future technologies landscapes and the resultant graduate profile.* [Internet] Available from:http://www.idcnet.info/html/IDCnet_D2.1.1.html [Accessed 20th September, 2002].

37. Cook, A. M. and Hussey, S. M. (2002). **Assistive Technology** *Principles and practice.* 2nd ed. p.8. USA, Mosby.

38. Bamforth, S. Brookes, N. J. (2001) *Effective design methodologies for rehabilitation equipment*, **The CACTUS Project,** Proceedings of International Conf on Engineering Design-ICED01. Glasgow, Scotland.

39. Anonymous (1998) Page Turners. Centre for Assistive Technology *'Real Times'* **University at Buffalo** The State University of New York [Internet] Available from:<http://www.cforat.org/articles/pageturn.html>[Accessed 10th January, 2002]

40. Anonymous, (2003) Postural Management and Assistive Technology, **Enable Ireland** [Internet] Available from: <http://www.enableireland.ie/services/postmanage.html> [Accessed 15th may, 2003].

41. Maddack Inc. [Internet] Available from: http://www.cooper.edu/engineering/projects/gateway/me/concurrent/feeders/maddack.html [Accessed 23rd July 2004]

42. The Innovator Page-turner design team [Internet] Available from: http://www.asel.udel.edu/robotics/conlab/innovator/ptqar.htm [Accessed 23rd February 2002]

43. Sauvage, S. Pigasse, O. 'DUNE' Page-turner [Internet] Available from: http://www.slysauvage.com/pages/portfolio/indus/1dune.html [Accessed 23rd October 2002]

44. Blanco, E. (1999) MIT Page-turner [Internet] Available from: http://web.mit.edu/newsoffice/nr/1999/pageturner.html [Accessed 3rd July 2002]

45. 'Compagnie' page-turner LEEntreprise (Product). [Internet] Available from: http://www.techdis.ac.uk/ [Accessed 18th July 2002]

46. Quest Enabling Design (QED) page-turner (Product) [Internet] Available from: http://www.qedltd.com/page_turners.htm [Accessed 8th July 2002]

47. GEWA page-turner (Product) [Internet] Available from: http://www.ndipat.org/products/fact/ecu/gewa.htm [Accessed 8th July 2002]

48. POSSUM Environmental Controls (Product) [Internet] Available from: http://www.possum.co.uk/ [Accessed 8th July 2002]

49. TURNY- page-turner (Product) [Internet] Available from: http://www.davecarthy.com/pageturner.htm [Accessed 20th July 2002]

50. Touch Turner- page-turner (Product) [Internet] available from: http://www.touchturner.com/ [Accessed 25th July 2002]

51. CETR centre for tribology inc. 'Advanced Paper Tribometer' [Internet] Available from: http://www.cetr.com/cetr_paper_body.html [Accessed 13th January 2003]

52. Grummer, A. 'All about paper' [Internet] Available from: http://www.arnoldgrummer.com/information/about_paper/articles/papers_nature/index.cfm [Accessed 13th July 2002]

53. MIT 'Touch Lab' [Internet] Available from: http://touchlab.mit.edu/oldresearch/currentwork/humanhaptics/roleofskinbiomechanics/ [Accessed 4th July 2002]

54. Okamura, A. M. Turner, M. L. Cutkosky, M. R.(1999) Haptic Exploration of Objects with Rolling and Sliding. Center for Design Research Stanford University 560 Panama Street Stanford, CA 94305 USA.

55. Tremblay M. R.. Cutkosky, M. R. (1993) Estimating Friction Using Incipient Slip Sensing During a Manipulation Task. Proc. 1993 IEEE Int. Conf. on Robotics & Automation, pp. 429-434, 1993 Stanford, CA 94305-4026 USA.

56. Anonymous, (2003) Fingerprints [Internet] Available from: http://www.peelpolice.on.ca/FIS/FIS-Print.html#top[Accessed 24th June 2003]

57. (Anonymous) Estimating Force Based on Biomechanics [Internet] Available from: http://umrerc.engin.umich.edu/jobdatabase/RERC2/HAL/Biomech.htm [Accessed 24th November 2002]

58. Agilent technologies – Semiconductor products group. Optical mice and how they work. [Internet] Available from: http://literature.agilent.com/litweb/pdf/5988-4554EN.pdf [Accessed 28th March 2004]

59. Hiroshi, I.Masayoshi, K. (2003), Slip Detection and Trajectory Correction for Walking Robots Using Optical Sensors. Department of Electronic Engineering, Tokyo Denki University,2-2, Nshiki-cho, Kanda, Chiyoda-ku Tokyo, 101-8457 JAPAN {igarashi, kakikura}@isl.d.dendai.ac.jp

60. Nakamura, K. Shinoda, H. (2001) Tactile Sensing Device Instantaneously Evaluating Friction Coefficients. TECHNICAL DIGEST OF THE 18TH SENSOR SYMPOSIUM, 2001. pp.151 154. The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033 Japan shino@alab.t.u-tokyo.ac.jp

61. Tada, Y. Hosoda, K. Asada, M. (2003) Sensing Ability of Anthropomorphic Fingertip with Multi-Modal Sensors, *Adaptive Machine Systems, HANDAI Frontier Research Center,* Graduate School of Engineering, Osaka University, Osaka , Japan

62. Murakami, K. Hasegawa, T. (2002) Novel Fingertip Equipped with Soft Skin and Hard Nail for Dexterous Multi-fingered Robotic Manipulation, Department of Intelligent Systems, Kyushu University,6-10-1 Hakozaki, Higashi-ku, Fukuoka 812-8581 JAPAN.

63. McConkey, R. (2001) Development of an Automatic Page Turner for Disabled Children. Undergraduate Final Year Project. School of Mechanical and Manufacturing Engineering, Dublin City University. Dublin 9, Ireland.

64. Central Remedial Clinic (CRC) Clontarf, Dublin. [Internet] Available from: http://www.crc.ie/ [Accessed 30th October 2002]

65. USERfit group discussions [Internet] Available from: http://www.ipo.tue.nl/homepages/mrauterb/lecturenotes/UFMoverview.pdf [Accessed 26th July 2002]

66. Ibid. – Focus groups [Internet] Available from: http://www.ipo.tue.nl/homepages/mrauterb/lecturenotes/UFMoverview.pdf [Accessed 26th July 2002]

67. Omega Engineering inc. Load Cell Designs [Internet] Available from: http://www.omega.com/literature/transactions/volume3/load.html[Accessed 20th April 2002]

68. FSR [Internet] Available from: http://www.steadlands.com [Accessed 30th August 2002]

69. Steadlands, FSR tecnhnology [Internet] Available from: http://www.steadlands.com/pst.htm [Accessed 13th April 2002]

70. Biomch-L archive for (1995-04) Delay in settling [Internet] Available from: http://isb.ri.ccf.org/biomch-l/archives/biomch-l-1995-04/00008.html [Accessed 30th August 2002]

71. Dycem Limited [Internet] Available from: http://www.dynamic-living.com/dycem-nonslip-mats.htm [Accessed 30th August 2002]

72. Canadian Plywood Association (2001) Plywood technical centre [Internet] Available from: http://www.canply.org/literature_media/TN02-2001.pdf [Accessed 30th August 2002]

73. Radionics - (Component) Ref Code: 419-8296 [Internet] Available from: http://www.radionics.ie [Accessed 18th March 2003]

74. (Anonymous) Gauge Installation [Internet] Available from: http://web.singnet.com.sg/~wgnmfn/dms/dms/applic.htm[Accessed 16th November 2003]

75. Vishay measurements group. p.4. Force and Torque measurement- Bending Beam Half Bridge [Internet] Available from: http://www.vishay.com/brands/measurements_group/guide/ta/ftm/ftmb.htm [Accessed 16th November 2003]

76. Vishay Measurementsgroup. p.8 [Internet] Available from: http://www.davidson.com.au/products/strain/mg/technology/technotes/msg.pdf [Accessed 16th November 2003]

77. Measurement of Force, Torque, and Other Mechanical Variables With Strain Gages Page 15 [Internet] Available from:

http://www.vishay.com/brands/measurements_group/guide/ta/msg/msg7.htm [Accessed 3th May 2003]

78. Radionics - (Component) Ref Code: 918D100112. [Internet] Available from: http://www.radionics.ie [Accessed 19th March 2003]

79. BX 24 – Netmedia (Electronic component) [Internet] Available from: http://www.basicx.com/[Accessed 30th may 2002]

80. Industrial circuits application note : Stepper Motor basics[Internet] Available from: http://library.solarbotics.net/pdflib/pdf/motorbas.pdf [Accessed 30th October 2002]

81. L293D – Texas Instruments (Electronic component) [Internet] Available from: http://www.the-starbearer.de/Files/datenbl%E4tter/l293d.pdf [Accessed 3rd April 2003]

82. Sen, P. C. (1997) p.193. Principles of Electric Machines and Power Electronics, 2nd Ed. Wiley. USA.

83. UCN5804B - Allegro (Electronic Component) [Internet] Available from: http://www.allegromicro.com/datafile/5804.pdf [Accessed 16th November 2003]

84. Franco, S. (1998) p. 422 Design with Operational Amplifiers and Analog Integrated Circuits, 2nd Ed. McGraw-Hill, NY. USA.

85. Strain gauges and load cells Radionics data sheet [Internet] Available from: http://www.elis.ugent.be/ELISgroups/tfcg/student/IEM/DS%20rek_2.pdf [Accessed 16th March 2003]

86. Radionics (Component) Ref Code: 632-180 [Internet] Available from: http://www.radionics.ie [Accessed 16th November 2003]

87. Analogue Devices AD623 [Internet] Available from: http://www.analog.com/Analog_Root/static/pdf/solutionsBulletins/Amps_Bulletin_5-98.pdf [Accessed 16th November 2003]

88. Nash, E. a practical review of common mode and in amps. Analog Devices [Internet] Available from: http://www.sensorsmag.com/articles/0798/amp0798/main.shtml[Accessed 26th May 2002]

89. Motion group inc. [Internet] Available from: http://www.motiongroup.com/smbt.htm [Accessed 10th June 2002]

90. Images SI inc. [Internet] Available from: http://www.imagesco.com/catalog/motors/servo.html [Accessed 16th July 2004]

Appendix A.

THE SEVEN PRINCIPLES OF UNIVERSAL DESIGN Version 1.1 - 12/7/95

PRINCIPLE ONE: Equitable Use
The design is useful and marketable to any group of users.

Guidelines:

1a. Provide the same means of use for all users: identical whenever possible; equivalent when not.
1b. Avoid segregating or stigmatizing any users.
1c. Provisions for privacy, security, and safety should be equally available to all users.

PRINCIPLE TWO: Flexibility in Use
The design accommodates a wide range of individual preferences and abilities.

Guidelines:
2a. Provide choice in methods of use.
2b. Accommodate right- or left-handed access and use.
2c. Facilitate the user's accuracy and precision.
2d. Provide adaptability to the user's pace.

PRINCIPLE THREE: Simple and Intuitive Use
Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.

Guidelines:
3a. Eliminate unnecessary complexity.
3b. Be consistent with user expectations and intuition.
3c. Accommodate a wide range of literacy and language skills.
3d. Arrange information consistent with its importance.
3e. Provide effective prompting for sequential actions.
3f. Provide timely feedback during and after task completion.

PRINCIPLE FOUR: Perceptible Information
The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.

Guidelines:
4a. Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information.

4b. Provide adequate contrast between essential information and its surroundings.
4c. Maximize "legibility" of essential information in all sensory modalities.
4d. Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions).
4e. Provide compatibility with a variety of techniques or devices used by people with sensory limitations.

PRINCIPLE FIVE: Tolerance for Error
The design minimizes hazards and the adverse consequences of accidental or unintended actions.

Guidelines:
5a. Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded.
5b. Provide warnings of hazards and errors.
5c. Provide fail safe features.
5d. Discourage unconscious action in tasks that require vigilance.

PRINCIPLE SIX: Low Physical Effort
The design can be used efficiently and comfortably and with a minimum of fatigue.

Guidelines:
6a. Allow user to maintain a neutral body position.
6b. Use reasonable operating forces.
6c. Minimize repetitive actions.
6d. Minimize sustained physical effort.

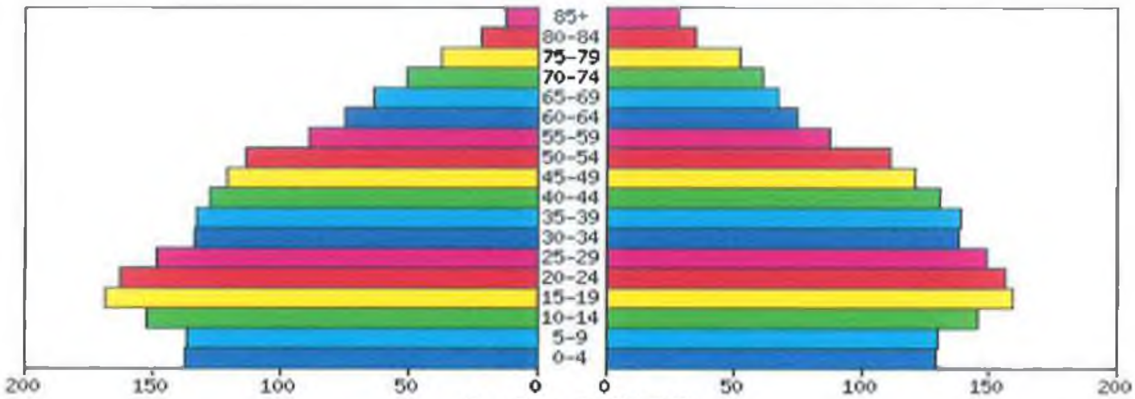
PRINCIPLE SEVEN: Size and Space for Approach and Use Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.

Guidelines:
7a. Provide a clear line of sight to important elements for any seated or standing user.
7b. Make reach to all components comfortable for any seated or standing user.
7c. Accommodate variations in hand and grip size.
7d. Provide adequate space for the use of assistive devices or personal assistance.

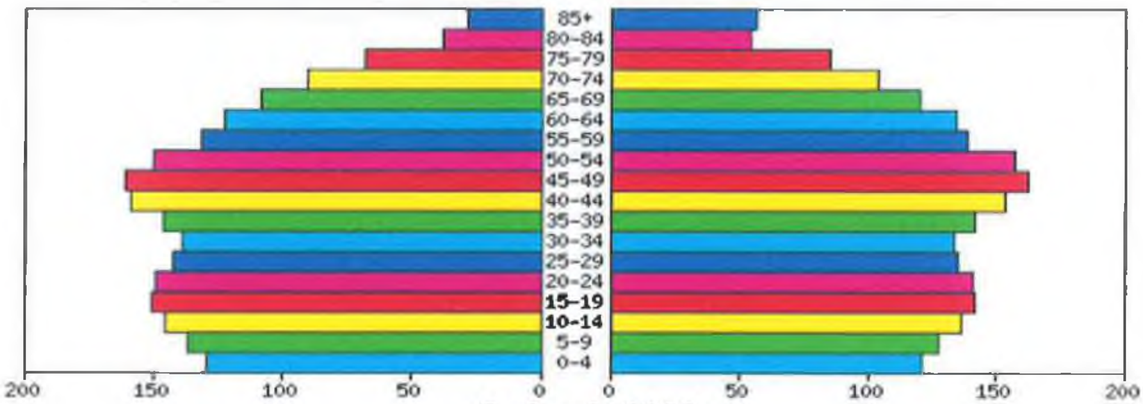
It must be acknowledged that the principles of universal design in no way comprise all criteria for good design, only universally usable design. Certainly, other factors are important, such as aesthetics, cost, safety, gender and cultural appropriateness, and these aspects should be taken into consideration as well.

Demographic predictions for Ireland 2000 - 2050

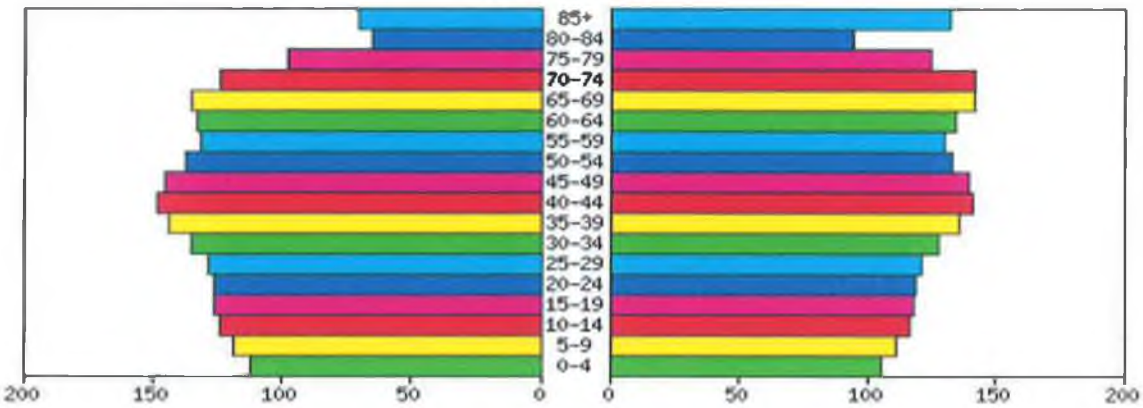
Male **Ireland: 2000** **Female**



Ireland: 2025



Ireland: 2050



Consumer Innovation Laboratory

Pageturner Questionnaire and Results

*Note: the number of responses to some questions vary due to the fact that some individuals did not answer all questions.

1. How many hours per week do you currently spend reading ?

Number of Respondents = 47							
under 1 hour		1-3 hours		3-5 hours		over 5 hours	
Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
6	12.77%	9	19.15%	15	31.91%	17	36.17%

2. If you had a pageturner, would you spend more time reading ?

Number of Respondents = 45			
Yes		No	
Number	Percentage	Number	Percentage
17	37.78%	28	62.22%

3. A) How important would it be for a pageturner to be able to handle each of the following reading materials:

-	(a)	(b)	(c)	(d)	(e)	(f)
Number of Respondents	47	46	45	42	41	41
-	Very Important		Somewhat Important		Not Important	
-	Number	Percentage	Number	Percentage	Number	Percentage
(a) Hard-cover books	25	53.19%	10	21.28%	12	25.53%
(b) Soft-cover books	22	47.83%	12	26.09%	12	26.09%
(c) Magazines	20	44.44%	14	31.11%	11	24.44%
(d) Newspapers	11	26.19%	11	26.19%	20	47.62%
(e) Loose sheets	11	26.83%	8	19.51%	22	53.66%
(f) Loose-leaf notebooks	13	31.71%	9	21.95%	19	46.34%

3. B) How difficult is it for you to currently handle each of the following reading materials:

-	(a)	(b)	(c)	(d)	(e)	(f)
Number of Respondents	46	46	45	42	41	38
-	Very Difficult		Somewhat Difficult		Not Difficult	

-	Number	Percentage	Number	Percentage	Number	Percentage
(a) Hard-cover books	14	30.43%	11	23.91%	21	45.65%
(b) Soft-cover books	11	23.91%	9	19.57%	26	56.52%
(c) Magazines	9	20.00%	10	22.22%	26	57.78%
(d) Newspapers	12	28.57%	9	21.43%	21	50.00%
(e) Loose sheets	9	21.95%	3	7.32%	29	70.73%
(f) Loose-leaf notebooks	8	21.05%	3	7.89%	27	71.05%

4. How do you currently turn pages?

Most people who responded to this question are able to use their hands to turn pages. Some people say they have trouble with large and heavy books or need the reading material placed directly in front of them in order to handle turning pages. Others say that they usually wet their fingers in order to help them turn the pages. A few require assistance from others to help turn pages and some get tired after turning pages for a significant amount of time.

5. Would you rather read: (a) pages from a book or (b) a computer screen ?

Number of Respondents = 46			
(a) pages from a book		(b) computer screen	
Number	Percentage	Number	Percentage
40	86.96%	7	15.22%

Note: one person had no preference between the two choices.

6. For what activities would you use a pageturner:

Number of Respondents = 39					
Work		School		Leisure reading	
Number	Percentage	Number	Percentage	Number	Percentage
15	38.46%	14	35.90%	34	87.18%

7. What type of power source would be best ?

Number of Respondents = 41					
Batteries		Plug-in cord		Both	
Number	Percentage	Number	Percentage	Number	Percentage
7	17.07%	9	21.95%	25	60.98%

8. How would you describe your ability to load a pageturner ?

(a) I would need to have the book completely set up for me.

(b) I could put the book onto the pageturner, but would need help opening the book.

(c) I could envision being able to load a pageturner unaided.

Number of Respondents = 34					
(a) Complete help		(b) Some help		(c) No help	
Number	Percentage	Number	Percentage	Number	Percentage
15	44.12%	2	5.88%	17	50.00%

9. Do you feel that it is important for the pageturner to:

(a) Turn pages both forward and backward ?

(b) Turn a large number of pages at one time?

(c) Have a magnification option?

-				(a)		(b)	(c)
Number of Respondents				40		37	40
(a) Turn pages both forward and backward				(b) Turn a large number of pages at one time			
Yes		No		Yes		No	
Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
37	92.50%	3	7.50%	25	67.57%	12	32.43%
-		(c) Have a magnification option				-	
-		Yes		No		-	
-		Number	Percentage	Number	Percentage	-	
-		31	77.50%	9	22.50%	-	

10. Should the pageturner come with a table with wheels for mobility?

Number of Respondents = 33			
Yes		No	
Number	Percentage	Number	Percentage
22	66.67%	11	33.33%

11. Which is more important: (a) independence of use or (b) cost ?

Number of Respondents = 42	
(a) independence of use	(b) cost

Number	Percentage	Number	Percentage
26	61.90%	18	42.86%

Note: two individuals felt that both choices were equally important.

12. If a pageturner was easy to use, worked correctly, and had all the features that you wanted, how much would this device be worth ?

Number of Respondents = 35							
under $500		$500-$1000		$1000-$1500		over $1500	
Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
25	71.43%	7	20.00%	2	5.71%	1	2.86%

13. Do you feel that you would benefit from a pageturner ?

Number of Respondents = 44			
Yes		No	
Number	Percentage	Number	Percentage
23	52.27%	21	47.73%

14. List any features, suggestions, or comments which you feel would be important in the design of a pageturner.

Respondents listed several features which were important to them including:

1. The ability to read in a reclined position such as in bed.
2. The pageturner should not be too large in size (compact & portable).
3. The pageturner should not be heavy so it could easily be moved from place to place.
4. The pageturner should be easy to learn how to use.
5. A basic inexpensive design should be made with extra items such as wheels, bulk page turning, and magnification as add-ons for those who need them.
6. The pageturner should be an easel-like table that tilts.
7. The pageturner should be able to handle a wide range of reading materials.

Other comments include:

1. Some feel that they do not currently need a page turner but may find it beneficial in the future.
2. Others say that problems with their eyesight makes a page turner of little benefit to them.

Consumer Innovation Laboratory

PAGETURNER PRODUCT DESIGN SPECIFICATION Version 2.0

Last updated: August 15, 1995

NUMBER	D/W	CATEGORY	SPECIFICATION
#1.		Features	Capable of handling the following types of materials
	D		hard-cover books
	D		soft-covered books
	D		magazines
	W		loose-leaf notebooks
	D		newspapers
	W		loose sheets
	W		pamphlets
#2.	D	Pagin optins	Turns pages forward or backwards.
#3.	D	Paging options	Speed of pageturning is controllable.
	W		Turns to index or table of contents directly.
	W		Turn a large number of pages at a time.
	W		Open book half way through.
	W		Able to count pages.
	W		Able to go to a specific page number.
	W		Includes a bookmark.
#4.	D	Interface	Compatible with popular adaptive control methods, to include:
			Voice input
			Wheelchair joysticks
			Switches
			PC software
#5.	D	Cost	Retail cost in the neighborhood of $1500.

	W		Less than $500.
6.	W	Size	Portable.
7.	W	Attachment	Accommodates reclined position such as occurs when sitting in bed (ie. may be hung from ceiling or other suitable location)
8.	D	Size	Footprint under 21 inches wide by 13 inches deep.
9.	W	Function	User can set up independently.
10.	W	Aesthetics	Unobtrusive.
11.	W	Feature	Easy to store.
12.	W	Features	Built-in light source.
13.	D	Size	Weigh less than 11 pounds.
14.	D	Function	Holds book steadily.
15.	D	Feature	Orientation of material should be adjustable.
16.	W	Feature	Remote control switch
17.	W	Feature	Magnifying lens attachment
18.	D	Feature	Easy to engage and disengage book
19.	D	Feature	Accommodates sleaves; does not damage book
20.	W	Feature	Includes an adaptor that puts image to a TV monitor
21.	W	Feature	Opaque projector
22.	W	Feature	Automatic loading of multiple books
23.	W	Feature	Reads the book out loud.

Placed top two priority specifications (as determined at the August 2, 1995 meeting) as #1 and #2. Placed other top priorities (those being considered for priorities #3 through #5) above a single line. Placed other specifications that were rated highly above a double line.

Appendix B.

Microcontroller comparison table A

	Language	Compiler	Program Loader	Ram Size	Ram Expandable?	Flash/EEPROM	Program Location	ATD/DTA	Multitasking
BasicX	BASIC	BasicX 2.00	BasicX 2.00	400 Bytes	No	32K/none	Flash	Yes	Yes
HC12	ASM/C	MiniIDE CodeWarior	miniIDE Any term prog	1Kb	Yes	32K/768 Bytes	Ram (initially) Flash or EEPROM	Yes	No
FPGA	VHDL	Xilinx ISE	XSTools	16M	No	No	CPLD Memory	No	No
TI DSP	ASM/C/C++	CodeComposer, Command Line Tools	CodeComposer	32k Internal 32k External	No	No	Ram	Yes, No Digital Out	No

	ATD/DTA	Multitasking	Timers	PWM	IO Technology	MAX Prog Size	Speed
BasicX	Yes	Yes	Yes (RTC)	Yes	TTL	8000 lines	~8000 lines/sec
HC12	Yes	No	Yes	Yes	CMOS	Varies	8MHz
FPGA	No	No	No (You can make one though)	No	TTL Compatible	DEPENDS[1]	Wire speed (100MHz external clock)
TI DSP	Yes, No Digital Out	No	Yes	No	N/A	VARIES[2]	80MHz

Microcontroller comparison table B

Features:	BasicX-24 TM	BASIC Stamp2	BASIC Stamp SX
I/O Lines	16+	16	16
EEPROM	32KBytes	2KBytes	16K Bank Switched
RAM	400 Bytes	32 Bytes	96 Bytes
Program Execution Speed	65,000 Instructions/sec.	4000 Instructions/sec.	10,000 Instructions/sec.
Max. Program Length	8000+ instructions	~500 instructions	~500 instructions Per 2K Bank
Analog Inputs	8 (10 Bit ADCs)	No	No
Multitasking OS	Yes	No	No
Floating Point Math	Yes	No	No
PC Programming Interface	Serial	Serial	Serial
Serial I/O	Yes	Yes	Yes
On-Chip LEDs	2 (Red & Green)	No	No
SPI Interface	Yes	No	No
On-Chip Regulator and low voltage reset	Yes	Yes	Yes
Package	24-pin DIP module	24-pin DIP module	24-pin DIP module