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Problems and Solutions in Medical Color Imaging

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Abstract

Intensive use of the multimedia technology is rapidly progressing and digital images will soon be common not only in medical practice, but also in medical education and research activities. In the medical field, exact recording and reproducing of colors are essential because recent investigations have shown that inappropriately reproduced colors may incidentally cause erroneous diagnoses.
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. 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.
Unfortunately, these technologies used for digital color imaging will not be sufficiently standardized for medical application in a short time. Therefore, 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.

Introduction

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. Today, telemedicine and electronic medical recording 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. However, a large amount of color data lost by the A-D conversion and the differences in reproduced colors of commonly used display equipment may incidentally cause erroneous diagnoses.

From this standpoint of view, this paper reviews the present status of the color imaging in various medical fields at first, and then summarizes these problems and the possible solutions for them.

Digital Imaging and Color in Medicine

(1) Gastrointestinal endoscopy [1]

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 mucosa showed a significant difference between normal controls and other cases affected by atrophic gastritis and early cancer, though no statistically significant difference in color was shown among them. Besides, the affected area of mucosa could be detected and made visible by computerized image processing in one case of early cancer of the IIc type, and in one case of early colon cancer of an elevated type, though in most cases this was not possible.

(2) Anatomical pathology and cytology [2]

Color has been one of vital factors for pathology, not only in scientific research, but also in the transmission of specialized experience and dissemination of accumulated knowledge, and photography has taken a major role in carrying them out. Recently, shortage of both space and personnel which are required for preserving specimens for macroscopic pathology and the rapid spread of telemedicine in microscopic pathology have encouraged the adoption of digital filing.

Diagnoses on microscopic pathology, in which most colors observed are made of various stains, seems 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, have been investigated to improve its performance.

(3) Clinical pathology and laboratory medicine [3,4]

In this field, laboratory information systems, which have been widely used already, encourage the spread of digital imaging. Its problems include inaccurate color reproduction, rough gradations of color and insufficient density of pixels, with varying degrees of relevance as regards their seriousness in the areas of urinalysis, hematology, microbiology, immunology, cytology, chromosome analysis, physiology and ultrasonography.

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 as extremely important.

(4) Nursing [5]

Today's highly progressed medicine is supported by various medical professions including nursing staffs, and health services are provided not only at clinics and hospitals, but also at local communities and homes. For maintaining close cooperation among them, they must have a means to share all information necessary to give excellent services using the best of advanced technologies, and the concept of the critical path gives standardized care plans to be carried out by them. Under expanding needs for nursing services provided at home which consumes a lot of manpower, easily understood nursing information including visual ones should be supplied to patients and their families to maintain the quality and the effectiveness of the service.
Although color of visual data is one of the most important factors in nursing information, recognition of the problem in nursing is not enough yet. Therefore, nursing professionals should have opportunities to actively join in the discussion on clinical applications of digital imaging, especially accurate reproduction of color.

(5) Dermatology [6,7]
In dermatology, macroscopic pathology of the live lesions can be directly observed, which is essential for diagnosis. Skin color is produced by a combination of complex mechanisms and utilized as vital information in dermatology to interpret the characteristics of a lesion and the depth in skin at which the lesion exists. Therefore the morphological changes of skin and their distribution should be recorded precisely. Photographs have played a substantial role for a long time in serving this purpose, and recently digital cameras have been introduced. But these are not yet believed to be able to substitute for the observation of the real objects.
However, if advanced digital imaging technologies are in a position to reproduce images that can be equally well used as real objects in dermatological diagnosis, revolutionary changes are expected in medicine. Precise dermatological findings will be conveyed when a patient is introduced to a distant physician or a medical consultation is made with a distant specialist. Besides, the importance of morphological records in dermatological practice as well as in dermatological education will be highly augmented.
If, on the other hand, the technology of digital imaging fails to achieve such quality as mentioned above, a huge investment in electronic patient records and telemedicine would run the risk of having been made in vain in the field of dermatology.

(6) 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 recorded images usually have differences according to the preference of each physician and the characteristics of each equipment used for recording images, and they may not be compared properly to each other.
Only few problems related to color have been experienced in this field yet, but the importance of color will become larger as application of digital imaging spreads to the movies. Therefore, though there is an effective solution using a color chart used to adjust reproduced colors, stable input and compatible output of still and video images should be pursued fundamentally.

(7) Neurosurgery [9]
In neurosurgery, one of leading applications of advanced medical technologies is the minimally invasive surgery, which will bring great reduction in both patients' burdens and medical expenditure. The essential elements to realize it are (1) a substitution of human hands which can manipulate accurately

the object tissue, (2) a substitution of human eyes to identify and observe the object of the operation and (3) visual information superimposed on the image of the object which navigates to assist a surgeon in the operation.
In microsurgery, stereoscopic video microscope systems equipped with a flat panel display and a video camera are substituting ordinary microscopes for microsurgery. With these systems, a surgeon can sit in a comfortable free position during the operation, all staffs engaged in the operation can share the same images as the operator watches, and all information required for the operator can be visualized on the same display for microscopic images. Besides, augmented virtual reality technology can superimpose the 3-D maps made for navigation of the operation on real objects. In these systems, endoscopic images give fundamental visual information and they must have high fidelity in color because erroneous color appearance of blood and tissue may directly affect surgery operations.
Solutions of how to visualize the image acquired using invisible light, how to reproduce the feel of a material in a virtual space and how to reproduce the same color using different illuminations and different monitors should be pursued to meet the clinical requirements.

(8) Legal medicine [10]
Although the color problem is considered to arise in the case of toxicosis and so on, only little discussion has been held yet about it. Some rules, for example, what the technological specification of red color is, should be established.

Problems at Present

(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 [11].
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 [12]. 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.

(2) The quality of color reproduction required for medical diagnosis
Empirically, pictures should be more precise than movies, and grayscale images should be more precise than color ones. Previous researches revealed that the medical findings which should be detected in a

image as well as its physical characteristics greatly affect the required degree of digitizing precision to maintain the same diagnosis that is made by observing the original.
The diagnostic qualities of most of digitized medical images properly prepared were almost the same as slidefilms. But, as Fig. 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 [13]. 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 [14].

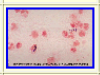
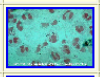
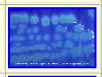
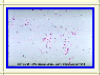
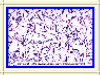
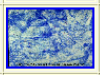
Image No.	Image	Display equipment						
		No.1	No.2	No.3	No.4	No.5	No.6	No.7
		CRT1	CRT2	CRT3	CRT4	LCD1	LCD2	LCD3
M-01		6.0	6.0	6.0	6.0	6.0	6.0	6.0
M-02		6.0	6.0	6.0	3.0	6.0	4.0	4.0
M-03		6.0	6.0	6.0	6.0	6.0	6.0	3.0
M-04		6.0	6.0	6.0	6.0	6.0	6.0	6.0
M-05		6.0	6.0	6.0	6.0	6.0	6.0	3.0
M-06		6.0	6.0	3.0	2.0	4.0	2.0	2.0
M-07		6.0	6.0	4.0	4.0	4.0	4.0	4.0
M-08		6.0	6.0	6.0	4.0	6.0	6.0	4.0

Figure 1 Evaluation of quality of medical images displayed with various equipment [13].

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.

The influence of the color on the medical diagnosis has been still unclear, but these experiment has 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.

The process of visual 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.

Solutions in Prospect

(1) Doing test run in advance
In order to prevent erroneous diagnosis caused by these problems, each digitized files should be displayed using at least both a CRT and a flat panel display, followed by examination and revision by specialists of the respective fields before putting them into practical use [4].

(2) 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 [11,15,16,17]. 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.
Its practical applications include development of a system to distribute the calibrator images through the internet and a simultaneous processing system to combine, imprint and compress them for safe distribution through the internet [18,19]. And also, there is a plan to publish a CD-ROM based educational atlas of blood cells, in which typical specimens are grouped according to the similarity of their colors and most typical ones are picked up from each group to compose a set of practical calibrators [20].

(3) Multispectral imaging
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 [21]. There has already been a number of excellent research works on its medical and biological application [22-26].
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

illuminanted 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.
Another aspect of its challenges other than the solution of present problems is establishment of new clues to assist morphological diagnoses using spectral reflectance of mucosal lesions.
The realization of these expectations requires improvement of its costs, its sensitivity and its speed of data acquisition and affordable multispectral displays [27].

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 collaboration of researchers among these fields is considered to be indispensable. For this purpose, Digital Biocolor Society (http://biocolor.umin.ac.jp/) was recently established and any specialists or researchers interested in are invited to join it.

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