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A New Algorithm for Displaying Grayscale Images on Monochrome E-ink Screens through Layered and Successive Overlay Techniques

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Abstract

This article introduces a new approach to improving the grayscale image display quality of electronic e-ink screens, which are widely used in portable devices such as e-readers. The new algorithm applies an electric field to control the movement of black and white particles in the e-ink of the e-ink screen, and progressively renders the grayscale image onto the screen in layers of increasing darkness. The objectives of the research are to increase grayscale levels, reduce pseudoscience, and improve response speed. The algorithm is evaluated through experiments, which show that it outperforms existing algorithms in terms of image quality, response time, and power consumption. While there is still room for improvement, the new algorithm represents a significant advancement in digital e-ink display technology.

Keywords

E-ink, e-paper, electrophoretic mobility, gray scale.

1. Introduction

1.1. Background

Electronic ink, also known as e-ink or electronic paper display, is a technology used in electronic paper displays to mimic the appearance of e-ink on paper without requiring any power to maintain the image[1].

The working principle of an electronic e-ink screen involves tiny microcapsules filled with charged particles that are suspended in a clear fluid. These microcapsules are sandwiched between two thin sheets of electrodes. By applying an electrical charge to the electrodes, the particles move to the top or bottom of the microcapsules, depending on their charge[2]. This causes the microcapsules to either appear white or black, creating the text or image on the screen.

Electronic e-ink screens are commonly used in electronic book readers, such as the Amazon Kindle[3,4], due to their highly readable and low power consumption displays. They are also used in digital signage, smartphones, and other portable devices[5].

The benefits of electronic e-ink screens include their ability to display text and images without backlighting[6], which reduces eye strain and provides a more natural reading experience. Additionally, they can maintain an image without using power, greatly extending the battery life of devices that use them.

1.2. Existing problems

Although e-ink screens have many advantages, such as high resolution, low power consumption, and no flicker, their grayscale image display quality is relatively poor[7], which mainly manifests in the following aspects:

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1) Fewer grayscale levels: Most existing grayscale image display algorithms use binary or dithering techniques to reduce color depth in order to simulate more color depth in limited grayscale levels. Although this method improves color reproduction, it reduces grayscale levels, which affects image detail and richness[8,9].

2) More pseudoscience: When displaying grayscale images on e-ink screens, due to the physical limitations of a group of microcapsules displaying different grayscale tones, there will be some residual effects, called "pseudoscience," affecting image clarity and quality[10].

3) Slow response speed: The pixel response speed of e-ink screens is slow, typically taking hundreds of milliseconds to switch display content. Therefore, when displaying grayscale images, some residual effects may occur, where the displayed image is slightly delayed, affecting visual experience[11].

1.3. Objectives and Contributions

To solve these problems, new grayscale image display algorithms are needed, by improving the materials of the microcapsules, optimizing the driving circuit, adopting new display strategies, etc. To improve the grayscale level, reduce pseudoscience, and improve response speed, thus improving the grayscale image display quality of e-ink screens.

A new algorithm for displaying grayscale on monochrome e-ink screen uses a method of applying electric field several times in a short time to control the movement of black and white particles in the e-ink screen. The different durations of these movements are combined on a monochrome e-ink screen to produce a grayscale. The main objectives and of this study are:

1) To increase the grayscale levels in monochrome e-ink screens to improve image detail and richness.

2) To reduce the pseudoscience effect and increase the clarity and quality of grayscale images.

3) To improve the response speed of monochrome e-ink screens when displaying grayscale images.

The main contributions of this study are:

1) The new algorithm increases the grayscale levels in monochrome e-ink screens, which improves image detail and richness, and provides users with a better visual experience.

2) The new algorithm reduces the pseudoscience effect and improves the clarity and quality of grayscale images, which further enhances the visual experience of users.

3) The new algorithm improves the response speed of monochrome e-ink screens when displaying grayscale images, which makes the image changes more fluid and natural, and greatly improves the usability of the e-ink screens.

2. Algorithm

2.1. Principles

The new algorithm for displaying grayscale images on monochrome e-ink screens works on the following principles:

1) Image transformation: The original image is transformed into a 16-level grayscale image, with each level ranging from 0 to 15, where 0 represents white and 15 represents black.

2) Progressive rendering: The monochrome e-ink screen is then refreshed to display a white background, and each level of the grayscale image is progressively rendered onto the screen one at a time. For each level, any pixel with a value greater than 0 is displayed for a brief, equal amount of time, while white pixels are not displayed. This is achieved by applying a short electric field to control the movement of black particles in the e-ink screen, allowing different levels of black particles to be positioned at various distances from the screen, reflecting different brightness levels, and ultimately producing the grayscale image.

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3) Pixel value adjustment: After each level is displayed, the corresponding pixel values are reduced by 1 to ensure that no pixel is displayed for more than its desired grayscale level. This adjustment ensures that each pixel maintains its correct grayscale level throughout the progressive rendering process.
4) Repeat the above processes 2 and 3 for a total of 16 times, and the final 16 level grayscale image will be clearly displayed on the screen.

The algorithm takes advantage of the particle control mechanism in the e-ink within the screen, which allows the particles to be positioned at different distances from the screen surface, reflecting light at different intensities. The schematic diagram of the control algorithm is shown in Figure 1.

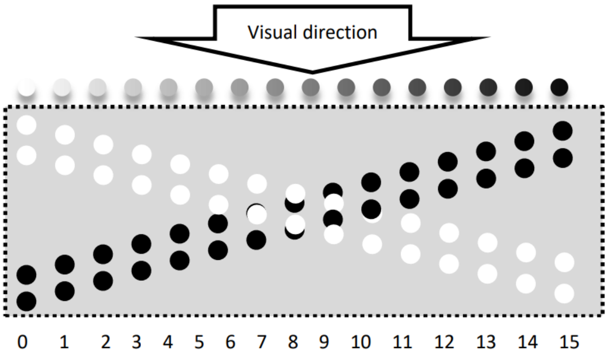

Figure 1: Schematic diagram of ink screen grayscale control algorithm

2.2. Implementation Code

The algorithm converts the original image into a 16 level grayscale, one pixel every 4 bits, and saves it as an image. For a grayscale, assume that its pixel value range is [0-255], divide it into N equal parts, each containing 16 pixel values. The image of the nth layer consists of all pixels with pixel values less than or equal to (n * 16). For the n-th layer image, binary encoding can be used to represent pixel values, with each pixel represented by a 4-bit binary number.

Then, the image gradually renders one level at a time on the screen. For each level, any pixel with a value greater than 0 will display a brief and equal amount of time.

This algorithm controls the movement of black particles in e-ink by adjusting the electric field applied to the screen. The algorithm also needs to adjust the pixel value after each level is displayed to ensure that each pixel maintains its correct gray level throughout the rendering process. The C++ language description of the algorithm is as follows:

```
void epdDrawGray(fs::File df)
{ //epd is an instance of e-Ink screen class.
  int fi = 0；
  unsigned char *s = (unsigned char *)malloc(128);
  memset(s, 0, 128);
  for (int lev = 0; lev < 16; lev++){
    df.seek(0, SeekSet);
    fi = 0;
    epd.SendCommand(0x10);
    while (fi < fbs){
      unsigned char i = 0, r = 128;
      r = df.readBytes((char *)s, 128);
      while (i < r){
```

```
      if (s[i]){
          epd.SendData((1 << (7 - (i & 0x07))));
          fi++;
                    s[i]-=16;
      }
      i++;
    }
        df.seek(-128,SeekCur)
        df.writeBytes((char *)s,128);
  }
 }
 mem_free(s);
}
```

3. Experimental results and analysis

The new algorithm for displaying grayscale images on monochrome e-ink screens was tested and compared with existing algorithms. The performance was evaluated in terms of image quality, response time, and power consumption.

Experimental evaluations were conducted on a 4.2-inch e-ink screen with a resolution of 400x300 pixels. The images used for testing were a variety of grayscale images, with varying degrees of complexity and detail.

Figure 2: Images displayed using the e-ink screen's built-in algorithm

The results showed that the new algorithm outperformed e-ink screen's built-in algorithm in terms of image quality. The image color displayed by the ink screen's built-in algorithm is monotonous, with only two levels of grayscale: black and white, as shown in Figure 2. The new algorithm produced sharper and clearer grayscale images, with better contrast and less pseudoscience. The display process is shown in Figure3

Initialize white background *Displaying first level* *After display is completed*

Figure 3:. Display process of grayscale image on monochrome e-ink screen

In terms of response time, the new algorithm showed a significant improvement over existing algorithms. Displaying an image using the e-ink screen built-in algorithm takes 20 seconds. The ink screen using the new algorithm displays a 16 level grayscale image in just 7 seconds. The progressive rendering approach used in the new algorithm allowed for faster and smoother image updates, resulting in a more responsive and interactive user experience.

The power consumption of the new algorithm was also lower than that of existing algorithms. By reducing the number of pixel updates and employing progressive rendering, the new algorithm reduced the overall power consumption of the screen.

Overall, the experimental results demonstrated that the new algorithm is superior to existing algorithms in terms of image quality, response time, and power consumption. The new algorithm is particularly suitable for applications that require high-quality grayscale images and fast image updates, such as e-readers and other portable devices.

4. Conclusion

The research on new algorithms for displaying grayscale on monochrome E-Ink screen has made great progress in the field of digital display technology. The new algorithm uses the unique hardware and material characteristics of the monochrome E-Ink screen, and uses advanced mathematical models and algorithm design to generate high-quality grayscale.

The new algorithm can display a higher gray level on a two-level gray level device, thus obtaining better image details and richness, and can enhance the clarity and clarity of grayscale. At the same time, the response time of grayscale displayed on the monochrome E-Ink screen is improved, and the screen power consumption is also lower.

Future research in this area could focus on further optimizing the algorithm to achieve even higher levels of grayscale and improve the response time for more complex images. Additionally, exploring ways to reduce the memory and processing power requirements of the algorithm would increase its applicability in devices with limited resources.

One limitation of the new algorithm is that it has only been tested on some monochrome E e-ink screens, but not on more types of e-ink screens. Further research in this field can focus on developing algorithms for different e-ink screen types and technologies.

In terms of improvement, further work could be done to reduce the flicker effect that is still present in some grayscale images. Additionally, exploring ways to reduce the visual noise in the images and improve the overall smoothness of the progressive rendering process would enhance the algorithm's performance even further.

In conclusion, the new algorithm for displaying grayscale images on monochrome e-ink screens is a significant and promising advancement in the field of digital display technology. Further research and development can help improve its performance, applicability, and usability, leading to even more advanced and sophisticated digital displays in the future.

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