Digital Imaging and Color in Medicine

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Abstract
Many cases of critical decisions in medicine rely on color images and they will soon be commonly digitized with the rapid spread of the multimedia technology not only in medical practice, but also in medical education and research activities. But possible problems that inappropriately reproduced colors of digitized images may incidentally cause erroneous diagnoses has been left behind. On the basis of the RGB system, color-matching technologies, color calibrators for displays and color charts used to adjust displays have been introduced to prevent such accidents. Because these technologies will not be sufficiently standardized for various medical applications in a short time, another temporary and practical solution based on the concept of 'diagnostic equivalent', in which a set of typical medical images with authorized diagnoses is used as a practical calibrator for common displays, should be considered at present. In future, multispectral imaging is a more promising solution which can reproduce precise colors and compensate the difference in illuminant conditions, and furthermore, may be used to reproduce even fine textures of skin lesions in medical practice.

Keywords
Medical Diagnosis, Digital Color Imaging, Diagnostic Equivalence, Multispectral Imaging

1. Introduction

Today, telemedicine, electronic medical records and electronic medical textbooks are expected to spread widely together with progress of digital imaging technologies, in which digital images can be duplicated and transferred without losing any information. Especially, many cases of critical decisions in medicine are made on morphological evidence observed in various color images, therefore accurate as well as precise recording and reproducing of colors should be essential. However, a large amount of color data lost by the A-D conversion and the differences in reproduced colors of display equipment may cause serious potential problems. This paper gives an overview of the color imaging in various medical fields and a comprehensive model of the relationship between color and medical diagnosis, and then summarizes problems and solutions in the digital color imaging in medicine.

2. An overview of color in medicine

2.1 Anatomical pathology and cytology [1]
Diagnoses on microscopic pathology, in which most colors observed are made of various stains, seem to be less affected by shifting into digital filing than diagnoses on macroscopic pathology, in which fine variations of natural colors are important. Although when consultations on pathological diagnoses over the network become generalized some demands for standardization will surely arise, current commercial products for telepathology are considered to be satisfactorily used in practice. Computerized screening in cytology is another challenge of digital imaging in pathology. Effective use
of various color data, such as absolute color values, ratios of each tristimulus color, differences in colors against adjacent areas and estimated illumination data, has been investigated to improve its performance.

2.2 Clinical pathology and laboratory medicine [2]
Because laboratory information systems, which are widely used already, encourage the spread of digital imaging, early investigations on diagnostic quality of digital color images have been progressed in this field. Problems with digital imaging in this field include inaccurate color reproduction, rough gradations of color and insufficient density of pixels, with varying degrees of relevance as regards their seriousness in various sub-fields. In hematological diagnosis, the colors of stained dyes themselves, as well as their change in color caused by various chemical reactions with the components of each blood cell, are considered extremely important.

2.3 Gastrointestinal endoscopy [3]
Introduction of digital imaging with electronic endoscopy is expected to realize (1) computerized endoscopic diagnosis based on digitized images, (2) computerized laser cauterization on the basis of automatic detection and targeting of early cancer and (3) real time superimposition of various referential information on endoscopic images. In a study, primary wavelength of light which comes from diseased mucosa, though no statistically significant difference in color was shown among them. In only few cases, the affected area of mucosa could be detected and made visible by computerized image.

2.4 Dermatology [4]
Because skin color directly reflects every pathological change of skin that causes modification of its optical characteristics, it is vital information in dermatological diagnosis. Photographs have played a substantial role for a long time in recording skin lesions, and recently digital imaging has been introduced for this purpose. But the quality of skin color images reproduced by any currently available imaging system does not meet the requirement for dermatological diagnosis; therefore, they are not yet considered a substitute for the observation of the real objects and only subsidiary roles are given to them. However, if advanced digital imaging technologies including multispectral imaging are in a position to reproduce images which can be equally used as real objects, revolutionary changes are expected in dermatological practice as well as in dermatological education. If, on the other hand, the technology of digital imaging fails to achieve a higher quality as mentioned above, a huge investment in electronic patient records and tele-medicine would run the risk of having been made in vain in the field of dermatology.

2.5 Plastic surgery [5]
In plastic surgery, color matching between graft and skin has vital importance. Conventional instruments used for measuring skin color have some problems: 1) they are affected by pores and wrinkles in the skin, 2) they are affected by various illuminant conditions and 3) they have the edge loss error caused by the semitransparency of skin. A new measuring system for the color of skin based on a noncontact-type spectrocolorimeter equipped with a globe for light integration is under development.

2.6 Forensic medicine [6]
Color is one of the most important findings because it reflects critically the cause of death in certain cases such as carbon monoxide intoxication or suggests aging of subcutaneous hemorrhage. Therefore, illumination in the autopsy room should be adjusted to reflect the natural color of the objects. Digitized images are increasingly used in the fields and strict device calibration is a prerequisite for utilizing digitized images instead of photographs for storage of autopsy findings.

2.7 Neurosurgery [7]
In neurosurgery, one of the outstanding applications of advanced medical technology is minimally invasive surgery. The essential elements to realize this are (1) substitution of human hands, (2)
substitution of human eyes, (3) visual information superimposed on the image of the object which provides navigation to assist the surgeon in the operation. Because endoscopic images give fundamental visual information of the system, they must have high-fidelity color.
Solutions for visualizing the image acquired using invisible light, reproducing the feel of a material in a virtual space, and reproducing the same color using different illumination and different monitors, should be pursued to meet the clinical requirements.

2.8 Otorhinolaryngology [8]
In the field of otorhinolaryngology, various visual data are recorded for later reference using digital still cameras, video cameras, stroboscopes, electronic endoscopes and so on. But such recorded images usually have differences depending on the preference of the physician and the characteristics of the equipment used to record them, and they may not be compared properly to each other. There is an effective and practical solution, in which a color chart taken simultaneously with the object is used to calibrate color values of the displayed images, but uniform input and compatible output of still and video images should be pursued as fundamental techniques.

2.9 Nursing [9]
With expanding needs for nursing services provided at home which consume a lot of staff resources, easily understood nursing information including visual information should be supplied to patients and their families to maintain the quality and effectiveness of the service. In nursing information, the color of visual data is one of the most important factors in all contexts mentioned above, and nursing professionals should have opportunities to actively join in the discussion on clinical applications of digital imaging, especially accurate reproduction of color.

3. A comprehensive model [2]

3.1 Diagnosis using conventional images
To investigate the problems concerning color reproduction, a comprehensive model was assumed, in which the process of medical diagnosis based on conventional visual data was broken down into the following steps.
(A1) The subject of observation emanates proper light waves of various wavelengths. This step is affected by the characteristics of the surface of the subject and the illumination. Penetrated light or invisible electromagnetic waves converted into visible light, etc. require more complicated processes, but light waves finally emanated are functions of the characteristics of the subject and the illuminants.
(A2) The light waves pass through an iris, a lens and a vitreous body, and reach the retina. This step is affected by the color of the iris and the transparency of the path of the light waves.
(A3) The rod cells convert the brightness of the light waves and the three kinds of cone cells each convert the color of the light waves into frequency modulated pulse signals and transmit them to the optic nerves. There may be many interactions between these sensor cells, but most of these processes are unclear. One important fact is that adaptation of the human retina to surrounding illumination is greatly affected by the signals produced by the sensor cells in the aspects of both color and brightness.
(A4) The signals are transmitted to the brain and converted into image data. This step is called visual sensation and includes the specialized process of various image abstraction.
(A5) Each image is connected to some concepts accumulated in the memory and given particular meanings. This step is called visual recognition and most of its processes have been only fragmentarily elucidated.
(A6) Each concept is compared to the experiences accumulated in the brain, and deduced by the knowledge established in the brain. This step is called decision making and the study of the relationship between visual recognition and medical diagnosis is as yet in a hypothetical stage.

3.2 Diagnosis using digitized images
On the other hand, the process of medical diagnosis based on digital images is broken down as follows.
(B1) Same as (A1).
(B2) The light waves are converted into digitized image data that are composed of color information of each pixel represented by the RGB system and the coordinates of the pixel on a two-dimensional plane. In this step, not only large parts of information of the original light are lost, but also various biases that depend on the characteristics of the equipment used for A-D conversion are added.

(B3) The digitized image data are stored or transferred for use at another time or place.

(B4) According to the color information of each pixel of the digitized image data, the red, green and blue dots of the display equipment corresponding to the pixel emanate light of each color with appropriate combination of intensities to give the same stimulus to the retina as the original color. Because there is a large discrepancy between the wavelengths of red, green and blue light and the peaks of the response curve of three types of the cone cells, some type of approximation is indispensable in this step.

(B5) The light waves pass through an iris, a lens and a vitreous body, and reach the retina. This step is affected by the color of the iris and the transparency of the path of the light waves. Unlike natural light, these light waves include only three bands of the wavelength. Therefore, these influences may cause different results from (A2).

(B6~9) Same as (A3~6)

The steps from (B2) to (B5) considerably affect the quality of the original images and could possibly cause wrong diagnoses when observing digitized images instead of conventional analog ones.

4. Problems

4.1 Accurate reproduction of colors
At present, the reproduction of the color of CRT displays and some LCD displays can be calibrated with proper commercial equipment. But others such as plasma displays, digital projectors and head mount displays, which are possibly also used to observe the medical images, cannot be yet.

As the range and the variety of colors synthesized by the equipment are very different, it is impossible to equalize the physical color specification among them. The device to adjust the colors of digital images according to the characteristics of each display so as to be sensed as equally by human eyes as possible is called the color management technology. It has been developed initially in the DTP field and must be modified to satisfy the medical requirements. The former should make each printed image equal to the original one, and the latter should make each displayed image equal to the standard image acquired in the brain of experienced physicians [10].

Colors transmitted to a distant place and reproduced on a display possibly affected by difference in illumination, characteristics of the camera and modification made during transmission. For compensating these influences, a color chart taken simultaneously with the object is used to adjust color values of displayed images so as to reproduce the same color as the original chart. A computer program is available to perform this process automatically [11]. But this technique cannot reproduce the same colors on a display under different illumination. Besides, the human sensation of color is affected by illumination surrounding displays.

4.2 The quality of color reproduction required for medical diagnosis
The diagnostic qualities of most of digitized medical images properly prepared were almost the same as slidefilms. But, as Table 1 shows, a few microscopic photographs of microbiology were not diagnosed properly with some displays that can reproduce less number of colors than others, though they have the same resolution as others. This situation was greatly improved when a prototype flat panel display of extra high resolution of 200 pixel per inches was used instead [2,12].

Another study suggested that the artificial lesion recorded as a digital image might be diagnosed differently according to the spatial densities of pixels composing the image [13]. These results implies that the medical findings which should be detected in an image as well as its physical characteristics may greatly affect the required degree of digitizing precision to maintain the same diagnosis that is made by observing the original. The process of visual recognition, including stereoscopic recognition, of the human brain has been only fragmentary elucidated, and the study of the relationship between the recognition process and the
medical diagnosis is still in a hypothetical stage. The influence of the color on the medical diagnosis has been much still unclear, but these experiment has clearly shown that the poor reproduction of color information possibly interferes the proper diagnoses, and that the resolution of displays is another one of the most important factors related to the diagnostic reliability.

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<th>Image No.</th>
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<th>Display equipment</th>
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These displays have almost the same resolution, and the major difference among them is the performance of color reproduction. The highest grade is 6, and grade less than 3 means unusable. Beyond prior expectation, grades of equipment No. 7 was varied from the highest to unusable. Specimen M-01 etc. got the highest grade with all equipment, but specimen M-06 varied from the highest to unusable according to equipment. Usually users looks at only one display, so they cannot notice this fact, which may incidentally cause erroneous diagnoses according to the combination of medical images and displays.

5. Solutions

5.1 Verification of diagnostic equivalence

It will take still a more time to establish a comprehensive theory to manage the color in medical imaging. And it will be not practical that every medical terminal should be equipped with expensive displays exclusively for the medical use. Therefore some simple and inexpensive methods to calibrate common displays should be urgently provided.

To meet this demand, a novel concept of ‘diagnostic equivalence ’ was introduced, which means that two displays reproducing colors differently are considered as medically equivalent if the same diagnosis is gotten observing the two medical images reproduced with each of them [10,14,15,16]. In medical application, physical differences between a digitized image and original one can be allowed as far as they do not affect the medical diagnosis. To verify this kind of equivalence, a set of typical medical images
with their diagnoses decided by authorities in advance are proposed to be used as a practical calibrator. Medical professionals can evaluate and adjust their displays by comparing the diagnoses made observing the images using their displays with authorized ones. Although this is not a complete solution, if these ways of thinking will work successfully, most of practical problems will be prevented.

5.2 Multispectral imaging
There is the possibility that the conventional RGB systems, which records colorimetric values of only three primary colors, red, green and blue, cannot reproduce precise colors required for reliable diagnosis. Multispectral imaging, which makes it possible to record the spectral reflectance of objects for accurate color reproduction, will give an important solution. There has already been a number of excellent research works on its medical and biological application [17-19]. One of its unique advantages is the ability to reproduce the precise colors under various illuminations. A multi-channel image of the objects is taken using a multispectral camera and spectral reflectance of the object is deduced from the image using its statistical characteristics. Simultaneously, spectral power distribution of the illumination used to take the image is measured. The image data, from which the component of the illumination is removed, converted with the spectral power distribution of the illumination used for observation to reproduce same colors under it. Another large potentiality is emerging by introducing the photometric stereo technique that can obtain the absolute spectral reflectance and the normal vector of a surface by taking multiple images of a object illuminated from more than three different directions. It can reproduce multiple images of the object viewed from different directions, therefore recording and reproducing of fine textures of skin lesions for practical use, which could not be done by any other methods, are expected to become possible.

The RGB system loses a large amount of the original color data in the digitizing process. Not all but a few of medical images are supposed to require more precise color representation than RGB system. In such cases, the enough number of principal components to represent required colors should be clarified using the techniques of multispectral imaging. Previous studies reported its number for representing colors of skin or mucosa is fairly small, but a wide range of pathological changes including abnormal or artificial pigmentation should be taken into account before making a conclusion. The concept of diagnostic equivalence is very practical, but requires a huge try and error process to be put into practice. When we will succeed to accumulate a number of concrete cases, the boundary between digitized medical images used properly and ones causing erroneous diagnoses will expected to be made so clear that some quantitative index for prediction is available. For this purpose, multispectral imaging will provide more reliable methods than the RGB system.

The realization of these expectations requires improvement of its costs, its sensitivity and its speed of data acquisition and affordable multispectral displays [20].

6. Conclusion

Investigation of color problems concerning digitized medical images requires specialists not only from the medical fields but also a wide range of engineering fields. Besides, multispectral imaging will play an essential role in medicine and biology of multimedia era, so international and interdisciplinary collaboration, which Digital Biocolor Society (http://biocolor.umin.ac.jp/) is going to organize, is considered to be indispensable.

References


