Next Generation Display Technologies for Electronic Books in Japan

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Introduction

With the advent of personal digital assistants (PDAs) with built-in third-generation cellular phones and other viewing devices with high-bandwidth wireless communication capabilities, information-rich content such as sound, color pictures, and video clips literally becomes available at the fingertip. While high-bit rate wireless systems, signal processing, and storage technologies are all available, low-power technologies for high-resolution multimedia displays are yet to be developed.

Book authoring in Japan is, as in most countries, still being done in the traditional way of linear writing without any hypermedia links. Although many paper books are accompanied by multimedia CD-ROMs containing information on the author etc., the titles themselves are still text- or cartoon (*Manga*) based with little adoption to hyper linked multimedia. As a result, Ebook publishing in Japan, at least initially, does not require full-color or full-motion displays and the attention is therefore being drawn to high-resolution displays without color capability. As the multimedia content of titles gradually increases, though, the requirements on more advanced display devices become more pronounced.

In contrast to Western languages, Japanese and Chinese use ideographs (*kanji*) with considerably larger complexity than, for example, roman letters. As a result, photo typesetters, laser beam printers, and displays with higher resolution are needed to make the characters appear legibly. Rasterizing ideographs accurately on output devices using scalable fonts also presents problems and non-scalable bitmaps are therefore still common in many viewing systems.

Book publishers in Japan keep a large portion of their manuscripts originals on paper and digitizing and adopting them for multimedia publication is therefore an insurmountable task. Although technologies for Japanese optical character recognition (OCR) have advanced considerably, older manuscripts containing archaic characters are not recognized accurately. This together with a desire to preserve the often delicate page layout and typography of the original manuscripts, make publishers prefer digitizing the titles as bitmap images, a fast and straightforward approach which ensures rapid distribution of existing titles. The promotion of bitmap data over tagged XML text is also fueled by the cartoon version (*manga*) of a story, which often sells more than ten times the number of copies compared to the text version.

Given these circumstances, it is clear that the Japanese publishing industry, at least initially, will require display devices with high resolution but not necessarily with grey scale or multimedia capability. This talk reviews the EBook display requirements by publishers and compare different technologies.

Display Requirements for Electronic Books

A majority of the Japanese EBook consortium member companies are publishers which require the displays to render pages as closely as possible to conventional books. In addition, consumers will require low weight, pocket book size, small thickness, good reading legibility, low cost, portability, and ruggedness. These requirements are particularly severe in Japan since most people read books while commuting in crowded trains, often standing for several hours. To gain consumer acceptance, EBooks must comply with the same portability as ordinary commuter editions of novels.

The battery life of notebook computers was originally heavily dependent on the choice of display technology (reflective or backlit). Now that processor speeds have been increased and peripherals options added, the display is no longer the power budget-limiting device. Progress in battery technology and a wider array of display choices make system designers focus on limiting the power of other components instead.

Electronic books have a form factor and cost limit that do not allow for large battery capacity. As they do not require the full functionality and processor speeds of a notebook, however, they consequently consume less power. On the other hand, since the display will have to be switched on continuously without frequent recharging, the power consumption of the display device becomes a key parameter.

Assuming that the electronics of today's PDAs are sufficient for electronic books, the remaining power budget for the display calls for a maximum power consumption of about 50 mW, a requirement that presently only reflective displays can meet. This should give the user a battery life comparable to that of a mobile phone. Thanks to reduced voltages in CMOS circuitry, system power consumption is falling and will soon reach 2.5 V which puts further requirements on display driving.

Although no display technology today can challenge the resolution of photo type setting and printing, a resolution sufficient for displaying 12-point ideographs legibly is a minimum requirement. This translates to a resolution of at least 200 dots per inch (DPI). Many displays are, in contrast to printing, capable of showing grey scales which reduces the need for spatial dithering (screen) when showing images. Moreover, fast displays can also perform time-domain dithering which further reduces the need for screening. A fast 200-dpi device with some grey scale is therefore in most cases sufficient for displaying both simple black-and-white images and text legibly.

Apart from resolution, optical properties such as brightness, contrast ratio, and viewing angle should be similar or better than printing paper. One advantage over paper is that illumination can be incorporated in the reflective display and an EBook can therefore be used even if there are no external light sources present. When optimizing the performance of a reflective display, there is generally a trade-off between contrast ratio and brightness. For text-only displays, a moderate contrast ratio of 1:10 is in most cases sufficient and the reflectivity can thereby be brought to more than 60%. Symmetric light scattering over the entire viewing cone is essential to keep glaring low.

The size of the display is essentially determined by the form factor of the EBook which corresponds to the size of a pocket book. It is also essential that a page can be viewed in full without scrolling. For non-book applications such as newspapers this might prove difficult but increasing the resolution and displaying the content at a reduced size can partially solve this problem.

Bistable Displays

Bistable displays are sometimes referred to as "electronic paper" because grey scales are simulated by dithering. As a potential replacement for printing, the resolution must be sufficiently high for preserving typography, rendering of complex Japanese ideographs and line-art drawings (cartoons), and dithering of images.

Bistable displays are promising candidates because they do not consume any power except when the contents is changed. A drawback is that dithering is necessary which reduces the line density available for images.

Ferroelectric liquid crystal displays

One of the first commercial bistable technologies is surface-stabilized ferroelectric liquid crystals (SSFLC) which was used by Canon in their 15-inch desktop monitor. A passive matrix driving scheme allowed for small pixel pitches without the then high production costs of thin-film transistor (TFT) LCDs. Because desktop computers require grey scale, some of the available subpixels were used for spatial dithering which reduced the pixel count to 1024x768 (XGA). Canon later demonstrated a modified prototype of this display ("document viewer") with 3200x2560 pixels and a resolution of 282 pixels per inch (PPI). In contrast to the monitor, this display had no spatial dithering or subpixelation and could consequently not display grey scales. The viewer was considered to be a replacement of a printer when viewing proofs.

With its fast switching speed, bistability, low power consumption, wide viewing angle, and simple structure, SSFLC is an interesting candidate for electronic books if it can be made in the reflective mode, and if the temperature range can be extended. For ruggedness, it is also desirable to employ plastic substrates. Idemitsu Kosan has demonstrated an SSFLC device (no pixels though) with a flexible substrate and prof Shunsuke Kobayashi's group at the Tokyo Science University at Yamaguchi, has an interesting approach of incorporating the plastics (polymers) into the FLCs themselves.

Sumitomo has developed a plastic substrate for manufacturing inexpensive FLCDs by a printing technique[6]. The displays, which primarily are aimed at smart cards, can presently be manufactured up to a size of six inches and prototypes with 1:8 contrast ratio, <5V driving voltage, and <100 ms response, have been demonstrated. The flexible substrate allows for a bending radius of 1.5 cm and a pressure of 10 kg/cm^2.

Employing active matrix (AM) driving to bistable FLCs enable temporal dithering and extension of the temperature range. However, this leads to a more complex structure, increased power consumption, and a smaller aperture ratio so this approach is likely to be limited to multimedia displays.

Bistable twisted nematic displays

Bistable twisted nematic (BTN) displays is a passive-matrix technology being developed by Citizen and incorporated in display devices from Kyocera. A fast response of a few ms, high contrast ratio and brightness and a low power consumption are its main advantages but the number of colors is limited. With dithering, BTN may prove applicable to multimedia displays but the presently limited resolution does not make it suitable for electronic books for the time being.

Micro optoelectro-mechanical displays

Reflective displays based on bistable micro optoelectro-mechanical systems (MOEMs) are potentially very attractive because of the mirror-like surface which ensures brightness and contrast performance on par with or better than paper. So far, this technology has predominately been used in projection displays with devices developed by Texas Instruments, Echelle, and Daewoo. If the display size can be increased from today's ~2 inches, MOEMs technology can prove very promising for direct-view displays for both multimedia and text. Toshiba has recently proposed[2] an electromagnetically actuated film display (AFD) which is based on addressable stacked Cyan, Magenta and Yellow (CMY) subtractive color filters on a white background, thereby mimicking conventional color printing. The prototype measures only 8x8 pixels with a pitch of 0.5x1 mm but recent developments in MOEMs manufacturing will allow finer pixel pitches.

Cholesteric LCDs

Cholesteric LCDs (ChLCDs) are another bistable display device with good contrast ratio and reflectivity. Because of the bistability, power is only consumed when the contents changes. Its major disadvantages have been a high driving voltage of more than 40 V, slow response of several seconds, and lack of achromaticity and grey scale capability. The passive matrix structure is inexpensive to manufacture at a high resolution of more than 200 DPI which makes it a suitable candidate for electronic books. In Japan, ChLCD research is mainly on the material level but Toshiba has demonstrated a prototype display with an active matrix that reduces the driving voltage to below 20 V. Kent Displays have demonstrated prototypes on plastic substrates with some grey scale capability and improved response speed although it is still far from video requirements. Given this progress, ChLCDs might therefore be the choice for high-resolution Ebook displays in the immediate future.

Displays without memory effects

Backlit passive and active matrix twisted nematic (TN) and super twisted nematic (STN) LCDs exhibiting grey scale capability have long been employed in both notebook and desktop computers. Because of the need for constant power, high backlight power consumption, low transmittance, and limited resolution, though, they have not been suitable for EBooks. Reflective versions of these displays have been employed in PDAs but the brightness has been poor due to the two crossed polarisers. Color TN displays are even darker because of the limited transmission of the color filters. Instead, one polariser and polymer dispersed liquid crystals (PDLCs) or guest-host LCDs have been employed to increase brightness. TFT driving ensures video speed and reflective TFTLCDs are already commercially used in PDAs and still video cameras.

Sharp recently presented[4] a new 2.5-inch reflective TFTLCD with a 30% brightness, a contrast ratio of 1:32, and a response speed of 12 ms. This is close to printed paper and it is in addition capable of showing video. However, the resolution is still limited to 140 PPI which is too low for Ebook requirements.

IBM recently demonstrated[3] a 320-DPI 4-inch reflective guest-host LCD prototype with a contrast ratio of 8:1 and a reflectivity of 60%. If this display can be made twice as large and the high driving voltage of 10 V reduced, it is an interesting candidate for EBooks.

Transmissive high-resolution TFTLCDs for document viewing are also being pursued although the power consumption of the backlight makes it less suitable for low power portable EBook viewers. NEC[1], for example, has shown a 11-inch diagonal document viewer with a resolution of 177 DPI and 1600x1200 pixels capable of showing a US letter-size page in full. The display has a luminance of 110 cd/m^2, a contrast ratio of 130:1, and can display 262,144 colors. The company recently[5] released an analog (i.e. full color) 9.4-inch display with the same pixel number but at a resolution of 211 DPI. With an aperture ratio of 52% and a brightness of 250 cd/m^2, the backlight power consumption is likely to be too high for portable EBooks. NEC hopes to market the product to manufacturers of EBook and digital still cameras, the pixel count of which is approaching 3 million.

Conclusion

EBooks for text and dithered images have a vast array of display technologies to choose from. Bistable technologies on plastic substrates offer cheap, portable, and rugged solutions with high resolutions and low power consumption. Due to a slower switching speed, FLCDs have an advantage over ChLCDs but issues such as mechanical stability, cost, and temperature range still remain. Furthermore, FLCDs do not, in principle, have any resolution limit and small crosstalk which make them the most likely candidate.

As multimedia content increases, emissive display technologies with high color purity and fast response will be required. As the bulk of information in EBooks will be text-based in a foreseeable future, there is no immediate demand for a high-resolution, full-color, full-motion display. Instead, multimedia-capable EBooks will possibly comprise two display technologies. One strong candidate is likely to be organic light emitting diodes (OLEDs) on plastic substrates which indeed can be integrated on the same substrate as, for example, a flexible FLCD.

Finally, user interfacing will require advanced touch screen technologies integrated into the displays.

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