

CT Image Enhancement by Colorization for Brain Infarct Detection

T. L. Tan¹, K. S. Sim¹, C. K. Tan¹, and A. K. Chong²

¹Faculty of Engineering and Technology, Multimedia University, Jalan Ayer Keroh Lama, 75450 Melaka, Malaysia

²Department of Diagnostic Imaging, Melaka Hospital, Jalan Mufti Haji Khalil, 75400 Melaka, Malaysia

Abstract - *The identification of brain infarct in computed tomography (CT) images is difficult due to the nature of the infarct tissues similar to the normal tissues in the brain CT images. In this paper, a histogram-based colorization method is presented in order to enhance the visualization and interpretation of brain CT images. The presented method is aimed to improve the diagnosis of brain CT images, in terms of shortening the duration and minimizing the human error. The presented approach performs contrast stretching on the brain CT images and applies colorization to the contrast-stretched images based on standard parameters which is set from the observation of the histogram of the images.*

Keywords: brain infarct; computed tomography (CT); image processing

1 Introduction

Stroke is a serious brain disease where there is a sudden interruption to the vessels that supply blood to the brain [1]. Stroke, also called as brain attack, occurs when the blood supply of the brain is interrupted or there is a disturbance of brain function, often permanently [2]. There are mainly two types of stroke, which are ischemic stroke and hemorrhagic stroke [3]. Ischemic stroke, or brain infarct, happens due to an abrupt blockage of the arteries to the brain, in other words, lack of blood supply. On the other hand, hemorrhagic stroke is caused by a sudden rupture of an artery, which results in bleeding into brain tissue. There is an estimation of 15 million people suffer stroke worldwide annually. Out of the 15 million, there are one-third of deaths and another 5 million of permanently disability cases [2].

Currently, there are a lot of imaging techniques that allow scientists and doctors to view and monitor the areas of the brain [4]. Generally, all of the brain imaging techniques can be classified into two: structural and functional imaging techniques [4]. Structural imaging procedures, such as CT scans and Magnetic Resonance Imaging (MRI), are designed to identify brain abnormalities, for examples, bleeding, strokes, tumors and etc. On the contrary, functional imaging strategies, for instances, functional MRI (fMRI) and Positron

Emission Tomography (PET), are used to study the brain at rest or during activities such as seeing, feeling, moving, and thinking [4].

CT scans and MRI are brain imaging techniques regularly used to examine the brain lesion. These two techniques can effectively disclose the brain hemorrhage and fractures. The images for these two techniques are in Digital Imaging and Communications in Medicine (DICOM) format which incorporates patient data together with the images [5]. However, due to lower cost and wider availability, CT imaging is preferably used more often than MRI [6]. Moreover, CT imaging is sensitive to early stroke. Multi-slice CT scan can speed up to 64 slices per scan, producing an enormous amount of images for a single patient in hospitals [7].

Some methods and approaches have already been proposed and used to detect the lesion in the brain images. Chan had adapted a mid-line detection to detect the brain lesions [8]. The symmetry for each line will be checked. An asymmetrical mid line of the brain may indicate the presence of a hemorrhage. Hara et al. also adapted a similar method [9]. They determine the mid line accordingly to the skull contour in their approach. Besides mid line detection, Gong et al. used segmentation and features extraction to classify the brain lesions [5]. A similar method was introduced by Paradowski et al. too [7].

Nevertheless, most of the existing works focus mainly on the hemorrhagic stroke but not the ischemic stroke. The diagnosis of brain infarct by direct observation of CT brain images is hard and sometime prone to misinterpretation due to human visual error. The situation becomes worse when the appearance of early infarct in the images is subtle due to low contrast difference between damaged brain tissues and normal brain tissues. Hence, in this paper a method of colorization of the CT brain image is proposed to give a better visualization which will ease the interpretation of the CT images. The proposed method consists of two main parts: image contrast stretching and histogram-based colorization.

2 Proposed method

2.1 Image Contrast Enhancement

The maximum allowed number of pages is seven for Regular Research Papers (RRP) and Regular Research Reports (RRR); four for Short Research Papers (SRP); and two for Posters (PST). The quantitative scale of CT image is in Hounsfield unit (HU) and the range of the scale is very large, which is from -1000 HU to 1000 HU. CT images are as read 16-bit DICOM images in the computer. In the DICOM format, 4-bit is used to store the meta information and 12-bit is used to view CT images in 12-bit grayscale level. The relationship between the HU value and the 12-bit gray level (12-bitGray) is given in (1), where the rescale intercept (R) value can be found in the meta information of the slice.

$$HU = 12\text{-bitGray} + R \quad (1)$$

Interpretation of the CT images will be almost impossible if the images are directly read as DICOM images. Fig. 1 shows an example of CT image that is directly read as a DICOM image. The wide range of contrast level in Fig. 1 does not allow a clear visualization. And hence, the first task is to select the appropriate range of 12-bit grayscale levels to extract major brain structures and then stretch the range into 8-bit grayscale levels.

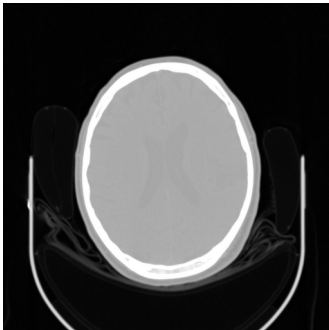


Fig. 1. A CT image of early infarct where the image is directly read as a DICOM image with $R = -1024$.

The 12-bit grayscale intensity distribution of a given slice is calculated to plot a histogram. There are two tips in the histogram. The tip with the largest intensity level corresponds to the major brain soft tissues, whereas the other one corresponds to the background. The histogram of Fig. 1 is shown in Fig. 2.

A windowing operation is performed by using (2). Since most of the CT slices have similar window center (C) (32HU – 40HU) and to show a good contrast, the window center is set as 40 HU, whereas the window width (W) is set as 80. The remaining intensity values outside the range will be clipped, and displayed as black or white, in which gives no effect on losing information since the major brain soft structures are extracted. This standard is used for all of the

CT images. All of the variables in (2) are in 12-bit grayscale level (Old Level), and thus (1) is first performed for any HU values. The windowing operation converts a DICOM image that is in 12bit grayscale level into an 8-bit grayscale image. The output image in this step will be used in the next steps. An example of windowed operation is shown in Fig. 3.

$$New\ Level = \frac{Old\ Level - (C - W / 2)}{W} \times 255 \quad (2)$$

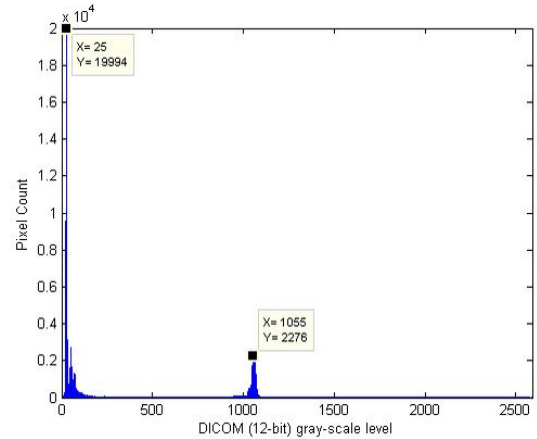


Fig. 2. The histogram of Fig. 1 shows the pixel intensity distribution of the brain. The peak value at gray level = 1055 (31 HU) in the histogram corresponds to the major brain soft tissues.

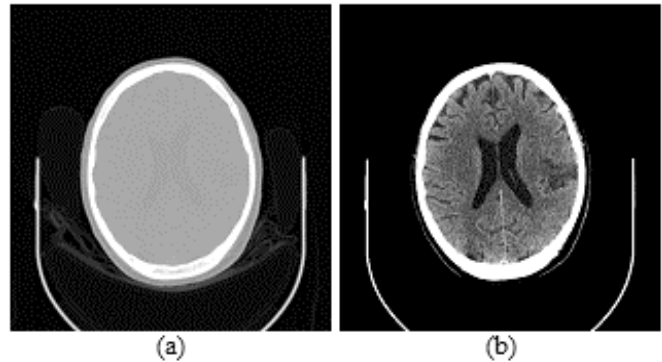


Fig. 3. An example of windowing operation: (a) is the image before windowing, and (b) is the windowed image with $R = -1024$.

2.2 Color Setting

Type the title approximately 2.5 centimeters (1 inch) from the top of the first page and use 20 points type-font size in bold. Center the title (horizontally) on the page. Leave approximately 1 centimeter (0.4- inches) between the title and the name and address of yourself (and of your co-authors, if any.) Type name(s) and address(s) in 11 points and center them (horizontally) on the page. Note that authors are advised not to include their email addresses. After stretching the contrast level of a CT image, color setting is performed for the major brain soft tissues before the colorization is applied to the windowed CT image.

The major brain soft tissues can be simply categorized into two: white matter and gray matter. The typical HU range for white matter and gray matter is approximately 20 HU-25 HU and 30 HU- 35 HU [10]. However, [11] states that the HU range for both white matter and gray matter is about 20 HU-30 HU and 37 HU-45 HU, respectively. As in [12], the HU difference between white matter and gray matter is only 6 HU. By taking consideration on all the ranges stated by difference references, a standard of the HU range of each component is proposed and shown in TABLE 1. From TABLE 1, it can be observed that the infarct (including old infarct and early infarct) tissues may have similar attenuation with the white matter tissues, and hence it is sometimes difficult to detect the brain infarct.

TABLE 1
MAJOR COMPONENT AND APPROXIMATE HU RANGE

Major component		Approximate HU range
Infarct tissues	Old	0-10
	Early	10-20
White matter		20-30
Gray matter		35-45

The 8-bit grays level (8-bitGray) of each component is calculated by combining (1) and (2). However, in order to provide a more outstanding visualization, the HU range of each component is slightly increased by 10 HU. The combination of (1) and (2) into an equation is shown as (3). The finalized Hu range and calculated 8-bit grayscale range of each component in Fig. 3(b) is shown in TABLE 2 where the mean level is the middle level in the range.

$$8\text{-bitGray} = \frac{(HU - R) - ((C - R) - W / 2)}{W} \times 255 \quad (3)$$

TABLE 2
MAJOR COMPONENT AND 8-BIT GRAYSCALE RANGE

Major component		Finalized HU range	8-bit Grayscale range	Mean level
Infarct tissues	Old	10-20	32-64	48
	Early	20-30	64-96	80
White matter		30-40	96-128	112
Gray matter		45-55	143-75	159

After setting the 8-bit gray-scale range of each component, one unique color is assigned for the components. Too many colors will somehow complicate the observation of the image. Since there are only three major components, a color is assigned to each component. Experiments had been done on the different combinations of colors to investigate which combination gives best visualization of the image. TABLE 3 shows the color setting for the component. To normalize the visualization, black and white colors are used to represent the background and the skull, respectively. Brain infarct tissues can be categorized into, which are old infarct and early or new infarct. These two types show different

contrast level where the old infarct has darker intensity. Hence, black and red colors are used to represent the brain infarct tissues, each for old and new infarct tissues. To show an obvious contrast difference between damaged tissues and normal tissues, cyan and blue colors are used to represent white matter and gray matter, respectively.

TABLE 3
COLOR SETTING FOR DIFFERENT COMPONENT

Component		Assigned color
Background		Black
Infarct tissues	Old	Black
	Early	Red
White matter		Cyan
Gray matter		Blue
Skull		White

2.3 Colorization

Number section and subsection headings consecutively in numbers and type them in bold. Use point size 14 for section headings and 12 for subsection headings and 10 for subsection within a subsection. After assigning the color for the major components, a colormap is constructed based on the color setting given in TABLE 3, as shown in Fig. 4. The color for each component is set only at the mean level of the corresponding 8-bit grayscale range on the colormap. The colormap constructed for the the colormap is directly applied to the windowed-image. Pseudo coloring method is used in the colorization, where the 8-bit grayscale image is colonized by mapping each pixel value to the color according to the colormap in Fig. 4. Fig. 5 shows an example of colorization operation using the colormap in Fig. 4. The constructed colormap will be used as a standard colormap that will be applied to all similar CT images in the presented method.

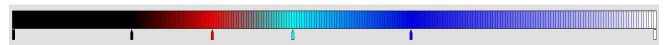


Fig. 4. The colormap is constructed based on the color setting of TABLE 3. The colormap corresponds to 8-bit grayscale level from level 0 (the left most) to level 255 (the right most).

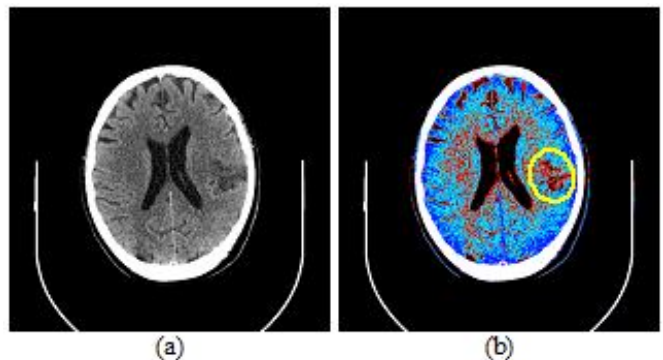


Fig. 5. An example of colorization operation: (a) is the image before colorization, and (b) is the image after colorization, where the infarct region (in yellow ellipse) is shown clearly.

3 Experimental results

The presented method was tested on 30 CT images collected from a local hospital together with the diagnosis results verified by experience radiologists. In the experiment, the presented method was applied on the images and the output images are saved. After that, diagnosis was performed again on the pre-colored images and then on the post-colored images. In this time, the diagnosis was done by university students with essential biomedical knowledge instead of the radiologists in order to investigate the effect of the presented method on the images. In order to simplify the experiment process, a graphical user interface (GUI) was developed to run the diagnosis and save the results. The performance of the presented method was measured based on the experiment results. Since the method is aimed to enhance the visualization of the CT images, the main focus is on the accuracy and the time taken for the diagnosis. The accuracy is calculated by using (4) in the general measurements of performance. Nevertheless, all the parameters: True Positive (TP), False Positive (FP), True Negative (TN), and False Negative (FN), True Positive Fraction (TPF), False Positive Fraction (FPF), True Negative Fraction (TNF), and False Negative Fraction (FNF) are measured. The measurement and evaluation results are shown in TABLE 4. The evaluation results are convincing, showing a good improvement on the accuracy and time taken from the diagnosis of pre-colored images to the diagnosis on the post-colored images.

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (4)$$

TABLE 4
EVALUATION OF PERFORMANCE

Parameter	Pre-colorization	Post-colorization	Improvement (%)
TPF	0.786	0.929	18.0
TNF	1.000	1.000	0
FPF	0	0	0
FNF	0.214	0.071	66.8
Accuracy	0.833	0.944	13.3
Time Taken (s)	102	80	21.6

Three images from the experiment result are shown in Figs. 6, 7, and 8. In Fig. 6, the old infarct region can be found obviously. Same case happen to Fig. 7, the old infarct can be easily discovered. However, the early infarct region is subtle in Fig. 8(a), and apparently, the region can be observed clearly in Fig. 8(b). Detection of early infarct is difficult due to the contrast level, especially when the CT images are examined rapidly and the infarct region is too small, the early infarct region may be missed. The presented method enhances the visualization of the CT images and thus accuracy of the diagnosis.

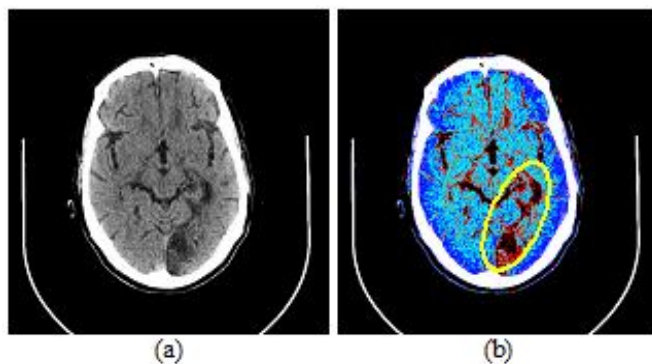


Fig. 6. A CT brain image of old infarct: (a) is the image before colorization, and (b) is the image after colorization, where the infarct region (in yellow ellipse) is shown clearly.

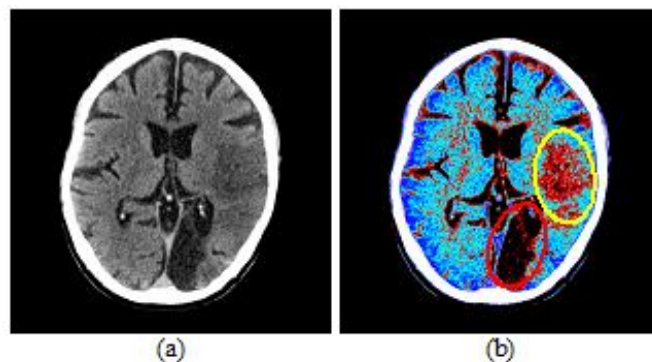


Fig. 7. A CT brain image of both types of infarct: (a) is the image before colorization, where the infarct region is ambiguous in the image, and (b) is the image after colorization, where the infarct regions (old infarct region in red ellipse and early infarct in yellow ellipse) are shown clearly.

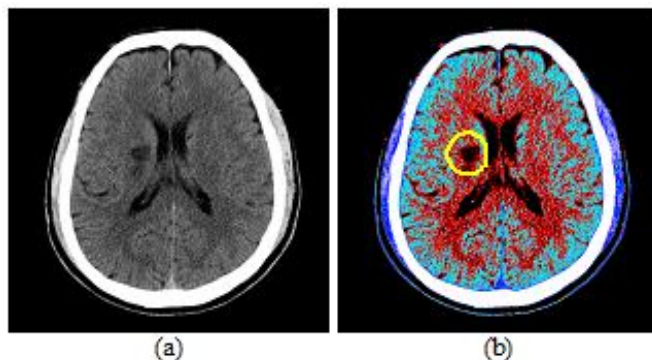


Fig. 8. Another CT brain image of old infarct: (a) is the image before colorization, and (b) is the image after colorization, where the infarct region (in yellow ellipse) is shown clearly.

4 Conclusions

The diagnosis of brain trauma by observation of CT brain images is difficult and sometime prone to mistake due to human visual error. Therefore, the method presented in this paper is important in improving the visualization of CT brain images, and thus, reducing the diagnosis mistake. Besides, the method presented in this paper is a standard method that can be applied to all similar CT brain images. A

preliminary testing on CT brain images shows encouraging results. Future works can be carried out to develop a new segmentation technique based on the colorization method presented in this paper where the brain infarct region in the CT images can be accurately segmented.

5 References

[1] About Stroke. (Last Modified: 2008, January 30). The Internet Stroke Center. [Online]. The Internet Stroke Center, Washington University School of Medicine. Available: <http://www.strokecenter.org/patients/about.htm>

[2] L. M. Brass, Stroke. B. L. Zaret, M. Moser, L. S. Cohen, G. J. Subak-Sharpe, D. M. Goetz, and B. L. Mitchell (eds.). Heart Book. New York: Yale University School of Medicine, vol. 1, 1992, pp. 215–233.

[3] A. Downie. (2001, May). Tutorial: CT in Head Trauma. [Online]. Victoria Infirmary, Glasgow. <http://www.radiology.co.uk/srs-x/tutors/cttrauma/tutor.htm>

[4] J. Illes and J. T. Giacino, “Brain Imaging: Understanding the Basics. Frequently Asked Questions”. The University of British Columbia, 2008.

[5] T. Gong, R. Liu, L. T. Chew, N. Farzad, C. K. Lee, B. C. Pang, Q. Tian, S. Tang, and Z. Zhang, “Classification of CT Brain Images of Head Trauma,” *Pattern Recognition in Bioinformatics*, 2007, pp. 401–408.

[6] M. Chawla, S. Sharma, J. Sivaswamy, and K. L. T., “A method for automatic detection and classification of stroke from brain CT images”, *Proc. Ann. Int. Conf. IEEE Eng. Med. Biol. Soc. (EMBC 09)*, 2009.

[7] M. Paradowski, H. Kwasnicka, M. Tabakov, J. Filarski, and M. Sasiadek, “On Automation of Brain CT Image Analysis,” *Proc. Int. Multiconf. Comp. Sci. Info. Tech. (IMCSIT)*, 2008, vol. 3, pp. 215–220.

[8] T. Chan, “Computer aided detection of small acute intracranial hemorrhage on computed tomography of brain,” *Computerized Medical Imaging and Graphics*, 2007, vol. 31, pp.285–298.

[9] T. Hara, N. Matoba, X. Zhou, S. Yokoi, H. Aizawa, H. Fujita, K. Sakashita, and T. Matsuoka, “Automated Detection of Extradural and Subdural hematoma for Contrast-enhanced CT Images in Emergency Medical care,” *Proc. SPIE*, 2007.

[10] R. R. Gonzalez, J. A. Hirsch, W. J. Koroshetz, M. H. Lev, and P. Schaefer, “Unenhanced Computed Tomography,” in *Acute ischemic stroke: imaging and intervention*, 2nd ed., E. C. S. Camargo, G. Gonzalez, R. G.

Gonzalez, and M. H. Lev, Eds. Berlin Heidelberg: Springer-Verlag, 2006, pp. 45.

[11] Musculoskeletal imaging: Hounsfield Unit. (Last Revised: 2009, March 23). Medcyclopedia. [Online]. GE Healthcare. Available: http://www.medcyclopaedia.com/library/topics/volume_iii_1/h/hounsfield_unit.aspx

[12] B. C. Lee, B. Kneeland, R. J. Knowles, and P. T. Cahill, “Quantification of gray/white matter in neonates and adults,” *American Journal of Neuroradiology*, 1983, vol. 4, pp. 692–695.