I-22.1: Display Requirements for Mobile Information Terminals

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Abstract

The cost-optimized display performance of wireless terminals is largely determined by available bandwidth, service contents, physical and luminous environment, industrial design, and energy budget. Commoditizing of mobile phones, increasingly design-driven product development, and high relative system cost of display modules suggest product diversification by display technology. Ubiquitous terminals require higher brightness and lower power while bandwidth limitations and expected range of services suggest that color depth and response speed requirements remain moderate compared to state-of-the-art display technologies for other applications.

Introduction

Mobile information terminals can largely be categorized into 1) wireless, real-time, highly interactive devices and 2) devices for off-line reading and viewing. From the display horizon, wireless terminals can furthermore be classified according to the available network bandwidth and viewing environment. Whereas the notebook computer industry together with broadband Internet access has been driving the flat panel display industry for more than a decade, focus is being shifted to mobile phones, which by the end of 2003, are expected to overtake personal computers in terms of number of units connected to the Internet [1].

Meanwhile, progress in hardware technologies and miniaturization has enabled information-rich handheld mobile terminals with high-resolution, full-color, and full-motion displays for off-line media consumption. Examples of such devices are portable digital versatile disk (DVD) players, electronic books, multimedia-enhanced personal digital assistants (PDA), and sub notebook computers.

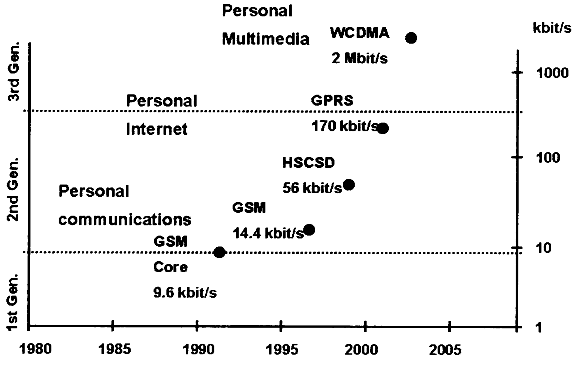

Figure 1. Evolution of mobile telephony and comunication speeds

With escalating bandwidths in mobile communications, contents will increasingly be available and consumed online and the role of wireless devices will gradually be expanded from today's voice-centric applications to also include information services and multimedia entertainment. This merger between traditional computer functionality and the ubiquitous mobile phone is often referred to as *digital convergence* [2].

A consequence of this development is enhanced visual experience and increased importance of the display device. Bringing the Internet to mobile terminals equipped with new displays will be an important enabler of the mobile information society. Business models for network operators will also have to be changed since the largest portion of network traffic will be visual communications.

Evolution of Mobile Telephony

The first-generation mobile telephony is analog and pioneered in the early 1980's by the Nordic countries who agreed on a standard called Nordic Mobile Telephony (NMT). Because of the dedication to voice communications, the display only needed to show phone numbers and, occasionally, alphanumeric characters in the phone book.

The second-generation (2G) mobile telephone introduced in the mid 1980's is digital and dominated worldwide by the Global System for Mobile communications (GSM). The economics of scale and open standards have allowed for inexpensive terminals and affordable services resulting in a penetration rate well above fixed telephony in several countries.

As shown in figure 1, the GSM system natively support a data bit rate up to 9.6 kb/s. With advanced voice encoding algorithms, this is sufficient for audio but only about 1/6 of the speed of fixed-telephony analog modems. This together with the time-based charging limits Internet browsing with the GSM phone as a modem. Nevertheless, the possibility of data communications and increased terminal functionality such as extended phone books, calendars, games, etc., required displaying of alphanumeric characters. One of the most popular services, short message service

(SMS), further spurred the need for displays with larger pixel count capable of showing at least four rows of 12-15 characters in a dot-matrix. The essentially text-based content and slow data transmission rate made film-compensated, super-twisted nematic (FSTN) displays the mainstream technology.

Using the existing fixed network, enhanced GSM terminals were later upgraded to 14.4 kb/s, mainly for use as data terminal equipment connected to laptop computers. Upgrading of the network via high-speed circuit switched data (HSCSD) and multi-channel GSM air interfaces further increased the bandwidth to 56 kbit/s, a figure comparable to analog fixed-telephony modems.

Without completely new investments in third-generation (3G) mobile telephony, GSM and other 2G networks are continuously being upgraded and prepared for general packet radio system (GPRS), a technology allowing continuous on-line connections, traffic charging per data packet, and a maximum bit rate of 170 kbit/s. The higher speed and new charging structure have narrowed the performance gap between 2G and 3G so the technology has been coined 2.5G. Actual bit rates in NTT DoCoMo's network, the world's first 3G operation, are in fact comparable to those of 2.5G systems. This together with huge investment costs required for 3G infrastructure have somewhat slowed the evolvement towards 3G and the immediate need for 3G is being argued. However, with a large number of the world's 3G licenses awarded and rapid progress in Japan's operations, there is no doubt that 3G is firmly established. As shown in figure 1, 3G promises bit rates up to 2 Mb/s.

Other wireless technologies

In parallel with the mainstream mobile telephony, there are other emerging wireless technologies that could partly compete in the area of higher-bandwidth ubiquitous network access. Already in 1995, Japan's personal handy-phone system (PHS) started to offer 64 kb/s, or 6.6 times the bandwidth of the regular 2G systems. PHS additionally offered inexpensive packet radio access via personal base stations and terminals of low power and cost, and small footprint. PHS is, however, a Japan-only standard and has consequently not gained considerable interest overseas.

Ad-hoc, short-range wireless access by BlueTooth™ (BT) and wireless local area networks (WLAN) currently offer bandwidths of about 1 and 10 Mb/s, respectively, high enough for video applications. However, the access range is limited and the devices still suffer from large size, high power consumption, high costs, and immature security solutions. So far, these technologies have therefore been deployed primarily in laptop computers. Recent SIM-card based security solutions for WLAN, miniaturization of BT devices and expanding installations at airports, hotels, etc., will increase the number of applications which further boost the demand for mobile terminals with video capability.

Terrestrial digital video broadcasting (DVB-T) [3] with IP-cast and upstream channels is another competitor to 3G telephony. Broadcasts have already started in the UK, Sweden, and Finland and Japan will follow in 2003. With bandwidths of several tens of Mb/s and high-speed mobility, this DVB-T will enable even more information-rich contents to be consumed on the move.

Display-centric applications

The plethora of future high-bandwidth wireless infrastructures with built-in interactivity will fundamentally change the framework for applications. Asymmetric networks like DVB-T with high downlink bit rates (IP-cast), will be used primarily for moderately interactive multimedia consumption such as customized television and full web cast viewing. These applications require high pixel count, large color depth, and high response speeds.

2.5G and 3G mobile telephony, WLAN, and BT have all a larger degree of interactivity in the sense that uplink and downlink bit rates in principle are equal and thus provide person-to-person multimedia communications. In this scenario, video conferencing is arguably the display-centric application with the highest expectations. Sending and downloading high-resolution digital images might also prove popular. A JPEG snapshot taken by a multi megapixel digital still camera, for example, occupies several hundreds of kilobytes (dependent on content and compression) and takes 3-4 minutes to download with a 2G phone. With a 2.5G phone, this time is reduced to tens of seconds. Beyond 2.5G, these download times will be even more comfortable and a display with higher pixel count is consequently needed for viewing the images. For video conferencing, on the other hand, the information content per frame is much lower because of the real-time requirements. Various compression technologies and formats exist but it is fair to say that even 2.5G phones can do decent video conferencing.

Downloading of games to Java™-enabled phones is already being introduced in 2G networks using NTT DoCoMo's I-Appli service. The bandwidth requirement is minimal and game applications are expected to change little even with 2.5G and 3G networks. The number of colors, resolution, and speed is comparable to stand-alone game machines such as GameBoy™ and should therefore not constitute any major hurdles for display developers either.

In highly dense cellular networks with or without the aid of global positioning system (GPS), the position information can be used in map-based services. For this purpose, higher resolution displays are needed but not necessarily with large color depth or high response speed.

A typical future mobile multimedia consumer does probably not want to carry one device for each application so there is a trend towards multimedia shown on smaller displays. A paradigm shift to an all-in-one display is rather far away but the portion of the display area of the total terminal area will increase and this constitutes a miniaturization and integration challenge for display developers.

Visual environment and eye limitations

Equally or perhaps even more important than bandwidths and applications in outlining display requirements, is the visual system and luminous environment which together with the display hardware determines what image actually is perceived by the user.

The human eye adapts its exposure and color, not only to the display being viewed, but also to the surroundings. As a result, the perceived image quality is determined not only by the display parameters, but also the color and the brightness of the phone cover and the background. A metallic phone cover with a reflectivity higher than that of the display, for example, will lower the perceived brightness and contrast of the display image because the eye adapts to the brightest spot in the field of view. To optimize the perceived image quality, a phone cover should therefore be achromatic, non-glaring, and non-reflecting, just like walls and ceilings in a movie theater.

Unfortunately, optimizing display appearance often conflicts with industrial designers' ideas on product image. Increasing commoditizing of phones leads to product diversification by design and the brightness requirements on displays become even more significant. In addition, touch screens, protective covers, hard coatings, decorative coatings, etc. further increase ambient light reflection and colorization which affects the perceived image.

With escalating bandwidths, images of higher pixel count and larger color depth will be possible but to what extent can such images be appreciated by the human vision? The eye's spatial resolution in the fovea, the central part of the retina used when reading, is often assumed to be on average 1 arc minute. With a viewing distance of 30 cm, this corresponds to 290 dots per inch (DPI). For color and grey scales, however, the spatial acuity is much lower due to limited spatial contrast sensitivity. A 290 PPI display for displaying photographic images is therefore not necessary and current laptop or phone displays would hence work satisfactorily [4]. However, applications involving viewing of text and maps, for example, can still benefit from high resolutions because of the higher contrast. There is also an interplay between the necessary resolution and perceived display brightness and contrast which complicate things further.

Mobile information terminals in general and mobile phones in particular, are used in a variety of environments with ambient light sources of different diffusiveness, color, and brightnesses. Whereas paper media has a reflectivity of often more than 80% and does not require any auxiliary lighting accompanying the media, mobile phone users expect the display to be viewable also in complete darkness as well as direct sunlight. Figure 2 shows the illuminances for major user environments and the approximate applicable intervals for today's reflective and transmissive LCD displays.

Which display technology?

External factors such as bandwidth availability user paradigms are well defined but as visual environments and user preferences vary by market and region as well as users traveling globally, the range of conditions is too wide to nail down a single display technology for mobile information terminals. In countries dominated by an outdoor lifestyle, for example, reflective displays are more suitable than in, for example, Japan where a large portion of the users operate their mobile terminals mainly on a dim-light commuter train. Another observation from Japan is the preference for colorful games and expressive, picture-based messaging whereas many users in the US and Europe tend to prefer reading news and watching stock market quotes. A recently published survey [5] among students in Sweden, commonly regarded as a

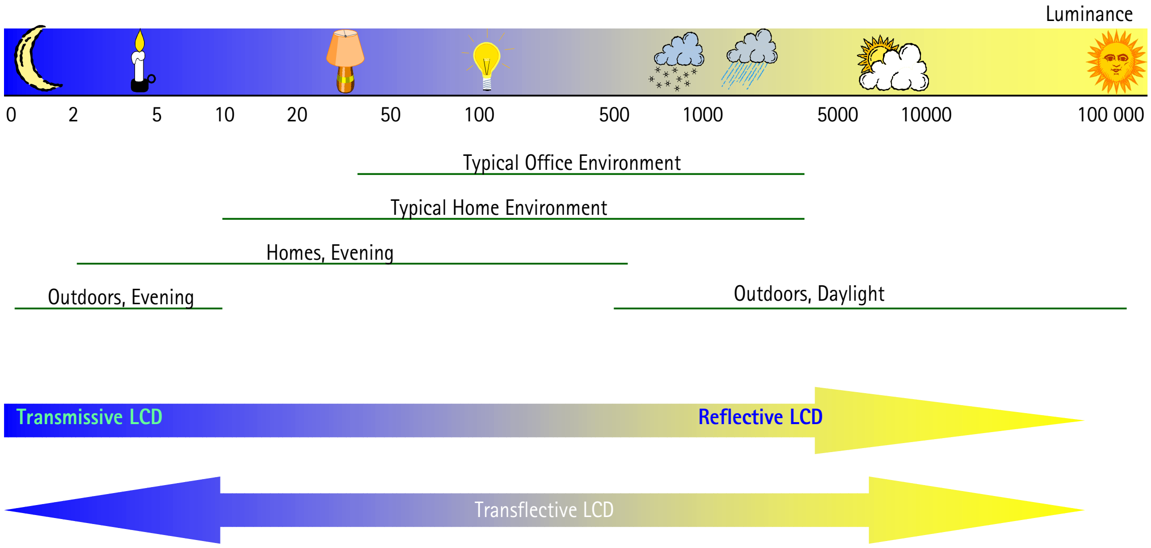

Figure 2. Various luminous environemtns (numbers in lux) and the applicability of different liquid crystal displays.

test bed market for mobile IT multinationals, reveals that video streaming and chatting are ranked low on the wish list of 3G services. Clearly, the application drivers, and hence the requirement on the displays, are dependent on the market expectations.

Product design also differs substantially by market. Users in some regions prefer foldable phones whereas others are in favor of always-on displays placed on the front cover. Finally, the subsidizing of terminals by mobile telephone network operators hugely vary by region (prohibited in some countries). This together with differences in disposable income makes the market demand estimation for display-centric phones difficult.

With phones increasingly becoming commoditized, however, there is a need to utilize the economics of scale to reuse as many components as possible, and to diversify products sensibly. Since the display device is the single most expensive component in a phone, this calls for a technology that satisfies as many of the end user scenarios as possible. In addition, the display device should have a small footprint, low power consumption, low environmental impact, and be mechanically rugged. Today, there is no “ultimate” display technology and a careful trade-off analysis is required.

The requirement for viewing in the dark suggests an emissive, transmissive, transflective display, or reflective display with front light. Except for reflective displays, the contrast ratio will decrease by increased illumination and hence the perceived color range. This is particularly true for terminals with highly reflecting areas surrounding the display. Transflective displays can handle this inevitable compromise to some extent but the ratio between transmittance and reflectance depends on the actual user environment (see figure 2), and hence the illuminance at which the backlight should be turned on. In many cases, the difference between two adjacent grey scale RGB values of an 18-bit display, for example, is much smaller than the perceivable color difference in a given environment which leads to unnecessarily high driver cost and power consumption.

A problem with transflective and reflective LCDs is the inevitable trade-off between color gamut and brightness caused by absorptive color filters. Recent transflective displays have separate filters [6] for the transmissive and reflective modes, which favor color gamut and brightness, respectively. However, the pixel structure becomes complex, resulting in increased number of mask steps and higher manufacturing costs.

Transmissive and emissive displays can deliver high picture quality if their luminance is sufficiently high or reflectance low enough to make the human eye adapt to the display even when illuminated by direct sunlight. With the present electrical-to-optical energy conversion efficiencies, however, the power consumption becomes prohibitively high. Compared to transmissive LCDs which waste 90-95% of the light energy emitted by the back light, OLEDs are promising because only addressed pixels consume power. However, a majority of users are accustomed to white background from laptops and paper media so the merit of OLED is only valid for contents with relatively few pixels being addressed, i.e. video streaming, video conferencing, and games. Recent research on OLED materials with high quantum efficiencies [7] is promising but issues of unsaturated colors, chemical instability, and life time are yet to be solved.

Reflective displays with front light could turn out to be interesting if the reflectance, color reproduction, and viewing angle approach that of printing. This requires a rethinking of LCDs since most of them employ at least one polarizer, effectively absorbing at least 50% of the incoming light. LCDs without color filters such as guest-host (GH) or polymer-dispersed liquid crystal (PDLC) displays are bright but slow or have low contrast. Although diffractive and interferometric color filters have been proposed, they suffer from a large color shift by viewing angle. Stacked, subtractive CMY filters absorb less light and therefore enable brighter reflective displays but at the expense of increased device complexity and parallax.

Conclusion

Commoditized, design-driven mobile phones require inexpensive, rugged, bright, and low-power displays whereas demands for small pixel pitch, fast response speed, and large colour depth remain moderate. Terminals with higher-bandwidth wireless technologies and off-line mobile multimedia appliances additionally require higher pixel count, color depths, and response speed.

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