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INVITED PAPER *Special Section on Electronic Displays*

Mobile Viewer System Consisting of Mobile Phone and 13.1-Inch 4096-Color Electronic Paper Display

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SUMMARY A prototype of a novel mobile viewer system consisting of a mobile phone and a 13.1-inch 4096-color electronic paper display has been developed. The basic concept of the system, the technological study for realizing the concept, and the specifications of the prototype are described. Possible applications of the system are also proposed.
key words: *electronic paper, mobile phone, mobile viewer system*

1. Introduction

Mobile phones have been explosively permeated worldwidely, and cutting-edge models are not just "mobile telephones," but are rather "mobile internet machines" in terms of processor speed, and provided services and contents. Mobile phones also function as secure data-access tools mainly for business uses, because security functionalities such as remote lock and/or remote data erasure are installable. Thus, a variety of custom applications that are specially designed for particular business uses have been developed to provide mobile solution services. On the other hand, the maximum display size of mobile phones is much less than 10 inches, and it is too small for users to view PC-compatible internet contents. Of course, it is almost impossible to see business documents that are usually subject to being printed in A4 or US Letter size on the mobile phone's display.

In this paper, a novel mobile viewer system that brings break-through into the above-mentioned size limit of mobile phone display is demonstrated for the first time. In the system, the pictorial data stored in a mobile phone is sent via infrared interface and is shown on an electronic paper display with the size as large as 13.1 inch.

2. Concept and Technological Study

2.1 Basic Concept

The basic idea of the mobile viewer system is to mitigate the size limit on display of a mobile phone for enabling a user to view contents in large enough size everywhere at anytime. For realizing the idea, we have set the guidelines for the properties of electronic paper display as listed in Table 1 [1]. Note that the values listed in Table 1 were extracted by rough estimation showing commercial electronic paper displays to various potential users, but the values are not strict ones and should vary depending on the usages.

Transmissive displays such as liquid crystal display (LCD) or self-luminescent displays such as organic electroluminescent (EL) displays consume large electric power, and thus it seems very difficult to meet the criterion for battery life. On the other hand, electronic paper displays, of which the term-definition is described in the latter section, are much less power consuming than transmissive or self-luminescent displays because they utilize reflection of outside light like papers. This property is the most important point that discriminate electronic paper displays from the others, and we have decided to select electronic paper display for the mobile viewer system. As a consequence of low power consumption, the display size can be large enough as to show A4 or US Letter documents in their original sizes, which should be useful to apply the viewer system in business applications, as discussed in the latter sections.

Recently, various portable document and/or book readers with electronic paper displays have been launched into market. However, the electronic paper display is embedded in the device in those portable readers, while the electronic paper display is used as "a stand-alone large display" that works in conjunction with outside mobile devices in this concept. The author would like to put emphasis on this difference in concept. In addition, a similar concept of mobile display has been proposed in Ref. [2], in which a display separated from a note computer is demonstrated. However, the idea seems to be rather oriented to "separation" of display from other functional units of PC, which would have arisen from a different point of view.

2.2 Selection of Electronic Paper Display

Various types of "electronic papers" have been proposed and demonstrated to date as summarized in Table 2, although several exceptions that do not exactly match the classifications exist. In general, the term "electronic paper" involves not only "paper like displays" but also "rewritable papers," which requires external "printing" apparatus besides the display media. In the present case, rewritable papers are not suitable in terms of required properties concerning to portability and mobility. The paper like displays can be classified into non-volatile type and volatile type. The non-volatile type paper like display can maintain the displayed image without electric power. This property is particularly

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Table 1 Guidelines for porperties of the display to realize the baisc idea of the mobile viewer system. The display is assumed to be A4 in size.

Strength of demands	Property of display	Roughly estimated criterion
"Must" properties	Lightweight	Less than 1 kg
	Thinness	Less than a few centimeters
	Long battery life	More than a day
"Favorable" properties	Expressiveness (1)	Multi-color
	Low cost	As low as possible
	Good visibility	Comparable to newspapers
	Robustness	As robust as normal portable electronic devices
	Rewriting speed	Less than 20 sec for rewriting a whole area of the display
"Convenient" properties	Versatility	Operable in conjunction with various electronic devices
	Expressiveness (2)	Motion picture when necessary
	Flexibility	Bendable like plastic films

Table 2 Definition of electronic paper display in this paper.

Nomenclature	*Electronic paper*			
	Rewritable paper	*Paper-like display*		
		Electronic paper display		
Display mechanism	Reflection of outside light			Internal luminescence
Image volatility	Non-volatile		Volatile	
Workable image	Static image only		Both static and moving images	
Distinguishing features	External drivers are required besides display medium.	Displayed image can be maintained without power consumption.	No luminous device is employed, but displayed image goes off without electric power supply.	Conventional displays.
Typical examples	• Thermal rewritable paper • Magnetic rewritable paper	• Electrophoretic display • Toner display • LPD	• Electrowetting display • Electrochromic display • Electrodeposition display	• LCD with backlight • Plasma display • Organic or inorganic EL display

Table 3 Various types of electronic paper display.

Type	Multi-color	Response time
Liquid powder type	Possible using color filter.	0.2 ms
Electrophoresis type	Possible, but alignment process of color filter is under progress.	~100 ms
Cholesteric liquid crystal type	Possible by stacking RGB layers.	>100 ms

Table 4 Comparison of local interfaces.

Type	Line rate	Security	Standby power	Usability
IrDA	4 Mbit/s (IrDA / FIR)	Good	Low	Fair
Bluetooth	2.2 Mbit/s (Bluetooth 2.x EDR)	Fair	Medium	Good
Wired USB [*1]	hundreds of kbit/s - tens of Mbit/s	Very good	Low	Not good

*1: Most of popular mobile phones are not equipped with standardized USB interface. In many cases, USB based communication from a mobile phone is possible using a dedicated cable and software, but the line rate depends a great deal on the model.

important to realize low power consumption, although several types of volatile paper like displays can maintain the displayed contents with very low power. Hereafter, the word "electronic paper display" is defined as "non-volatile paper like display." According to this term-definition, most of the electronic paper displays meet the criteria for "must" properties listed in Table 1, thus the selection depends on the other criteria for "favorable" or "convenient" levels. Among those properties, multi-color capability should be useful for a lot of applications that are discussed in the latter section. Potential rewriting speed is also a judging point in the selection when taking future evolvability into account. Table 3 shows the comparison of three typical electronic paper displays. Considering these features, passive-matrix liquid powder display (LPD) [3] was selected for the prototyping. An active-matrix LPD with organic driving circuits fabricated on a plastic substrate has been already demonstrated [4], but it is not taken into consideration because its yield and reliability has not been well-established yet.

2.3 Selection of Local Interface

As mentioned in the former sections, the mobile viewer system consists of a mobile phone and an external electronic paper display. These two devices should be interconnected with each other via local interface. Possible choice of interfaces, which are normally equipped in mobile phones, is listed in Table 4, in which the pros and cons of each interface are compared. As can be seen from the table, IrDA interface has no critical drawback. Especially, IrDA combines good properties of low standby power and good security. Thus IrDA was selected for this attempt of prototyping, but of course, other interfaces can be employed together with IrDA according to applications and use scenes.

3. Description of Prototype

3.1 Electronic Paper Display

As described in the former chapter, electronic paper display is based on passive-matrix LPD. The specifications are summarized in Table 5, and the outlook of the electronic paper display is shown in Fig. 1. Since the pixel of the display consists of four subpixels of RGBW ("W" is white), differently from conventional displays comprised of RGB subpixels, a special image-file format that has capacity about 1 MByte per image is required. The internal memory embedded in the display can store ten images for this prototype. As described in the former chapter, unlike commercial portable readers with electronic paper displays, there is no user-interface on the display except the power button at the bottom-right of the front panel as shown in Fig. 2. It is because the rendering speed of the display is not so high, and hence the operation using the display should be time-consuming and should irritate the user. The display can be operated only by using after-mentioned test software on the mobile phone. The LED indicates the display statuses of "power off (off)," "standby (blue)," "communicating (green lighting)," "rewriting (green blinking)," and "error (red)." At the "standby" state, electric power is consumed for keeping the main and IrDA processors standby as well as for lighting the LED.

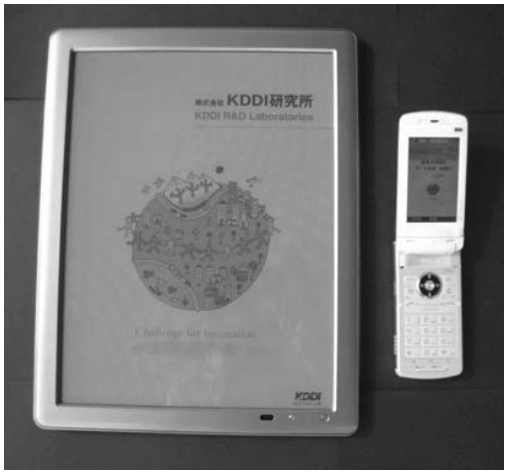

Fig. 1 Full view of the mobile viewer system.

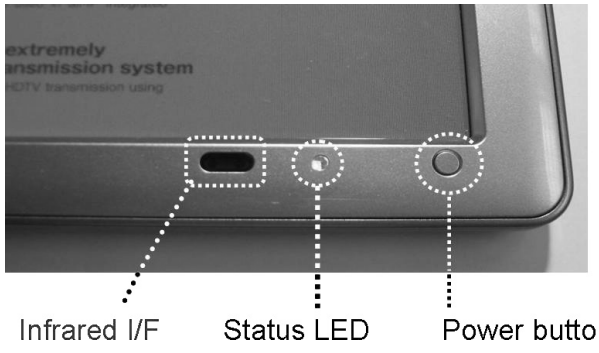

Fig. 2 Magnified view of the bottom-right corner of the electronic paper display.

Table 5 Specifications of electronic paper display.

Display area	Physical size	265.6 X 199.2 mm^2 (13.1 inch)
	Pixel / resolution	600 X 800 / 75 ppi
	Color scale	4096 by RGBW color filter
Total device	Physical size	237.8 X 304.2 X 14 mm^3
	Weight	820 g including two sheet-batteries
	Infrared interface	Compliant with IrDA / FIR
	Battery	Lithium polymer type, 3.7 V, 3300 mA/h X 2

Fig. 3 The thumbnail picture shown on the main display of the mobile phone.

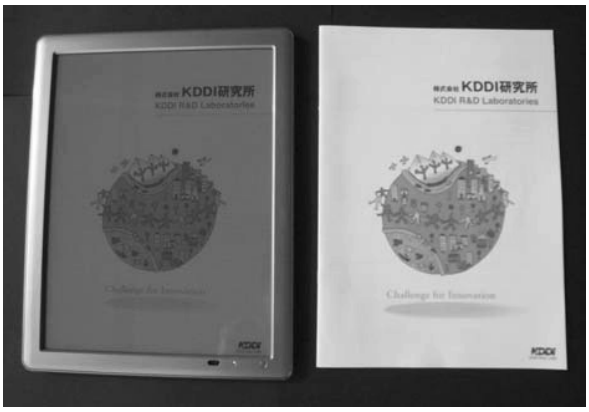

Fig. 4 The image shown on the electronic paper display and the original pamphlet. The photograph was taken in a normally-lighted room without flash.

3.2 Test Programs on Mobile Phone

Two preliminary programs based on BREW 3.1 are developed on a mobile phone. The first program is for sending the pictorial data stored in the mobile phone to the electronic paper display, while the second program is for selecting the picture that are already stored in the display. In both cases, the user can select the picture by conventional drop-down menu, and the user can see and check the picture before sending or selecting by looking at the thumbnail picture with 160×120 pixels shown on the main display (Fig. 3). In such a way, the user does not have to mind slow response of the electronic paper display. It is possible to erase all the data stored in the electronic paper display as well as those in the mobile phone by one command. When an error occurs on the display, it can be quickly checked by pushing a button on the mobile phone via IrDA.

3.3 Performances

The maximum communication distance between the mobile phone and the electronic paper display was about 20 cm. The speed for transferring one-page pictorial data of 1 MByte from the mobile phone to the electronic paper display was about 5 sec, which would be mainly governed by IrDA/FIR protocol overhead. It took about 12 sec for rewriting one-page image on the display. Note that these values can be improved in the future by employing a faster interface protocol such as IrSimple or by upgrading the driver IC on the electronic paper display.

Thanks to the low power consumption, the electronic paper display did not need recharging of the batteries for three days during demonstration at an exposition where the display was operated more than hundred times per day. As a calculation result, fully-charged batteries can support more than one thousand times of rewriting.

It should be noted that, as for reflectance and contrast ratio of the electronic paper display, the values have strong dependence on measuring method, but there is no method that is defined as technical standard. Thus the definitive values for these performances cannot be given in this paper. However, as can be seen from Fig. 4, the electronic paper display has enough readability in a normally-lighted room.

4. Possible Applications

4.1 Secure Mobile Presentation Tool for At-Home Sales

In this chapter, several possible applications of the mobile viewer system are described. Recently, business corporations are strongly required to protect their customers' personal confidential information from leakage as strictly as possible. On the other hand, they are also required to accomplish accountability to their customers. However, these two essential requirements sometimes conflict with each other. For example, it is not favorable for a field salesperson, who treats customers' personal confidential information, to bring such information by printed materials or in digital media due to possibility of loss or theft of the data. However, he cannot make explanation without such information when they visit his customer at home. In such a situation, the mobile viewer system would be very useful because the salesperson can download the data into the mobile phone and display them on the electronic paper display after he reached the customer's house. The most important point is that these actions can be completed just in front of the customer's eyes and thus he can gain the trust of the customer. IrDA communication between the mobile phone and the display is tolerant of wiretapping thanks to its directivity and short range. The security of the network between the data server and the mobile phone can be supported by closed-network services. As a result, a high-level end-to-end data security can be guaranteed.

4.2 Paperless Presentation Tool

In a similar situation described in the former subsection, the

salesperson may have to show various kinds of pamphlet as well as list of clauses, which are indispensable for accomplishing accountability to the customers but should be bulky and heavy if they are printed material. The system is also useful for such a case, because all the data can be stored in the internal memory of the mobile phone or an external memory device such as an SD card, and then printed material is not necessary any more. The electronic data is easier to handle for revisions and/or updates in comparison with printed material that requires reprinting. From social responsibility point of view, paper consumption is greatly reduced by utilizing the system, and hence the system is good for the ecology. Of course, paperless presentation is not necessarily limited to the case of a salesperson, but can be applied to a various use scenes. For such a kind of use case, Bluetooth would be a better choice for the local interface between mobile phone and the electronic paper, because the information is open and public and a tight security is not required.

4.3 Information Billboard

As described above, the basic concept of the viewer system is to use the display to see rich contents, which cannot be seen on the main display of the mobile phone, on a display with large enough size. When disregarding cost issues, if electronic paper displays are installed everywhere in a town such as at curbsides or beside show windows, anyone can use the display to see, for example, navigation or guide map of the town. This situation might be realized based on advertising business scheme in the future. In this case, the data hub is not necessarily a mobile phone but can be a different one such as a mobile internet device or a portable navigator.

5. Conclusion

In conclusion, the mobile viewer system employing electronic paper display for large-size viewing is demonstrated. The basic concept, the technological study for realizing the concept, details of the developed prototype, and the possible applications are described. The author believes that mobile viewer system consisting of a mobile phone and a large-size low-power-consumption display will be an excellent tool for a variety of ubiquitous applications, which could not be referred to in the present paper. As concluding remarks, expectations for further progress in the electronic paper display technology are referred below:

- Higher reflectivity for better visibility and for better expressiveness.
- Weight saving by employing plastic substrate.
- Active-matrix driver for moving picture. Note that even this is realized, the main usage of the electronic paper display should be still for displaying static images, because LPD might consume compatible or even more power than LCD to show the same moving images.
- Low cost. This should be possible when the electronic paper display is in mass production. In addition, printing-process technologies are much-anticipated not only for lowering the cost but also realizing true resource-saving during total life-cycle of the display.

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