Resolution and contrast requirements on mobile displays for different applications in varying luminous environments

Johan Bergquist
Multimedia Technologies Laboratory, Nokia Research Centre
Arco Tower 17F, 1-8-1 Shimo-Meguro, Meguro-ku, Tokyo 153-0064, Japan
Tel +81 3 5437 3675, johan.bergquist@nokia.com

Abstract
Illuminances in mobile display user environments range from 0 to 100,000 lx, presenting challenges in maintaining contrast and colour saturation in displays. Native web-browsing is possible with high-resolution 2.x" displays but requires a contrast which is difficult to achieve in high illuminances. Video content, on the other hand, requires much lower resolution and it is shown that 320x240 is a sufficiently large pixel number for 2.x" video displays.

1. Introduction
The progress of wireless infrastructures and hardware miniaturisation has made the mobile phone a multi-modal device capable of not only voice communications, but also office computing, entertainment, gaming, reading, i.e. applications that hitherto have been predominantly present on the personal computer. Whereas the applications and services of mobile devices are moving closer to those of the PC, there are many inherent challenges; limited power supply, ruggedness requirements, mobility, and small field of view of the display. This paper discusses these challenges and highlights necessary trade-offs in direct-view displays.

2. Application scenarios
High-speed mobile access is now available via a multitude of networks; third-generation mobile telephony (3G), wireless local area network (WLAN), BlueTooth connectivity, and digital broadcasting. In addition, portable hard disks and large-size solid state memories add to the availability of high-information content. This together with rapid progress in computer hardware performance is accelerating the convergence between the mobile phone and the personal computer[1-4] and hence creates a similar application scenario. There are also more mobile-specific applications such as navigation and location-based services. In any case, the users want an experience on par with that of a PC.

3. User environments
Contrary to the PC, a mobile device is used in a variety of luminous environments (see fig. 1). In addition, these environments vary by lifestyle preferences (indoor or outdoor), season, and geo-location (see fig. 2). To maintain or exceed the user experience of the PC as much as possi-

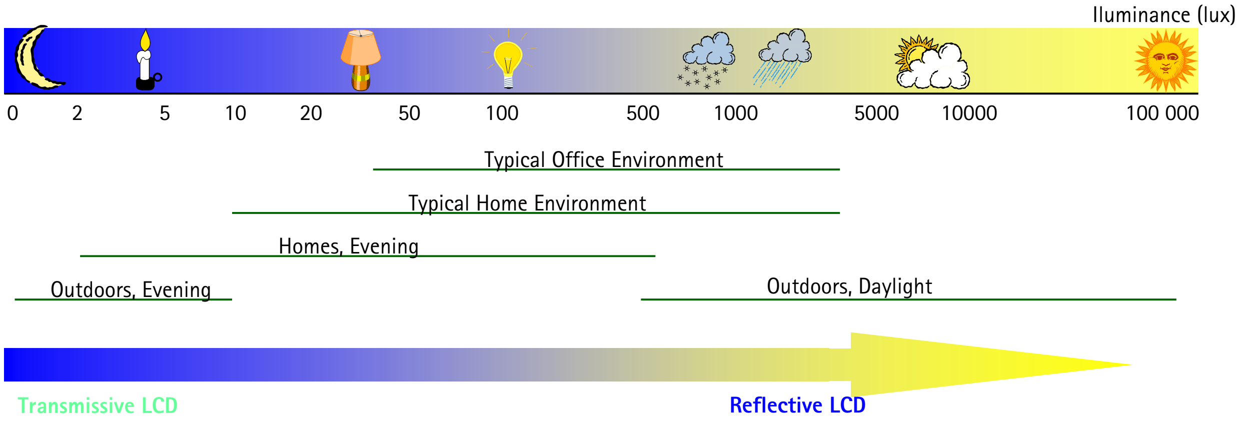

Figure 1. Illumination scenarios for mobile phones, their illuminances, and suitable display technologies

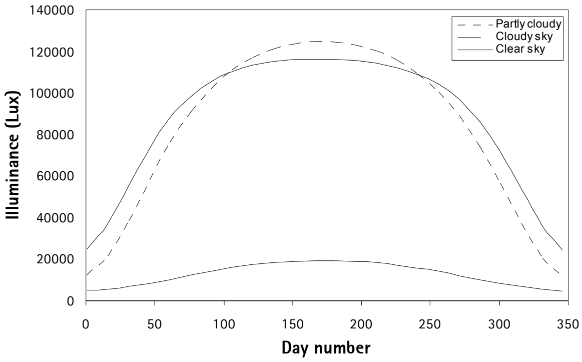

Figure 2. Annual distribution of the sky illumination in the Nordic countries (65 deg. north, Ref. 8)

ble, the mobile display must therefore be able to deliver saturated colours and high contrast under a multitude of illuminations. This is currently carried out by employing transflective displays which, however, exhibit unsaturated colours in the reflective mode due to contrast requirements. This together with difficulties in making them at high pixel densities has created a trend towards transmissive or emissive displays. To achieve sufficient contrast in high illuminances, however, the display luminance must be increased and the the power consumption hence compromised. This is one of the biggest challenges in continuous-use applications such as mobile television or personal multimedia.

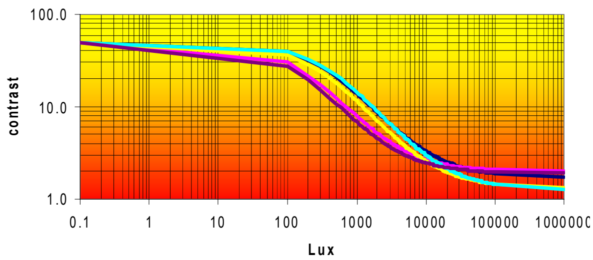

Figure 3. Contrast of some transflective displays as functions of diffuse D65 illuminance

4. Contrast requirements by application

Fig. 3 shows the contrast ratio of a couple of transflective displays as a function of D65 illuminance. It was calculated by dividing the total display luminances in the white and black state, respectively. The total luminance from a display under illumination is

$$L_{tot} = \frac{R_{diff} L_{diff}}{\pi} + L_{dir} R_{dir} + L_{disp} \qquad (1)$$

where R_{diff} and R_{dir} is the diffuse and specular (direct) display reflectance, respectively, L_{diff} and L_{dir} the diffuse and direct illuminances, and L_{disp} the display's transmitted luminance. As shown in the figure, contrast falls off quickly even for moderate illuminances.

The necessary contrast for minimum legibility is determined by the contrast sensitivity function (CSF) which is available both tabulated experiment data and analytical models.[5]. Fig. 4 shows experimental CSFs for various ages[6].

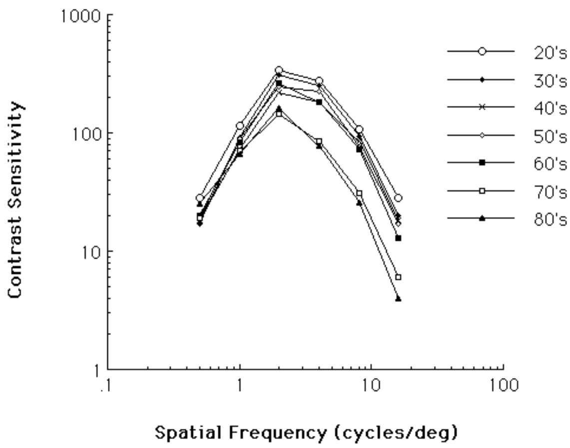

Figure 4. Contrast sensitivity function at different ages (after [6])

Using the sampling theorem, CSF, and assuming a viewing distance (usually 300-400 mm for hand-held), it is possible to calculate the maximum perceivable display resolution at a certain contrast *or* the required contrast for a certain pixel density. The contrast in this context is the *combined* contrast of the display and the image. Web page content, for example, consists of high-contrast text (=high spatial frequency) and requires 800 pixel width. For a 800x600 3" handheld device, this corresponds to a pixel density of 333 pixels per inch (PPI) and a spatial frequency of 23 cycles/deg at 400 mm. As seen in fig. 4, high contrast (contrast sensitivity is 1/contrast) is necessary to resolve this spatial frequency. Alternatively, the viewing distance can be decreased although this is an option only for younger people since the near point increases with age. Also, continuous reading at a short distance cause eye strain so the native-width web browsing experience could in fact be limited compared to the PC. Therefore, scalable fonts are needed to accommodate the needs for different users. Just as there are spectacles for office terminal work, similar aids for high-resolution mobile terminals can also be considered.

Compared to text, photos and video has much lower contrast. Also, the CSF shifts towards lower spatial frequencies for moving and/or flashing images[7]. Therefore, video with high spatial frequencies cannot be resolved as well as stationary high-contrast text. For example, an object moving at 2 deg/s shifts the maximum spatial frequency of the CSF to 10 cycles/deg, corresponding to 145 PPI of a 3" display viewed at 400 mm, even in the high contrast limit. This corresponds to a display pixel format of 350x262. As shown in fig 3, contrast decreases considerably at high illuminances so the requirement on resolution of mobile displays for video in the outdoors will be further relaxed.

Most displays are, however, multi-modal, and need high resolution for displaying text. Moreover, Asian characters with their complexity requires higher resolution compared to their Western counterparts because the matrices need more pixels to resolve each character. Using ergonomics recommendation of the International Standards Organisation (ISO) for character heights (in arc minutes) for different reading tasks, it is possible to calculate the necessary display resolution. Table 1 shows the result for a viewing distance of 400 mm. As shown, the display resolution for some Asian reading tasks is high enough to require high contrast.

Viewing distance (mm):	400		Font matrix/resolution (PPI)					
Reading task	Font size (')	Phone example	24	22	20	18	16	14
			Asian fonts			Western fonts		
User with reduced vision	22	All info on UI	238	218	198	179	159	139
Long complex reading	20	E-book	262	240	218	196	175	153
Short complex reading	16	Web page	327	300	273	246	218	191
Simple/familiar content	13	SMS/Email	403	369	336	302	269	235
Iconic reading/labels	10	Menu icons	524	480	437	393	349	306
Small details	10		524	480	437	393	349	306

Table 1. Reading tasks, recommended character heights, and the corresponding display resolutions for Asian and Western fonts

Whenever the contrast is not achievable due to poor display performance, viewing distance can be adjusted temporarily. This is not a problem for short tasks such as looking up a word in a dictionary but eye strain could develop for longer tasks. For iconic or graphic objects, it has been found[9] that users *prefer* a shorter distance because of a higher subjective image quality. This shows that the lack of contrast at least partly can be compensated for by shortening the viewing distance.

5. Conclusions

The large variety of illumination scenarios for mobile applications presents a big challenge in the design of information-intensive displays. In the high-contrast regime, native-width web pages can be resolved on hand-held displays whereas full-size TV images moving at 2 deg/s is beyond the eye's resolution. For 2.x" displays, 320x240 resolution is sufficient in video applications.

6. References

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