Design of a Head-Mounted Display for Image-Guided Surgery

6.973 Final Project

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16 May 2002

Introduction

Computers and digital images are increasingly important in health care, bringing technology into the operating room to be used by doctors and nurses. Current development involving head-mounted displays (HMDs) for surgical applications promises new advances in image-guided surgery. By projecting high-resolution images like digital X-rays, case notes, and other diagnostic tools into a doctor's line of sight during surgery and other settings, large amounts of information can be readily available and used for the patient's benefit throughout the treatment process. Based upon display specifications given by our clients, we designed an HMD with a true-color 1280 x 1024 Organic LED (OLED) micro-display for the next generation of medical imaging.

Objective

We are a design group whose goal is to develop a micro-display that can project onto a set of glasses worn by a medical doctor. The image would be sent from the graphics processor to a display, which is mounted on the glasses. The light from the display is then projected onto a lens of the glasses via an optical projection subsystem (Figure 1).
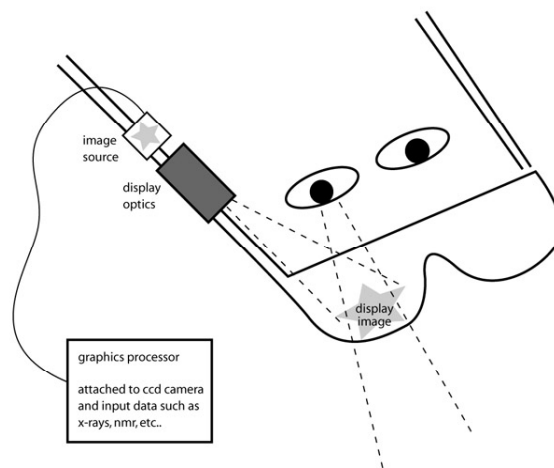
Figure 1: Modified from Project Handout

Any imaging to be used in surgery must be a true-color, high-resolution display with a fast response time. The technology used has to be bright and deliver a high contrast image in order to be visible in a operating room setting, which has a brightness of around 100 Cd•m^{-2}. Taking these characteristics into account, the minimum design specifications (Table 1) will be used for the target design of the head-mounted display.

Pixel matrix	1280 x 1024
Maxiumum pixel pitch	24 μm
Minimum frame rate	100 Hz
Grey scale	4 bits/color
Color	Full color (RGB)
Minimum contrast ratio	100:1
Minimum brightness	10,000 Cd•m^{-2}

Table 1: Design goals for the HMD for image-guided surgery

Display Technology

There are a variety of current technologies available for making small, high-resolution displays. This research will focus on active matrix displays (AM), which are brighter than passive matrix displays and have a greater range of viewing angles. The client suggested several micro-display technologies for our design, which include liquid crystal displays (AMLCD), electrophoretic displays (AMEPD), organic light emitting displays (AMOLED), and electroluminescent displays (AMELD). Of these, the OLED is the most appropriate choice for the HMD application.

In 1987, Kodak designed the first efficient AMOLEDs (Akinwande, 2002). Since then, AMOLED displays have reached market applications. Their advantages over other available displays include having

High brightness	Fast response time
High resolution	Low cost
Low operation voltages	Low weight
Wide viewing angles	Flexible substrates
High contrast ratio	

The OLED was selected for the HMD because these advantages weighted heavily above the deficiencies of the other display options. For instance, AMEPD technology is insufficient for use in a HMD because the technology is not far enough along in its development to produce good true-color displays. An AMELD would need a very high voltage to achieve the necessary contrast ratio, making it more difficult to power. This would require larger hardware to get the appropriate power dissipation,

thus generating more heat and resulting in an unsafe product. Although the liquid crystal display is a well-developed technology, it would not perform as well in this product as the OLED because it is less bright, less efficient, has a smaller viewing angle and contrast ratio, and requires a longer response time (Akinwande, 2002).

Pixel Structure & Circuit

The best structure for this display will be a pixel consisting of three OLEDs, one for each color Red, Green, and Blue, stacked on a glass substrate (Figure 2). This method gives the best results for true-color, high-resolution images with a good viewing angle. An alternative is to pattern the colors side by side instead of stacking them. However, patterning of RGB emitters would result in a much higher pitch per pixel. OLEDs can be reliably produced down to a pitch of 12 μm. Having a red, green, and blue OLED for each pixel would give a pitch of 36 μm, 150% larger than the client's design specifications. A second alternative, using color filters, results in high absorption loss but would otherwise be an apt choice for the HMD.
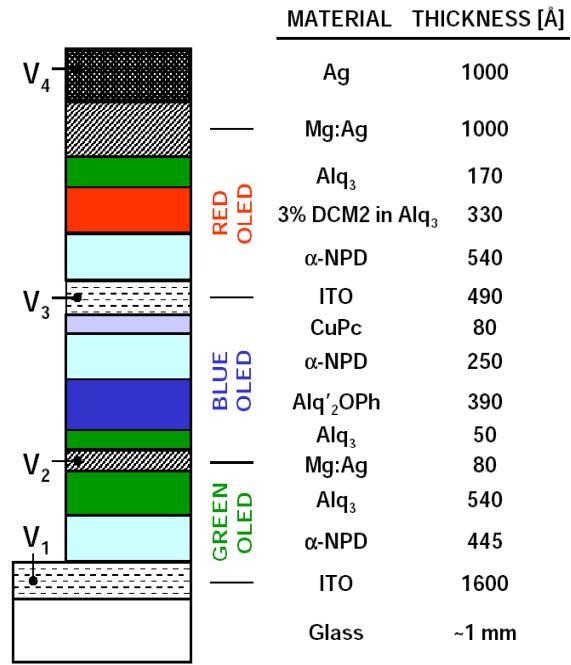

MATERIAL	THICKNESS [Å]
Ag	1000
Mg:Ag	1000
Alq$_3$	170
3% DCM2 in Alq$_3$	330
α-NPD	540
ITO	490
CuPc	80
α-NPD	250
Alq'$_2$OPh	390
Alq$_3$	50
Mg:Ag	80
Alq$_3$	540
α-NPD	445
ITO	1600
Glass	~1 mm

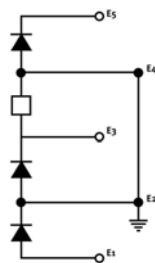**Figure 2: Stacked OLED Structure (Akinwande, 2002)**

Figure 3: Equivalent Circuit for a Stacked OLED

Figure 3 shows the pixel structure chosen for the OLED. It consists of two n-type transistors, one for switching the pixel on and off, the other for driving the pixel when it is on. The OLED is equivalent to a diode, and therefore there are three diode equivalents in our pixel model, one for each color (Figure 4). We require certain electrical characteristics for the current-driven OLED. First, it must take an input voltage of 9V in order to generate the required brightness of 60,000 Cd/m^2. This was calculated from the diagram on
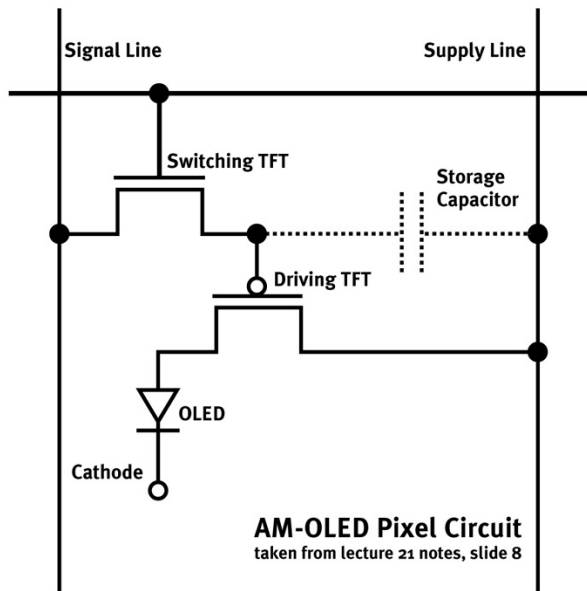
Figure 3

page 12 of Lecture notes 7 (Akinwande, 2002). Second, the area consumed by the pixel circuitry must not exceed 570 μm^2. This is calculated and discussed in detail in a later section.

Gray Scale and Color Methods

There are several ways in which gray scale is commonly achieved in micro-displays, including sub-framing, voltage modulation, and patterning. These were all considered for the HMD, as they each have positive and negative attributes. It was determined that sub-framing would be the method of choice, even thought it requires the display to be driven at a much higher frequency in order to generate the specified 16 shades of gray. The response time of an AMOLED is around 3 μs, which is fast enough to run at 1600 Hz, which is the required frequency of 100 Hz multiplied times the 16 gray sub-frames. The fast response time means that the display can successfully achieve 16 shades of gray without flicker.

Although the frequency is high when using sub-framing, other gray scale methods have stronger disadvantages. Voltage modulation would be challenging because we are operating with a small value of V_{Tn}. The circuitry would have to be very sensitive to a change in voltage, requiring a small storage capacitor. Pulse modulation can cause an optical illusion known as a false contour, which is difficult for the eyes to look at (Kasahara, 1999). Patterning is a good method for gray scale when only a few shades of gray are required. Our required 16 shades is too high, and implementing patterning for 16 grays would be challenging at lower frequencies. (?? This last bit doesn't make sense. What did you mean, Stephanie?).

Before this display is ready for mass production, a new technology developed by Matsushita Electrical Industrial Co., Ltd. (Kasahara, 1999) might be available, and should be considered for future generations of the HMD. Plasma AI technology can automatically change the number of sub-fields depending on the average signal level. Its advantages over traditional methods include a higher level of peak brightness due to an adjustable number of sub-fields (measurements show this is up to 50% higher), and Image quality equivalent to CRT monitors.

Driver Specifications

The characteristics of the control drivers needed for our display depend upon the material properties of our circuitry and OLEDs. First, we know from the data in Problem Set 4 that $K_n > K_p$. We also know that the OLED is a current driven device. We hope to minimize consumed power by reducing the required voltage to produce the same current, therefore we choose n-doped silican and use K_n.

Our luminance should be above 60,000 cd/m^2, which is calculated from the brightness of the room (100 cd/m^2) times the necessary contrast ratio (100:1), and divided by the efficiency of the optical subsystem (15%). Using the chart from page 12 of Lecture notes 7, we choose the voltage to be 9 Volts. Then, from page 3 of Lecture notes 21, we found that the current density corresponding to 9 Volts is 50mA/cm^2.

In order to calculate the current across the diode, we need to know the area of the diode,

> Area = Pixel area * Transistor area * 3(colors)
> Area = 24 μm * 24 μm –2 * 4 λ * 2 λ * 3
> Area = 570 μm^2

Thus, the total current across the OLED can be calculated,

> Current I_D = Current density * OLED area
> Current I_D = 50 mA/cm^2 * 570 μm^2
> Current I_D = 2.87 * 10^{-4} mA

From the saturation current equation of Problem set 4, we can get the transistor's voltage,

> $I_D = 0.5*K*(V_{GS}-V_{Tn})^2$
> V_{GS} = sqrt(I_D / (0.5 * Kn)) + V_{Tn}
> V_{GS} = sqrt(2.87E-4mA / (0.5 * 92uA/V^2)) + 0.5
> V_{GS} = 0.58 V

Now, the voltage across the diode should be 9V, so the voltage V_G of the transistor close to the OLED should be a diode drop greater, or 9.6 V (Ref. P.4 of Lec. 21, Akinwande, 2002).

This V_{G1} will also be the voltage for the Column, therefore the Column driver specification is 9.6 Volts. The gate voltage of the second resistor should be V_{G1} + V_{Tn} = 9.6 + 0.5 = 10.1V, which is just the row driver specification.

I/O data rate for row and column drivers

The data rates depend upon our methods for grayscale and color. We calculated the row data rate to be 204.8Kbps (1.6MHz) and the column data rate to be 786MBps (6.29GHz). The frequency of the row should be 1.6MHz, equivalent to our refresh rate with grayscale sub-framing.

Row data rate = (100 Frames/sec) * (# Rows) * (# Sub-frames) * (1 bit data/selection of row)
Row data rate = 100 * 1024 * 16 * 1
Row data rate = 1638400 Bits/sec
Row data rate = 204.8Kbps

Column Frequency = (100 Frames/sec) * (# Rows) * (# Columns) * (3 colors) * (# Grays)
Column Frequency = 100 * 1024 * 1280 * 3 * 16
Column Frequency = 6.29 GHz

Column data rate = 6.29 GHz / 8
Column data rate = 786 MBps

Power Requirements and Efficiency

The power requirements of our AMOLED display are reasonably low and efficient. In our most conservative estimation, we determined that the power consumed per pixel

$P = V * I$
$P = (9\ V) * (2.87 \times 10^{-7}\ mA)$
$P = 2.58 \times 10^{-6}\ Watts$

Therefore we can calculate the power consumed by the entire display circuitry,

$P_{total} = P * (pixels\ per\ width) * (pixels\ per\ height)$
$P_{total} = (2.58 \times 10^{-6}\ W) * 1280 * 1024$
$P_{total} = 3.39\ Watts$

We calculated the input power required to operate our display at the specified brightness by using the power efficiency of the OLED, which was determined to be 4 Lumens/Watt. This was estimated from Figure XXX, which is the diagram found on page 12 of Lecture notes 7 (Akinwande, 2002). From this value, we calculated the input power required by the display,

$P * (4\ lm/W) * (4\ \pi\ Cd/lm) = (60,000\ cd/m^2) * (Area)$
$P * (16\ \pi\ Cd/W) = (60,000\ cd/m^2) * (1280 * 1024 * 24\ \mu m * 24\ \mu m)$
$P = 0.9\ Watts$

Therefore, the efficiency of the display element can be calculated as the ratio of input power required to the power consumed,

Efficiency of Display Element = 0.9 Watts / 3.39 Watts
Efficiency of Display Element = 26.6%.

The total efficiency of the HMD is the product of the display efficiency and the optical subsystem efficiency, which was reported to be 15%.

Overall Efficiency = 26.6% * 15%
Overall Efficiency = 4%

Conclusions

References

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