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Low power consumption of smart phone reading mode enabled with electrophoretic electronic display

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Abstract. Smart phone usually has a short battery life time per single charge and poor readability outdoor as LCD screen consumes large power and has low contrast at strong light condition. In this paper, an intelligent case with electrophoretic electronic display (EPD) as the screen and RK2818 as the driver chip, which can be interacted with Apps on smart phones by using USB OTG communication technology, is designed and implemented. The intelligent case can be used as a second screen of smart phones and realized information exchange and display between smart phones and EPDs. Experimental results show that the display delay time between the intelligent case and the smart phone can be reduced to 300ms, which makes the dual-screen smart phone system practically usable. By using this second screen, the readability of a smart phone in strong light condition will be enhanced and the power consumption of the whole system will be reduced at a similar usage mode as the single LCD screen enabled smart phone.

Key words. The intelligent case; USB OTG; Electrophoretic Electronic Display; Android Technology.

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1. Introduction

Smart phones have shortened the distance among people, which have become necessities in people's lives. Conventionally, liquid crystal display (LCD) is used as display in screen smart phones [1]. However, the LCD screen is made of glass platen and has to be equipped with backlights [2], which gives rise to problems such as inconvenience to read in strong light [3], harmfulness to eyes in case of long-time reading and high power consumption [4],[5]. Fortunately, a new display material called electrophoretic electronic display (EPD) is designed which has many excellent characteristics, such as paper-like display, energy-efficient, environmentally friendly. So, an intelligent shell with an EPD as the screen is proposed to improve user experience of the smart phone [6],[7].

After years of development, EPD technology can be used for commercial purpose. Leading in the product development, E-Ink, an American scientific and technological enterprise, has published electronic book (E-book) with EPD screens. However, EPD technology has not been applied to smart phones until the launching of YOTA Phone that is the first dual-screen smart phone in the world [8]. For YOTA Phone, various application information can be displayed by an E-Ink screen, which settles above-mentioned problems caused by LCDs. Nevertheless, such dual-screen phone is still in its infancy and most phones do not have a LCD-EPD dual-screen display like YOTA phone [9]. In addition, a placecountry-regionSingapore scientific and technological company OAXIS designed and implemented a shell for smart phones named INKCASE which is intelligent and operable. It contains chip, battery and internal storage, and communicates with a mobile phone by the Bluetooth [10],[11]. Limited by the transmission rate of the bluetooth, there is a great delay for E-paper display. Worse still, data transmission is also unstable.

Therefore, we present an intelligent case or shell by using EPD as the display screen, RK2818 as the driver chip for smart phones. In the system, the USB OTG communication technology is used to interact with APP in a smart phone for obtaining the display contents which is customizable. Compared with 24 Mbps of Bluetooth 4.0, the USB OTG has a high transmission speed of 480 Mbps, which greatly shorten the display delay time of EPDs [12]. The experimental results show that the display delay duration between the intelligent shell and the smart phone can be reduced to 300ms, which practically makes the linkage display of dual-screen come true.

2. System design principle

USB OTG, namely USB On-The-Go, is added a function of power management (power conservation), which allows a piece of equipment can be used as both a main engine and a peripheral. For meeting the standard of USB 2.0, the OTG double-duty equipment has the ability of host detection and also supports the host negotiation protocol (HNP), as well as the session request protocol (SRP).

The overall system falls into two parts: hardware system and software system. The hardware system, which is named as the slave device, refers to the whole intelligent shell including the driver board, the EPD display screen, buttons and the driver program. In this system, RK2818 is selected as the driver chip, and an E-ink EPD is used as the display screen. Software system such as App program on smart phones is adopted as the primary device. Since the Android system is chosen as the development platform in the system, App mentioned in the paper refers to Android App. The system framework is shown in Fig.1, the intelligent shell is connected with the Android OS mobile phone by the USB OTG, and the Android App provides data for the intelligent shell according to the information required to be displayed. Then, the shell is driven by RK2818 chip can display contents in the EPD, which also can be controlled by operating buttons.

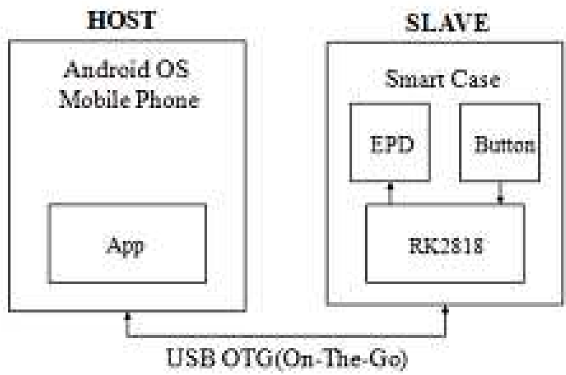

Fig. 1. The System Frame

The smart phone could send a USB-attached broadcasting when the intelligent shell is connected with a smart phone. Then, the App can be initialized, obtains related data after receiving the broadcasting, and lays the data out in the defined interface which hides in the phone. Then the App stores the gray value data of the defined interface into bite arrays according to the generated image and gray level transformation, and these data are transmitted into RK2818 chip at the same time. Finally, EPD driving waveforms are called by the driver program in RK2818 to refresh the display line by line in a proper way according to gray value data, and then, all the content is displayed in EPD.

3. Hardware design of the system

The first work of the hardware design is the component selection. In this paper, the design and implementation of the intelligent shell has strict requirements of the size and power consumption. Considering the requirement of supporting OTG USB, RK2818 is selected as the core driver chip. The ARM9 kernel is based on the DSP + ARM + GPU architecture, with USB 2 interface, is used to support OTG function according to the functional requirements of the design driver board. The system mainly includes USB interface module, power management module, EPD display interface, etc. The frame structure of the driving board and the circuit diagram are designed to realize the driver board. The driver plate is shown in Fig.2.

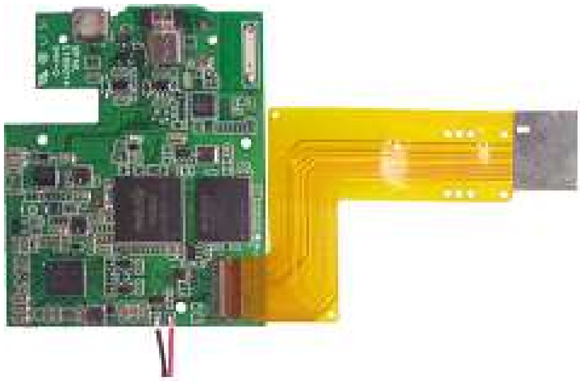

Fig. 2. Driver board physical map

With the driver board, the driver must be written and compiled. The development of the driver system is compiled in the Ubuntu 12.04 version to build a driver and compiler environment. The driver is written and modified by GEDIT text editing tools, and it compiled into image file by cross compiler environment. Lastly, the driver is burn into driver plate by using the burning software. So, the driver board has the function of responding to the USB event and driving EPDs.

4. Software Design of the system

4.1. Software system framework

The design of software system follows the design pattern and the object-oriented programming idea, the lamination structure MVC frame is used to carry on the design. The whole system is divided into a plurality layer of multiple modules to achieve high cohesion and low coupling. In the software system, the construction of the OTG USB communication framework and the realization of gray scale conversion are the main work for function realization. Software system framework is shown in Fig.3.

When the APP program is started, the APP.java is executed firstly, and then the MainActivity.java starts MainService.java, and the system environment is judged by the EpdiCellService.java (AIDL) at the same time. And now, the ContentProviderSystem.java, ContentProviderSystem.java, ModuleManager.java, DisplayManager.java, InputHandler.java and IO are implemented.

IO input and output management including two parts: DisplayManager.java and InputHandler.java management. DisplayManager.java includes a series of methods which are required to display the required getEpdiWidth (), getEpdiHeight (), setRefreshMode (), displayWhite (), displayBlack (), displayWaitScreen (), displayView (), displayColorBitmap (), etc. InputHandler.java mainly includes addHardWareKeyListener () and removeKeyListener () and other methods. The control of keys is realized by the radio, the system sends a corresponding broadcast when the key is used, and then, the appropriate program processing of distributing the identity must be done according to the radio when the program received the broadcast.

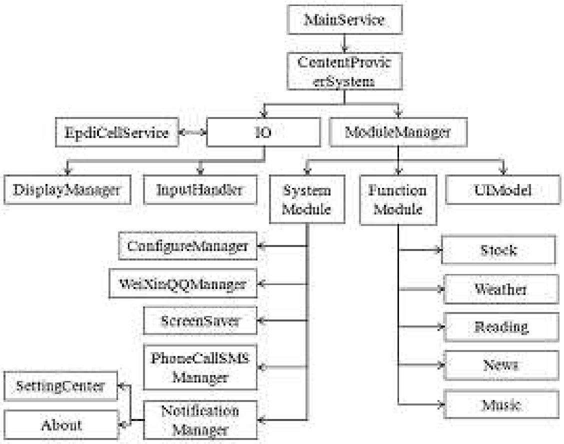

Fig. 3. Software system framework

ModuleManager.java carries on the management of each module, mainly including instanceModule (), killAllModules (), killRunningModule (), and so on. Modules are divided into SystemModule, FunctionModule and UIModule.

4.2. Communication realization

APP Android is designed as the main equipment for OTG USB communication. According to the AndroidMenifest.xml Reference document, we need to apply for permission firstly, the UsbManager is gotten through getSystemService (Context.USB_SERVICE) at the same time. The VenderId and ProductId enumeration USB is done for the device, and then, two Endpoint is opened when the communication interface is connected, one for transmitting data from the device, the other for receiving data from the device. Core code is shown as follows:

```
this.mUsbManager = ((UsbManager) this.mContext.getSystemService("usb"));
HashMap<String, UsbDevice> deviceList = this.mUsbManager.getDeviceList();
UsbInterface intf = this.mUsbDevice.getInterface(i);
conn = this.mUsbManager.openDevice(this.mUsbDevice);
this.epOut = this.mInterface.getEndpoint(1);
```

4.3. Gray conversion

The conversion principle between color and grayscale image is shown as follows. Color bitmap is composed by three components of RGB, the file storage format for the bitmapfileheader and bitmapinfoheader is followed by the principle: Each point is composed of three bytes to represent RGB if it is a 24 bit RGB image which is followed by the color information of the image. However, it is followed by the palette data if it is an 8-bit (256 level) image, or 4-bit (16 level) image, or 1-bit (single level) image. An array of RGBQUAD types whose length is determined by the BITMAPINFOHEADER.biClrUsed, and the followed is the image data.

Gray level image refers to the brightness information, and the color information of the image is not contained. As we see the black and white photos: change brightness from dark to bright, which is continuous. Therefore, the gray level image is required to be shown, and the brightness value is required to be quantified. The image gray level divided into 0 to 255 levels, where 0 is the darkest, and 255 is the brightest. In the method of representing color, there is a method called YUV. In this representation, the physical meaning of the Y component is the brightness, the Y component contains all the information of the gray scale, and only the Y component can be fully capable of representing a grayscale image. From RGB to YUV space, Y conversion formula: Y = 0.299R+chmetcnvUnitNamegSourceValue.587HasSpaceFalseNegativeFalseNumberTy

According to the palette of gray scale, the color palette of the specific color is required to be determined at first. As has been mentioned, the three components of the gray scale are equivalent. There are 256 colors in the palette when the conversion is 8, each of which is equal to 255 to 3 or 0. The interval is divided equally among 255 color values, the three components are equal when required to be converted to 4 bit. The color palette has 4 colors when it required to be converted to 2 bit, and the interval is divided equally between 255 colors, so the three color components are equal. When it required to be converted to 1 bit, the palette has two colors, which is 0 and 255 (black and white). According to the principle, the corresponding value of grayscale is calculated, and the value is actually the level of brightness. The brightness value can be change from 0 to 255 due to different levels, so, the Y value is shown as follows: Y = Y/ (1<< (8-Number of transition bits)).

In order to convert a color image into grayscale image, the following conversion is required: the image which is more than 16-bit has no color palette, it is only necessary to convert the image data into the same gray value according to the number of bits in each point. The image, which is below 16-bit, is required to modify the value of the palette, and gray index value must be modified according to the number of bits for per point.

5. Experiments and Results

According to the software and hardware design, the whole system is formed. Due to traditional intelligent shells which used Bluetooth scheme and the USB design scheme are based on EPDs, so, the refresh time mainly related to the driver waveform, and a large gap is not be present in this respect. According to our knowledge, the existing EPD driving time is from 100ms to 200ms. In the experiment, App is installed into smart phone at first, and the connection between the mobile phone and the intelligent shell is realized by using the USB interface. Secondly, news, pictures, stocks, reading and other content can be displayed after a long press on the middle button, as shown in Fig.4, these contents can be customized by App.

In this paper, the App terminal processing rate, data transmission rate and screen refresh rate are tested by the following method. In the process, an image is placed on the App, and the following code is added to test the response speed:

```
long startTime = System.currentTimeMillis();//start position
long stopTime = System.currentTimeMillis();//end position
long handleTime = stopTime - startTime;//finally result
System.out.println("App handle time" + handleTime);//show the result
```

The gray conversion time is 100ms by means of the logcat tool, as shown in Fig.5.

Fig. 4. The real figure of the system

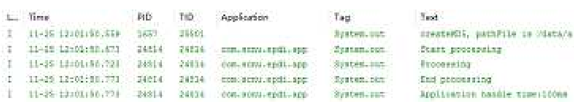

Fig. 5. The log map of application processing time

A 192000 byte image data array can be gotten by App processing. And the transmission speed is test by adding the following code in the program which is responsible for receiving grayscale data in RK2818 driver.

```
do_gettimeofday(&start_tv);//start
```

do_gettimeofday(&stop_tv);//end

pr_err("cost militime%d\n",stop_tv.tv_usec - start_tv.tv_usec);//show result

According to the High 480Mbps USB2.0, the calculation result should be about 3.05ms. The actual display duration is about 30ms, and it is twice faster than the theoretical maximum transmission rate of Bluetooth 24Mbps. As shown in Fig.6.

Fig. 6. Driver processing time

6. Conclusion

In order to reduce power consumption of smart phones, an intelligent shell design scheme based on EPDs is proposed. An EPD is used as the display in the system, RK2818 as the driver chip, and the communication with the mobile terminal application is realized by using the USB OTG technology. Experimental results show that the transmission rate of the system is twice higher than traditional schemes. It can be concluded that the proposed design scheme has the advantages of high transmission rate, low delay duration and clearer display compared with the existing Bluetooth design scheme.

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