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Why Multispectral Imaging In Medicine?

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Multispectral imaging will certainly provide an excellent solution to color problems in medicine, and may have significant impacts in many aspects of medicine, so that the realization of individual improvement forms a complicated network. Specific reports on the concrete medical problems that will be solved by a specific multispectral technology will therefore be indispensable. It is also important to understand some specific principles are appropriate from a marketing viewpoint for the chaotic medical field. Based on these considerations, two promising medical applications of multispectral imaging are proposed; digital images with spectral reflectance for each pixel, and digital images that are very accurate reproductions of real objects. The first technology will lead to new morphological diagnostic methods more powerful than human visual perception alone, and possibly even to the discovery of the mechanism of human color recognition, while the second advance will lead to a major improvement in the diagnostic reliability of digital color images and wider medical adoption of digital technology. The former will require considerable investment but will provide significant improvements in diagnostic ability, particularly for rare diseases, while the latter will provide practical and general improvements in medicine at relatively low cost.

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Introduction

Research and development of new medical equipment is a very risky enterprise. This may be the largest reason new technologies developed in an engineering field are seldom initially applied in medicine. Such technologies are usually applied in medicine after becoming established in other industry fields. Many existing technologies may therefore have lost potentially valuable contributions in medicine, and the medical field has been able to enjoy only a minor part of the benefits of new technology.

Multispectral imaging, which is surely one of the most promising of new technologies, should not be allowed to follow the same unhappy history as its technological predecessors. Through intensive interdisciplinary research, collaborating between engineering and medical fields, the authors and co-researchers have identified a number of principles from a marketing viewpoint and drawn a roadmap for the medical application of multispectral imaging.

Indeed, an engineer may see the medical field as a chaotic labyrinth with many dead ends. The proposed roadmap is presented here to inspire challengers to step bravely into this new field by reducing the risk in exploring it.

Color Problems in Medicine

Morphological Diagnosis and Color Problems

Morphological diagnosis that requires reliable color reproduction plays an essential role in medicine.[1–3] Looking at such an example, shown in Fig. 1, the importance of skin color in medical diagnosis is clearly important. However, no current imaging device has sufficient quality in skin color reproduction to be applied in dermatology or nursing. Therefore, the huge demand for recording dermatological and nursing findings has not been met as yet. The same situation is observed for oral mucosa and teeth in dentistry. For macroscopy in other medical sub-fields, the demand for precise color reproduction may be smaller, but various kinds and degrees of similar problems are observed.

Because endoscopic diagnoses on mucosal lesions require proper expertise, particularily for distinguishing cancer from benign lesions, supplementary methods to make lesions clear using mucosal color are indispensable. At present, a kind of vital staining is used, but more advanced optical devices are expected in the future.

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Supplemental Material—Figure 1 can be found in color on the IS&T website (www.imaging.org) for a period of no less than two years from the date of publication.

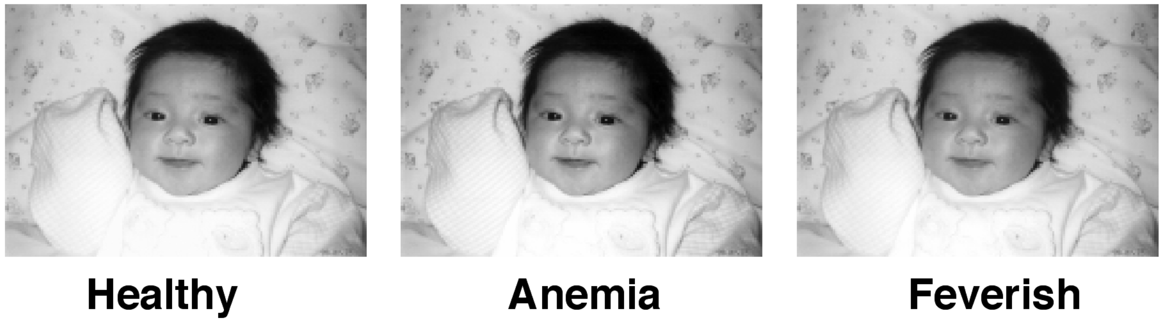


Figure 1. Artificial colorization of a picture of a healthy baby, demonstrating the potential for misdiagnosis if color reproduction is inaccurate. *Supplemental Material—Figure 1 can be found in color on the IS&T website (www.imaging.org) for a period of no less than two years from the date of publication.*

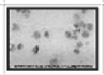
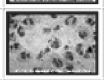
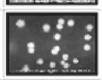
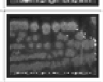
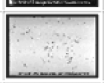
Image No.	Image	Display equipment						
		No.1	No.2	No.3	No.4	No.5	No.6	No.7
		CRT1	CRT2	CRT3	CRT4	LCD1	LCD2	LCD3
M-01		6.0	6.0	6.0	6.0	6.0	6.0	6.0
M-02		6.0	6.0	6.0	3.0	6.0	4.0	4.0
M-03		6.0	6.0	6.0	6.0	6.0	6.0	3.0
M-04		6.0	6.0	6.0	6.0	6.0	6.0	6.0
M-05		6.0	6.0	6.0	6.0	6.0	6.0	3.0
M-06		6.0	6.0	3.0	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 2. Example of the evaluation of microscopic pictures of various specimens displayed on various types of equipment. These displays have similar resolutions, and differ only in terms of the performance of color reproduction.

Microscopic medical findings have been recorded exclusively using conventional photography, but will soon be replaced by digital imaging. However, incidental diagnostic errors related to color might have been overlooked in the introduction of this technology. As shown in Fig. 2, the diagnostic ability of an individual instrument may range from very good to unusable depending on the specimen, with similar range of usability for an individual specimen on different displays. However, as any individual physician will typically only use one display, the possibility of the variation is not recognized, with the potential for misdiagnosis simply due to the limitations of the instrument. In addition, not only the colors of stained dyes, but also their changes in color caused by chemical reactions with the white blood cells are considered extremely important, particularly in hematological diagnosis.

Medical Color Problems and Multispectral Imaging

Colorimetric color calibration is used to compensate for differences between the optical characteristics of cameras and displays, but this technique is not capable of compensating for differences in color appearance caused by differences in illumination, which has not only a direct influence but also induces color adaptation of human eyes. Because this is a theoretical limitation of colorimetric color reproduction using three primary colors, only multispectral imaging is capable of managing this adjustment.

Trained physicians compare medical findings not with the examples in the literature but with the typical case in their memory. The color of a new medical finding is supposed to be compared with memorized cases, but discrepancies do not always cause erroneous diagnosis in

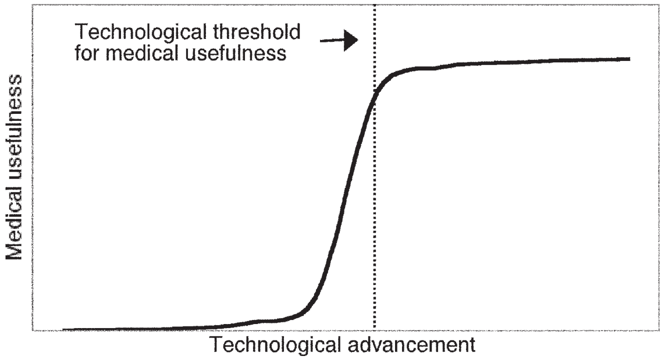


Figure 3. Conceptual model of technological advancement and medical usefulness.

our experience. Therefore, the question of how precise color reproduction is required to be in medical use will be answered only after multiple trial-and-error experiments on medical diagnosis, even if multispectral imaging is otherwise successfully applied in medicine.

Principles of the Medical Market

Frequency of Technology Use

In general, only a few diseases have high incidence rates, and there are a large number of rare diseases. In addition, the frequency of clinical situations that a specific technology is effective for varies widely by diseases. Therefore, if one expects a profit from a new technology, it should be applied selectively to common clinical situations observed in common diseases.

A high prevalence rate does not always mean a high incidence rate. A disease that has a long clinical course may accumulate in the population, and will consequently have a high prevalence. If a technology is required only once in each case of the disease then the technology will not be used frequently. When a technology is to be applied to preventive medicine or early detection of disease, estimation of frequency in use is more complicated, and there will be many more healthy clients than afflicted clients, bolstering the feasibility of application.

Technological Advancement and Medical Usefulness

It is important to understand that medical usefulness is not necessarily in proportional to technological advancement (Fig. 3). From the viewpoint of usefulness, there is a certain threshold of technological advancement that is determined by each application. If the advancement level of a technology applied to a product is slightly below the threshold, the product will be not just marginally useful, but almost entirely useless. From a marketing viewpoint, the threshold is the best level to aim at. Even if a technology has a much higher advancement level than the threshold, usually its usefulness will be only slightly improved. Such a product will inevitably be very expensive, and cannot be expected to survive in the medical market.

A highly advanced technology will become expensive because it will be rarely used. Therefore, demand for medical applications of such a technology should be carefully assessed beforehand. On the other hand, when the threshold of a technology for a certain medical application is relatively low, the application has a large possibility of success because it will sell well and will cost still less.

Determination Factors of Medical Demand

In general, the price of a product is proportion, not to the degree of advancement of technology, but to the demand for that technology. Therefore, it is important to understand what determines demand in the medical market. Based on our research, it appears to be dominated by two factors.

(1) Medical demand for a product becomes higher when there is no alternative.
(2) Medical demand for a product becomes higher when it has direct effects in medical decision making.

When there is only one product for a certain medical purpose, there will be a large demand for it even if its reliability of the technology is poor. However, once a more reliable product for the same purpose is developed, demand for the previous product will vanish.

Medical decision making is a more clinical matter. If a patient developed an untreatable disease, the meaning of exact diagnosis will be limited. In such a case, a demand for a diagnostic method will be limited even if it is extremely reliable. Once a curative is developed the demand will increase significantly.

Indispensable Clinical Research

In the medical field, a theory arrived at by deduction will be rarely correct, and there always remain unknowns. For example, while the entire human genome has recently been analyzed, the functions of most genes remain unclear. Similarly, although a functional model of human color sensation has been established, the process by which we recognize faces based on visual information, distinguish it from others and remember the person it belongs to, is unknown. The mechanism of medical diagnosis and medical decision likewise remains largely unrevealed, and is still wrapped in mystery.

In morphological diagnosis, the required quality of imaging systems used to record medical finding varies widely among medical findings. Even if there are recognizable differences between two imaging systems, such differences can be allowed as long as they do not affect medical diagnosis. In other words, two imaging systems that reproduce an indentical image differently are considered medically equivalent as long as the same diagnosis is obtained.

Therefore, positive as well as adverse effects of medical equipment should be proved through appropriate experiment not only prior to clinical application, but also in the early stages of research and development. When medical application of a new technology is planned, one should not believe it possible without trial experiments. In addition, it is more important that one should not believe it impossible without trial experiments.

A medical experiment is a resource consuming and risky project. Moreover, an experiment on human subjects may present ethical problems. In general, however, experiments for diagnostic methods are easier to conduct than for curative methods, and a non-invasive method is even more easily applied using volunteers. In this respect, multispectral imaging has great advantages in terms of experimental verification prior to medical application.

Promising Applications In Medicine

Two Promising Approaches

Considering the principles outlined above, two models emerge as promising approaches among the previous proposals and trials of medical application of

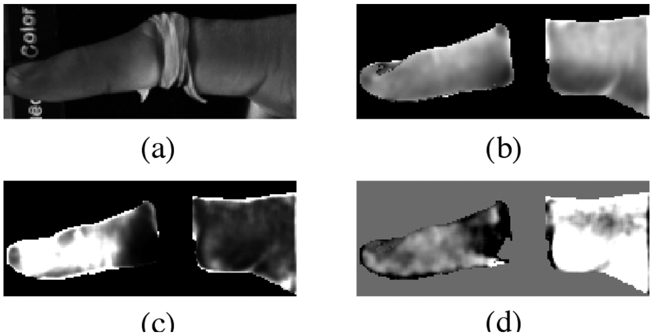


Figure 4. Example of visualization of skin pigments for an index finger bound with string at the second joint. (a) Original image, (b) melanin, (c) total hemoglobin, and (d) oxyhemoglobin (oxygen saturation).

multispectral imaging;[4–12] spectral color pictures, which include spectral reflectance information for each pixel, and absolute appearance pictures, which provide a highly accurate reproduction of real objects and are never affected by devices or illumination conditions.

Application of Spectral Color Pictures

New Diagnostic Strategies

The spectral reflectance of skin and mucosa provides a lot of biological and medical information about the human body. However, current imaging systems record only a small part of this reflectance, and do so inaccurately. Therefore, a variety of new morphological diagnostic methods based on information not detectable by human sensation may be developed if the spectral reflectance of skin or mucosa can be recorded as a picture. A specific range of wavelengths can be adaptively enhanced to reveal previously undetectable medical findings. The spectral reflectance in the infrared and ultraviolet regions will be also utilized.

Several multiband cameras have been developed to test these possibilities, and their medical use is currently under investigation. Although a multiband camera usually means a camera that has more than three color channels, there is the possibility that three color channels may be sufficient for some applications.

An example of some of the promising applications is visualization of the distribution of the three major skin pigments, melanin, hemoglobin and oxygemoglobin[12] (Fig. 4). The spectral reflectance of each pixel of a skin picture used to calculate the distribution of skin pigments can be estimated by observation from a picture taken using a current digital camera because the three principal components are sufficient to approximate the reflectance spectra of normal skin. Although different sets of color components may be selected for observed diseased and normal skin and the difference between them may have some importance in medical diagnosis, only one set of the three principal components are required to approximate the reflectance spectra of both normal and diseased skin if errors in calculated reflectance spectra do not affect medical diagnosis.

New Investigation Strategies

The characteristics of human color perception will be investigated in more detail based on comparisons of color spectra with qualitative observations of color. If a large difference in sensitivity of color difference by wavelengths is revealed, optimum compression methods that maintain the absolute appearance of the spectral reflectance can be devised. In addition, such knowledge will contribute to our understanding of the mechanism of human color perception.

How to Approach Spectral Color Pictures

Because spectral color pictures are completely new in medicine, the demands for this technology will initially be very low, but can be expected to increase when the full potential of the technique is realized. Although the impact of these medical applications may be quite significant, most applications will require a lot of further investigation using highly advanced technologies. In addition, each application will be effective for specific conditions in limited clinical situations. Consequently, the investment required for the development and implementation of this technology becomes large compared with the prospective sales. Therefore, the demand for these applications should be carefully investigated in detail in advance.

Application of Absolute Color Pictures

Application of Absolute Appearance

When a physician makes a diagnosis of a lesion, the medical findings should be recorded and reproduced as if the physician were observing the actual lesion, regardless of the illuminating conditions. Such an ideal image is considered to represent the absolute appearance. The quality of absolute appearance pictures will be determined by factors such as sharpness, graininess, tone reproduction, and color reproduction.[13] Although spectral color pictures may be an ideal solution for color reproduction, other factors should also be satisfied.

Using Common (Three Band) Equipment

As mentioned before, reflectance spectra of skin can be estimated from a picture taken by a three band digital camera. Thanks to the characteristics of three kinds of human cone cells, colorimetric color reproduction using the three primary colors will reproduce most colors of skin with good accuracy. In other words, the spectral reflectance of each pixel of a skin picture can be captured using a current digital camera and the color appearance under any illumination can be reproduced using any three band display.[8] Although reproduced colors in this way will have some margin of error, the images will still be highly useful in medicine if the discrepancies do not affect medical diagnosis.

Using Multiband Equipment

A multiband camera coupled with a multiband display can reproduce a much wider range of colors more accurately, independent of both devices and illumination. Although even a multiband display will have differences in color appearance caused by differences in the color matching functions of individuals, a calibration method should be readily available. This premise can also be applied to displays that provide color-blind users with the same apparent color sensations as other users.

How to Approach Absolute Appearance Pictures

Presently, digital color imaging has been adopted in fields that do not require high accuracy of color reproduction. However, the development of accurate color systems can be expected to give rise to huge demand for the technology in the fields of dermatology and nursing.

As most clinical cases do not require high fidelity of image recording and reproduction, an imaging system that provides partially device- and illumination-independent color reproduction using common equipment will have extensive practical and general effects throughout medicine. The adoption of this minor technology can be expected to generate demand for multispectral imaging in many other fields, fuelling the dissemination of other related technologies. Therefore, the first group to successfully develop and implement absolute appearance pictures may secure both a significant investment and a place in history as a pioneer of the practical application of multispectral imaging.

Conclusions

Although no new engineering technology can be introduced easily to medicine, there opportunity for success exists because of infinite demand for medical services, if only the characteristics of clinical demand can be exactly understood and a steady process followed.

At present, practical application of multispectral imaging is in a relatively early phase. Medical practice is an important target for the technology, with the largest demand for high fidelity color reproduction among major fields of serious business. Therefore, unlike most other technologies, it expected that multispectral imaging will be adopted to some extent within the medical field before widespread adoption in other industries.

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