Visual Ergonomics Challenges in Information-Intensive Mobile Displays

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Abstract

New wireless and portable applications require high-resolution displays with wide colour range and blur-free video images. Terminal motion and varying illumination present new challenges while requirements on cost, system power consumption, durability, and product design limit the range of display performance. Optimum mobile visual experience calls for joint optical, industrial, and user interface design, and improved adaptability of the display subsystem.

1. Evolution of mobile telephony

The first-generation (1G) mobile telephony was dedicated to voice communication and the terminal display therefore only needed to showed phone numbers and occasionally alphanumeric characters in the phone book. The user tasks associated with the display were very simple and visual ergonomics a minor concern.

The introduction of second-generation (2G) mobile telephony enabled non-voice data transmission, including text and simple images. As shown in Figure 1., the basic version of the global system for mobile communication (GSM) natively supports 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 dot-matrix displays and some colour capability to enhance the increasingly complex user interface. 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.

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 kb/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 kb/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. 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, there is no doubt that 3G is firmly established. As shown in figure 1, 3G promises bit rates up to 2 Mb/s.

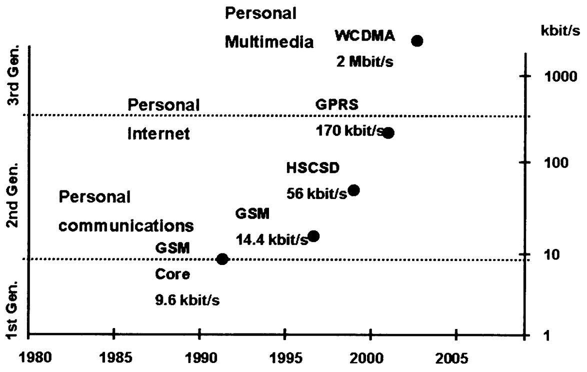

Figure 1. Evolution of mobile telephony and communication speeds

2. Other wireless technologies

In parallel with 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 50 Mb/s, respectively. 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) with IP-cast and upstream channels is another competitor to 3G telephony[1]. Broadcasts have already started in the UK, Sweden, and Finland and Japan will follow in 2003[2]. With bandwidths of several tens of Mb/s and high-speed mobility, DVB-T will enable even more information-rich contents to be consumed on the move.

3. High-capacity memory

In addition to high-bandwidth wireless access, progress in flash memory and video compression technology enables local playback of full-sized motion pictures at full frame rate.

4. Applications and display requirements

The aforementioned technologies together with highly developed interactivity will fundamentally change the framework for display-centric applications[3, 4, 5, 6]. 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 wireless technologies together with high-capacity memories enable video consumption at full size and frame rate, *i.e.* 640x480 pixels at 30 Hz. With this capability, however, users expect video image fidelity on par with stationary video contents consumption, that is, blur-free images with large contrast, colour depth, and wide gamut.

Camera-equipped phones enable applications such as telepresence, video conferencing, remote surveillance, multimedia messaging, and other see-what-I-see applications, also requiring displays with increased colour depth, colour gamut and contrast. Such displays will also facilitate the expansion of mobile electronic commerce, eventually including colour-critical purchase decisions. However, the tradeoff between brightness, colour saturation, and power consumption requires careful balancing of display parameters.

To achieve this in a hand-held terminal in a mobile environment is a daunting task and virtual displays are therefore widely considered to be the only option. It is well known, however, that near-eye displays (NEDs) potentially cause nausea and eye fatigue, particularly in an immersive configuration and while the user is moving. Although these problems are known, there has been a lack of tools for objectively assessing NED technologies. Nokia Research Centre has therefore developed tools and methods for accurate evaluation of NEDs.[7, 8]

Direct-view displays for information-intensive applications have progressed and pixel densities as high as 667 pixels per inch (PPI) have been reported [9] and a 3” 1600x1200 (QXGA) prototype has been built. Although this kind of display potentially can accommodate high-information content, a scalable user interface (UI) is required to assure legibility of characters and icons. As a result, the effective information density in terms of viewable characters per area would not necessarily increase over current displays. Viewed at a distance of 40 cm, a common figure for mobile devices, the spatial frequency of the 667 PPI display corresponds to 184 cycles/degree so, as is evident from Figure 2., such high pixel density will not add any benefit except for the possibility of spatial dithering.

Contrary to continuous-tone photographs and video, text and web-based content both have high contrast content and can consequently be resolved at higher spatial frequencies (see Figure 2.). The exact spatial frequency distribution in a large ensemble of photos used in typical mobile applications is difficult to estimate but the necessary display resolution is always lower than for text, maps, graphics, internet content, and other high-contrast content. However, if the perceived contrast is reduced due to environmental factors (see below), legibility of high-resolution content could be significantly reduced.

The key to solving these problems and to maximise the perceivable information density on high-resolution displays lies in a scalable and adaptive UI. More specifically, this means optimising the colour contrast and style of UI design to a given display performance in a given environment.

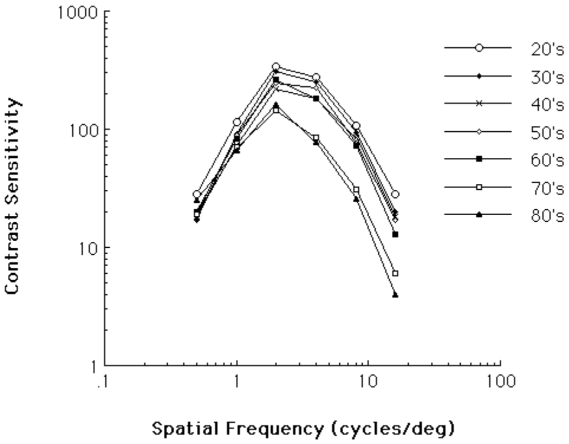

Figure 2. Contrast sensitivity function at different ages (after [10])

5. Mobile environment

Although the amount of information on a mobile display is approaching that of a desktop or laptop PC, the environment in which it is used differs significantly. Constantly changing illumination, for example, affects the perceived contrast ratio and therefore also the extent to which the eye can resolve details. Together with the age-dependent visual acuity, the contrast sensitivity function (CSF, see Figure 2.) dictates the usefulness of high resolution displays at a certain perceived contrast. As shown in the figure, a high contrast (=inverse of the CSF) is required to resolve fine details. Equally important is that there is a contrast ratio beyond which no additional gain in spatial resolution is possible.

Figure 2. refers to the *stationary case* and can be used to make basic UI hardware/software design to comply with visual ergonomics requirements. However, it is also known that the eye's *dynamic* contrast range and time to adaptation significantly limits the perceived contrast[11]. This is particularly evident when the eye adapts from a bright environment to a moderately luminous display in a dark environment, *e.g.* when driving at night. Consequently, the UI of high-resolution displays has to be carefully designed if the terminals are going to be used in changing illuminations.

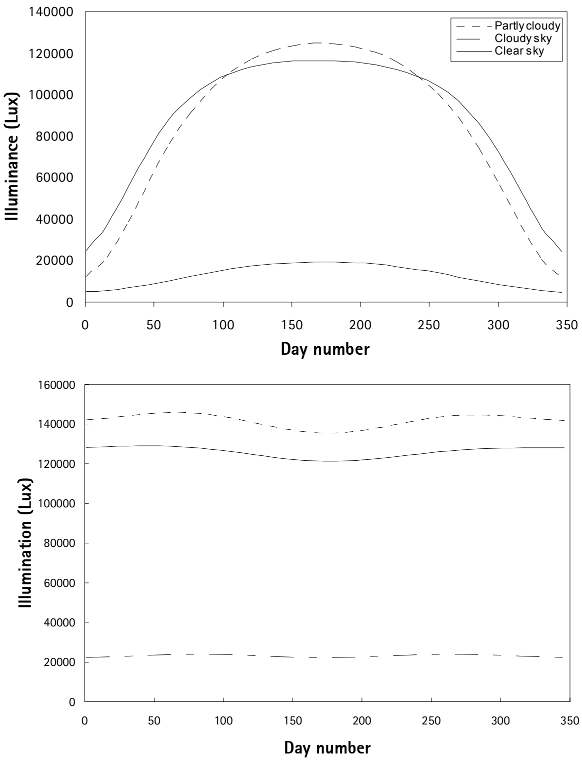

Figure 3. Annual distribution of the sky illumination in the Nordic countries (65 deg., top) and at the equator (0 deg., bottom)

Apart from the illuminance, chromaticity of the ambient light has some impact since all modern UIs use colour. Reflective and transflective displays alike appear differently in different illuminations and the UIs have to be designed for legibility (=good colour contrast) in all possible illumination scenarios. Also geographical location and time of the year impact visibility via varying colour temperature and illuminance (see Figure 3.). Designing the visual interface hard- and software in terminals for world-wide use therefore presents significant challenges.

The extent to which the display and terminal cover is Lambertian (diffusingly reflective) also affects the visibility in different illuminations. A cloudy sky, for example, has a very uniform illuminance distribution whereas direct sunlight from a clear sky exhibits extremely high intensities locally and therefore could result in annoying glare. Indoors, this corresponds to light from large-area fluorescent tubes or indirect lighting, and light from a halogen spotlight, respectively.

Avoiding glare via anti-glare (AG) coatings works well for low- and medium-resolution displays but could induce moire and interference artefacts in high-resolution displays. This problem exists for both reflective and transmissive displays and the former also exhibits non-Lambertian reflectance characteristics, *i.e.* deviation from paper-like appearance.

In order to improve the brightness and contrast ratio of reflective LCDs, active control of the viewing angle and diffusion angle has been proposed[12]. Although it is possible to achieve enhanced reflectance in a limited viewing cone, these methods introduce parallax which could lead to pixel cross-talk in high-resolution displays.

Displays with high reflectance and Lambertian characteristics ("paper-like") could solve these problems but for the more commonly available LCDs, there will always be a trade-off between brightness and glossiness. These problems can be avoided if the diffusiveness of the illumination can be detected and the amount of diffusion in the reflective display can be tuned dynamically[13].

In addition to non-stationary and non-homogeneous illumination, mobile visual ergonomics is challenged by display motion relative to the user, *e.g.* viewing the display while walking or riding in a vehicle. It is well known that moving display *content* on the most commonly employed mobile displays (sample-and-hold type) causes edges to appear blurred[14]. The same mechanism of spatio-temporal averaging leads to edge blur also in shaky mobile environments. Consequently, high-resolution displays have limited mobile applicability if edge blur is not taken into consideration. One way to reduce motion blur is to employ an impulse-type display which deliberately inserts a black fields between each frame. Unless the display device is very fast, however, this only works for transmissive displays and the commonly used 60 Hz frame rate leads to flicker.

6. Industrial design and visual ergonomics

With higher information density, display resolution, and wider use of colour, optical design of terminals is becoming increasingly important because it significantly affects the perceived contrast and hence the legibility at high spatial frequencies.

The human eye adapts its exposure and colour, not only to the display, but also to its surroundings. As a result, the perceived image quality is determined not only by the display parameters, but also the colour 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 optimise the perceived image quality, a phone cover should therefore be non-reflecting black, just like walls and ceilings in a movie theatre. Likewise, the display subsystem should be designed to minimise glare and reflection.

Unfortunately, optical optimization of the display appearance often conflicts with industrial designers' ideas on product image. Increasing commoditizing of phones leads to product diversification by design, often with curved surfaces and chrome details. As a result, 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 colourisation which affects the perceived image.

7. Conclusion

New wireless infrastructures and memory technologies enable video, native Internet browsing, and other information-intensive content to be delivered to handheld devices. Displays accommodating the amount of information are readily available but requirements on visual ergonomics and parameter balancing present a challenge for system designers.

Constantly varying luminous and application environments together with a strong demand for user-centric customization and design-driven products call for a higher degree of system flexibility. This, in turn, suggests more cross-disciplinary research and increased collaboration between display manufacturers and system integrators both in early research and development and more specific product programmes.

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