Flowdesk:
Prototyping a deformable interactive desk workspace

Bachelor's Thesis
submitted to the
Media Computing Group
Prof. Dr. Jan Borchers
Computer Science Department
RWTH Aachen University

by
Lukas Oßmann

Thesis advisor:
Prof. Dr. Jan Borchers

Second examiner:
Prof. Dr. Torsten Kuhlen

Registration date: 27.09.2016
Submission date: 29.09.2016

Eidesstattliche Versicherung

______________________________ ______________________________

Name, Vorname Matrikelnummer

Ich versichere hiermit an Eides Statt, dass ich die vorliegende Arbeit/Bachelorarbeit/ Masterarbeit* mit dem Titel

____

____

____

selbständig und ohne unzulässige fremde Hilfe erbracht habe. Ich habe keine anderen als die angegebenen Quellen und Hilfsmittel benutzt. Für den Fall, dass die Arbeit zusätzlich auf einem Datenträger eingereicht wird, erkläre ich, dass die schriftliche und die elektronische Form vollständig übereinstimmen. Die Arbeit hat in gleicher oder ähnlicher Form noch keiner Prüfungsbehörde vorgelegen.

______________________________ ______________________________

Ort, Datum Unterschrift

*Nichtzutreffendes bitte streichen

Belehrung:

§ 156 StGB: Falsche Versicherung an Eides Statt

Wer vor einer zur Abnahme einer Versicherung an Eides Statt zuständigen Behörde eine solche Versicherung falsch abgibt oder unter Berufung auf eine solche Versicherung falsch aussagt, wird mit Freiheitsstrafe bis zu drei Jahren oder mit Geldstrafe bestraft.

§ 161 StGB: Fahrlässiger Falscheid; fahrlässige falsche Versicherung an Eides Statt

(1) Wenn eine der in den §§ 154 bis 156 bezeichneten Handlungen aus Fahrlässigkeit begangen worden ist, so tritt Freiheitsstrafe bis zu einem Jahr oder Geldstrafe ein.

(2) Straflosigkeit tritt ein, wenn der Täter die falsche Angabe rechtzeitig berichtigt. Die Vorschriften des § 158 Abs. 2 und 3 gelten entsprechend.

Die vorstehende Belehrung habe ich zur Kenntnis genommen:

______________________________ ______________________________

Ort, Datum Unterschrift

Contents

List of Figures

List of Tables

Abstract

Computer screens play an important role in our everyday life and are used at every modern workspace. With the increasing capability of modern technology a variety of these screens exist which are suited for different tasks. A vertical screen is usually used for reading or viewing tasks and placed on a desk or a wall. For some brainstorming tasks multitouch tables with a horizontal screen are used. Systems specialized on graphic applications (that usually afford pen input) use angled screens because they are more comfortable for users to draw on. As screen ergonomics became more important, a lot of research has been done on screen systems which offer different screen positions for different tasks. But most of these systems either combine multiple, static screens or use just one, movable screen. These approaches fail to give the users a big variety of screen positions which are required for many tasks.

In order to tackle this problem we present *Flowdesk*, a first ergonomic prototype of a two screen system that can adapt the screen position dynamically corresponding to the users tasks. The main concept behind our system is based on two motorized screens which connect on one edge to form a seamless screen surface that can be used for a variety of different tasks. These screens can automatically move into positions similar to a touch table, a normal desktop environment, a drafting table or any other position the user prefers. Due to this the system can form an optimal screen surface for any specific task. *Flowdesk* is designed to be used both in sitting and standing position and is able to adapt in real-time, to the users needs. The prototype described in this work is still missing the touchscreen functionality and should be seen as an ergonomic prototype. *Flowdesk* should allow other researches to conduct user studies or design an improved system based on the experiences we collected while building this system.

Überblick

Computerbildschirme spielen eine wichtige Rolle in unserem täglichen Leben und werden an jedem modernen Arbeitsplatz genutzt. Mit den zunehmend wachsenden Möglichkeiten die die heutige Technologie bereitstellt, existieren immer mehr unterschiedliche Bildschirme die für verschiedenste Aufgaben ausgelegt sind. Ein vertikal ausgerichteter Bildschirm wird meistens genutzt um auf ihm etwas zu lesen oder zu betrachten und wird auf einem Schreibtisch oder an einer Wand platziert. Horizontale Bildschirme wie Multitouch Tables eignen sich am besten für Brainstorming. Bilschirmsysteme die spezialisiert sind auf grafische Anwendungen (die oft ein Eingabe durch einen Stift erfordern) nutzen geneigte Bildschirme, weil es für die Nutzer angenehmer ist auf diesen zu zeichnen. Da die Ergonomie der Bildschirme immer wichtiger wurde, wurde viel an Systemen die unterschiedliche Bildschirmpositionen bereitstellen geforscht, die dem Nutzer die Möglichkeit geben es für verschiedenste Aufgaben zu gebrauchen. Trotzdem nutzen die meisten dieser Systeme entweder mehrere statische oder einen einzigen bewegelichen Bildschirm. Diese Systeme haben damit nicht die Möglichkeit dem Nutzer eine große Auswahl von verschiedenen Bildschirmpositionen zu generieren, die aber für manche Aufgaben benötigt würden.

Um dieses Problem zu lösen stellen wir *Flowdesk* vor, einen ersten ergonomischen Prototypen eines Zwei-Bildschirm-Systems, dass sich dynamisch an die Aufgaben des Nutzers anpassen kann. Das grundlegende Konzept hinter *Flowdesk* basiert auf zwei motorisierten Bildschirmen, die an einer Kante aneinander liegen und damit eine große, nahtlose Bildschirmoberfläche bilde. Diese kann für eine Vielzahl von verschiedenen Aufgaben genutzt werden. Die Bildschirme können dabei automatisch in Positionen fahren, die ähnlich sind zu denen eines Touchtables, eines Desktop-Arbeitsplatzes, eines Zeichenboards oder einer beliebigen anderen Bildschirm-Konstellation. Dies ermöglicht dem System eine Bildschirmposition anzunehmen, die optimal ist für jede spezielle Aufgabe die ein Nutzer bearbeiten muss. *Flowdesk* ist darauf ausgelegt sowohl in sitzender als auch in stehender Position genutzt zu werden und kann sich in Echtzeit an die Wünsche des Nutzers anpassen. Der Prototyp, der in dieser Arbeit beschrieben wird, besitzt noch keine

Touchscreen-Funktionalität und sollte daher als Ergonomie-Prototyp gesehen werden. Er kann später Nutzerstudien ermöglichen oder als Grundlage für den Bau eines erweitertes System dienen.

Acknowledgements

First of all I want to thank Prof. Dr. Jan Borchers and my second examiner Prof. Dr. Torsten Kuhlen for giving me the opportunity to do this bachelor thesis.

Secondly, I want to thank my supervisor Simon Völker for giving advice and ideas that influenced this thesis. Additionally I like to thank Jan Thar and the Fab Lab Aachen for providing the technical support I needed for my work. Without their additional expertise and equipment, it would not have been possible to build the prototypes for this work.

Special thanks go to the graphic designers Hannah Möllenbrink and Angelo Baurmann for their extensive feedback, as well as to all the people from our chair i10 that supported me in any way.

Furthermore I like to thank Laura Jungbluth for checking my language and spelling and my family for general support.

Conventions

Throughout this thesis we use the following conventions.

Source code and implementation symbols are written in typewriter-style text.

`myClass`

The whole thesis is written in American English.

Chapter 1

Introduction

Nowadays computer screens take an important role in most workspaces. They are used in touch tables, placed on walls or put vertically on desks. The orientation and position of these screens always depends on how the user wants to interact with the screen and moreover what task he has to accomplish while using it. Touch tables are commonly used to allow brainstorming with a group of people, or generally having multiple users working with one screen. The users usually stand around the table and can directly see the input of the others [Muller-Tomfelde et al., 2008]. Computer screens on walls are mainly used for presentations and afford only direct input of one or two users [Weiser, 1995]. When working at a desk, the normal computer user sits in front of a vertical screen and has different input devices (like a mouse, a keyboard, a graphic tablet or even a smartphone) in front of him. In graphic applications, it is often preferred to draw directly on a horizontal or slightly tilted touchscreen.

different tasks need different screen ergonomics

In all of the cases listed above, different screen in a different position is used. Obviously there are a lot of situations, where a user sits at a specific workspace, where the screen is not in the optimal position for the users task. In order to use a screen suitable for his task, the user has to go to a different workspace. In general the computer screen never actively adopts to the users task.

most workspaces do not provide these ergonomics touchscreens offer advanced possibilities for interactive workspaces

To address this and similar problems, several approaches have been made. An important aspect for all of these approaches is touch input. Touchscreens used in interactive workspaces allow users to interact directly with interfaces on the screens by touching them. With multitouch functionality it is possible to work with the input of multiple users simultaneously. In graphic applications touchscreens are able to detect pen input and show the result of the interaction directly where the input has been made. Touch input is often intuitive and offers more possibility then normal input. This led to several interactive workspace systems using touchscreens.

BendDesk, a multi-touch desk with a bent surface

The *BendDesk* (Figure 2.2) introduced by Voelker [2010], combines a vertical and horizontal touch screen by connecting them with a bent touch surface that allows seamless interaction and dragging between both screens. This allows the user to position interfaces of applications horizontally or vertically corresponding to his personal preferences. The vertical screen, for example, can be used to edit text documents while the horizontal screen shows additional documents or acts as an input device similar to a keyboard. While opening up new possibilities for desktop workspaces, the *BendDesk* is still limited in its flexibility. Both screens are fixed in their position and cannot be adapted angle-wise to the users task.

FLUX, a system with a tiltable touch surface

A different approach has been made by Leitner et al. [2009] with the *FLUX* (Figure 2.1), which consists of a big, tiltable touchscreen that can be used either as a horizontal whiteboard, an angled sketchboard or a vertical touchtable. While this allows the user to angle the screen correspondingly to the task, the normal "desktop" interaction is lost because there is only one flat surface available for interaction.

combine *BendDesk* and *FLUX*

An obvious improvement over both of these systems would be to combine their advantages into one new system. This new system would base on the idea of two screens like in *BendDesk*, which optimally are connected to create one seamless surface, but are still movable similar to the screen in *FLUX*. Starting in the *BendDesk* position (one horizontal screen in front of a vertical screen) the screen in the back

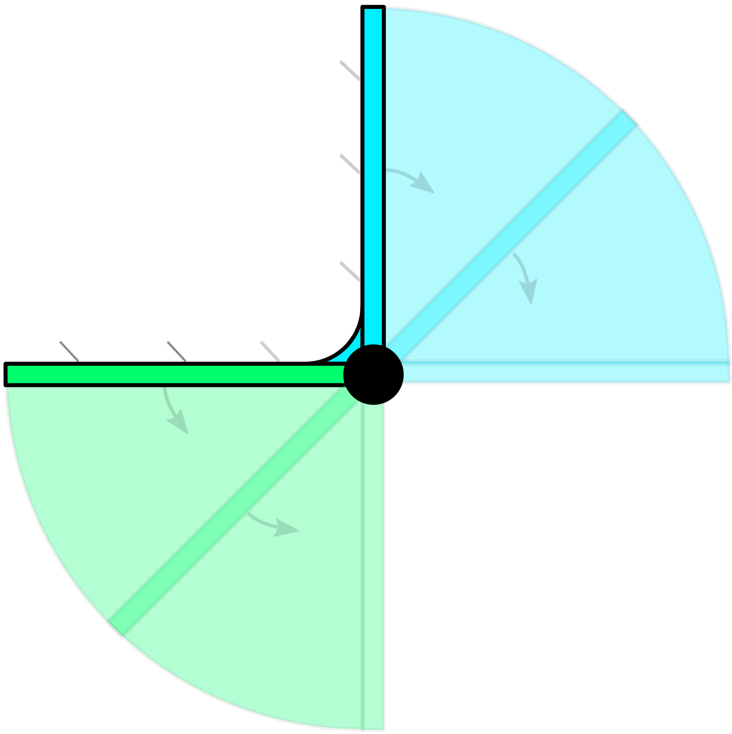

Figure 1.1: Possible screen positions for the new system

of the new system should be able to tilt down from $90°$ to $0°$, while the screen in the front should be able to tilt down from $0°$ to $-90°$ (Figure 1.1). The independent movement of these screens can be controlled by motors, to allow exact, reproducible positions that can be adjusted in real time to the users task.

Flowdesk, a prototype of a combined system

In this thesis we present *Flowdesk*, a first approach on a prototype of such a combined system (Figure 1.2). This prototype consists of two independent movable screens and is controlled by a computer that has the opportunity to adjust the screen position dynamically to the users task. The focus for this form factor prototype lies on the aspect of screen movement. The *Flowdesk* does only include normal computer screens and not touchscreens yet and does have a sharp edge between both screens instead of a bent surface. These features could be added in the future, when an advanced prototype will be build based on our system.

Figure 1.2: *Flowdesk* is a screen system with two independently movable screens that can adapt dynamically on the users task.

prototyping and evaluation of *Flowdesk*

The goal of this thesis is to describe the process of idea generation and prototyping that led to *Flowdesk* and to outline the hardware and software specifications of the final version of this system. We evaluate the system on two use-cases: a standard work environment in an office and a special case where the system is used for graphic applications. For both cases the *Flowdesk* should provide at least a normal desktop interface with the user sitting in front of the screens, a table interface for multiple users standing around the screens and a third interface for interaction where the user stands in front of the screens.

We now give a short overview over each chapter and its content:

Chapter 2 - "Related Work"
In this chapter we take a closer look at *BendDesk: Seamless Integration of Horizontal and Vertical Multi-Touch Surfaces in Desk Environments* and *FLUX – A Tilting Multi-Touch and Pen Based Surface* as well as other publications that inspired this work.

Chapter 3 - "Prototyping and Idea Generation"
In this chapter we discuss the initial design considerations as well as the process of idea generation and prototyping. The focus of this chapter lies especially on the technical challenges that occurred during this prototyping process and how these problems were solved or worked around to create the final prototype.

Chapter 4 - "Hardware Specifications"
In this chapter we present the hardware specifications of the final prototype and go into detail on technical aspects like the mounting of the screens, hardware sided safety mechanisms or the general motor control.

Chapter 5 - "Software Specifications"
In this chapter we describe the software used to control the movement of the screens and take a look at the software sided safety mechanisms.

Chapter 6 - "Usecase Analysis"
In this chapter we evaluate the full prototype that is presented in chapter 4 and 5 and how it is suitable for the use cases *"office workspace"* and *"graphic application workspace"*.

Chapter 7 - "Summary and Future Work"
In the final chapter, we summarize the previous work and give an overview over possible extensions of the system. Additionally we describe the current possibilities our system offers for future research.

Chapter 2

Related Work

Despite the fact that computer screens exist for more then 40 years, they are still an ongoing topic in current research. New interactive systems and ideas are published every year. The TV series *Black Mirror* shows in one episode a future screen system, used for graphic applications [1] that looks very similar to the systems *BendDesk* or *Curve* (described later on). Only a few month after we started working on *Flowdesk*, *Lenovo* introduced the *YOGA Book*[2], a two-screen device that is based on a similar concept. This shows that new ideas for screen systems are relevant today.

screen ergonomics are still important

This thesis was inspired by different publications, the main one being *BendDesk*. The main idea behind our system was to take the advantages from *BendDesk* and combine them with concepts of other interactive screen systems. This chapter will discuss the concepts of these systems and give a short overview over *BendDesk*.

Buxton [1996] introduced the *Active Desk*, a digital drafting table consisting of one big screen that was specialized for graphic design. Buxton [1996] already mentioned that in this system there is no desktop computer because the desktop is the computer.

the *Active Desk*

[1] Black Mirror (2013), Season 2, Episode 1: "Be Right Back"
[2] http://www.lenovo.com/

Figure 2.1: The *FLUX* system that has one tiltable screen surface [Leitner et al., 2009].

systems for graphic design

Based on the concept of graphic design Leitner et al. [2009] introduced *FLUX*. Similar to *Active Desk*, *FLUX* consists of one interactive screen surface. This surface is touch-sensitive and supports multitouch and multiple pen interaction. To enable a variety of interaction modes, this screen has been made tiltable and due to this can be used as a drafting table, a discussion table or even a presentation whiteboard (Figure 2.1). *FLUX* has an embedded accelerometer that tracks the rotation of the screen surface and allows applications to dynamically adapt on the position of the screen. Leitner et al. [2009] mentioned that different tasks need differently angled screen surfaces that cannot be provided by one static screen. The concept of a tilting screen allows increased flexibility, usability and productivity because all the advantages of different screen positions are combined in one system.

The major drawback of systems with just one, flat screen is that they are only useful for one simple task at a time. Even modern desktop workspaces consist of a vertical screen and a horizontal desk with input devices (for example mouse, keyboard or in some cases graphic tablets). Morris et al. [2007] conducted a user study where users were given reading and writing tasks on different screens in different positions. They explicitly told the participants that they were allowed to change any aspect of their workspace to be more comfortable. Morris et al. [2007] observed that all the participants that were given tablets lying flat on a horizontal desk, actually moved these tablets or even picked them up. 50% of these users preferred a tilted position of these tablets. A similar result could be seen when the users were confronted with horizontal displays. Some users raised the height of the desk, to work in a standing position, others tilted the screens to reach a drafting table like position. They found out that the users were generally uncomfortable with reading on a horizontal surface. Additionally the users liked the freedom to move the tablets, but disliked the inability to move information from one tablet to another and the lack of a keyboard. Based on the findings of their study, Morris et al. [2007] recommend a hybrid approach for screen systems with support for digital reading tasks that combines horizontal, vertical, and repositionable surfaces in order to capitalize on the affordances of the different positions. They also suggest that users should be able to adjust displays to their preferences and that the system should be highly configurable because the users preferred different angled screens for different tasks.

systems for reading and writing tasks

Such a hybrid system was introduced by Voelker [2010]. The *BendDesk* combines a horizontal and vertical surface with a curve to create one seamless multitouch desk (Figure 2.2). Corresponding to the users task the user is able to drag documents, files or application windows freely from the vertical to the horizontal surface or vice versa. Therefore this system allows users to work on different tasks that require different screen positions, on just one system. The*BendDesk* is designed to replace a normal desk at a work environment and has the ability to place objects like a mouse a keyboard or a coffee mug on the horizontal surface.

hybrid systems

Figure 2.2: The *BendDesk*, a desk with a bent multitouch surface [Voelker, 2010].

A very similar system to *BendDesk* is the *Curve* [Wimmer et al., 2010]. This system consists of a bent screen as well, with the main difference being that the vertical screen is tilted backwards by $15°$. Wimmer et al. [2010] built their system based on a user study and found out that users preferred this angle because the users fingers were able to rest on the surface. This allowed more precise input when the users rested the whole hand on the surface.

Chapter 3

Prototyping and Idea Generation

The first idea that later led to this thesis, was to take *BendDesk* by Voelker [2010] and make the screen surface movable. This would open up the opportunity to use the system for more tasks. However, to make this goal achievable a lot of initial design considerations had to be made and many problems had to be fixed during the process of prototyping.

BendDesk with movable screens

3.1 Initial Design Considerations

Already in the chapter *"Ergonomics"* of the *BendDesk*-paper, different screen orientations were considered (Figure 3.1). For the final version they chose option a) because it provided the most general usecase. If the screens of *BendDesk* would be able to move independently, it would be possible to cover most of these positions as well as additional positions.

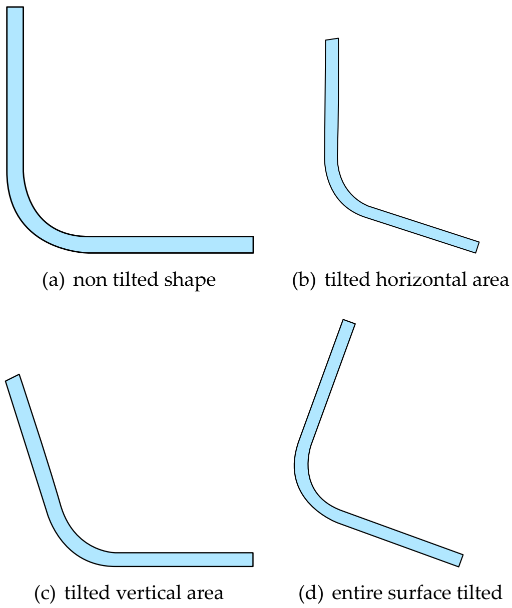

Figure 3.1: The screen positions considered for *BendDesk* [Voelker, 2010].

system with multiple screen segments

Our initial idea behind *Flowdesk* was to use an approach with multiple screen segments, connected to each other with motors that built the structure for the touch surface (Figure 3.2). We planned to provide the touchscreen functionality similar to *BendDesk*, where projectors and an IR-touch technology (FTIR) was used. This concept provides in theory create any screen layout a user could think of, when given enough segments. To keep down the complexity of our system, we reduced this initial consideration to a screen concept consisting of two screens. For nearly every task a user performs at a computer workspace, a third, differently angled screen does only bring a very small advantage over a system with just two screens. These initial considerations are similar to the system, described in the introduction that combines the advantages of *BendDesk* and *FLUX*. The upcoming chapter will outline how these initial considerations evolved into a working system while running through different prototyping cycles.

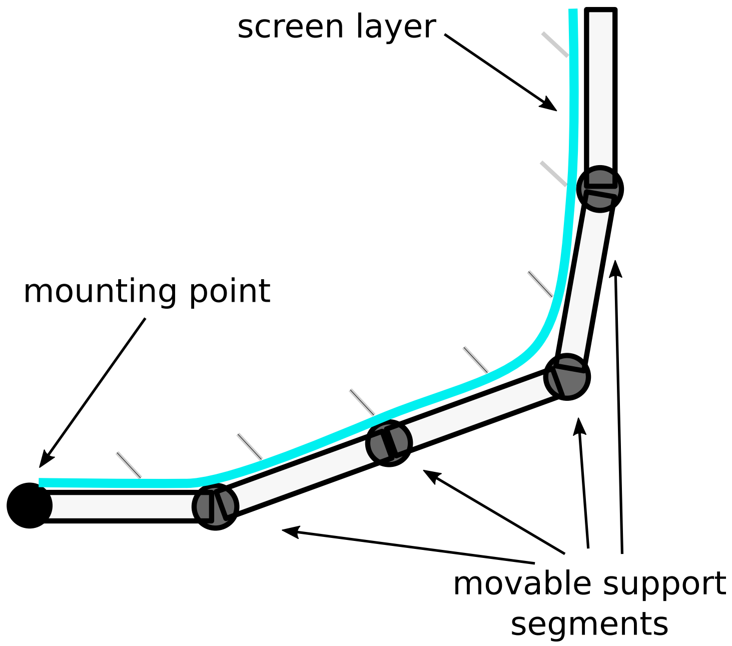

Figure 3.2: First conceptual idea for the system with many movable screen segments connected to each other with motors.

3.2 First Prototypes

The main concept behind the prototyping process was to focus on the most difficult and game breaking parts of the system first and when these were set, work on the dependent parts correspondingly.

The first bottleneck of our system was the general movement mechanics. In the initial considerations the first screen was connected to the table and the second screen was connected to the first screen (Figure 3.3). To keep the mechanical construction simple the only valid solution was to place the motor for the movement control into the axis between the first and the second screen. To allow precise movement and stability of our system this motor had to be enormously strong. The motor in the axis between the table and the first screen had to be even stronger because he had

problems with general movements mechanics

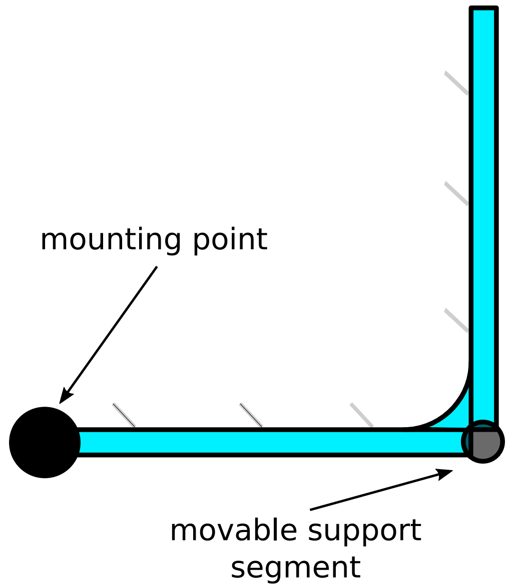

Figure 3.3: Second conceptual idea for the system with two screen segments connected to each other with motors.

to carry the whole weight of both of the screens. Even if it would have been possible for us to get motors this strong, small inaccuracies in any parts of the system would have led to severe consequences like crashing. This mechanical concept had to be replaced by a more simple and stable one because it was not only complicated to build but would lead to unsatisfying user interaction because of its instability.

move screens with gear racks

Our second approach on the mechanical construction was to move the main mounting axis of both screens to the middle and move them with gear racks connected to the screens (Figure 3.4). This would allow both screens to move independently of each other. Because both screens are mounted to the table in the middle and are just moved by gear racks, the main force from the weight is applied to the table and distributed over the rack instead of lying directly on the motors axis. This allows more precise motor control and a stable system. To test how such a system would work and how long the gear racks had to be made, we built a small

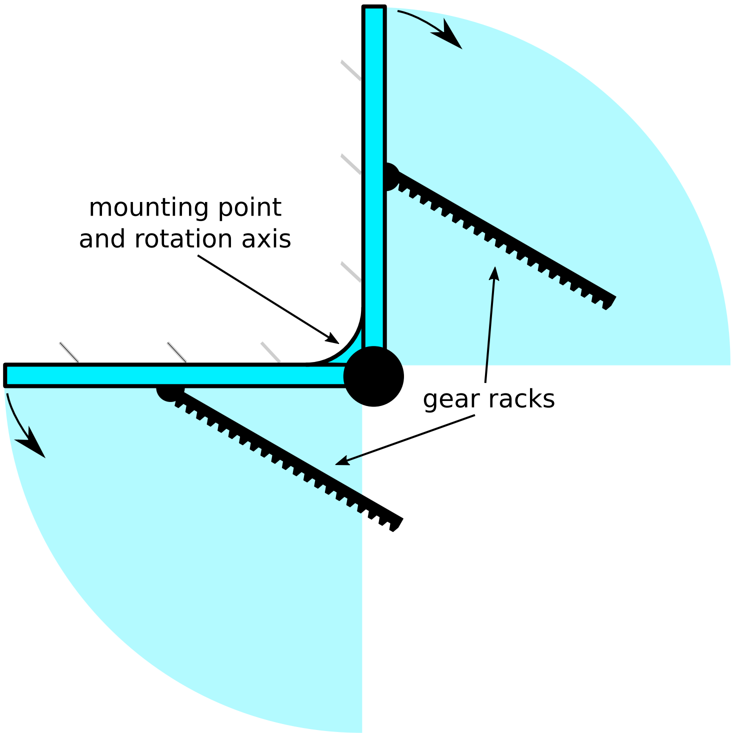

Figure 3.4: Third conceptual idea for the system with two screen segments connected to a central mounting point.

LEGO[1] prototype (Figure 3.5). This prototype showed that the gear racks can be placed under the screens without overlapping with other parts of the system or hitting the users. The connection between the gear racks and the motor can be done by just one gear and a movable part that holds the rack (Figure 3.6).

Another difficult part of our system, besides the movement mechanics, was the integration of screens in the construction given. The first approach to this was similar to *BendDesk* and considered projectors to throw an image on a surface from behind. In *BendDesk* there were two projectors mounted to the ground, one for each screen (Figure 3.7). To test this approach on movable screens we positioned a projector on the ground and projected the image in a 45° angle on a hand held surface. When tilting the surface by

screen tests with projectors

[1]http://www.lego.com/

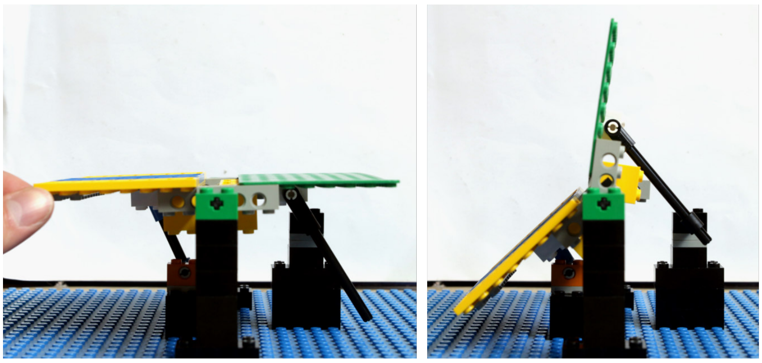

Figure 3.5: *LEGO* prototype for testing with different gear rack angles and length for the system.

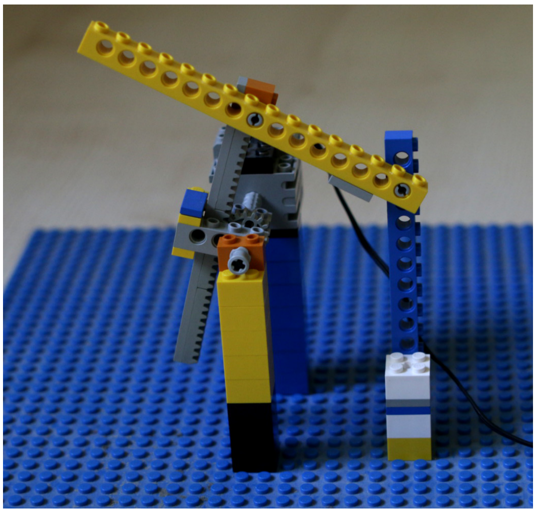

Figure 3.6: *LEGO* prototype for testing the movement mechanics and gears of the system.

$+45^\circ$ the image on the surface got distorted to an unusable amount. This showed us that even if we would straighten out the image with an algorithm, the drop in resolution would result in a bad performance of our system. This effect would even get worse because this straightening had to be applied differently for every angle the screen can be in. The only reasonable solution we could think of was to connect the projectors directly to the screens and move them together.

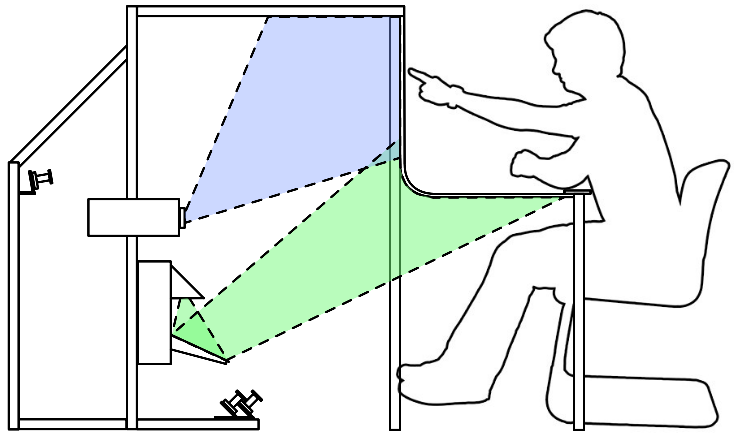

Figure 3.7: The projector setup in *BendDesk* [Voelker, 2010]

For this approach we first took a look at mini projectors because they are very light in weight and therefore easy to move. Besides the low resolution of these projectors, a main issue was the minimum focus distance. Because these projectors are so small, they do not have big lenses build in them that allow a small focus distance. This led to a minimum distance between the screen and the projector of about 1.5 meters, what made them unusable for our system. With a minimum focus distance of about 0.7 meters, a short throw projector was a more suitable option for this job. After mounting this projector to a aluminum rig, we had a projector that could produce a high resolution image, in a reasonable size, from a good distance (Figure 3.8). But this solution still had a big flaw. Because the projector was 0.7 m away from the rotation axis, it was too heavy to be moved by motors.

projectors are either to heavy or minimum focus distance is to high

This led to a completely new approach. Instead of moving projectors and having just one surface, we decided to move two simple touchscreens. Even if continuity of one seamless surface gets partially lost with this approach, it still allows basic interaction with the system and should be an achievable option. After looking at different touchscreens that are available to purchase, it quickly became clear that most of these screens have bezels bigger then 2 cm. This would led to a total bezel of 4 cm between both screens and

move simple screens

Figure 3.8: Projector prototype that allowed testing of the minimum projection distances, general mounting and how much force is needed to move the frame.

therefore to a complete loss of the screen continuity. Even most of the normal computer screens had a frame around them with a width greater then 2 cm.

The final approach on this problem was to take two normal computer screens, disassemble them and only take the parts that are needed to build a new, lighter screen with a small edge on one sight. For this approach we used two *Apple Cinema HD Displays*[2] (more details can be found in chapter 4: *Hardware Specifications*). Because these displays were really heavy, we tried to minimize the amount of parts we took from them. After some tests, we managed to reduce the amount of components to the glass plate of the backlight, the actual screen-plate and the basic circuit boards. Our idea was, to build theses parts into a movable system and try to add touchscreen functionality in a future prototype. All of the touchscreen overlays we considered for the first prototype had a minimum edge of 3 cm where conductor tracks were running through. With direct control over the complete framing of the screen, we were able to achieve an edge of $\sim 0.5cm$ per screen (Figure 3.9). This approach made it possible to build a first screen prototype.

build our own screen casings

[2] http://www.apple.com/

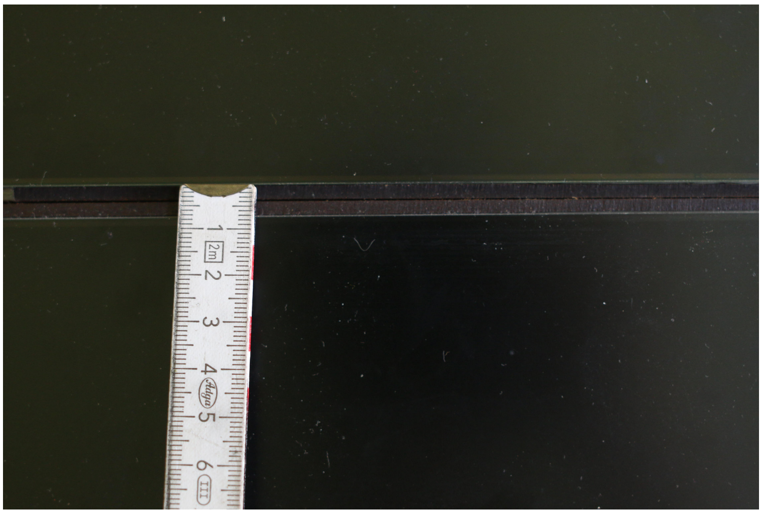

Figure 3.9: Gap between the two screens in *Flowdesk*.

3.3 Screen Prototype

The first prototype for the movable screen was held simple and consisted only of the glass plate from the original backlight, LED strips, and a simple casing. Because the original glass plate was too heavy we made the attempt to replace it with acrylic glass, but after some tests we found out that the even light distribution was only given with the original plate. To have better control over the backlight and to make the system weight even smaller, the original lights of the backlight where replaced by LED strips that offered a better performance while taking less space. Then we used a lasercutter to cut *POM* [3] and *MDF* [4] to build a simple case to hold the glass plate and the LED-strips. Afterwards we used ball-bearings to connect this case to aluminum profiles (Figure 3.10). For the second iteration of the screen prototype we used the casing files of the first prototype and added additional mounting places for the electronics of the screen and the gear rack. The mount for the gear rack had different holes to allow for different testing positions where the rack gets attached (Figure 3.11). Additionally a first framing to hold the prototype was

first casing prototypes

[3]Polyoxymethylene

[4]Medium-density fibreboard

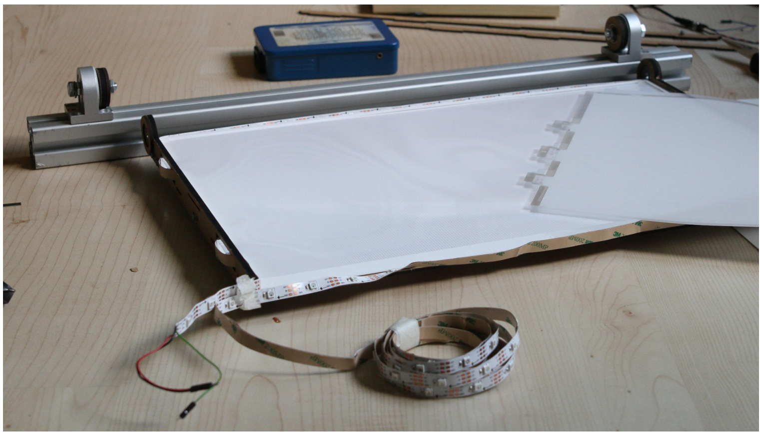

Figure 3.10: Backlight prototype for testing the LEDs and a simple mounting.

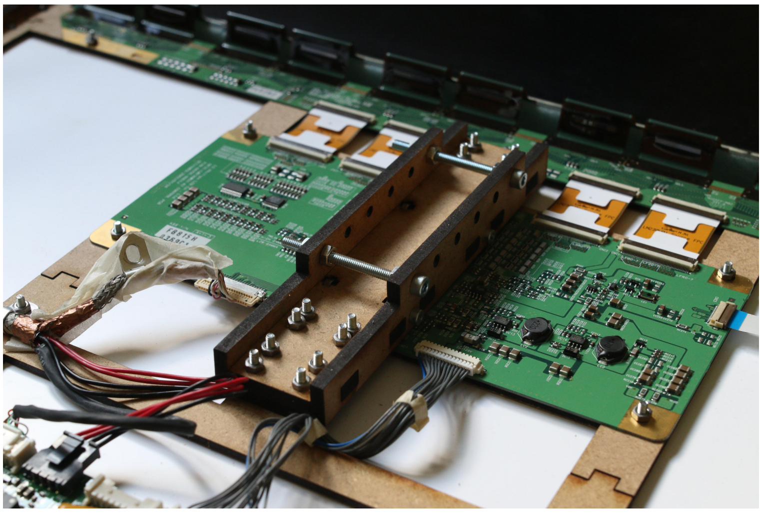

Figure 3.11: Prototype for the rack holder with different mounting points.

build out of aluminum profiles (Figure 3.12and 3.13). With this setup it was possible to go on with further motor tests.

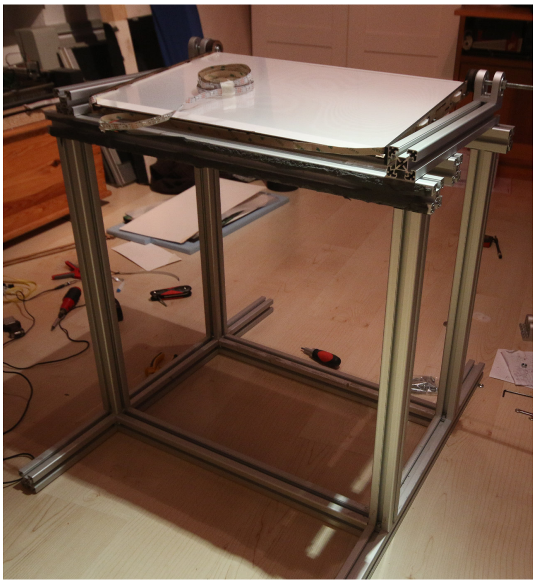

Figure 3.12: First framing prototype that allowed testing manual movement of the backlight and first motor tests.

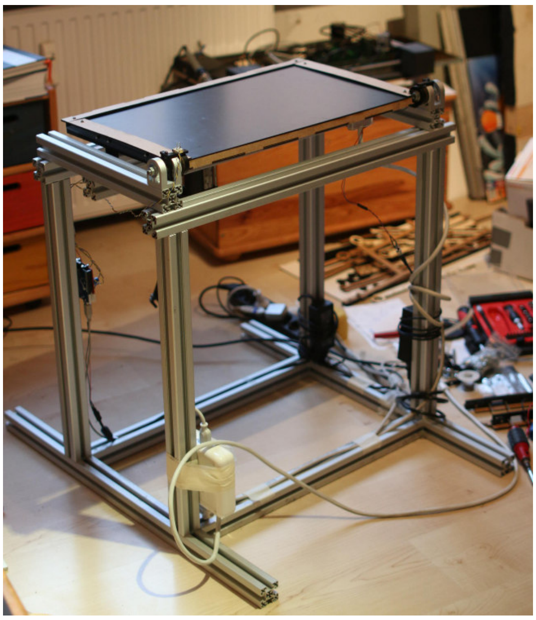

Figure 3.13: Second framing prototype that allowed movement tests with a working screen.

3.4 Motor Prototype

The motors we used were special gear motors that would lock themselves, when no power was applied. This prevents the screen from crashing, when the power connection of the whole system is lost. Additionally this leads to more stable screen positions because the motors hold the positions by themselves. Before testing the motors on the prototype, we first measured the weight of the screens and then used the motors to lift a similar weight. These tests where useful as well to check if the motor drivers and the microcontroller worked as planned. We then used *POM* for the gear rack and gears and tested their stability with the weights as well. All these components had to hold the weight because if they would crash later on they would harm the system badly. After these tests where successful the first movable system could be build. We connected the motor to the aluminum frame, mounted the rack and the case with the screen, but left the actual screen electronics and overlay aside, to be sure to only damage the glass plate if anything would go wrong. To make first software tests possible, end switches where added to the aluminum frame and both the switches and the motor drivers were connected to a microcontroller. With this setup it was possible to program first routines to control the movement, check for endstops and assure different safety mechanisms that would provide the system from destroying itself (more information in chapter 5 *Software Specifications*).

first motor tests with the casings

With these general conditions met, we could focus on the building of the casing for the screens. This process was done in many small iterations, where a lot of case pieces were produced. With every iteration, problems from the previous iterations were fixed. To allow rapid prototyping plywood was used. One of the prototypes is shown in (Figure 3.14). Because of the high complexity of the system, given by the many electronic and mechanical parts, a lot of small details had to be improved over time, to create a working casing that holds the backlight and the screen secure. The final casing version was build two times, for both screens and mounted to the aluminum frame. This led us to software fine tuning for operating with two screens. Af-

casings go through many iterations of prototyping

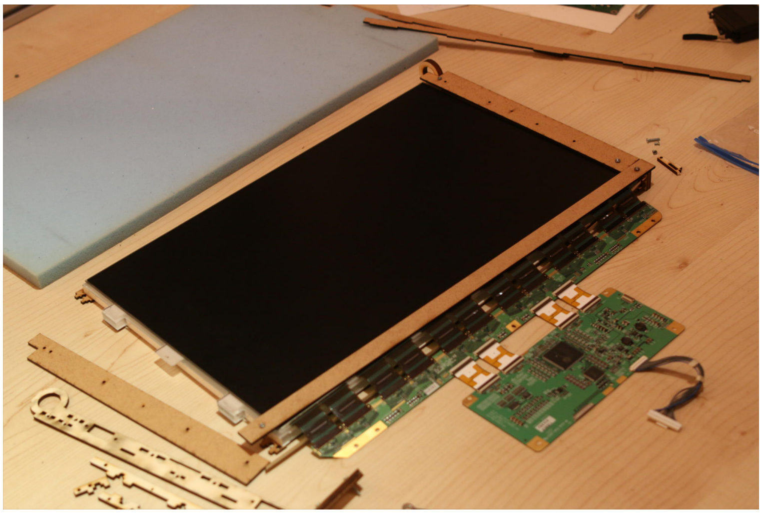

Figure 3.14: Screen casing prototype made out of plywood and *MDF*.

ter everything worked movement wise with both screens, we were able to mount both screens on the final version of the aluminum frame and adjusted small details of the new system.

The exact hardware and software specifications of the final version will be described in the upcoming chapters.

Chapter 4

Hardware Specifications

The hardware setup of *Flowdesk* consists of different mechanical and electrical parts that work together to realize a system with movable screens. In the following we will go into detail on these parts and describe how they are build up and what their function is in the system. We will start with an overview over the system and then focus on the technical aspects of the screen casing and the components mounted to the framing.

describe hardware setup

4.1 System Overview

Figure 4.1 shows the final state of the screen system. The main framing is build out of aluminum profiles and holds the motors, electrical components and the screen casings. Both screen casings are set up identically and hold the same electronics. The only exception is the mounting where one casing has the ball bearings outside, to allow a symmetrical build up while rotating around the same axis (Figure 4.2). The casings are mounted towards each other on this axis to create one seamless screen surface. Both screens have screen diagonals of 23 inches and a resolution of 1920 x 1200 pixels that add up to a combined resolution of 1920 x 2400 pixels. The total screen size is 49.5 cm x 63 cm. The rotation axis of the screens is at a height of 99 cm to allow likewise

system consists of two casings and aluminum framing

Figure 4.1: The complete system setup of Flowdesk.

interaction in a sitting and standing position (Figure 4.3). The top screen is able to rotate down from $90°$ to $0°$, while the bottom screen can rotate from $0°$ to $-90°$. The complete dimensions of the system as well as the possible positions of the screens are shown in Figure 4.4 (all aluminum frames have a diameter of 4 cm). The details of the screen casings and the system framing are outlined in the next two sections.

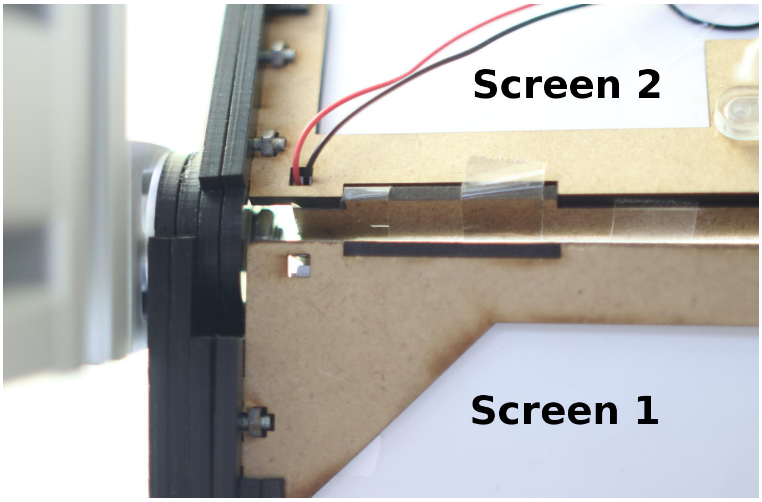

Figure 4.2: Intersecting parts of the screen casings used in our of system.

Figure 4.3: *Flowdesk* allows for likewise interaction in sitting and standing position.

4.2 Screen Casing

The screen casings are the movable segments of the system that hold the screen electronics and the backlights of the screens. They consist of many different, interlocking parts that are designed and laser cut especially for this system.

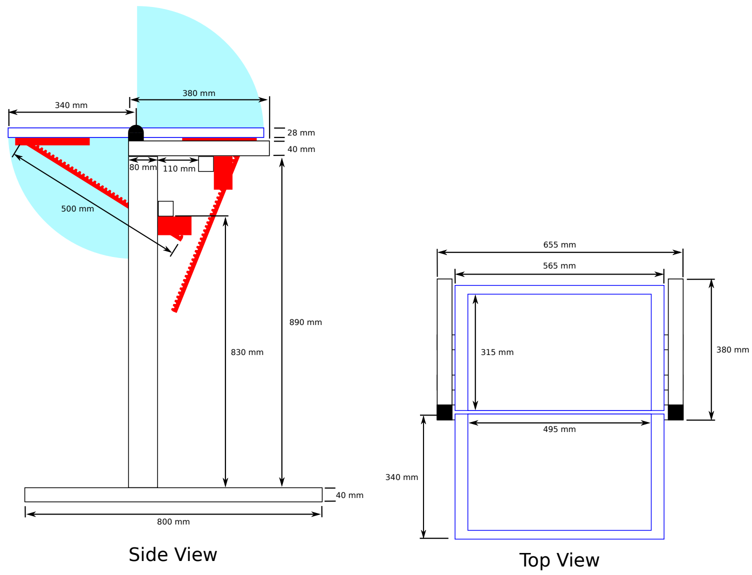

Figure 4.4: Technical overview of the system with dimension specifications.

4.2.1 Screen Electronics

use only minimum electronics from screens

For the screen electronics we used two old *Apple Cinema HD Displays*[1] (modelnumber M8536, made 2002). We extracted only the minimum hardware that was needed to run the display and removed all other parts of the framing and electronics because of their weight (standard display casing: $\sim 11.5kg$, selfmade casing in this system: $\sim 3kg$). Figure 4.5 shows these minimum electronics. The big black screen is connected to a big and a small circuit board on two sides. Both of these circuit boards are connected with a small ribboncable and manage the image processing of the screen. The second big circuit board is used for the power supply management and is hooked up to the screen circuit board as well as to the cable that connects the screen to the PC. This cable transfers both the power supply and the image signal to the display.

[1] http://www.apple.com/

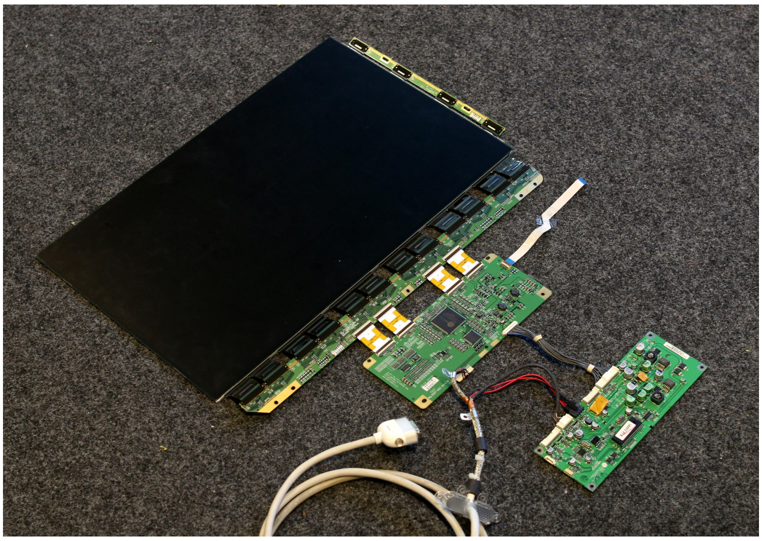

Figure 4.5: Minimum screen electronics required to run the screen

4.2.2 Backlight

An important part of a display is the backlight. Without an additional light source behind the actual screen layer, it would be impossible to see an image on the screen. To make the system even lighter in weight, but still remain the original brightness distribution of the screens we used the backlight parts of the original *Apple Cinema HD Display* but replaced the old light source (that was connected to the heavy metal framing) with LED strips. The backlight consists of a glass plate with a riffled white side for light distribution and three plastic layers that work as diffusors (Figure 4.6). For each backlight two LED segments are used that light the glass plate from the long side. Each LED segment has a height of 1 cm and a length of 53 cm and consists of two strips of warm/white *2835 SMD* LEDs that are soldered together and glued next to each other on a stripe of cardboard (Figure 4.7). With a density of 240 LEDs per meter these segments are able to generate more then enough light to replace the original light source. The LED segments, the glass plate and the diffusors are held in place by the actual casing and the covers mentioned in the next section.

backlight consists of glass plate and diffusors

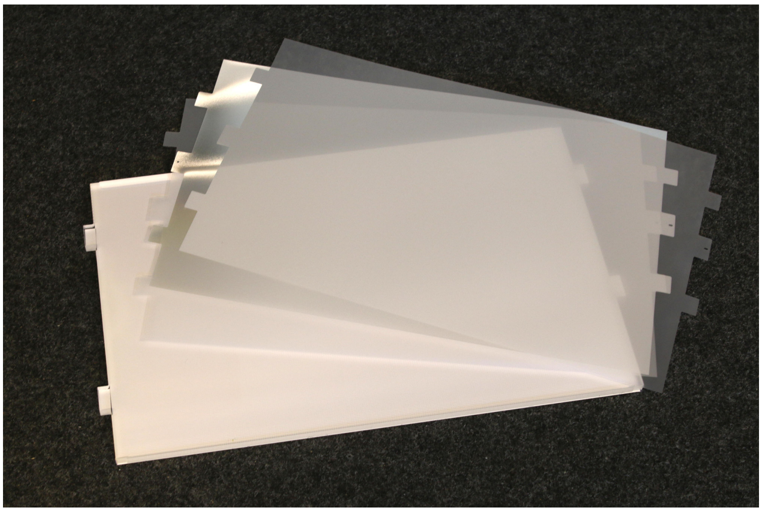

Figure 4.6: The backlight components used in our system consisting of glass plate and diffusors.

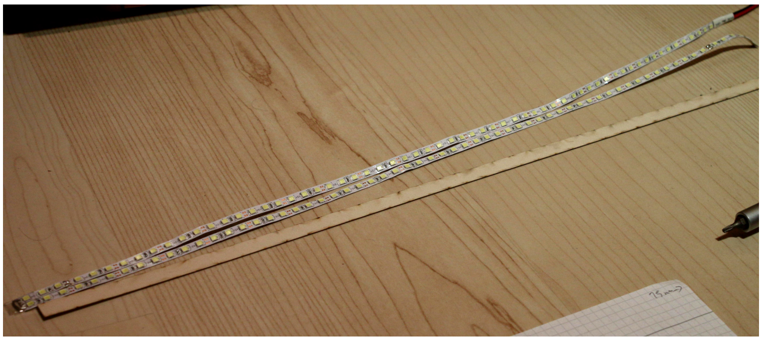

Figure 4.7: One of four LED segments that illuminate the backlights.

4.2.3 Casing

The basic casing consists of a base plate, two side parts (that hold the weight and are connected the axis) and covers that hold the screen in position and close the casing. All the parts had to be designed especially for this purpose and ran through different iterations to allow exact positioning of all the mechanical and electrical parts.

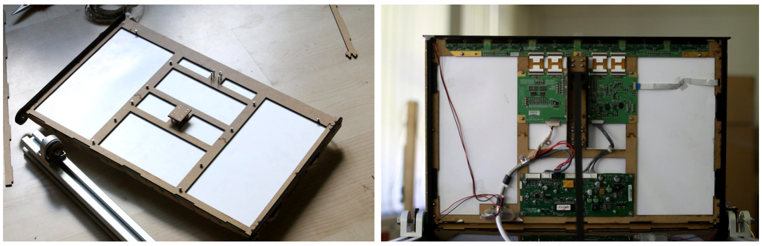

Figure 4.8: The *MDF* baseplate that holds the screen casing together.

Figure 4.9: The *POM* side part of the screen casing.

The baseplate itself is made out of two pieces of 3 mm *MDF*. These pieces form a framing to hold the backlight in position and mount the electronic of the screen behind the backlight (Figure 4.8). On the short sides of the baseplate the plate is connected to the side parts (Figure 4.9). The side parts are build out of different layers and interlocking pieces of 4 mm *POM*. They are held together with m3 screws and have 25 mm holes on one side to hold the ball bearings. The u-elements seen in Figure 4.9 are holding the backlight. The diffusor layers are held in place by special screws (Figure 4.10). The actual screen is positioned on the diffusor layers and held by the covers that are locked in position with vertical screws. This setup is illustrated in (Figure 4.11). To cover up the backlight and to hold the LEDs we used two pieces of *MDF* that are connected to the long side of the baseplate.

casing consists of baseplate, sideparts,backlight and screen electronics

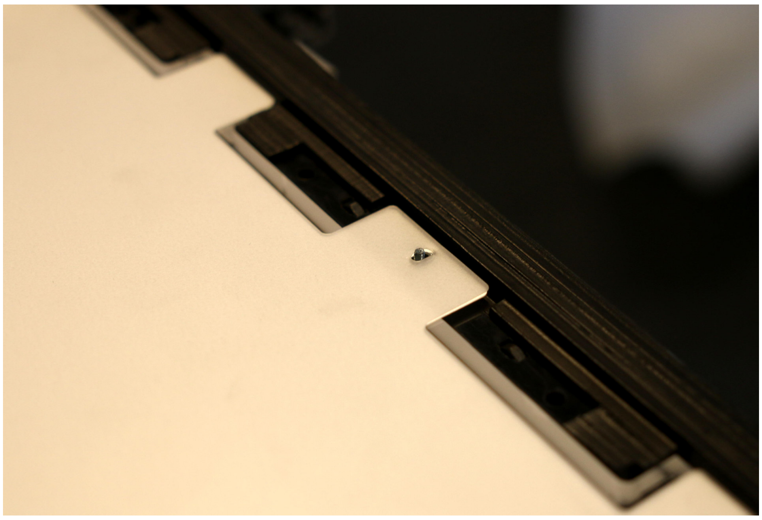

Figure 4.10: The pin that holds the diffusors in position.

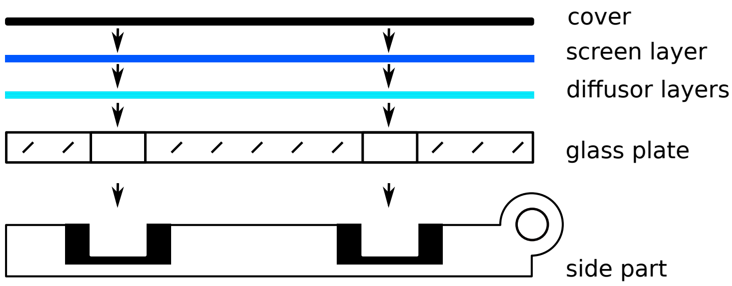

Figure 4.11: This sketch shows the mounting of the screen casing.

4.2.4 Stability Considerations

To assure the stability on one hand but a lightweight casing on the other hand, a trade-off had to be made construction wise. The side parts are made out of light *POM* that can resist stronger forces and therefore hold the weight of the heavy screen and glass plate. For the electronics and other less heavy or critical parts the framing is made out of thin *MDF* that is even lighter in weight than *POM*.

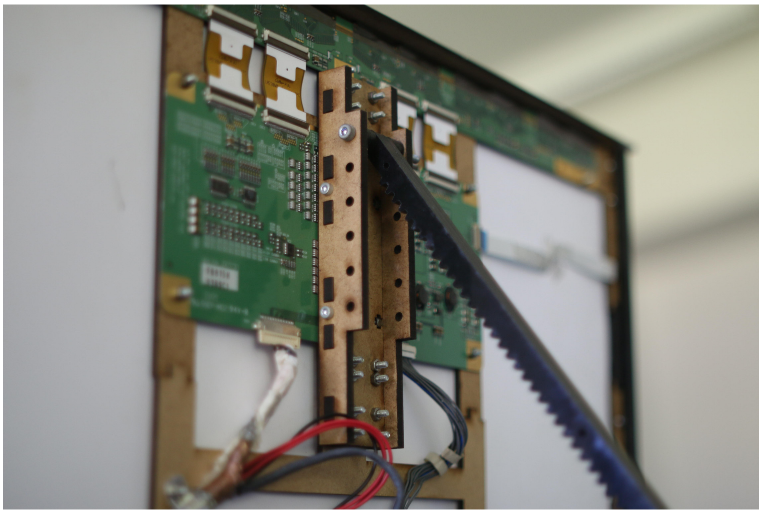

Figure 4.12: The connection between the gear rack and the screen casing.

To distribute the weight of the screen equally over one surface the connector for the gear rack is placed directly under the baseplate (Figure 4.12). The connector does not touch the electronics and only applies the force to the baseplate and from there directly on the heavy glass plate and the side parts. This allows safe and controlled movement of the whole screen casing.

equal force distribution grants stability

4.3 System Framing

The system framing holds all important parts of the system together and grants stability. It is built out of 4 cm x 4 cm aluminum profiles that can hold heavy weights. Mounted to the framing are the screen casings, hardlimits, the motors, gears and driver electronics as well as the power supplies. Additionally there is a mount next to the system to hold a computer that uses the screens.

system framing holds all parts of the system together

Figure 4.13: The end switches that allow for basic tracking of the screen position.

4.3.1 Rotation Axis and Hardlimits

end switches are used for positioning

The screen casings are connected to the system framing on one axis. On one side, close to the axis, there are hardlimits with end switches mounted on the aluminum frame. They detect when the screens reach this position (Figure 4.13). Two more hardlimits with end switches are mounted close to the motors to detect when the screen reaches the opposite side. The switches are mounted on black *POM* pieces that block the screen in emergency situations when the switches fail to detect the screen casings. These total of four switches are also used to check the position when moving the screen to certain positions (homing cycle) and stop unwanted movement. More information on these software side safety mechanisms can be found in the chapter 5 *Software*.

4.3.2 Motors and Gears

worm gear motors guarantee stability

The motors that move the screen casings had to met different conditions. Obviously they had to lift the weight of the screen casings but also had to accomplish a certain speed so that the screens reach the desired position in an acceptable time. Because the screens should be used later on for touch interaction and should be able to hold the weight of a resting hand (for example in graphic applications) the motors had to be able to hold their position without giving in. To meet all these conditions, we used a 12V DC-motor

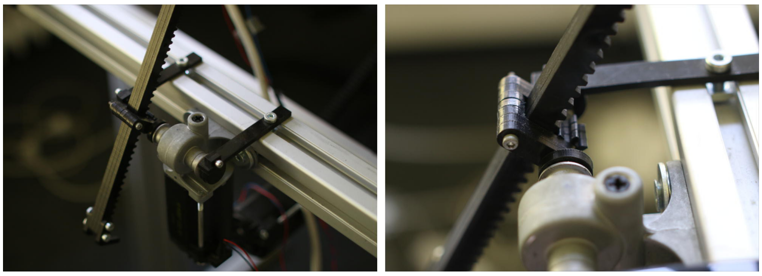

Figure 4.14: The motor that moves the screen shown together with gears and gear rack holder.

(MY2007U222) with a torque of 18 Nm, 580 revolutions per minute and a build in worm gear. The worm gear and high torque allowed strong movements while the high rotation speed of the motor still granted an acceptable movement speed. Additionally, because of its mechanical characteristic, the worm gear made sure the screen casing would stay in position when the motor stops moving and further more hold the position when the system is not connected to a power supply. This is an important characteristic because it would be very unfortunate if the screens would immediately crash down when the power supply gets disconnected.

The motors are mounted directly on the aluminum frame together with *POM* parts that hold the motor axis (Figure 4.14). The gear rack is held close to the gear by a special holder that can rotate freely around the motor axis. The gear rack itself has a length of 50 cm and is laser cut out of 4 mm *POM* similar to the gear and the holder. To grant extra stability we combined three layers of the 4 mm material to gain a total of 12 mm thickness for extra stability of the rack. To prevent the rack from running out of the gear (when it reaches the end of its length) we mounted a stopping mechanism at the end of the rack. The other end of the rack is attached directly to the screen casing.

gear racks move the screens

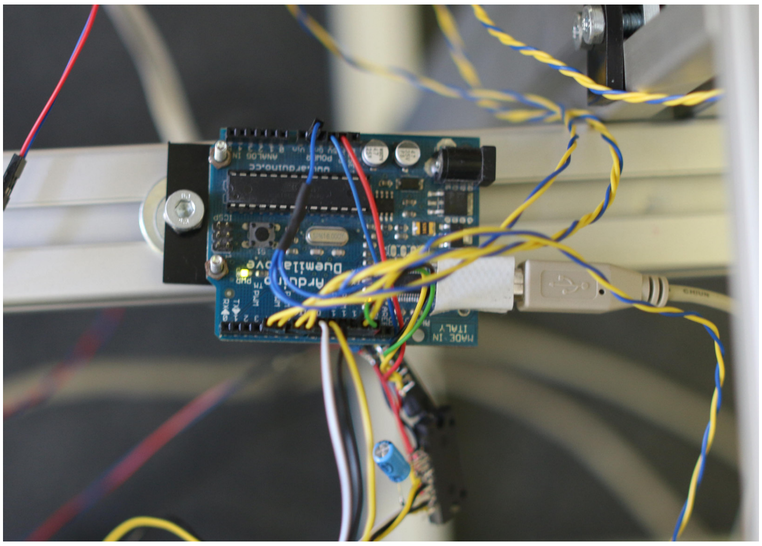

Figure 4.15: The microcontroller *Arduino Duemilanove* that controls the movement and establishes a connection to the computer.

4.3.3 Driver Electronics and Power Supply

microcontroller controls motor movement

The motors are controlled by two *STK681-360-E* motor drivers. These are soldered together in the standard usage configuration and connected to an *Arduino Duemilanove*. The *Arduino* runs the software described in the upcoming chapter 5 and sends signals to the motor drivers that then move the motors. The end switches are plugged into the microcontroller as well and are also managed by the software. The technical setup of these parts is shown in (Figure 4.15 and 4.16).

On the left side of the framing is a mount for a computer that in our case holds a *Mac*, that runs a demo application. Both screens are connected to this computer with *DVI* cables. The microcontroller is connected via an USB-port and is controlled through a serial connection from the demo application. To power all the system components a number of different power supplies are used that are also attached to the aluminum framing. The screens are powered with their default power adapters. The microcontroller is powered over the USB cable and LEDs are powered by a 4A

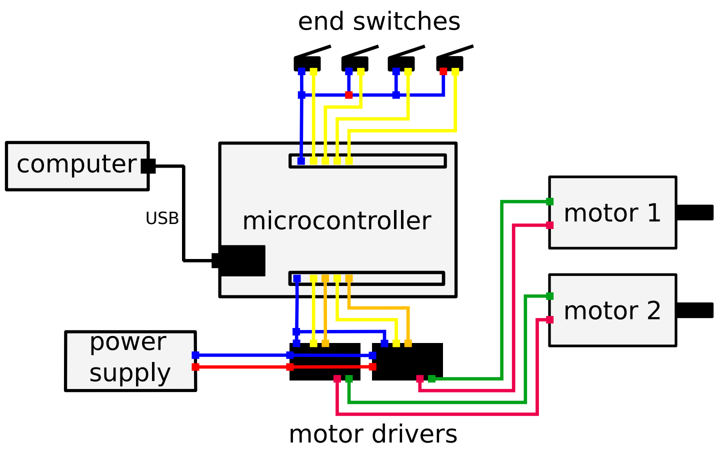

Figure 4.16: A sketch that shows the simplified technical setup of the system.

13V power supply. The Motors are powered with a 9V 4.5A Power supply.

All layout files for the lasercut parts can be found on the attached CD.

Chapter 5

Software Specifications

The main task of the software that runs on the microcontroller is to translate the input from the computer to motor commands that move the screen to the desired position. For this prototype we limited the software to allow five fixed screen positions which the system is able to reach. The reason for this will be discussed later on in this chapter.

software translates input

5.1 API

The microcontroller is connected to the computer via an USB-port and tries to establish a serial connection with a rate of 9600 baud. As soon as this connection is available the controller will start with the initialization of the motor driver ports and other software parts. As soon as the microcontroller is ready for input commands over the serial connection it will send the line *"Ready for serial input"*. If the computer then sends one of the characters 1,2,3,4 or 5, the system will try to move in the corresponding position. If the input is unknown the microcontroller will respond with an error message. The positions corresponding to the numbers can be seen in Figure 5.1. As soon as the microcontroller reads a valid input from the serial connection it starts the corresponding movement routine which itself runs different functions that control the movement of the motors.

the microcontroller accepts simple inputs and gives feedback

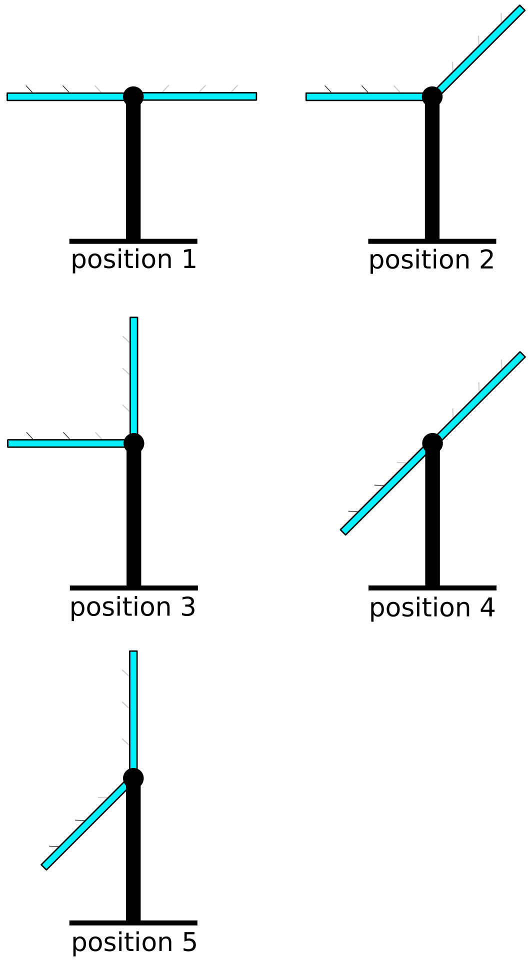

Figure 5.1: The software focuses on safe accessibility of these five screen positions.

While doing so the controller prints the current status of the system in the serial connection to allow better debugging. This status contains the homing cycles that get started, the motors that are being started or stopped, additional motor parameters or the errors the warnings that occurred during the run, for example. We will explain these functions in the next section.

5.2 Movement Functions and Safety Mechanisms

The reason why there are only five positions available in the software relies on to two facts. First of all the system does get too complex for a first user analysis if there were a lot of positions the screens could be in. Most of these positions would be similar and would not bring an advantage for users because users tend to stick to simple solutions. We selected the five positions according to the results of the *Usecase Analysis* 6. The second reason are safety considerations that were made for the system. In theory it is possible to move the screen to every desired position software wise. The problem that occurs in practice is that the more positions we use, the harder it gets to know where the system is because we depend on the motors to do the exact same thing every time they get the same command. This is not always the case and will be discussed later on in this section to explain the problems with safe moving and position prediction.

stick to five positions

The main problem when moving screens to certain positions is that the system does in most cases not know where the screens are. With the current hardware setup the only way to know where the screens actually are is when they hit the end switches. A second problem is that if we move the motors we can only turn them on with a certain power percentage for a certain time (because they are DC motors) and hope that they actually reach the desired position. If the screens are harder to move for some reason (when there is dust in the ball bearings or the gears fit not perfectly, for example) the motors might move slower or completely stop without the system noticing it. The power values we use to move the motors are shown in Table 5.1. These values already show that both motors need totally different power values to move the screens at approximately the same speed. A third problem is that both screens cannot be moved independent from each other. This is because both of the screens have the backlight under the rotation axis. If the angle between both screens would be greater then $180°$ the screen casings would crash into each other. These problems lead to only using five positions where the screens are

position of the screens hard to determine

	move upwards	move downwards
Motor 1	*60%*	*40%*
Motor 2	*100%*	*40%*

Table 5.1: The power values we used for the motors.

in $90°$, $45°$ or $0°$ positions and use software safety mechanisms.

use end switches to stop uncontrolled movements

The first safety mechanism is build into the lowest functions that try to move the motor in a certain direction for a certain time. If these functions detect that the end switches are getting triggered while moving the screen the movement is being interrupted and an error message is send out. This prevents the motors from crashing the system when they try to move further then the hardlimits.

use smart homing cycles

The second safety mechanism is the usage of smart homing cycles. Whenever the system has to move into a position where an end switch is available the corresponding homing cycle is called. This cycle moves the motor towards the switch until it gets pressed. This also allows to get the screens from unknown positions into known positions. Additionally the homing cycles have a timer that checks if the motors run too long in one direction without touching the end switches. If the motors take longer then a certain time the system assumes that the end switches have failed and stops the motors to prevent the system from taking further damage. The worst case times used in this prototype for all homing cycles are 4.5 seconds.

move safely close to the goal position first

The third safety mechanism is used in the functions that are called when the system has to move in one of the five desired positions. The idea is to bring the screens in a safe position close to the goal position first (with the help of homing cycles) and then move the screens to the final position without exceeding the $180°$ angle between both screens. This allows the screens to get to the desired position without knowing the start position.

```
Serial.println("Moving screens to position 2");
do_homing_cycle_top_2();
delay(200);
do_homing_cycle_bottom_1();
delay(200);
move_screen_1(MOTOR_UP, MOTOR_POWER_UP_1, BOTTOM_TO_45_TIME_1);
delay(200);
```

Figure 5.2: The code segment contained in the *position_2()* function that moves the screens in position 2 (shown in Figure 5.1).

Figure 5.2 shows the function that is called to move the screens into position two. At first we move the bottom screen to the $0°$ position (line 3). This can be done safely to do because in any case it does not violate the $180°$ angle between both screens. We then are safe to move the second screen to $0°$ position as well (line 5). We now have both screens in a safe and known position and only have to make the last adjustments to reach the goal position. For this we call the *movescreen*-function that moves the top screen in the upwards direction, with the given speed, for the given time that it (approximately) takes to reach a $45°$ angle. The system should now be in the desired position. The delays between the function calls are used to give the motors some time to actually stop their movement.

example of safe movement

With a hardware setup that allows better knowledge about the screen position it would be possible to implement a system that moves faster and more precise. This possibility is further discussed in the chapter 7.2 *Future Work*.

The source code that runs on the microcontroller can be found on the attached CD.

Chapter 6

Usecase Analysis

In this chapter we will give an overview over the tasks and applications where *Flowdesk* could bring improvements over current systems. To demonstrate this we focused on the usecases *office* and *graphic applications*. The goal was to find out which system characteristics are needed for different tasks and if our system is able to meet them. To get an quick overview over these characteristics we conducted unstructured interviews with users from both usecases and took a look at similar research. We will present the results in the upcoming sections. In the first section we will go into detail on the screen positions of the system and in the second section we will focus on the additional system characteristics that are important for the usecases.

unstructured interviews in two usecases

6.1 Position Analysis

One goal of the unstructured interview was to gather a small amount of example positions that cover most of the scenarios that appear in the usecases. We therefore asked the users what they usually do on the computer, how many screens they use and which screen position they prefer for different tasks. Additionally we talked about what they were missing in their current systems and most importantly which characteristics they would like to have for different

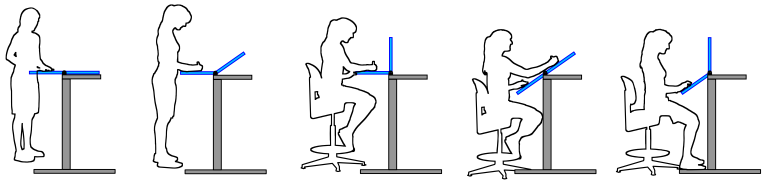

Figure 6.1: The screen positions of our system that cover the requirements from the usecases.

five positions cover the two usecases

tasks and why. From these interviews we acquired five general screen positions that cover most of the requirements for both usecases and can be achieved with our system. These positions are shown in Figure 6.1. The requirements proposed in our interviews and from user studies other researchers did, are described in the upcoming sections.

6.1.1 Usecase: Office

Most of the tasks on a computer, in an office environment, can be broken down to reading and writing. According to Morris et al. [2007], when given simple reading tasks users highly prefer vertical or tilted screens over horizontal ones. They also found out that some users liked to work in sitting and others in standing positions even when given the same tasks. In our interviews we got similar results. At modern workspaces users often like to have the ability to raise the table for ergonomic reasons, to work alternately in a standing and a sitting position. When sitting down, users tend to prefer the normal desktop environment for office tasks. Position 1 of our system represents this environment and gives the ability to place a keyboard on the horizontal screen if needed.

users like to work sitting and standing alternately

While standing in front of the system the users preferred an angled over a vertical screen for reading tasks because it allowed them to relax. The interaction area remained horizontal, similar to the sitting position. This led to position 2 of *Flowdesk*.

For brainstorming sessions the users emphasized that the screen system should allow multiple users to interact with it simultaneously. The system should have the ability to be accessed equally from all users standing around it similarly to a touch table. This is represented in position 3. Additionally Muller-Tomfelde et al. [2008] found out that a tilted table top in combination with a horizontal screen is fitting best for collaborative work. In their study they showed that users preferred this position over the normal screen setup with one horizontal and one vertical screen. Position 5 of *Flowdesk* is based on the setup Muller-Tomfelde et al. [2008] found out, the majority of their users preferred.

reading, writing and brainstorming afforded different screen positions

6.1.2 Usecase: Graphic Applications

In the unstructured interviews we also talked to users who use graphic applications at work and at home. These users told us that in general there are three different categories of interfaces. The first category consists of the actual drawing or working area. The second category of interfaces is used for input options. In this category are interfaces that hold the tool selection, general tool options, color selections or general settings for the working area, for example. The third category consists of passive interfaces that are just being viewed most of the time . These hold reference images, documents with requirements or notes for example. When working at home on private projects some users mentioned they like to watch videos, listen to music or chat while drawing. These interfaces also fall into the third category. These three categories are important when thinking about screen positions. The first category has to be close to the user and accessible in a comfortable manor because input is often pen based. The interfaces from the second category has to be close to the interfaces from the first one and will be placed on a screen correspondingly to how often they are being used. The third category of interfaces are just being viewed and therefore should be placed accordingly. One of the users compared the graphic work on a two screen system with a *Nintendo DS*[1]. The top screen is used for viewing, the bottom one for drawing. This already

three interface categories in graphic applications

use top screen for viewing and bottom screen for drawing

[1]http://www.nintendo.com/

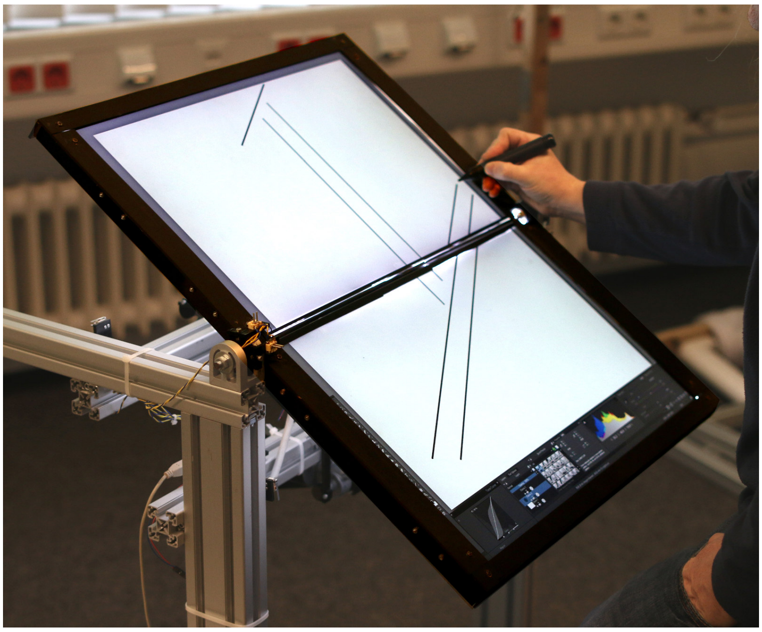

Figure 6.2: *Flowdesk* in position 4, used for a drafting table like application (with a GUI mockup).

position 4 fits work at drawing table

suggests how users want to use a system for graphic applications. In tasks where the drawing area needs to be as big as possible and other interfaces are not that important users preferred a position similar to a drafting table. This could be the case in architectural design for example. Position 4 from *Flowdesk* allows this kind of interaction. Figure 6.2 shows a user in a possible use scenario for this position.

positions 2 and 5 fit simple drawing tasks

When the user's task affords more space for interfaces from the third category positions already mentioned in the office usecase are appropriate. Positions 2 and 5 allow drawing on the bottom screen while looking at reference images on the top screen. A usage scenario for both positions is shown in Figure 6.3 and Figure 6.4.

position 1 fits brainstorming task

For quick sketches with a team users had the same affordences as for brainstorming sessions from the office. The screen should be flat to allow users to stand around it. The users should be able to work together on one big drawing surface, with just a small, simple tool interface. Figure 6.5 shows such a usage scenario with *Flowdesk* in position 1.

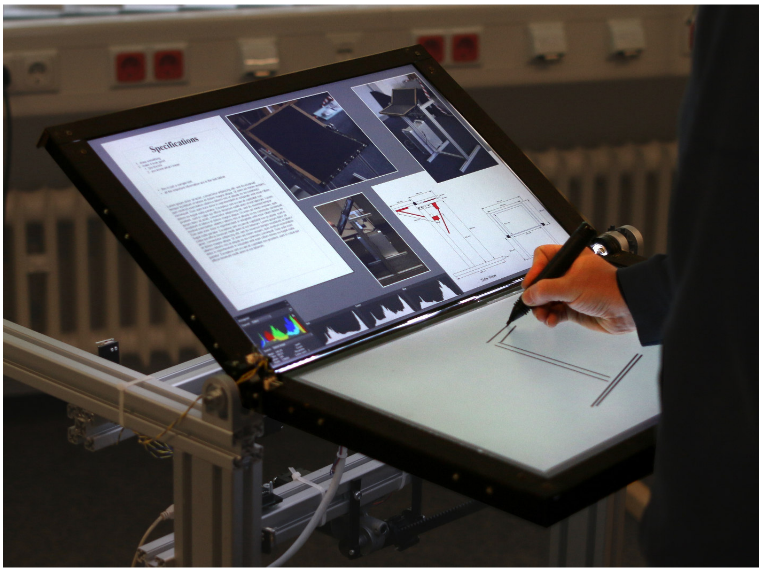

Figure 6.3: *Flowdesk* in position 2, used by a standing user (with a GUI mockup).

Flowdesk can provide a variety of screen positions that are useful for different tasks in both usecases.

6.2 Additional Characteristics

Apart from the screen positions, there were other aspects the users mentioned to be important for the system. Especially in the graphic application usecase users mentioned it was important to rearrange application windows on the fly. To be able to place an interface whereever they like was an important aspect that supported the effort we made to make the gap between the screens (bezel) as small as possible. This was also significant when the users wanted to use both screens as one seamless big screen in position 1 or 4, for example. For a future system it would be optimal to remove the bezel completely.

small bezel benefits the system

Relevant for the use in position 1 was that the screen surface is accessible from all sides. The small and open framing of our system allows this.

Figure 6.4: *Flowdesk* in position 5, used by a sitting user (with a GUI mockup).

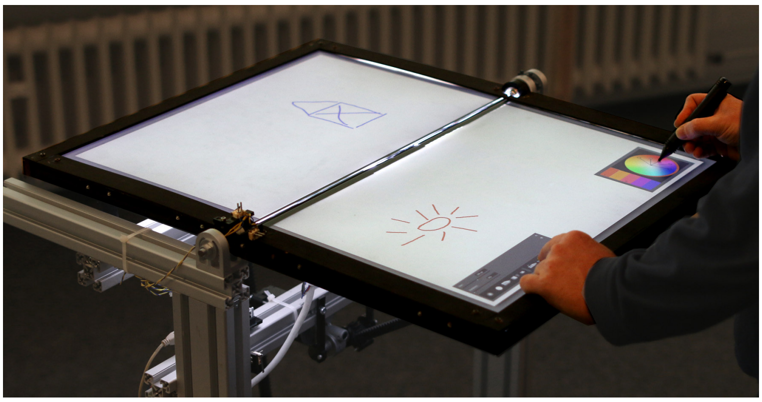

Figure 6.5: *Flowdesk* in position 1, used for a touchtable like application (with a GUI mockup).

Another aspect that had to be considered was the screen stability. In graphic applications users emphasized that they want to rest their hands on the screens while drawing because this allows more accurate movements and prevents the arms from getting tired. Because the screens in our system are supported with gear racks and a motor with a worm gear they are able to hold these weights. Future versions equipped with metal racks could be even more robust.

screen stability is important

One of the most important features *Flowdesk* offers, is the ability to move the screens dynamically and adapt to the users in realtime. Many users reported that when they work on a task at some point they are tired from sitting and would like to continue in a standing positions. On most workspaces this is not possible or makes the static screens harder to use. With our system we are able to remain ergonomic screen position and adapt to the users in seconds. Users in graphic applications made the suggestion to link different software interface layouts to corresponding hardware screen positions. In every modern software application for graphic usage (and even in some office applications) there is the possibility to save different window and interface configurations and layouts. If the current task affords the corresponding layout the user can then swap to these configurations by pressing simple shortcuts. *Flowdesk* could provide the opportunity to save the screen position together with the interface layout. This will allow the user to always have the ergonomic optimal position for every interface layout. When selecting a different layout the screens are able to adapt to the users choice in seconds.

realtime position adjustment brings benefit over other systems

link software and hardware layouts

Our system allows applications to be content aware because it is possible to get the screen position from the system and change the shown interfaces accordingly. We will further discuss the possibilities this system offers for applications in the section 7.2 *Future Work*.

The GUI mockup seen in the images can be found on the attached CD.

Chapter 7

Summary and Future Work

In the previous chapters we presented our ergonomic prototype *Flowdesk*. We described the process of prototyping as well as the actual hardware and software setup of the final version. Additionally we presented a usecase analysis of our system. In this chapter we will summarize the previous work and furthermore discuss future aspects and ideas of our system.

7.1 Summary and Contributions

Flowdesk is a two screen system that can adapt automatically to the users task

In this work we build *Flowdesk*, an first ergonomic prototype of a two screen system that can adapt the screen positions dynamically on the users tasks. The two screens are connected on one edge and form one interactive surface. Our system is able to move its screens into different positions automatically that allow different interactions with the system. This gives the users the opportunity to have the best fitting screen ergonomics for their current task and therefore brings an improvement over current screen systems.

We described the prototyping process of this system and pointed out the initial design decisions that led to our system. Furthermore we discussed flaws of earlier prototypes and compromises that had to be made in order to achieve a working final system.

We then gave an overview over the final system and explained the hardware and software in detail. In the hardware setup we mostly focused on technical details that were important to guarantee that the system meets certain criteria. The movement speed and screen stability as well as small bezels were just some of the aspects that had to be considered. Additionally we describe the hardware and software sided safety mechanisms.

the positions of our system fit the tasks of the usecases

To get an idea which requirements our system had to meet for certain tasks we conducted related research and did unstructured interviews. We then analyzed our system with two usecases, where the system should be used for office and graphic applications. We found out that the screen positions *Flowdesk* could achieve are covering most of the tasks users perform in the usecases. The ability to adjust the positions in realtime and the general multiplicity of the positions were important aspects where users could imagine to prefer our system over current setups. Especially in the usecase graphic applications the users liked that the system offered using it both in sitting and standing positions, as a touch table, a drafting table or simply a task specific drawing setup.

7.2 Future Work

many possible improvements for future prototypes

The goal of this thesis was to build a first ergonomic prototype and collect initial experience on how a screen system that can adapt dynamically to the users might look like. This already implies that there are a lot of improvements we discovered during the process of prototyping and building the system that may be considered for future versions and did not make it into this prototype. Furthermore our system could be used to conduct user studies or develop ideas for applications. Many characteristics are not optimized yet and may be improved with the feedback from users.

7.2.1 Screen Improvements

One of the major drawbacks of our current system is the missing touch functionality of the screens. For a future version this functionality is absolutely necessary to allow meaningful interaction with the system. The optimal solution for our system, as soon as it is possible to get them, would be a bendable *graphene* touch surface. Together with the rising *OLED* technology it could be possible in the future to build one bendable touchscreen unit, that replaces the two screens in our system. This would make the bezels of our current system disappear as well. A more doable solution, for a next prototype, could be achieved with two *Apple iPad Pros*[1] that replace the screens. This approach would make the bezels even bigger but introduce the touchscreen functionality to the system.

add touchscreen functionality

7.2.2 Further Hardware Improvements

When it comes to the actual movement mechanics of the system there are some aspects that could be improved to make the system even more accurate. As already mentioned in the chapters *Hardware Specifications* 4 and *Software Specifications* 5, the current setup does not have the ability to track precisely where the screens are and depends greatly on end switches. To allow precise movement and exact positioning the motors could be replaced by similar strong stepper motors and the axis could be expanded with motion tracking sensors (like potentiometers). Replacing the current gear racks with similar metal racks could also lead to a more stable system that would be able to resist stronger forces applied to the screens.

track screen movement precisely

Another possible improvement could be to make the system configurable in height. With the ability to move the

make the system configurable in height

[1]http://www.apple.com/

system up and down automatically positions similar to a whiteboard would be achievable. With this feature the screen ergonomics could improve in general because obviously different users prefer different screen heights.

7.2.3 Investigate User Behavior

conduct user studies with the system

To get a better insight about what users could expect from a system similar to ours it is suggested to conduct further user studies. These could be done to gain knowledge about the general perception of our system and possible improvements. Information on aspects like the preferred amount of screen segments, size of the screens or the general system size could be obtained in this way. Additionally it could be interesting to gain precise information about which screen positions are useful for which tasks. This could lead to new positions the system should provide. Already in the unstructured interview one user from the graphic usecase imagined to use the screens in an angle similar to an easel for drawing.

7.2.4 Developing System Applications

develop applications for the system

As soon as the system is equipped with touchscreen functionality it suggests to develop applications that use the special movement abilities given by the system. But even with our system it is possible to think about applications that could make use of the possibility to change the screen positions. It would be possible to design simple interfaces that allow the users to set the positions of the screens and test them with our system. Another possible use would be the combination of interface layouts in software with hardware screen positions (discussed in the chapter *User Analysis* in the section *Additional Characteristics* 6.2) that could be investigated.

Bibliography

W. Buxton. Living in augmented reality: Ubiquitous media and reactive environments. In K. Finn, A. Sellen, and S. Wilber, editors, *Video Mediated Communication*. Erlbaum, Hillsdale, NJ, 1996.

Jakob Leitner, James Powell, Peter Brandl, Thomas Seifried, Michael Haller, Bernard Doray, and Paul To. Flux: a tilting multi-touch and pen based surface. In *Proceedings of the 27th International Conference on Human Factors in Computing Systems, CHI 2009, Extended Abstracts Volume, Boston, MA, USA, April 4-9, 2009*, pages 3211–3216, 2009. doi: 10.1145/1520340.1520459. URL `http://doi.acm.org/10.1145/1520340.1520459`.

Meredith Ringel Morris, A. J. Bernheim Brush, and Brian Meyers. Reading revisited: Evaluating the usability of digital display surfaces for active reading tasks. In *Tabletop*, pages 79–86. IEEE Computer Society, 2007. ISBN 0-7695-3013-3. URL `http://dblp.uni-trier.de/db/conf/tabletop/tabletop2007.html#MorrisBM07`.

C. Muller-Tomfelde, A. Wessels, and C. Schremmer. Tilted tabletops: In between horizontal and vertical workspaces. In *Horizontal Interactive Human Computer Systems, 2008. TABLETOP 2008. 3rd IEEE International Workshop on*, pages 49–56, Oct 2008. doi: 10.1109/TABLETOP.2008.4660183.

Simon Voelker. Benddesk: Seamless integration of horizontal and vertical multi-touch surfaces in desk environments. Diploma thesis, RWTH Aachen University, Aachen, Jun 2010.

Mark Weiser. Human-computer interaction. chapter The Computer for the 21st Century, pages 933–940. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 1995. ISBN 1-55860-246-1. URL http://dl.acm.org/citation.cfm?id=212925.213017.

Raphael Wimmer, Fabian Hennecke, Florian Schulz, Sebastian Boring, Andreas Butz, and Heinrich Hußmann. Curve: revisiting the digital desk. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction 2010, Reykjavik, Iceland, October 16-20, 2010*, pages 561–570, 2010. doi: 10.1145/1868914.1868977. URL http://doi.acm.org/10.1145/1868914.1868977.

Index

Typeset September 27, 2016