St. Pölten University of Applied Sciences

Paper with new Possibility

Electronic paper displays and creating an adaptable keyboard.

Research Paper

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Brunn am Gebirge, 01.03.2017

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Abstract

The e-paper technology is its early stages and has yet to find many applications in the technical world. Implementing the electronic paper technology with a keyboard, an interface many use daily, when working on a computer, can be one of many applications. An adaptable keyboard that would allow the user to visualize keyboard commands at the tip of their fingers could increase efficiency in many fields that use many keyboard shortcuts. Switching between different language layouts on the keyboard can be made very simple through this implementation. In order to fully understand the meaning of the keyboard usage, this paper deals with the general usage of keyboard shortcuts and the development of its layout and predecessor the typewriter. Mainly this paper is dedicated to the general application of the electronic paper display technology. Electrophoresis and other methods are described and their potential in the future market, while also giving an overview on the current electronic paper market.

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1 Introduction

In the past decades some sort of screen technology surrounds us in everyday life. May it be TVs, computer monitors, phones, billboards, or smartwatches, the variety is endless and each one differs in size, brightness, color rendering, and more. While the common active lighting technologies are incorporated in all of these devices, another display technology has come forth in the past that shows different properties. Active lighting displays are characterized by either being backlit or using light emitting substances in their pixels. In contrast to this technology the passive lighting displays mainly reflect the atmospherical light to generate an image, and sometimes only use a backlight to brighten up the image.

These passive lighting technologies are known under many different terms: electronic paper, e-paper, the brand name E Ink, and so on. All of these names describe a display technology that, just as traditional paper, reflects light to give a more natural and more comfortable displaying experience. The technology itself is still in its early stages and has only been implemented in few products thoughout the market. Most commonly electronic paper displays are used in e-readers, because of their paperlike feel, which allows users to read off the screen, as they would from a printed book.

This display technology also has different advantages than active lighting displays. As opposed to light emitting and backlit displays, e-paper displays has a greater power efficiency, due to the bistable property of the most widespread electronic paper technology. Bistabilty allows the device to continue showing a static image, even though there is no charge applied anymore; this means that once the image is shown on the device there is no power needed to keep the image for weeks without being disrupted. Regarding these features of this display technology, there are many opportunities that these displays can be implemented in. (Bai et al., 2014)

One suitable application could be an electronic paper keyboard. Through the rise of computers in many work environments, using computer software has become one of the key qualifications for the emloyees. Although, many people are using computers everyday, only few use the most efficient interaction with the computer:

the keyboard shortcuts. This method would mean more effort and therefore users hardly ever learn them. This topic will be elaborated later on, but is something can could be improved through visually depicting keyboard shortcuts onto the surface of the keyboard. Another great concern in the working field is the international collaboration. Using an adaptable keyboard would allow users to simply switch between languages on the keyboard, writing with Latin, Arabic, and Cyrillic letters. Additionaly, in this age individuality has become more and more present and despite the widespread application of the QWERTY keyboard layout, many choose to use other keyboard layouts such as the DVORAK or an alphabetical one (Donald A. Norman & Diane Fisher, 1982). One can see that an adaptable keyboard that can visuallize commands could have a range of application.

To approach this subject, a short summarization of the development of the typewriter, the predecessor of the keyboard, will be given, and also the meaning and application of different keyboard layouts. Afterwards the technology of passive lighting displays will be explained deeper, with special focus on the most wide-spread electrophoretic technology, that is used in the majority of consumer products at the moment. Before engaging with the application of a electronic paper display in an adaptable keyboard, other examples of e-paper products will be given to give further comprehension of the potential. The adaptable keyboards prototyping is presented together with conceptualizations of the past and the startup Sonder Design, which is planning on releasing an electronic paper keyboard later this year. Lastly, other planned and future orented inputs are given on the subject of electronic paper displays and its potential.

2 Method

Information on the state of the art electronic paper displays was gathered through research papers and scientific journals. Additionally, technical specifications of products to assemble information on certain electronic paper products. Furthermore, online articles and reviews gave information on release dates of many products that do not show up in scientific research paper. Some data was gained through direct contact with correspndents of E Ink, being the worlds largest electronic paper display manufacturer, and Sonder Design, a starup company planning on releasing the first electronic paper keyboard later this year.

In order to build a prototype of an electronic paper keyboard, information exchange also was done with E Ink in order to find the right components, which only helped partially. Even though the prototype is only basic and far from being a finished product, it can show how such a product could work.

3 Keyboards

Since its invention, the typewriter has been a major cause for progress in industry and technology. Also, itself was given a makeover when it was introduced to the computer. However, the typewriter or the keyboard has still kept its main purpose, as C. V. Oden (1917, p. 5) describes:

> *The fundamental purpose of the typewriter is to enable the typist, or operator, to do more and better work with less effort in a given time than can be done with the pen, and the value of the typewriter is measured by the extent to which it increases speed and legibility in making records or preparing messages for delivery.*

Even though this was only addressed to writing texts, it still holds up, not only in writing speed, but also in work speed through keyboard shortcuts. The typewriter has led to acceleration in writing eleven times as fast as normal handwriting (Oden, 1917, p. 7), research has shown that using keyboard shortcuts is twice as fast as using the mouse (Lane, Napier, Peres, & Sandor, 2005).

3.1 The Layout of Keyboards

3.1.1 The History of the QWERTY–Keyboard

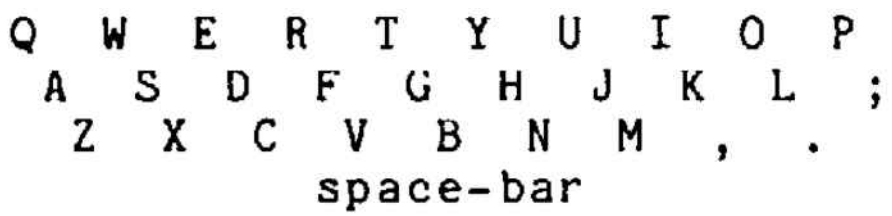

Figure 3.1 QWERTY layout. (Donald A. Norman & Diane Fisher, 1982)

The now most common keyboard layout is the so called “QWERTY”, named after the first six letters in the first row of the layout. The QWERTY had its origins with Christopher Latham Sholes, the 52nd man to invent the typewriter, in 1867. The first design, he had built with his friends Carlos Glidden and Samuel W. Soule, had an alphabetical layout, as Sholes’s typewriters predecessors. However, this layout was very flawed, because a lot of letters tended to get stuck, if the operator typed too quickly, which would result in an array of the same letter over and over again. (David, 1985)

His partner James Densmore urged Sholes to improve his typewriter design and get rid of the error-prone keyboard. This led to a layout which was already very close to the QWERTY design. It took another six years, until 1873, that Densmore managed to give E. Remington and Sons the manufacturing rights. Remington made some modifications to the layout, especially exchanging the period mark "." with the the first letter of Remington "R", so that it is placed in the first row. Changes were also made just so it was facilitated for salesmen to type out the product name "TYPE WRITER" as quickly as possible using only letters from the first row to impress customers. (David, 1985)

The sales of typewriters were not an immediate success due to its high price of $125. Many typewriter manufacturers tried their luck in this time, but none was able to compete with the Remington TYPE WRITER, simply from a business point of view, despite designs such as the "ideal" DHIATENSOR, which was able to write 70 percent of word in the English language using only the first row. (David, 1985)

In spite of all these competitors the QWERTY managed to succeed due to several possibilities. One main reason was that the QWERTY was the first typewriter to introduce touch typing and give trainings for typists, and since most of the typewriters were purchased by companies and not individual customers, operators were trained to use the QWERTY layout. In further consequence people with the ability to write using touch typing were more likely to be hired. Not even improvements to the QWERTY were successful. (David, 1985)

3.1.2 The DVORAK–Keyboard

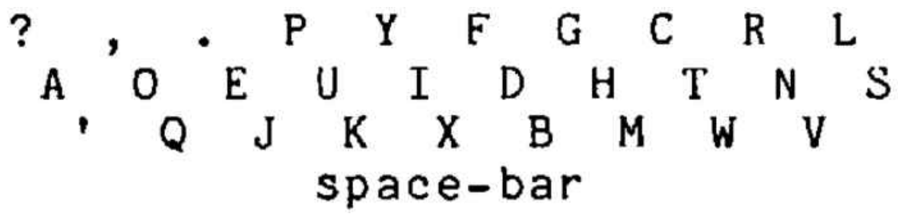

Figure 3.2 DVORAK layout. (Donald A. Norman & Diane Fisher, 1982)

The DVORAK keyboard is the most well-known enhancement of the QWERTY layout. The patent was filed for in 1932. Research was done on the speed achieved by the DVORAK by the U.S. Navy, which confirmed the efficiency of its design. The tests showed that the training operators the DVORAK would have redeemed itself after only ten days of full time employment. Still the layout was rejected by customers. One of the only exceptions was Apple IIC computer, which had a built-in switch which allowed the customer to switch between the QWERTY keyboard and a virtual DVORAK design. (David, 1985)

Figure 3.3 Switch on Apple IIC computer keyboard to switch between the QWERTY and an virtual DVORAK layout.*(Vectronic's, 2009)*

3.1.3 Using an Alphabetical Keyboard

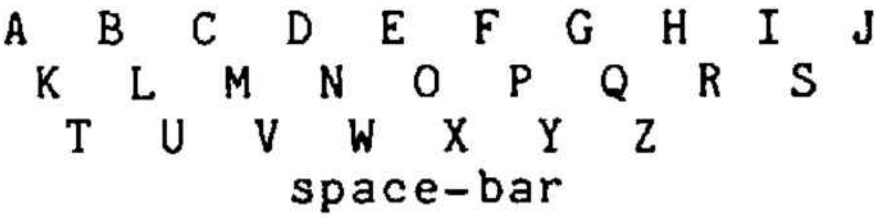

Figure 3.4 Alphabetic layout. (Donald A. Norman & Diane Fisher, 1982)

When the well known layout of the QWERTY was developed, it primarily served the purpose of preventing excessive jamming of the keys. However, now that mechanical typewriters have become extinct and computer keyboards are not in danger of jamming, the question is whether an alphabetical layout of the keys would be more convenient for the typist, especially for people who have no prior experience with using the QWERTY-keyboard.

Figure 3.5 Ticket machines oft he ÖBB, being able to switch between an alphabetic (left) and the QWERTZ (the German equivalent; right) layout.

The concept of an alphabetic keyboard has caused many interfaces that allow people without novices to use the keyboard with less effort, for example the ticket machines of the ÖBB (see Figure 3.5). One would assume that an alphabetic keyboard layout would be more convenient, but surprisingly, studies have shown that little to no improvement can be seen, when using an alphabetic keyboard. This is due to several reasons: It is hard to find anyone nowadays who has no experience with the well-known QWERTY arrangement. Further, even if the keys are organized alphabetically, a novice user still has to look for the keys, since they do not rely on their knowledge, but on visual references. Lastly, the alphabetic layout is as random for touch typing as any other, as the allocation of keys to one finger are a group of keys without connection; for instance, the left middle finger would be assigned the letters C, M, and V. (Donald A. Norman & Diane Fisher, 1982)

3.2 Using Keyboard Shortcuts

Nowadays, typing speed has become less of an indicator for efficient keyboard use. Working with various computer software has become the norm in many industries, and due to the graphical user interface (GUI) of these computer applications, specially trained operators are often no longer needed. A good interface nowadays is expected to be easy to learn for beginners, but efficient for experts. Additionally, it should give the user the opportunity to change from the inefficient use of menus and icons to a more efficient but more difficult interaction with the software through keyboard shortcuts. (Lane et al., 2005)

A lot of software achieves this by showing the keyboard shortcuts next to the menu item or display it when the user hovers over the icon, but many users fail to make this transition to shortcuts. The main reason for this is that functions that are visible on screen are to use than commands that require memorization (Zhang & Norman, 1994). That does not imply that keyboard shortcuts are not used by anyone. (Peres, Tamborello, Fleetwood, Chung, & Paige-Smith, 2004)

There are certain circumstances in which keyboard shortcuts are used. One would think that experience would indicate the amount of keyboard shortcuts used, but this is rarely the case. However, surveys showed that most people learn shortcuts through others. It also turned out that people are often not motivated to learn shortcuts by themselves, regardless of whether it would save time, but would rather want someone else teach them. This is why in work environments where many people use shortcuts, it is more likely that this technique is adopted. (Peres et al., 2004)

Interestingly, there is a group of shortcuts that are more often used than any others. The mostly software independent editing commands Cut, Copy, and Paste have shown to be applied through keyboard shortcuts more often than other shortcuts, but still less frequent than the icon toolbar. (Lane et al., 2005)

In order to make keyboard shortcut usage easier, keyboard manufacturers have started to producing keyboards that would have the keyboard shortcuts printed onto the keys. Manufacturers such as LogicKeyboard sell a variety of keyboards for different computer programs, mainly in the creative sector, but this is only handy when using one software (Logickeyboard, 2016), but dealing with different computer software, this would result in an accumulation of keyboards.

Figure 3.6 LogicKeyboard with a Adobe Photoshop CC layout. (Logickeyboard, 2016)

4 State of the Art ePaper

4.1 An Overview on Electronic Paper Displays

The development of electronic devices at the moment is rapidly increasing. Reaching from smart phones, to smart TVs, tablets, and wearable electronics, this market pushed forward the advancement of displays that constitute the main interface of such devices. This market not only increased the improvement of existing display technologies, but made way for the development of new technologies that could revolutionize the market. (Bai et al., 2014)

There are two major categories that displays can be divided into: the active lighting display (ALD) and the passive lighting displays (PLD). These two groups distinguish each other from the light sources they use. Active lighting displays use a lighting source that is within the device, either through a backlight, represented in LCDs, or through materials inside the individual display pixels that can emit light themselves, seen in OLEDs. The second group, the passive lighting displays, merely reflect the ambient light, similar to traditional ink on paper, which is why the term “paper-like display” is often used to describe this second form of display technology. One of the most common technologies of creating PLDs is called electrophoretic display (EPD). (Bai et al., 2014)

One of the main factors that support the use of PLDs is the outdoor readability. Especially mobile electronic devices that are often used outside, sometimes even under direct sunlight, can profit from such a technology. The currently more widespread LCD cannot offer this requirement, giving chance to alternate approaches. Figure 4.1gives a comparison of suitable environments in which displays are best used.(Bai et al., 2014)

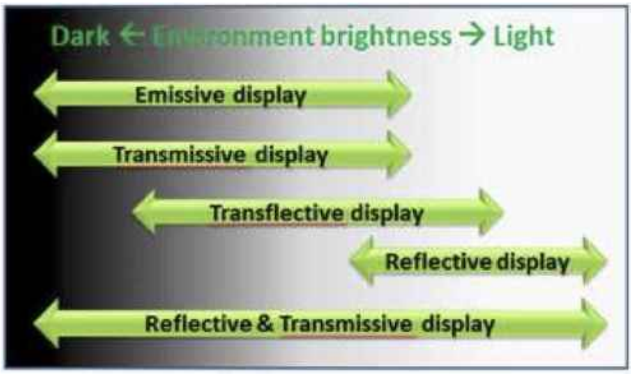

Figure 4.1 Environments for flat panel displays. (Bai et al., 2014)

Active lighting display in general are usually not satisfying regarding outdoor readability because of their low contrast ratio in direct sunlight due to the sun being much brighter than the light source of the ALD. In order to support a better readability, the light source would have to so much stronger so that the low power consumption would be compromised. This is why the development of PLDs has been under closer observation to give mobile devices the opportunity of giving the consumer the possibility of good readability and low power consumption. (Bai et al., 2014)

Low power consumption has been one of the biggest concerns in the mobile industry, which, due to the limited space available for batteries, has caused the momentum of wearable technologies to slow down. The power consumption of active lighting displays, both emissive and transmissive, is relatively high. In LCDs only 10% of the backlight is capable of reaching through the multilayered structure. This is why technologies such as electrophoresis are more power efficient, because they simply reflect ambient light. In contrast to the ALDs, PDLs brighter ambient light, as encountered outdoors, causes sharper images and better readability. (Bai et al., 2014)

Readability is usually determined by two factors: luminance/brightness and contrast. “Luminance/brightness is the amount of light that reaches the human eye” (Bai et al., 2014, p. 96) In the case of a ALD brightness can be seen as an absolute amount. The luminance of a reflective display is determined by a the amount ambient light, and is therefore stated by its reflectivity compared with a “standard white source” (Bai et al., 2014, p. 96)The reflectivity of a sheet of paper is usually between 70% and 90%, that of newspaper around 60%, as seen in Figure 2. The contrast is detected by the ratio between the luminance or reflectivity of the displays white and black representation. This determines if the human eye is capable of registering details on the screen. In general, it is easier and more comfortable for the human eye to read off of reflective surfaces, making paper a favored display medium. (Bai et al., 2014)

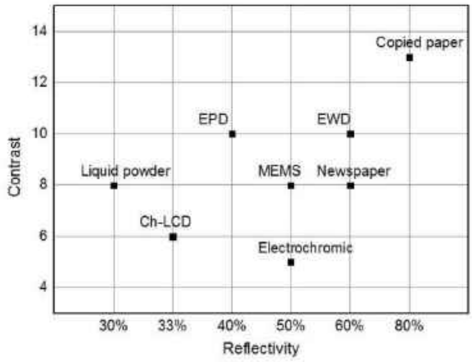

Figure 4.2 Comparing reflectivity and contrast of passive lighting displays. (Bai et al., 2014)

The electrophoretic display, also shown on Figure 2, is only capable of a reflectivity of 40%, which is less than paper and newspaper, but it still is the most mature technology at the moment in the field of passive lighting displays. A big backlog that the EPD has to overcome, in order to compete with ALDs, is its response speed. With a response time of over 500 ms, it is only suitable for static images and not usable for video playback. A passive lighting technology that is capable of a higher response speed is the electrofluidic display (EFD). It has a response time of only 10 ms or less, which makes the EFD capable of showing video content. Also it is capable of a higher reflectivity, which could make the EFD a possible competition in the future. (Bai et al., 2014)

4.2 Electrophoretic Display Technology

The concept of the electrophoretic display was first introduced in 1973, but it took until 1997, when Joe Jacobson presented his work on the “Electrophoretic ink” and published his paper in 1998, that the electrophoretic display had its breakthrough. At the same time the term “electronic paper” was first used by Nick Sheridon. 6 years of further development followed until Sony announced the first commercial product using an E-ink display. The Amazon Kindle was released in 2007 and established a new business model providing electronic content, which is now a well-known approach by publishers. (Bai et al., 2014)

The basic mechanics of the electrophoretic display is as follows: The display is comprised of many microcapsules containing charged pigment particles that are stacked by an electrical field. The black particles inside these microcapsules are charges positively whereas the white particles negatively. According which particles are on the top side of the microcapsule defines whether the pixel is showing black or white. If a shade of grey is desired an interim value is applied to the microcapsule to show said grey level. (Bai et al., 2014)

The current electrophoretic contain carbon black as dark pigments and TiO2 as white pigments. Both already have different charges which allow the process described above. The microcapsule that enclose these particles are created through interfacial polymerization reaction, a process that is also used to create other synthetic materials such as nylon. The microcapsules are then combined together into a front panel laminate which in further consequence can be easily attached to an electronic backplane. Currently a major concern is that, due to the conductive property of carbon black, it is hard to manipulate these particles in an electrophoretic display; this is why researchers are trying to find other black pigments to work into an electrophoretic display. (Bai et al., 2014)

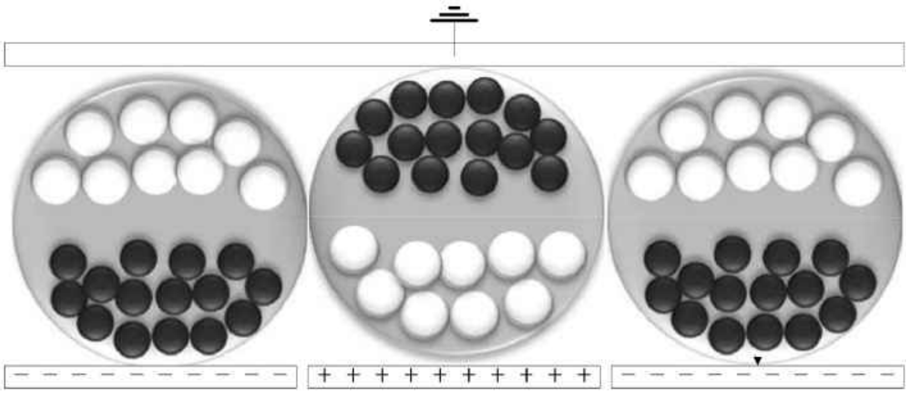

Figure 4.3 Microcapsules of an electrophoretic display with black and white charged particles. (Bai et al., 2014)

After the microcapsules have been laminated onto a thin-film transistor, the film is laminated onto a common electrode. Due to the UV sensitivity of the microcapsules, a UV filter has to be applied on top of the film. Further steps are similar to those of a LCD module: If desired a touch panel layer will be added before a final edge sealing is applied to send it to a waveform testing. This test examines the screens features of driving time, grayscale, flicker and ghost. The driving time is the response time or refresh time, which in the case of the electrophoretic display is more than 500 ms, which makes it impossible to play videos smoothly; the greyscale test examines how accurate the representation of certain shades of grey can be displayed; flickering in case of EPD is caused every time a change of voltage occurs, and ghosting is the residual of the previous image that are still visible. All of these factors are by far not perfect with electrophoretic displays, but are sufficient to display static images. (Bai et al., 2014)

The electrophoretic approach to the construction of electronic paper displays has another very beneficial characteristic. The display is bi-stable which means that once an image is displayed on the surface, the screen is in no need of power supply in order to sustain it. This leads to a very low power consumption and therefore a long battery life span. Another feature is that the display is flexible which allows the display to be used not only on flat surfaces. (Bai et al., 2014)

4.3 Other ePaper Technologies

Although, the electrophoretic display is the most matured passive lighting display technology at the moment, it still carries a lot of flaws. While some research is engaged with improving the current technology, other research is dedicated to find other passive lighting display technologies.

4.3.1 Liquid Powder Displays

The liquid powder display technology is very similar to the electrophoretic approach. It has been developed by Bridgestone, who called the technology QR-LPD, quick response liquid powder display, due to its faster response time than the electrophoretic display. The LPD uses polymer nanoparticles as pigments, but the major difference towards the electrophoretic display is the medium inside the microcapsules: Instead of using liquid the microcapsules are filled with air, allowing the nanoparticles to travel faster inside the pixels. The fabrication of the liquid powder display is very simple and is achievable in low temperature, meaning that flexible plastic materials can be applied. The differently charged particles are enclosed between two electrodes, which determine the shade of grey that can be seen on the display. (Bai et al., 2014)

4.3.2 Electrofluidic Technology

The electrofluidic display technology is maybe the second most advanced passive lighting display technology after the electrophoretic method, and most likely to replace the current utilization of electrophoretic displays. As opposed to the two differently colored pigments inside an electrophoretic microcapsule, the electrofluidic display operates with clear water and black oil. (Bai et al., 2014)

The transparent electrode at the top of the pixel is covered with a fluoropolymer insulator coating, which gives the electrode a hydrophobic surface. This causes that the oil to form a thin homogenous film, when there is no voltage applied, and the display appears black. If voltage is applied between the electrode and the water, the coating loses its hydrophobic property and the water is able to break through the layer of oil and exposes the reflective substrate at the bottom of the pixel. The water is not able to completely edge the oil aside, but the oil can be restricted to less than 20% of the pixel area (see Figure 4.4). (Bai et al., 2014)

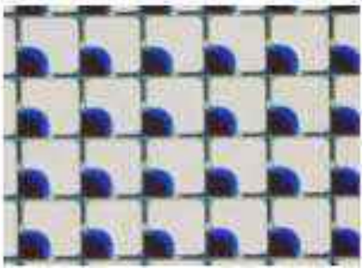

Figure 4.4 Electrofluidic displays with the black colored oil restricted to 20%. (Bai et al., 2014)

Figure 6. Images of 160 µm electrofluidic pixels. Figure 7. Using material a ties to pin the oil/water int

The electro-optic properties of electrofluidic display pixels can be seen in Figure 4.5. In order for the water to break though the oil, it requires a threshold voltage; once reached, further opening of the colored oil film can be achieved more gradually. This way any shade of grey can be achieved in an analog way. The increase of brightness does not behave linearly to the applied voltage. At one point the brightness will plateau, which is typically at about 80%. (Bai et al., 2014)

The optical 'stack' consists of solid components — reflective substrate, a tran indium tin oxide), a fluoropolymer insulator coating and the liquids: oil and wate is colored and is confined by 'pixel walls'. In the absence of a voltage the oil form microns thick as determine ... at covers the entire pixel s the hydrophobic surface (i ... mer) has a strong preferen with water. When a volt ... ater and the electrode th interface becomes polariz ... he layer becomes water w eÆect of pushing the colo ... er the voltage and the c forces, the smaller is the ... due. So during the on-sw results from the balance b ... forces. For the oÆ-switch forces prevail. This curtai ... ch contains optically abs of a simple, yet highly e± ... ure 6 images of 160 µm e shown. It can be seen tha ... ned to less than 20% of th

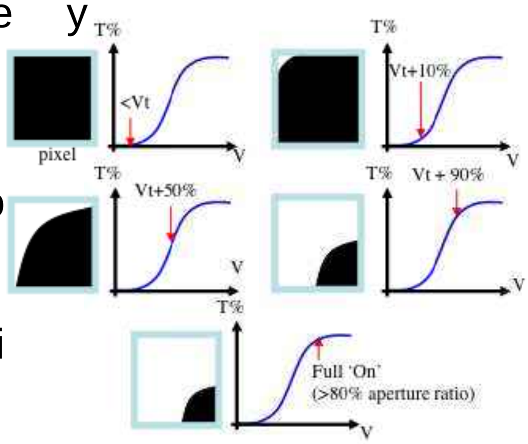

Figure 4.5 Electro-optic characteristics of electrofluidic display pixels. (Bai et al., 2014)

An electrofluidic pixel contains two key solid material components, a fluoropolymer coating of the substrate as well as a crystalline polymer that ma While the oil/water interface moves over the fluoropolymer in a highly reversibl angle hysteresis), it remains strongly pinned at the top of the pixel wall — t well as the more heterogeneous nature of the pixel wall photoresist angle hysteresis). This situation is shown in Figure 7.

The pixel wall material being hydrocarbon in nature, is more hydrophilic t surface, as such forming a surface with chemical contrast (hydrophobic/hydrop important to ensure that the oil film does not migrate to adjacent pixels, which if there is insu± cient chemical contrast between the pixel area and the pixel w mentioning that the pinning of the oil/water interface is at the top of the pixe bottom which is also a potential pinning site. In actual fact the oil is preferenti

its brightness any more when the voltage is increased further. The degree of modulation that can be achieved depends on a number of pixel parameters and can be controlled. The maximum open pixel area ... is about ... at a ... of ...

One of the key properties of electrofluidic fluidic elements is their switching speed. Compared to other chemical and physical phenomena, e.g., electrophoresis (used in E-ink), electrofluidic motion is very fast. The speed of the fluid motion is basically constant. As the fluid element becomes smaller the switching time therefore decreases linearly. For elements with dimensions of around 10 µm, such as display pixels, the switching time is therefore of milliseconds (ms). Typical switching data is shown for 315 £ 150 mm² pixels in Figure 9. In this case both the on- and oÆ-switches occur in 7–8 ms. Switching times of this order are more than su± cient to show video content on information displays and are in fact shorter than the large majority of LCD's. Video displays are one of the main application areas for electrofluidic technology. As the display resolution is increased (smaller pixel size) the switching time will be further reduced.

The advantages of EFD Technology are its optical e± ciency, video capability, low power (no backlight) and LCD-like manufacturability. The disadvantages of EFD Technology are that it is not intrinsically bistable, has a non-white oÆ-state and is still an immature technology. This combination of which allows is even quicker than most LCDs. Increasing the display resolution would allow an even faster switching speed, allowing the display of playing videos smoothly. (Bai et al., 2014)

While the switching speed is without peer and a great advantage, the electrofluidic display lacks some properties that the electrophoretic display can. The electrofluidic technology has a non-white off state and is not bistable. (Bai et al., 2014)

4.3.3 Cholesteric Liquid-Crystal

The Cholesteric liquid-crystal works similar to the regular LCD technology. A class of nematic liquid crystals, which naturally has the tendency to twist its molecular orientation, in order to reflect certain parts of the light. Just as the electrophoretic display it is bi-stable, but its disadvantages are high voltage and a comparably low optical performance. (Bai et al., 2014)

4.3.4 Microelectromechanical Systems

The pixels of this display technology are small chambers of air confined through aglass substrate and a movable reflective membrane. The size of the air-gap between the glass substrate and the reflective membrane is adjusted through electrostatic attraction and defines whether a pixel reflects or absorbs the light. This technology has been commercialized, but is problematic due to its limited viewing angle and its complexity and thereby cost in fabrication. (Bai et al., 2014)

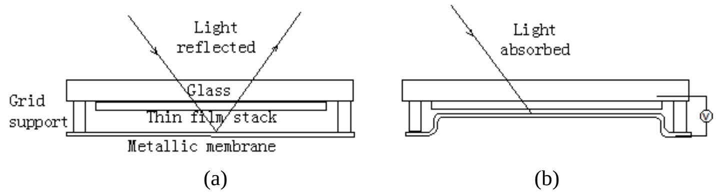

Figure 4.6 Structure of Microelectromechanical Systems in its open and closed state. (Bai et al., 2014)

4.3.5 Electrochromic Display

The electrochromic display uses materials that have the ability to change their colors when charge is applied. Every pixel contains electrochromic materials, which makes the fabrication simple. The electrochromic display can be controlled with voltage as low as 1 V. The major disadvantage of this technology are the low switching speed and a short switching lifetime, which are issues that are being worked on. (Bai et al., 2014)

4.3.6 Photonic Crystal

Photonic crystals are able to reflect different wavelength according to the applied charge. This allows every pixel to be controlled seperatly and reflect any color. The technology is being commercialized by Opaluxcompany, cofounded by University of Toronto. The fabrication of a photonic crystal display is simple, the photonic crystal material itself is complex, and its controllability is very limited. As with other passive lighting display technologies, the switching speed is very slow. (Bai et al., 2014)

4.4 The Current ePaper Market

Due to the beneficial properties of an electrophoretic display, its usage has found many applications when the playback of videos is not needed. Its passive lighting technology, low power consumption, and flexibility have high appeal to the E-reader market, but also on billboards, labels, and many mobile devices. (Bai et al., 2014)

At the moment, the electronic paper displays market is dominated by the E Ink Holdings Inc, formerly Taiwan PVI (“E Ink: Technology: Display Products,” n.d.). Currently it is almost rival free and is thereby the major supplier for most of the electronic paper products. (Bai et al., 2014)

4.4.1 E-readers

The biggest application of the electrophoretic display is its use in E-readers, especially due to its paper-like readability. Many companies have started bringing E-readers to the market, but the two most noteworthy are Sony, being the first company to bring a commercial electronic paper display to the market, and Amazon, having the biggest market share on E-readers. This is mostly due to the case that Amazon created a new business model which gives the consumer the access to a large library of digital resources through the Amazon Kindle store. (Bai et al., 2014) The Amazon Kindle 1 was released in 2007 and was equipped with a 6 inch display (“E-Book-Reader: Alle Kindle-Modelle von Amazon im Überblick,” n.d.), which has stayed the same in all four current Amazon Kindle products (Amazon.com, 2017a). The first E-reader released by Sony, the Sony LIBRIé EBR-1000EP, in 2004 was less successful, especially because the purchased books expired after 60 days (Rojas & Block, 2010).

Figure 4.7 Amazon Kindle Paperwhite. (Amazon.com, 2017a)

Figure 4.8 Sony LIBRIé EBR-1000EP. (Rojas & Block, 2010)

4.4.2 Adaptive Billboards and Labels

The electronic paper technology has also been used in advertisement and labeling. In Japan Hitachi has installed electronic paper displays at Tokyo Station and later in December 2006 colored displays inside the Yamanote Line light rail train. Shelf-edge labeling with the help of electrophoretic displays has also become very common. (Bai et al., 2014) Regionally, in November 2012 all of the 1020 stores of the Austrian supermarket chain BILLA AG were using E-labels (Gruber, 2013).

Figure 4.9 BILLA AG E-labels. (Gruber, 2013)

With the support of Mercedes-Benz, RoadAds interactive developed truck advertisement working with electrophoretic display modules. The 32 inch screens mounted onto trucks is meant to show location customized advertisement and also traffic reports. (RoadAds interactive GmbH, 2015) RoadAds interactive is working together with Visionect. This company has worked on e-paper traffic signs in Australia (Visionect, 2015).

Figure 4.10 ePaper displays on Mercedes trucks by RoadAds. (RoadAds interactive GmbH, 2015)

Figure 4.11 ePaper traffic signs in Sydney, Australia. (Visionect, 2015)

4.4.3 Wearable ePaper

The first watch using an e-paper display won a price in 2004 at the Hongkong Electronic Chamber of Commerce Innovation Award and was made by Solomon Systech. Since then many watch manufacturers have introduced an electrophoretic display to their products. The most mentionable watches are the Seiko SPEKTRUM, with its first introduction in 2006, the GREEN VIEW, introduced in 2012 as the first Chinese electronic paper watch, and lastly the Sony FES Watch U, released in 2015; Additionally to its e-paperdisplay on the watch face, it is equipped with a display around the wristband that allows the user to change the design of the whole watch (Lamkin, 2015). (Bai et al., 2014)

Figure 4.12 Sony FES Watch U with epaper watch face and wrist band. (Lamkin, 2015)

4.4.4 ePaper Phones

Electrophoretic displays have also been introduced to the mobile phone. The most mentionable product is the Motofone F3 by Motorola. It was released in 2007 and was very successful in India, but could not withstand smartphones which entered the market the following years. In 2013, popSLATE brought an iPhone case to the market that adds another screen to the iPhone through an electronic paper display. According to the website it is only available for pre-order (popSlate Media, Inc., 2017). (Bai et al., 2014)

Figure 4.13 popSlate iPhone cases with electronic paper displays. (popSlate Media, Inc., 2017)

In context with this paper, the most noteworthy mobile device is the Alias2 SCH-u750 by Samsung Electronics. The phone using an electronic paper display to enhance the keyboard, which allows the the phones buttons to change to accordingly. (Bai et al., 2014)

Figure 4.14 Samsung Alias2 SCH-u750 with adaptable e-paper keyboard. (German, 2009)

5 The Adaptable Keyboard

The first hardware keyboard concept was released in 2005 and the corresponding product was released in 2007 of an adapltable hardware keyboard was in 2005. Even though a patent for a display keyboard was released in 1998 (Acevedo, 1998), the Optimus keyboard was the first to make it to the market. It would have OLED displays incorporated into every single key, in order to show the user what function the key currently has (Figure 5.1). Currently, there is no OLED keyboard available from Optimus. Their last product, the Optimus Popularis was released in 2011 and introduced at the Consumer Electronics Show in 2012, but it is still only available for pre-order at USD 1500. (Art. Lebedev Studio, 2017b)

Figure 5.1 OLED keys of the Optimus keyboard. (Art. Lebedev Studio, 2017a)

The first concept for an electronic paper keyboard was released in 2013. This design by Maxim Mezentsev and Aleksander Suhih (see Figure 5.2) also planned on having a display for every single key. This product never developed further than its concept (see Figure 5.3). (Seth, 2013) Another notworthy electronic paper keyboard design was the Jaasta. It was presented as a crowdfunding idea on CrowdTild, but turned out be a scam. (Dunne, 2015)

Figure 5.2 E-paper keyboard concept by Maxim Mezentsev and Aleksander Suhih. (Seth, 2013)

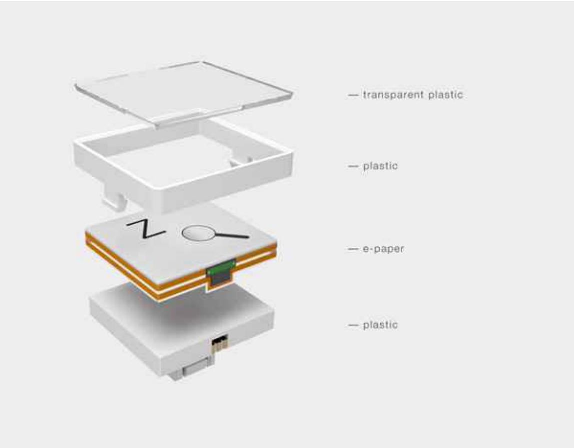

Figure 5.3 Mockup of the structure of a key of the electronic paper keyboard by Maxim Mezenstev and Aleksander Suhih. (Seth, 2013)

Currently the Sonder Design, an Australian based startup company, is planning on releasing their electronic paper display in 2017. In contrast to the previous concept designs of e-paper displays the Sonder keyboard uses one single display that spans amost the whole keyboard and the seethrough keyboards, that allow the user to see the display underneath. (Sonder Design, 2016)

Figure 5.4 Sonder Design electronic paper keyboard design. (Sonder Design, 2016)

5.1 Assembling a Prototype

5.1.1 Assembly of Components

For the creating a very simple prototype of an adaptable electronic paper keyboard, in this case, there is the need of three components: a keyboard, to use the internal architecture; an electronic paper display; and lastly a haptic interface, which is accomplished through a silicone keyboard cover.

The choice of keyboard was a flexible keyboard by LogiLink (Figure 5.5), mainly because of the easy access to the internal mechanics of the keyboard. The silicone keyboard cover was a product of MiNGFi (). Lastly, for the electronic paper display a Kindle Paperwhite from Amazon was used, both due to budget and availability reasons (Figure 4.7).

Figure 5.5 Flexible and waterproof keyboard by LogLink. (Amazon.com, 2017b)

Figure 5.6 MiNGFi silicone keyboard cover. (Amazon.com, 2017c)

5.1.2 Construction Process

The construction process was rather simple. The silicon keyboard was cut open and revealed three layers of transparencies. The top and bottom layer contained circuits that would deliver the information on which key was pressed. The layer in the middle had holes at the positions the keys would be. This layer serves as a separator between the the top and bottom layer, and if the key is pressed those two layers would connect through the openings.

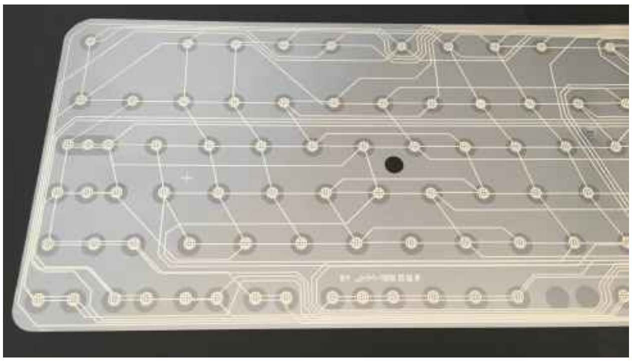

Figure 5.7 LogLink keyboard inside transparencies with circuit.

Further the silicone keyboard cover was just layed over the trancparencies to give the user visible access to what lies underneath the keys, and at the bottom the electronic paper display would have visibly show the keys.

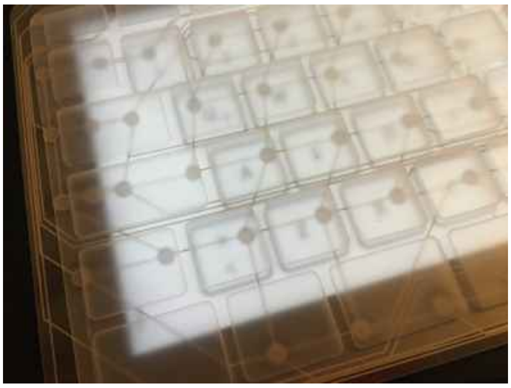

Figure 5.8 Stack of Amazon Kindle Paperwhite, the inside circuit oft he LogLink keyboard and the MiNGFi silicone keyboard cover.

As seen in Figure 5.8 the image of the electronic paper display can be see through, but due to the texture and material of the keyboard cover a completely sharp view of the image underneath is not possible.

Due to limited access to programmable electronic paper displays that the market provides at this moment, the electronic paper was not able to be programmed, but through putting images onto the Kindle Paperwhite the keyboard layout can be displayed underneath the keyboard cover Figure 5.9. Uploading images onto the Amazon Kindle Paperwhite is done through the Send to Kindle App (Figure 5.10).

Figure 5.9 Keyboard layout loaded onto the Amazon Kindle Paperwhite.

Figure 5.10 Send to Kindle App interface for loading files onto the Amazon Kindle Paperwhite.

6 Pending ePaper Applications

6.1 Colored Electronic Paper Technologies

Looking at the current successful electronic paper technologies, there is one major concern that researchers are working on at the moment. The monochromatic property of the electrophoretic display is applicable for current products, but in order to move forward colors need to be implemented.

Even though Fujitsu has already released their self-claimed “first color e-reader” (Kroeker, 2009) in 2009 – it was only capable of displaying 260,000 colors, a fraction of the 16.7 million colors a common desktop monitor is able to display – color has not been successfully implemented to the consumer market of electronic paper displays. In order to do so, the manufacturing techniques to date are not easily transferred to render a good color quality. However, the electrophoretic display technology described in section 4.2 is tried to be modified to work with print colors cyan, magenta, yellow, and black, to create a color capable electronic paper display. Also the electrofluidic display technology is attempted to be applied to color rendering. If color rendering and a faster switching speed can be achieved in a low price range, the electronic paper display could change the display market dramatically. (Kroeker, 2009)

6.2 Applications

While there are traditional displays that the electronic paper technology could replace, there are also other prodcuts that could benefit and be transformed due to the properties that passive lighting displays have over now wide-spread active lighting displays.

Heavily dependend on the color rendering capability of future electronic paper displays scientist are considering not only to equip electronic devices with a single flat panel display that would serve as the screen, but to cover the whole device with a color capable electronic paper surface. This would allow users to choose the color of their device individually to their personal preferences. This not only works with solid colors, but can also be used for patterns. (Kroeker, 2009)

Another application field is architecture. Similar to the skins working on an industrial design level, electronic paper display technologies can also be applied to architecture. E Ink is already advertising their E Ink Prism (Figure 6.1), which would allow colorfull and adaptable wall textures. This technology would be possible to create new modern architecture that could change according to trending color schemes and corporate branding. (E Ink, 2015)

Figure 6.1 E Ink Prism animated textured wall. (E Ink, 2015)

7 Conclusion

Seeing the variations of the passive lighting displays side by side, it is noticeable that these technologies are still in their early stages. Even though the electrophoretic display is already widespread, the interaction and image representation are still in need of improvement. The reflective brightness of the screen is far less than traditional paper and therefore the display technology uses backlighting, similar to active lighting displays, to achieve a bright white. Although there are passive lighting technologies that are able to have a rapid switching speed, and thus being able to display video content, they lack in many different fields, which has not allowed them to be commercialized to date. The current electrophoretic displays switching speed is far from having switching speeds in a scale that allow it do black back videos smoothly.

In contrast to all the scarce properties of the current electronic paper technologies, there are many fields that are not sufficiently explored, which could have potential for a market that is not yet established. One of those examples may be the electronic paper keyboard that might be introduced to the market this year. If this technology is used, the question remains, if the visualization of keyboard shortcuts and other language layouts at the surface of the keyboard is able to cause a more productive and more efficient workflow. This could also be the object of further investigation. Nevertheless, it is more or less clear that the adaptive keyboard is a niche product, and will have success only in certain areas.

However, other prodcuts such as billboards and labes are only at the beginning of being transformed to have more opprotunities for representation of businesses to their customers. This market will probably have a boost when colors are effectively introduced to electronic paper modules. Furthermore, colored passive lighting display surfaces will bring a transformation to personalizing wearables and other devices.

Additionally, as energy efficiency and long lasting battery life become more and more important, the electronic paper displays have the potential to replace many dispalys in current mobile devices and wearables, if both color capability and switching speed have come to a state in which they are comparable to common active lighting displays. All in all, the electronic paper industry will probably gain momentum, if and when it is able to overcome certain challenges, that it has to face at the moment.

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