The Role of Color in User Interface Design of Wireless Mobile Devices

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Abstract

This paper provides an overview of the role of colors in the evolution of mobile phones from basic industrial design to the recent convergence of using them as color imaging and multimedia device from the user experience perspective. The use of mobile phones as image capture device is a natural synergy with voice and visual communication. While the user experience of using these phones as image preview/review device is adequate for the purpose, their value for quality image consumption (e.g., watching movies or high quality pictures) is limited until virtual display (or similar immersive technology) for mobile devices becomes commercially practical. Mobile user interface is highly constrained by the form factor of the device and the usage environment. The inherent human perceptual limitation and ecological constraints of pose a limit to the growth of using mobile devices for quality entertainment or photo album collection and perusal.

A Short History of Using Color in Mobile Phones

In the early days, monochrome display LED 7-segment character-based display (e.g., Motorola phones before 1997) was used. The display gradually evolved to monochrome character-based dot-matrix graphics display (e.g., Samsung SCH1000 7×9 pixels per character, 2-line display 2ith 12 characters per line) and full graphics dot-matrix display (1998, e.g., Sprint TouchPoint 100×64 pixels display).

Display technology has undergone a rapid transition from 7-segment LED and LCD in early or mid 90s to monochrome full graphics (pixel addressable) and then to color full graphics about 4 or 5 years time span (around 2000) with devices launched into the market.

The first color and color embedded camera handsets with carrier input and design were launched in the US Nov 2000 and Nov 2002 respectively. Both were exclusive products from Sanyo jointly designed with the wireless operator Sprint PCS. The later device was designed in conjunction with Sprint Picture Mail service launched in 2002. Since then, major carriers in the United States launched products with cameras and/or color display from handset vendors including Sanyo, Samsung, LG, Hitachi, Sharp, Audiovox, Motorola, Siemens, Sony-Ericsson, PalmOne and Nokia. Today, many high-tiered or mid-tiered devices support display with 65K or 252K colors.

By 2004, phones launched by major carriers in the US support color CSTN or TFT display.

Figure 1. Samsung SCH1000 (1997) and Samsung a940 (2005). The former has a monochrome 3-line 12 character LCD (5×7 pixels for each character) voice only phone while the later has a 176×220 pixels 262K color full graphics TFT display, an external 96×96 pixels 65K color TFT LCD with 2Mp camera and 2x optical zoom

Mobile Imaging Devices

Contemporary camera phones are both imaging and communication devices with the additional advantage of being able to transmit images without wires. Not only a camera phone can capture, record, render and transmit images, but it can perform other important communication functions such as voice calls, text messaging, picture mail, instant messaging. Virtually all camera phones also come with other handy features such as wireless internet browser, calendar, alarm clock, downloadable ringers and games etc.

Many camera phones also support recording and playing moving pictures, capturing and playing video clips or even “movies”. Because of the availability of data networks, many camera phones (mid to high tier) support streaming multimedia including video and audio-only content (e.g., live TV or radio). Users of the majority of data-capable wireless phones can also personalize their phones by purchasing and downloading music ringers, video ringers, wallpapers and games from all major carriers in the US.

Mobile phones and imaging are synergistic products. The success of camera phones come from the fulfillment of deep human needs to preserve memory and precious moments (and recording important and possibly unpredictable events) without deliberate planning to carry a camera around. The integration of almost ubiquitous network coverage and the compact size of the mobile device prove to be a distinct competitive advantage of camera phones.

One of the most critical hallmarks in the usability of digital camera is the capability of reviewing the picture taken with a built-in LCD display. This feature substantially enhances the usability of the camera as users can decide whether the picture taken immediately after capture should be kept and change the plan of action if necessary. With the advent of low-tiered embedded camera phones, the market for single-use film or digital cameras as well as low-tiered DSCs without built-in LCD preview becomes unsustainable.

The conditions for success for mobile imaging have ripened when carriers started to launch data network with higher speed (2.5G or 3G networks) and with the increased sophistication of image sensor, computing and digital image processing techniques since 2001.

The mobile operators in SouthEast Asia have been the pioneers of both new products and services. Mobile phones supporting video calls, satellite or terrestrial TV services are being marketed actively in Korea, Japan and Hong Kong in 2005. The role of having a state-of-the art color display in mobile device is vital in the user experience of such services. A cursory review of LCD display technology for the advanced mobile phones in Japan and Korea showed the trend of using a large LCD (2.4" or above) with high contrast ratio (e.g., 300:1 in Sharp's Aquos ASV display), 16:9 aspect ratio and a wide viewing angle (160+ degrees) in supporting a better experience of multimedia and TV services. The following showed the distribution of camera phones among all the phones actively marketed by the major carriers South-East Asia as of July 2005.[1-6]

Carrier	Phone Models	QVGA display	camera	Memory Card
DoCoMo (Japan)	Total 33 FOMA 18 MOVA 15	23	Total 29 1Mp+ 23 2Mp+ 8 3Mp 1	Total 24 miniSD 19 T-Flash 1 Duo 4
AU (KDDI) (Japan)	Total 21 WIN 11 1 X 10	8	Total 21 1Mp+ 16 2Mp+ 4	Total 10 miniSD 9 Duo 1
VodaFone (Japan)	Total 14 3G 6 V4-5-6 8	12	Total 14 1Mp+ 14 2Mp+ 3	Total 14 SD 7 miniSD 5 Duo 1 RsMMC 1
SK Telecomm (Korea)	Total 74	13	Total 73 1Mp+ 55 2Mp+ 17 3Mp+ 6 5Mp+ 3 7Mp 1	Total 24 T-Flash24
KTF (Korea)	Total 49	21	Total 49	Total 23 SD 3 miniSD 13 T-Flash 6 RsMMC 1

Mobile Picture Display Devices

The newer multimedia phones support mpeg4, mp3, aac, aac-plus content on top of digital imaging. An increasing number of multimedia phones also support memory cards (SD, miniSD or T-Flash). This class of convergent devices is similar in features as the personal digital recorder market where digital audio, imaging or "personal digital recorder" manufacturers (especially those without presence in the wide-area wireless network technology) are launching multimedia products (examples include products from Apple, Epson, Olympics, Kodak). Many of these products are "portable" but are still inconvenient to carry around because of the form factor. Many of them are also display/play only products without camera or camcorder functions. These devices tend to be relatively large and have limited market appeal compared with the multimedia camera phones.

The following features table shows the comparison between a high-tiered multimedia phones and a comparable 5-in-1 device (camera, video, music player, image viewer, voice recorder).

High-tier Multimedia Phone[7]	Typical Personal Digital Recorder[8]
2.1" 262K colors 240 x 320 pixels display with 1.1" color 72 x 96 pixels external display	2" LCD 117,000 pixels
1.3 Mp CMOS camera - 1-16X digital zoom, macro, multi-shot, white balance, EV compensation, stitch shot, self timer and flash, PictBridge compatible, image viewer	2Mp CCD camera – 2.5X digital zoom, white balance, EV compensation, flash, image viewer
MPEG4 Video Recorder (176 x 144 and 128 x 96)	MPEG4 Video Recorder (240 x 320 and 176 x 144)
Music Player (MP3, AAC)	Music Player (MP3, AAC)
Multimedia Streaming (on demand video)	Not supported
miniSD card (16MB included)	SD card (8MB included)
Phone - Voice Calls, PTT	Not supported
voice dial, name and digits	Not supported
Messaging (2-way SMS, Picture Mail, Voicemail etc.)	Not supported
Web Browser & Downloads (Ringers, Games, Apps)	Not supported
Phone Book, Alarm, World Clock, Calendar, To-Do List, Calculator, Voice Recorder..	Voice recorder only
USB FlashDrive	Not supported
Not supported	TV program recording
3.66" x 1.91" x 1.04" (4.52oz)	4" x 1.9" x 0.8" (4.24oz.)
Price: $250 with contract	Price: $345 (amazon.com)

Essential Features for a Reasonably Good Camera Phone

The user experience of a multi-function multi-feature device is significantly more complex than a dedicated device with single purpose. The design trade-off and constraints of usability versus complexity are inherent and universal in virtually all modern mobile digital equipment.

Designing the critical applications of a modern convergent device and keeping the basic operations simple within the cost and form factor constraints is a highly-disciplined process. A "point and shoot" paradigm (with reasonably good pictures quality output) in imaging application has to be deliberately designed without sacrificing the "dial and call" user experience of mobile phones. Most camera phones have dedicated "camera" buttons so that the consumer can launch camera and related sub-applications easily and quickly. Mobile phones are versatile devices focusing on the convenience of capturing "spur of moments" without the need to produce impeccable results as in prosumer or professional dedicated devices.

For a product to be useful, it is sufficient to satisfy a certain threshold level of performance. In the imaging world, a camera capable of relatively faithful color reproduction with a reasonable sharp focus for most 4" × 6" pictures (or maybe 8" × 10") will be sufficient for everyday purpose for average consumers. That translates to a 2 to 3 Mp sensor with good performance in outdoor and relatively bright indoor conditions. A handset with a 2 to 3Mp sensor with similar performance as in the current 2 to 3Mp DSCs in the market should be adequate for everyday use in the intermediate future. With the increasing availability of computing power, sophisticated digital signal processing techniques can be performed during or after image capture, enhancing the quality of the image. Most of the issues like dynamic range, backlight control, red-eye reduction can be resolved by either include a consumer friendly setting or by the device automatically.

In all the research reviewed or conducted in the past 3 years, quality/resolution of the pictures captured remains the most important feature. Resolution and quality of the pictures taken remains the first and most important improvement consumers will want to see in camera phones.[9]

The features available for camera phones are also approaching low-tier DSCs. The Sanyo MM 5600 has a 1.3Mp CMOS image sensor and supports different color filters, stitching, rotation, white balance. Samsung a800 uses 2Mp CCD sensor with autofocus, supporting picture mode, white balance etc. Support of different scene modes with appropriate adjustment of white balance, depth of field and exposure becomes an in dispensable feature for novice photographers.

The major drawback of the current generation of camera sensors in mobile devices is the trade-off of the size of the sensor and camera module to fit in a small form-factor and high noise in low-light conditions. This problem is also common in many consumer DSCs.

The quality of LCD viewfinder is less important feature if it satisfies users' need beyond a threshold. The resolution of LCD viewfinder in mobile phones still lags behind mid or high-end consumer DSC but the gap is rapidly closing. The high-tier mobile handsets support QVGA with 2-inch (or more) display (86,400 pixels) vs. a high-end consumer DSC with 2-inch display (118,000 pixels).

Figure 2. pictures taken by a 1.3M CMOS fixed focus camera phone and a Canon SD-500 with 7.1Mp sensor set at 3Mp fine quality. Automatic settings were used in both exposures (no post-processing)

Figure 3. Some example options available for a mid to high-tiered camera phone (Samsung a800 with 2Mp camera). White balance, EV compensation, multi-shot, self-timer, flash, resolution are standard features.

The Use and Misuse of Colors in Multimedia Phones

The evolution of the mobile user interface design is, by and large, driven by interactions between usability, technology and marketing needs. Display supporting 65K colors was a standard in 2004. With the devices launched in 2005, 262K colors support becomes the standard in 2" or larger display. All the mid-tier products will have at least 220 × 176 pixels or larger LCD in most Korean and Japanese carriers and some US carriers. The development of color display for mobile devices has almost come to the point of diminishing return unless a new display technology/paradigm can satisfy or create new unfilled user needs with the socio-cultural and usage conditions becoming germane to such adoption.

Handset software designers tend to exploit graphics and color to show off the capability of the display. Random and arbitrary association of plethora of colors and graphics in different applications, complex visual design and layout of the user interface affect the efficiency, learnability and memorability of the basic operations of the device. Coupled with the ever-increasing number of features that the device needs to support, usability of many top-of-line devices becomes worse than their predecessors. While such use of graphics and colors capture prospective customers' initial impressions and promotes purchase, indiscriminate over-design of those features can adversely affect the long term usage, the brand and loyalty of the vendor.

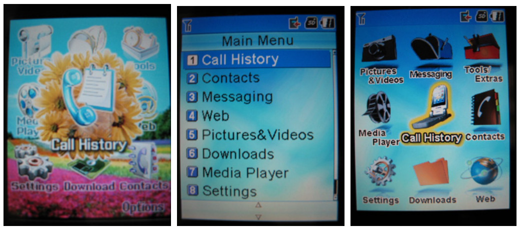

Figure 4. Main menu display of a fancy grid-based graphic versus a text-based main menu organization. Note the second and third screens are images from the same handset with main menu shown in "text" and "graphics" mode setting.

With a text-based user interface, users can understand the main menu options available to them and the supplementary "access" key mappings (using DTMF keys) at a glance without much effort. The icon-based grid menu looks nice but requires extra effort to understand and navigate. Instead of a linear list with up/down navigation or using quick access keys, a grid will require 2-dimensional navigation. In many implementations, only the text label of the current selected option is displayed. Even when the text label of each menu option is displayed with the icon, the text labels for unselected menu options are usually too small. The location cues and the corresponding mapping to the DTMF keypads are implicit and require more effort to discover and remember. The use of graphic icons requires users to learn a new "iconic" language. All these will require more attentional resource to perceive, understand and act upon, which is a scarce resource in mobile environment.

Sometimes, the business needs of highlighting specific capability in a device impact negatively on the usability. A handset vendor wants to highlight the capability of the display to render moving 3-D images. 3-D rendering is definitely a nice feature for applications like games. While the pseudo 3-D rendering is a technological feat in the mobile device at the time the device was launched (July 2004), the impact on the usability of this specific main menu layout is substantial. Only one menu option is visible at a time and the background 3-D animation has little meaning in the context of menu selection.

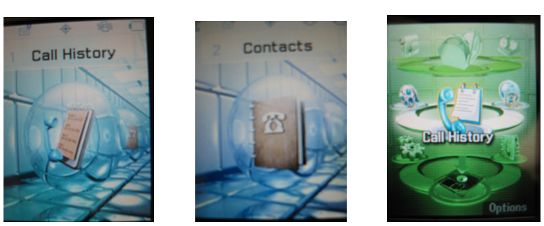

Figure 5. Examples of 3-D rendered main menu options with awesome 3-D images but awful user interface. The first 2 are examples of a main menu using 3-D rendering and animations showing different menu objects moving into focus. The third illustrates a menu system with 3 "serving trays".

Usability of Color Graphics in Mobile Devices

To understand the appropriate user interface design for mobile devices, we have to consider the following factors affecting the design:

1. Physical-Biological Characteristics of the Human Machine

Color perception depends on the biological characteristics of our eyes. Humans have approximately 7 million cones and 120 million rods in each retina and the distribution of cones are concentrated near the fovea. Human eyes, like optical lenses also suffer from all kinds of imperfection including chromatic aberration. In human visual perception, eyes move in saccades and fixate on different parts of the scene to extract pertinent information at various points of interest of the scene.[10]

During a fixation, the eye has access to three regions for viewing information: the foveal, parafoveal, and peripheral. The foveal region is the area being in focus with detail processing. It subtends 2 degrees of visual angle around the point of fixation, where 1 degree is equal to three or four letters (six to eight letters are in focus). The parafoveal region extends to about 15 to 20 letters, and the peripheral region includes everything in the visual field beyond the parafoveal region. Perception beyond the fovea result in a marked drop in acuity; words presented to locations removed from the fovea are more difficult to identify.[11]

The design for display can be effectively bounded by the setting a minimum of 72dpi as in computer monitor. A higher dpi (96dpi or more preferred) should be used because of the small form factor of the display. Since portability and convenience are some of the most important factors in the purchasing decision of a mobile device, the size of the display should not exceed 2.5" to maintain the form factor. With a typical 2" display (approximately 1.25" by 1.75") there is little need to cramp more than 240 by 360 pixels (QVGA with 252K colors). In many cases, even QQVGA display with 65K color (120 × 180 pixels) in a smaller 1.5" LCD display will be adequate.

2. Attention (Perceptual and Cognitive Resource Distribution)

Constraints as a Result of the Physical-Biological Constraints of Human Machine

The perceptual and cognitive resources required to understand the options available in an application on a small display depend on a wide range of factors including the visual organization as well as the textual label of the options (including the size and length of those labels). To minimize both the time needed to perceive the display and to interpret cognitively the objects on the display, users should be able to extract as much pertinent and unambiguous information relevant to the context gathered from the minimum number of fixations. The inclusion of complex graphics and lengthy textual labels/descriptions will increase the time and number of fixations to decipher the underlying meaning of the graphics or meaning. A mobile device, by its nature, is a device supporting the consumption of information when users have very limited attention span in a multi-tasking environment. If the design of color inhibits or slows down feature extraction of the graphics or text in task completion, it becomes problematic and should be revamped to better support important tasks. Techniques such as dithering the background image have been used to smooth out the transition from a graphics-rich screen to a more task-oriented display within an application user interface flow so that the overall theme of the user interface can be maintained.

3. The Ecological Constraints for User Interface Design of Mobile Devices are Driven by the Unpredictable Mobile Environment and the Widely Different Usage Scenarios

Users may use the mobile device to complete a task while driving. They may get distracted or interrupted in the task. The very nature of the environment would mean that the options and action available to the users at any specific time should be simple to decipher and execute. This is where most modern devices fail to satisfy users' long term needs. While it is important to keep the device attractive through flashy graphics and top-notched features, users should be able to transition from those flashy graphics to the rapid and easy completion of primary tasks.

The ecological constraint plays a critical role in the typical usage model of mobile devices. The user experience of using the mobile device as an entertainment or image peruse device is meant for rapid and impromptu consumption. It has no match with the experience afforded by big-screen TV or fine photographic prints.

The simple rule to follow in such design is to keep the flashy graphics, pictures, videos and colors to circumstances where users will not need to make an active interaction or decision with the device, e.g., in "idle state" when users are not actively engaged in a task. The visual design of such idle state should afford a simple and quick interaction to perform the critical tasks users are likely to engage. The user interface paradigm plays a critical role in the learnability. At the idle state, for instance, pushing a DTMF key should remove or gray out the flashy graphics and put users into the "digit-entry" mode where users should not be distracted. Additional user interface elements can be used to frame the digit entry input box. Similarly, pushing other function keys such as menu or soft-keys or shortcuts should enable users to focus on the task quickly without distraction. The ideal is to keep those displays simple but attractive and consistent with the overall "theme" of the device users have selected or customized. Designing main menu access without taking account into usability issues is a disservice to the customers.

4. Socio-Cultural and Psychosocial Environment

From the social and cultural (sub-cultural) perspective, users should be able to customize the colors they want whenever possible. One relatively straightforward way to ensure that users will not select any color combinations that are not usable is to provide a predefined set of color palettes. It is interesting to note that cultures in SouthEast Asia tend to have a higher tolerance to rich graphics and complex interactions of user interface. It is a common practice in Korea and Japan to mix English with their native language in mobile user interface and use very rich and complex graphics and interaction design.

5. Market Segment and Business Needs

If flashy graphics or colors are being used for business and marketing and such usage may impact usability of the product, we should provide a usable menu organization where users can switch to easily to a usable theme and color. A better strategy of highlighting the capabilities of graphics and colors is to put the device into a demonstration mode where those graphics and images can be shown off after a short time of inactivity.

6. Legal and Political Consideration

Another dimension of user interface design is driven by legal and political consideration. A color that leaves no ambiguity to the users that certain events must be known before they take any action (e.g., receiving or initiating a roaming call). For color-blinded users, properties other than color must be used redundantly to denote the differences.

Future Direction

In this paper, we argue for a more task-based approach in mobile user interface design with the inclusion of graphics and colors more conservatively. Ironically, the old text-based user interface is the easiest for people to understand and work with. It should be the basis of the user interface flow for critical tasks supported by the mobile device. Graphics and colors should be used in such a way that the interference with task completion is kept to a minimum. Thus, heavy color/graphics can be used in circumstances that users will need to wait for certain actions the device has to complete before proceeding further (e.g., search for service, power on/off display) or the user interface is sitting "idle". Advanced customization options to change the user interface should be nested and exposed through a deeper level of menu navigation

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