Double window: definition of a new pseudo-color mapping scheme for medical imaging

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Double window: definition of a new pseudo-color mapping scheme for medical imaging

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ABSTRACT

The number of gray levels in medical images significantly exceeds the range of human eye recognition. In this paper, we propose a series of definitions for real-time pseudo-color enhancement based on the hue, saturation, and value (HSV) color space. First, the definitions of gray window and color window are given as follows: in the HSV color space, the gray window means mapping pixel values to value, and saturation is set to zero. Thereafter, the color window was defined by mapping pixel values to hue, with the maximum saturation and value. Moreover, pixel values greater than the upper bound of the gray window were converted to hues in the double window. The images in the double window display the details shown in the lung window, mediastinal window, and bone window for chest computed tomography and showed more details than the grayscale image in brain magnetic resonance imaging. The proposed method enhances the display effect in some cases; for example, when the image histogram has more than one peak, the information displayed white in a regular grayscale image is displayed in color.

Introduction

It is well known that the number of gray levels in medical images significantly exceeds the range of human eye recognition. Although the human eye's resolution for color is lower than that for black and white, it is still an effective method for improving the visual resolution by increasing the color categories. There are various contrast enhancement methods, such as density slicing, gray level transformation, and spatial domain methods[1].

Compared with other fields, the main characteristics of medical images are as follows: First, by adjusting the window width and level, doctors can observe details of different tissues and structures. For example, when chest computed tomography (CT) was performed, the lung was observed with a window level of -700 and a window width of 1,000 (lung window), as shown in Fig. 1, where the alveoli were black and the lung texture and alveolar septum were white, whereas we could hardly distinguish the heart, aorta, ribs, vertebrae, and other structures in the mediastinum. A window level of 400 and width of 2,000 should be used to observe the bone (bone window, Fig. 1). The window technique greatly compensates for the limitation of the number of gray levels recognized by the human eye. On the other hand, the gray level was approximately linear with the pixel value (e.g., CT value), which means that not only the different structures need to be distinguished but also the relative magnitude of the signals is meaningful. In short, differences in pixel values should appear in a way that doctors can intuitively understand. This study aimed to explore a new definition of pseudo-color, with the coexistence of grayscale and color window techniques, to enhance the display effect of grayscale images.

Results

Following the proposed definition, we chose chest CT (Fig. 1) with contrast and brain MRI (Fig. 2) images as an example. Medical images from the National Cancer Institute Clinical Proteomic Tumor Analysis Consortium (CPTAC) are used to verify the effectiveness of the proposed method[2–4].

Fig. 1 illustrates the chest CT images displayed in the lung, mediastinal, bone, and double window. In the double window, the details shown in the mediastinal window and bone window are displayed in the color component, whereas the gray window shows the same details as the lung window. In addition, an intrinsic density difference in the lung node and aorta can be observed, which can hardly be distinguished in grayscale images. The gray and double windows of the brain MRI image are shown in Fig. 2.

With an increase in pixel value, the pixels displayed black, gray, white, red, orange, yellow, green, cyan, blue, and purple, respectively. This means that the size of the pixel value can be determined from the gray level and color.

Discussion

We introduced a series of definitions for the pseudo-color mapping scheme. The proposed pseudo-color encoding technique is easy to understand and operate. As shown in Fig. 3, when the image histogram has more than one peak, the color window may function well, as shown in Fig. 1. The gray component of the double window has already displayed similar details as grayscale images; it will display more details when the "whitest" part is replaced by color.

Similar to the operation in grayscale images, real-time adjustment is necessary to determine a suitable window level and width for the target field. Color can not only improve the display effect, but color and grayscale can also be complementary in one image to improve the ability to distinguish different components. The proposed method can take use of hue and value, and we can also adjust the saturation according to the display effect, although not mentioned in the article. Our next plan is to implement the solution as an extension for real-time adjustment in open-source software, such as 3D Slicer.

Methods

Compared with the red, green, and blue color space, the hue, saturation, and value (HSV) color space is more in line with human eye intuition. When the saturation is set to zero, the image appears as a grayscale image. When saturation is greater than zero, the image appears orange, yellow, green, cyan, blue, purple, magenta, and red as the hue increases[5]. The hue range varies in different programming environments, for example, hue $\in$ [0, 1], [0, 180], or [0, 360]. For the convenience of programming, we used the range hue $\in$ [0, 1], saturation $\in$ [0,1], and value $\in$ [0,1]. Python 3.7.3 was used to generate pseudo-color images.

Gray Window

In the existing window technique, the pixel value (for example, the CT value) is displayed at the lowest gray level (black) below the lower bound of the gray window, and the highest gray value (white) is displayed when the pixel value is higher than the upper bound of the gray window. We use WLgray and WWgray to represent the window level and width in the gray window, respectively. We use P (pixel value) to represent the value of each pixel recorded in the image, for example, CT value, magnetic resonance imaging (MRI) signal... The lower bound of and upper bound of pixel value in the gray window are represented as $G_{\min}$ and $G_{\max}$, respectively. Then, the gray window is defined as follows:

$$S = 0 \tag{1a}$$

$$V = \begin{cases} 0, \text{for } P < G_{\min} \\ \frac{P - G_{\min}}{\mathrm{WW}_{\text{gray}}}, \text{for } G_{\min} \leq P \leq G_{\max} \\ 1, \text{for } P > G_{\max} \end{cases} \tag{1b}$$

where $G_{\min}$ = $\mathrm{WL}_{\text{gray}}$ - $\mathrm{WW}_{\text{gray}} \times 0.5$; $G_{\max}$ = $\mathrm{WL}_{\text{gray}}$ + $\mathrm{WW}_{\text{gray}} \times 0.5$; Besides, H has no meaning when $S = 0$.

Color Window

Inspired by the gray window, a color window was proposed. Compared to other methods, color is not only used to distinguish different components but also to reflect the relative value. The point of the color window reflects the relative value and keeps it readable while adjusting the window level or width. Thus, we mapped pixel values to the hue component, and the saturation and value were set to the maximum value.

We used $H_{\max}$, $\mathrm{WL}_{\text{color}}$, and $\mathrm{WW}_{\text{color}}$ to represent the maximum value of the hue, window level and width in the color window, respectively. In contrast to the gray window, the hue corresponding to the upper bound of the color window cannot be equal to one, causing the upper bound to display the same color as the lower bound. Thus, $H_{\max}$ was set to $\frac{5}{6}$ in this study, which is corresponding to the purple color of HSV space. The lower and upper bounds of the pixel value in the color window are represented as $C_{\min}$ and $C_{\max}$, respectively. The color window is defined as follows:

$$
\begin{aligned}
H &= \begin{cases} 0, & \text{for } P < C_{\min} \\ \frac{P-C_{\min}}{\mathrm{WW}_{\text{color}}} H_{\max}, & \text{for } C_{\min} \leq P \leq C_{\max} \\ H_{\max}, & \text{for } P > C_{\max} \end{cases} && \text{(2a)} \\
S &= 1 && \text{(2b)} \\
V &= 1 && \text{(2c)}
\end{aligned}
$$

where $C_{\min}$ = $\mathrm{WL}_{\text{color}}$ - $\mathrm{WW}_{\text{color}} \times 0.5$; $C_{\max}$ = $\mathrm{WL}_{\text{color}}$ + $\mathrm{WW}_{\text{color}} \times 0.5$;

Double Window

Pixel values that exceed the upper bound can be displayed in a color window, which we call the double window. In the double window, only the window width and level of the gray window were selected, and the rest were shown in color or black. The double window is defined as follows:

$$
\begin{aligned}
H &= \begin{cases} 0, & \text{for } P < C_{\min} \\ \frac{P-C_{\min}}{\mathrm{WW}_{\text{color}}} H_{\max}, & \text{for } C_{\min} \leq P \leq C_{\max} \\ H_{\max}, & \text{for } P > C_{\max} \end{cases} && \text{(3a)} \\
S &= \begin{cases} 0, & \text{for } P \leq C_{\min} \\ 1, & \text{for } P > C_{\min} \end{cases} && \text{(3b)} \\
V &= \begin{cases} 0, & \text{for } P < G_{\min} \\ \frac{P-G_{\min}}{\mathrm{WW}_{\text{gray}}}, & \text{for } G_{\min} \leq P \leq G_{\max} \\ 1, & \text{for } P > G_{\max} \end{cases} && \text{(3c)}
\end{aligned}
$$

Moreover, the hue, saturation, and value were not independent. Saturation and hue had no meaning when the value was set to zero; therefore, when the color window exceeded the upper bound of the gray window, the gray component could be fully utilized. The adjustment of window level and width is more complicated in the double window, and adjustment in real time optimizes the display effect.

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Data availability statement

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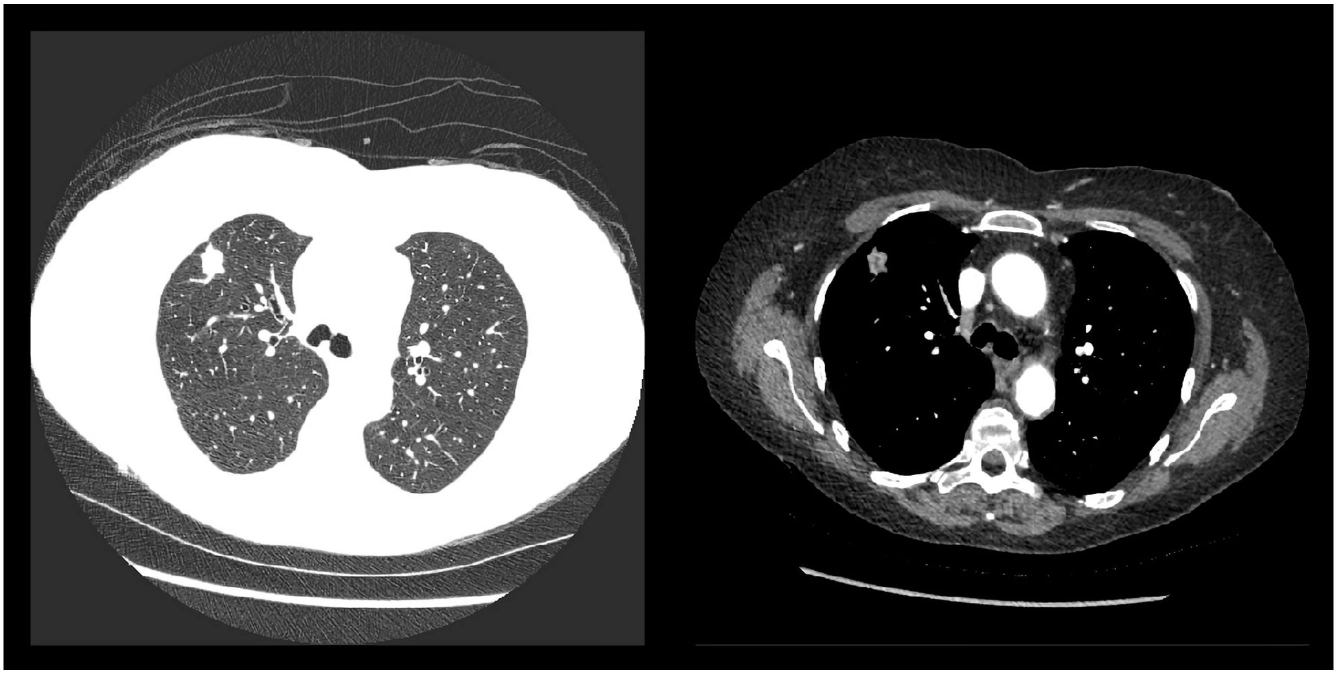
Author contributions statement

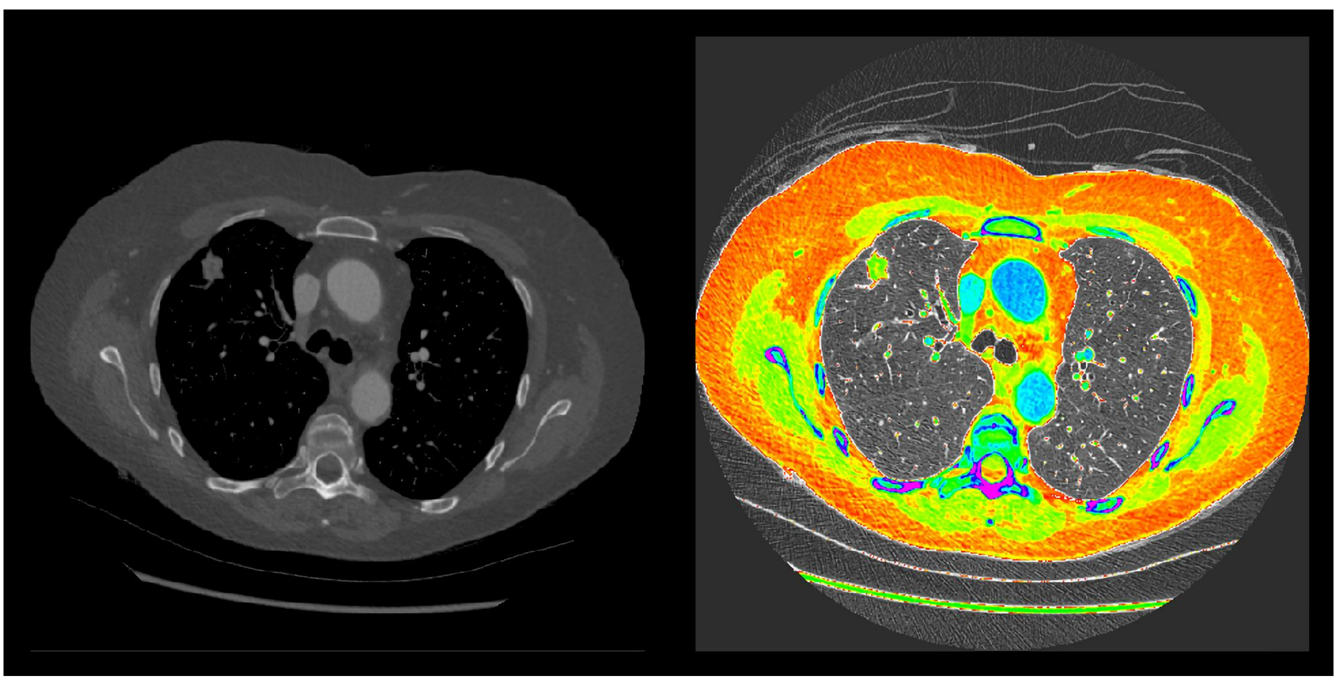
Chong Chen and Jia Huang contributed equally to the manuscript. All authors reviewed the manuscript.

Additional information

Competing interests: The author(s) declare no competing interests.

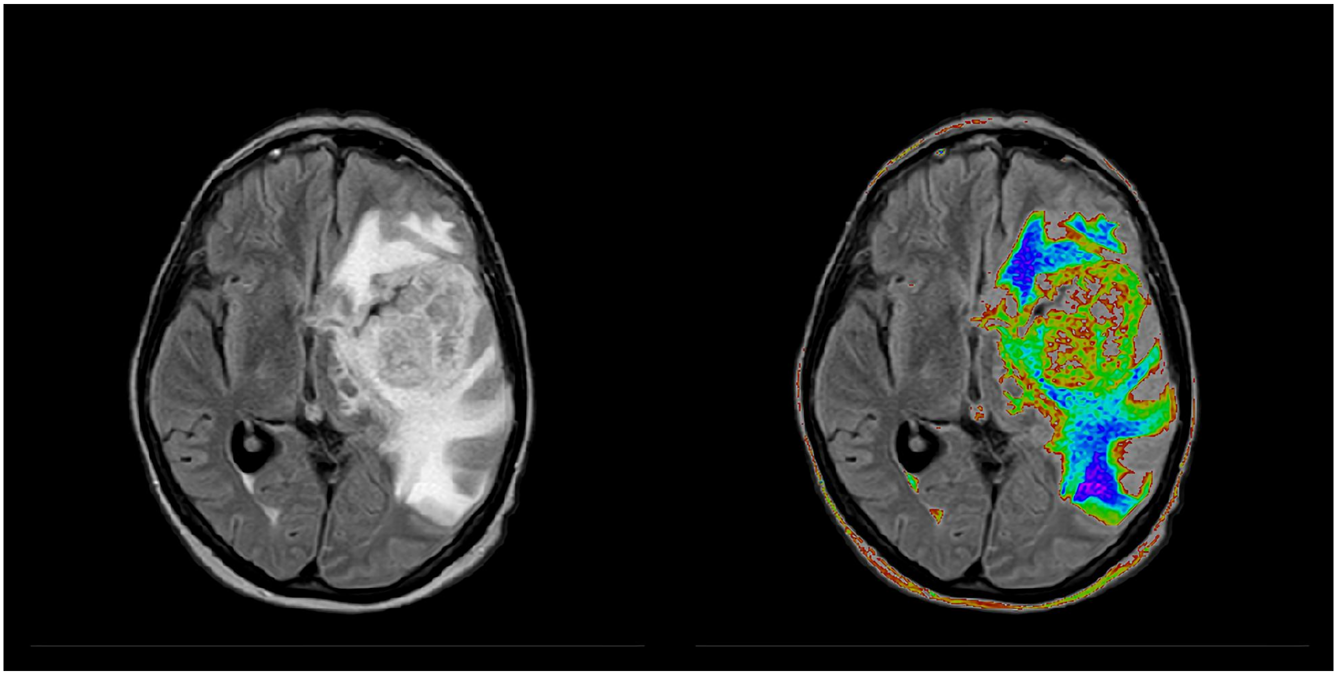


(a) **(b)**



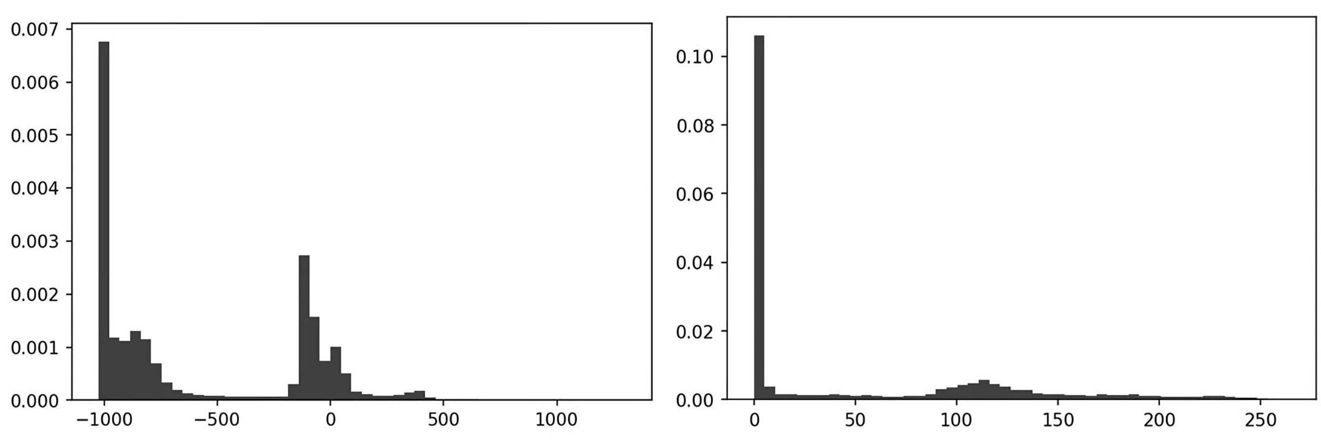
(c) **(d)**

Figure 1. The chest CT displayed in lung window, mediastinal window, bone window, and double window, respectively. (a) lung window: $WW_{\text{gray}} = 1,000, WL_{\text{gray}} = -700$ (b) mediastinal window: $WW_{\text{gray}} = 426, WL_{\text{gray}} = 45$ (c) bone window: $WW_{\text{gray}} = 2,000, WL_{\text{gray}} = 400$ (d) double window: $WW_{\text{gray}} = 1,000, WL_{\text{gray}} = -700; WW_{\text{color}} = 900, WL_{\text{color}} = 250$



(a) (b)

Figure 2. The brain MRI displayed in gray window and double window, respectively. (a) gray window: $WW_{\text{gray}} = 240, WL_{\text{gray}} = 144$ (b) double window: $WW_{\text{gray}} = 240, WL_{\text{gray}} = 144; WW_{\text{color}} = 100, WL_{\text{color}} = 214$



(a) (b)

Figure 3. The histogram of images used in this study (a) Histogram of chest CT slice in Fig. 1 (b) Histogram of brain MRI slice in Fig. 2