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Design of false color palettes for grayscale reproduction ☆

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ABSTRACT

Design of a false color palette is quite easy but some more effort is required to achieve a good dynamic range, contrast and overall appearance of the palette. Such palettes, for instance, are commonly used in scientific papers for data presentation. However, to lower the cost of the article, most scientists decide to let the data be printed in grayscale. The same applies to e-book readers based on e-ink most of which are still grayscale. For the majority of false color palettes reproduction in grayscale results in ambiguous mapping of the colors which may be misleading for the reader. In this article design of false color palettes, suitable for grayscale reproduction, is described. Due to the monotonic change of luminance of these palettes, grayscale representation is very similar to the data directly presented with a grayscale palette. Some suggestions and examples, of how to design such palettes, are provided. To compare the palettes and indicate the best one, a survey and numerical calculations were made.

1. Introduction

False color palettes are used to display information in a variety of fields like physical sciences (e.g. astronomy, optics) [1–3], medicine (e.g. in different imaging systems) [4] and industry [5]. In most applications palettes are optimized for better contrast, dynamic range and overall appearance of the palette [6,7]. They are adjusted to particular data being presented. One of the first papers on designing false color palettes appeared in the 1960s and 1970s [8,9]. The main goal was to achieve the palette which emphasizes details and the edges of the objects. This was done, for instance, by rapid changes in luminance and hue. Different maps were proposed for different images. With the development of computer graphics and displays, quantization and color map design gained in importance [10–12]. Recently much effort has been made in the field of colorizing night vision images [13–15] and grayscale images [16]. Some work has also been done to prepare a mapping algorithm for combining grayscale images into one with higher information content [17]. In most cases the palettes are effective and improve visualization, but still even the most commonly used "rainbow" palette is a subject of criticism. Some works point out that it obscures the data and may produce artifacts [18,19]. Summarizing, there is no unique algorithm or easy rules to make a good false color palette and according to the author's best knowledge none of the previous works considered reproduction of false color images in grayscale. Moreover, most of commonly used palettes printed in grayscale or displayed on a monochromatic e-ink reader lead to ambiguous mapping and misleading artifacts. This article presents some rules and algorithms designed to prepare an appropriate color palette which will look good after conversion into grayscale. Some sample palettes ready to use are also shown. In Fig. 1a propagation of an optical beam (soliton) [20–22] in a nonlinear medium is presented. It is clearly visible that after converting the data encoded with rainbow palette into grayscale (Fig. 1c), the image becomes confusing. Dark colors represent both the lowest and the highest beam intensities. The main idea to overcome this issue is to achieve the luminance which is monotonically increasing or decreasing with the color index of the palette.

2. Theoretical background

Each color in the palette has its index i. For instance, to get monotonically increasing luminance of the palette the luminance of the $i+1$ color has to be greater than luminance of the i color. According to ITU BT.601 recommendation [23] luminance can be defined as

$$L_i = 0.299\,R_i + 0.587\,G_i + 0.114\,B_i \qquad (1)$$

where i - is a color index and R_i, G_i, B_i represent values of the red, green and blue channels respectively. This is the most common and widely used definition of luminance in digital image processing. Thus it is likely that most software will use it to convert a color

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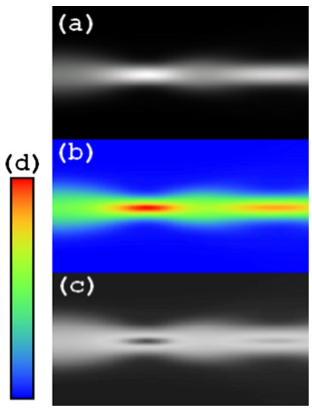

Fig. 1. (a) Soliton propagation (original image), (b) image presented with a common (rainbow) false color palette, (c) luminance of the false color image, and (d) false color (rainbow) palette used.

image into grayscale. The same applies also to printers, e-book readers and other popular devices. Consider 24-bit color space (8 bits per channel), so the maximum value of the channel is 255. In this color space there are a few basic colors which are presented in Fig. 2 with their corresponding luminance. Now it is even more evident that rainbow palette with red representing high values, blue representing low values and green representing middle values cannot have monotonically changing luminance.

Starting from these 8 basic colors it is easier to build an appropriate palette. To design a palette a few main colors have to be properly chosen and then interpolated. At first, consider a palette based on 4 points having two end points at $i = 0$ and $i = 255$ and two middle points at $i = 85$ and $i = 170$. The luminances of these colors have to fulfill the following relation $L_0 < L_{85} < L_{170} < L_{255}$. Subsequently, these colors have to be interpolated, for instance, with a line function for each channel (red, green and blue) separately. To obtain smoother color change Lagrange interpolation can be employed. An example of a palette interpolated using both methods is presented in Fig. 3.

The Lagrange interpolation of 4-point color palette can be written as:

$$P(i) = -\frac{(i-85)(i-170)(i-255)}{3684750} \cdot c_0 + \frac{i(i-170)(i-255)}{1228250} \cdot c_{85} - \frac{i(i-85)(i-255)}{1228250} \cdot c_{170} + \frac{i(i-85)(i-170)}{3684750} \cdot c_{255} \quad (2)$$

where $P(i)$ - color value at index i. Constants $c_0, c_{85}, c_{170}, c_{255}$ - are fixed color values at points $i = 0, i = 85, i = 170$ and $i = 255$. This interpolation has to be done for all color channels i.e. red, green and blue. For 3-point palettes, Lagrange interpolation can be noted in a general form as:

$$P(i) = \frac{(i-m)(i-255)}{255 \cdot m} \cdot c_0 + \frac{i(i-255)}{m(m-255)} \cdot c_m + \frac{i(i-m)}{255(255-m)} \cdot c_{255} \quad (3)$$

where m is an index of the middle point. When the middle point c_m is at index $m = 127$, then it simplifies to:

$$P(i) = \frac{(i-127)(i-255)}{32385} \cdot c_0 - \frac{i(i-255)}{16256} \cdot c_{127} + \frac{i(i-127)}{32640} \cdot c_{255} \quad (4)$$

Lagrange polynomials can give values higher than the maximum color value (in this example higher than 255) or negative values due to oscillations. It is important to fix this problem by substituting negative values with zero and values higher than 255 with 255. Both interpolation methods will give real color values which have to be converted to integer values. Irrespective of which function is used: round, ceiling, floor, etc. there might be some non-monotonic behavior of the luminance caused by this conversion. These fluctuations are minor (typically the luminance change is much less than 1) and are not visible to the human eye. Lagrange interpolation was chosen because it is much simpler in implementation and faster than spline interpolation or orthogonal polynomials. In fact, spline interpolation in some cases may introduce fewer oscillations than Lagrange interpolation, but it is much more complex and needs longer computation times. Differences are visible

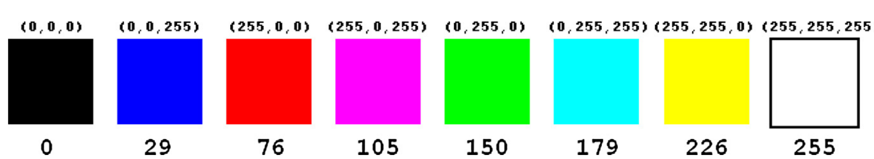

Fig. 2. Basic colors and their luminance (bottom) and RGB channels (top).

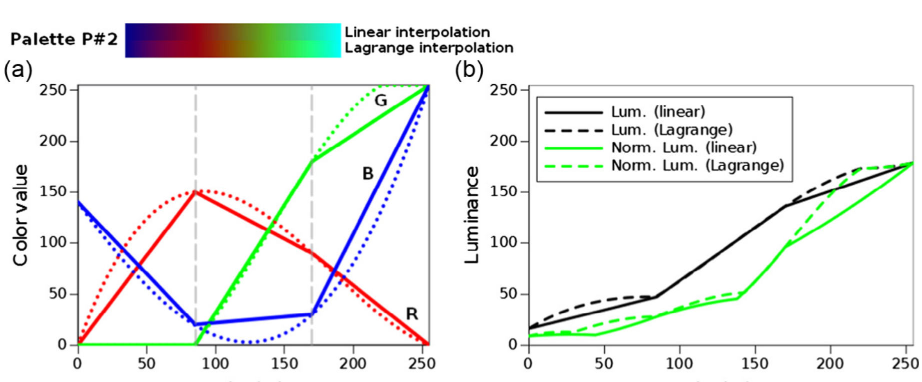

Fig. 3. (a) Color value of the red, green and blue channels as a function of color index. Four basic points are interpolated with line functions (solid line) and with Lagrange polynomials (dotted line). (b) Luminance and normalized luminance of the palette. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)