特集論文／医療におけるカラー画像

Practical Methods of Color Quality Assurance for Telemedicine Systems

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Abstract

Telemedicine is experiencing significant growth in the U.S. and around the world, with a strong focus on improving the delivery of healthcare to remote rural areas. The Arizona Telemedicine Program has operated a statewide program since 1996, which provides multi-specialty care and educational content. Three of the most active specialties are image based: radiology, dermatology and pathology. Teleradiology is well established in the U.S. and well integrated into standard department practice. Teledermatology offers similar characteristics and fits well into the paradigm of remote practice, but introduces the additional factor of color fidelity. Color provides significant information for the dermatologist. It is critical that the color in a dermatology image captured at a remote site is reproduced faithfully at the consulting site. However, in many telemedicine applications the remote rural sites present significant challenges of lack of high-speed communications infrastructure, reliability of power and availability of skilled technical personnel. In this type of setting it is useful to establish practical methods for quality assurance that are inexpensive and do not rely on complex technology. The Arizona Telemedicine Program employs these practical methods in two programs involving very rural sites and has found them to be effective and appropriate for remote sites with limited resources.

Key words: Telemedicine, Teledermatology, Color quality assurance, CRT calibration

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1. Background

The Arizona Telemedicine Program is among the most active programs in the U.S. and was awarded the President's Award for excellence by the American Telemedicine Association in 2001. The program includes both store-and-forward applications and real-time video applications. Image based specialties such as radiology, dermatology and pathology are among the most active specialties and are heavily oriented to store-and-forward technologies. For real-time video conferencing the dominant specialty is psychiatry 〔1 ～ 3〕.

The issues of spatial and contrast resolution have long been a topic of investigation in the digital radiology community and requirements for teleradiology are well established and accepted. For rapidly growing fields of teledermatology and telepathology the discussion must be expanded to include color fidelity. Color provides significant information for the dermatologist and it is critical that the color in a dermatology image captured at a remote site is reproduced faithfully at the consulting site.

1) CRT displays

In most telemedicine workstations today color cathode ray tubes (CRT) are the electronic display of choice. They offer the best performance, and they are the most highly developed and reliable displays in common use. Currently there is great interest in flat-panel displays, especially active-matrix liquid crystal displays. However, it is

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expected to take many years for these systems to displace the CRT in medical applications [4].

Despite popular perceptions to the contrary, current high-resolution CRT display systems can present all information in digital medical images with the detail and richness of a film hard -copy printed by laser-image- recorder. In many instances, however, user interactions are required to achieve the same detail rendition. Required interactions typically include presenting only part of the image at one time by means of panning and zooming, and manipulation of image contrast.

2) Color and Color Fidelity

The trichromatic theory holds that the retina of the eye consists of a mosaic of three different receptor elements. Each element responds to specific wavelengths corresponding to blue, green and red light. These three elements, which appear to overlap considerably in response, are separately connected through nerves to the brain where the sensation of color is derived by the brain's analysis of the relative stimulus from the three elements [5].

The operation of color displays is based on the fact that the mixture of three primary colors in suitable quantities can match most color sensations. The three primaries may be but are not necessarily monochromatic. Typical primaries may be red, green, and blue. In fact red, green and blue emitting phosphors in colorCRTs or red, green and blue filters in LCDs are the elements which provide these primary colors in small enough size for the observer not to see the elements individually, but to permit their superposition and mixture in the eye.

Following the recommendations of the Commission Internationale de l'Eclairage (CIE), colors may be specified by points on a two-dimensional graph known as chromaticity diagram. The x,y coordinates in this diagram range from 0 to 1. Colors can also be specified in terms of color temperature. These hold for those colors emitted by sources following Planck's radiation law. Color temperatures are not defined for pure spectral colors. Accordingly, color fidelity is achieved if the color coordinates of the object to be imaged and the color coordinates of the images on the color display are identical. Color coordinates as well as color temperatures are measured with colorimeters, which are basically photometers with three detectors, calibrated to provide chrominance and luminance information on the colors within the field of view of these detectors.

Accordingly, color fidelity is achieved if the color coordinates of the object to be imaged and the color coordinates of the images on the color display are identical, or if the color temperatures are identical.

3) Display Function

One of the most important parameters of a display is the display function. It provides the information on the dynamic range of the display (i.e., the ratio of the maximum and the minimum luminance) and on its greyscale response. In order to ensure the highest quality standards for telemedicine the display function should be standardized for all medical imaging devices. This will prevent users at different systems from rendering different interpretations of the same image.

For radiology the DICOM (Digital Imaging and Communication in Medicine) committee has recognized the importance of standardizing the display function for the medical imaging community. The specific display function selected by DICOM is based on perceptual linearization [DICOM Part 14 Display Function Standard]. The specific function adopted, however, is not as critical as reaching agreement on an industry-wide approach. The accepted standard allows devices from multiple manufacturers to exchange data and to present images consistently [4, 6].

4) Calibration and standardization

Calibration procedures and their value are well understood with regard to many radiology tools. Radiation sources, film processors, and laser film printers all have a long history of calibration, which simply consists of the process of measuring the response of a component or system and, if necessary, correcting it to that expected. For some time, hospital accreditation organizations have required that a log of this monitoring and correction be kept and it is only natural, that such procedures will be extended to include imaging workstations. Calibration and standardization are required in the areas of color fidelity and the display function. We should expect to develop practical methods to apply this standardization in telemedicine applications.

However, one of the greatest challenges presented by telemedicine comes stems from its greatest benefit. Telemedicine is frequently intended to deliver improved access to healthcare to very rural regions with only small hospitals or clinics. Rural sites in which the Arizona Telemedicine Program is active include isolated communities in the Navajo Reservation in Northeastern Arizona as well as small communities in remote areas of Panama. These settings present significant challenges such as lack of high-speed communications infrastructure, reliability of power and availability of skilled technical personnel or other resources to support sophisticated calibration. In this type of setting it is useful to establish practical methods for quality assurance that are inexpensive and do not rely on complex technology.

2. Materials and Methods

For practical situations in rural areas the design of clinical examination rooms used for telemedicine should begin with the following room treatments before the equipment is delivered. The existing light fixtures in the room should be color corrected to warm, white light (3200 degrees K). This selection is based on experience with professional television productions that determined that lighting for video requires that light be a color temperature of 3200-3500 degrees Kelvin. Augment the room with additional standard fluorescent fixtures if possible to ensure that light is evenly distributed throughout the room. This is critical for dermatology whether using store-and-forward or real-time video imaging. The goal is to communicate actual lesions rather than shadow or artifact.

Walls that will appear in the background of images should be painted with a light blue, flat latex paint. It is useful to use a color chip from a popular hardware store chain to ensure consistency among different sites. We want to be sure that if a dermatologist virtually travels to different geographic locations during a clinic that there is not a dramatic difference in the environment of each location. Install carpet to eliminate as much audio distortion as possible (for real-time video interactions). The color should be neutral (medium gray or blue) so that it will also be a nice background when seen on camera. **Fig. 1** shows a clinical room prior to treatment. **Fig. 2** shows the same room after treatment and installation of telemedicine equipment.

During equipment installation our technical personnel spend a great deal of time fine-tuning the color on all CRT monitors used to support telemedicine clinical activities. This is done to ensure that color is accurate at both the remote site, where telemedicine based patient examinations originate, and at the clinical service provider site, where the information is reviewed. Because of the challenges of rural sites we have selected practical methods and tools that can be used by clinical personnel who do not have a significant degree of technical skills. One of the

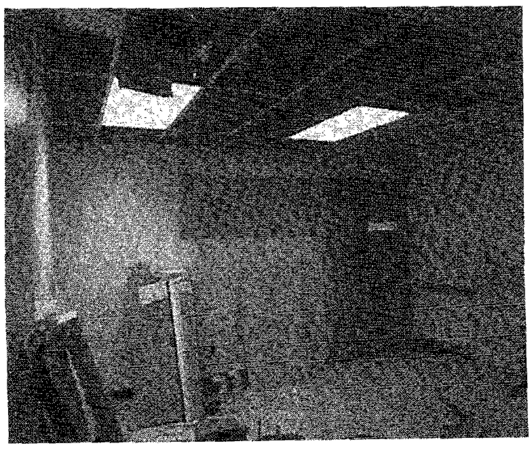

Fig. 1 A rural clinic room prior to treatment.

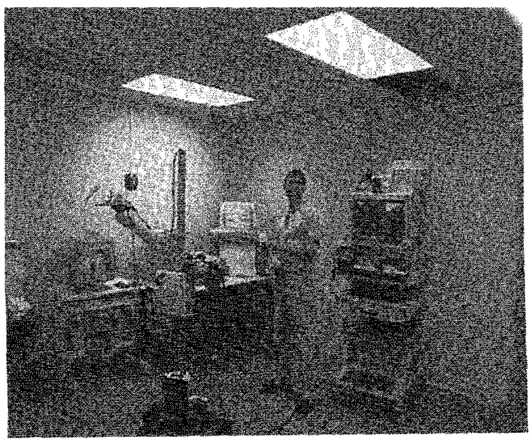

Fig. 2 The clinic after treatment and installation of equipment.

best tools we have found is the GretagMacbeth ColorChecker Chart.

The GretagMacbeth color chart is also available as a jpeg image file that can be installed on the computer driving a monitor so that it can be compared to the actual physical chart. For real-time videoconferencing a camera at the originating site images the physical chart while a technician at the receiving site tunes the monitor by comparing it with a physical chart. This process is simple and effective for rural areas where skilled technical personnel are often not available. **Fig. 3** illustrates the calibration of a computer used for store-and-forward applications at a remote site in Panama.

In more technical applications, such as radiology, where there may be more sophisticated personnel available, there are additional tools and process that can be applied to reduce subjectivity. In a larger clinic or hospital with complex imaging systems such as CT scanners, there will generally be a quality assurance process in place. These processes can be adapted to general telemedicine applications, and have proven useful in calibrating monitors for uniformity in pathology board certification examinations [7]. The calibration tools for color calibration as well as grey-scale calibration consist of a colorimeter, software package and look-up tables in the display controller. Most important are those display controllers that offer a 10-bit Digital-to-Analog Converter (DAC). A very popular software package is VeriLUM Version 4.2, offered by Image-Smiths in Germantown, MD [8].

1) Color and Grayscale Calibration

It is to be understood that any color or grayscale calibration should be performed only after the proper set-up of the display.

Calibration for color fidelity requires making a decision on what the desired color coordinates are or what the desired color temperature is. Using the Macbeth color chart and the desired illumination, the color coordinates or the color temperature for the desired field of the Macbeth color chart are determined with the aid of a colorimeter. This particular field is then displayed and the color controls of the display are adjusted until the color temperature has the desired level.

At this point the VeriLUM Version 4.2 software package is used to do the grayscale calibration. As illustrated in **Fig. 4**, the DICOM testpattern is used for this procedure. This consists of a white square in the center of the dislay, (the area of which is 10 % of the total display area), and a background area (the area outside the white square), the luminance of which is 20 % of the maximum luminance of the white square. The respective Calibration Pro-

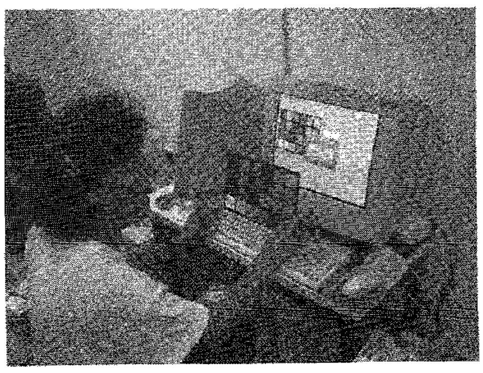

Fig. 3 Use of the GretagMacbeth ColorChecker Chart and corresponding jpeg image to calibrate a telemedicine store-and-forward system monitor.

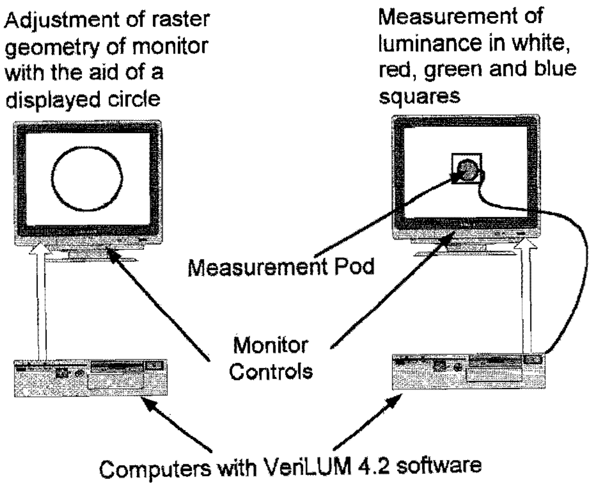

Fig. 4 Illustration of some aspects of the set-up procedure for color monitors to be used pathology images

gram generates the DICOM 14 Display Function Standard. This program generates various luminance values in the white square, which are measured with the photometer while it is held firmly against the white square. These luminance values are used to generate look-up tables on the display controllers that in turn produce the DICOM 14 Display Function Standard.

After the proper set-up of the display, the photometer is placed directly on the CRT faceplate to measure the luminance of the CRT for the specific drive voltage applied. The data from the photometer are digitized and used to generate the CRT's display function. The resultant gamma is compared with the desired gamma and corrections are made in the drive voltages to restore the desired gamma, taking advantage of additional look-up tables stored in the display controller. After the calibration procedure the user should display the SMPTE pattern and make sure that the 0 to 5% and the 95 to 100% contrast patches are clearly visible.

2) Display Set-up

It is desirable to turn off the pedestal option on the display controllers, if this option is available, so brightness control and contrast control are independent.

Set brightness and contrast controls to zero. Then the brightness control is increased until one just barely discerns the scanned raster on the otherwise dark CRT. This luminance level is called the blacklevel. If there is noticeable ambient level, set the blacklevel slightly above the ambient level. Then increase the contrast control until the maximum luminance, the working luminance or white level, is reached. A good white level is about 300 cd/m^2, while a good blacklevel is about 0.2 cd/m^2.

3. Results

These techniques have proven to be very effective in ensuring that color clinical images for dermatology have consistent quality. By using the physical GretagMacbeth ColorChecker Chart chart on site to compare with the image on the CRT we have a simple method that is less subjective than just looking at the monitor with no reference. When used in conjunction with proper training (see Discussion section below) these simple methods can help to ensure the color quality of images used for telemedicine is appropriate for diagnostic activities [9, 10].

Our program conducted a study comparing in-person diagnosis of dermatology conditions with diagnosis using digital photos of the lesions displayed on a color CRT monitor. A total of 309 patients were examined in person by one of three dermatologists. Digital photographs were obtained of the lesions on these 309 patients. The same 3 dermatologists viewed all 309 cases on the display monitor. There was 83% concordance between in-person versus digital photo diagnoses. Decision confidence was rated as "very definite" to "definite" 62% of the time. Concordance with biopsy results was achieved in 76% of the cases. Image sharpness and color quality were rated as "good" to "excellent" 83% and 93% of the time respectively. Only 1% of the images were rated as having "poor" color quality [11].

4. Discussion

Training is a critical factor in obtaining the highest quality images possible with these techniques. This includes training not only in the calibration process, but also in the techniques used to obtain clinical images. Clinicians are taught basic photographic technique covering framing, camera angle, background, and lighting. Training workshops are provided by the Chief of Dermatology and covers these areas based on clinical experience. Framing is critical to provide appropriate context and includes the use of appropriate background. Camera angle is very important to convey depth information that may be of importance to the diagnosis. Lighting and the use of flash are important to be sure that colors are not washed out or features obscured by glare.

5. Conclusions

These methods are simple and practical. They are easy to deploy and inexpensive. The techniques do not require complex systems that require sophisticated technical support and it is easy to train personnel at rural sites to apply these methods. As automated tools that are small, portable and inexpensive are developed they can be incorporated into active practice to complement or replace these techniques.

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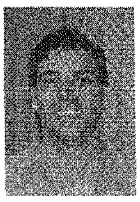
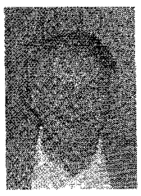


Kevin M. McNeill

Dr. McNeill received his B.S. in Mathematics, M.S. in Computer Science and Doctorate in Computer Engineering from the University of Arizona. He has been involved in the development of computer software, systems and networks for application in medicine, especially Radiology, since 1977. He has consulted on Radiology workstation implementation and object-oriented software design internationally and taught programming, object-oriented design and networking in both the engineering and business colleges. Dr. McNeill designed the Arizona Rural Telemedicine Network, the state-of-the-art telecommunications network supporting the video and data needs of the Arizona Telemedicine Program. As Chief Information Officer he is now focused on developing business models for telemedicine, telehealth and e-health services, addressing HIPAA and electronic medical records for telemedicine. Dr. McNeill is also the co-Director of the Teleradiology Section in the Department of Radiology.

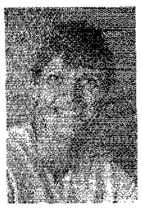
Janet Major

Ms. Major received her degree in Telecommunications from Northern Arizona University in 1980, with an emphasis on production and directing. From 1981 to 1987 she was Stage Manager for one performing group of Up With People, and later served as Technical Operations Manager for all six performing groups. From 1987 to 1990 she was Technical director for the University of Arizona's Centennial Hall, responsible for the production of all events. Since 1990 Ms. Major has been the Distance Programs Coordinator in the College of Medicine's Division of Biomedical Communications. She added responsibilities as Technical Coordinator for the Arizona Telemedicine Program in 1996. Ms. Major received the Most Outstanding Individual Award in Distance Learning for the category of Healthcare/Telemedicine from the Arizona Distance Learning Association in 2000



Hans Roehrig

Dr. Roehrig was born in Giessen, Germany on November 29, 1934. He received both his MS (1961) and Ph.D. (1964) in experimental physics from the Justus Liebig University in Giessen, Germany. In 1967 Dr. Roehrig joined the US Army Night Vision Laboratory in Fort Belvoir, Va, to do research on far-infrared sensitive imaging tubes. In 1973 he joined the Optical Sciences Center and the Department of Radiology at the University of Arizona to work on the application of photoelectronic imaging devices to diagnostic radiology. Much of this work has contributed to the evolution of Digital Subtraction Angiography (DSA). Dr. Roehrig's main focus is the development of the Totally Digital Radiology Department. He has worked extensively on the physical evaluation of x-ray imaging devices like x-ray image intensifiers as well as on computed radiography systems. Presently he is concentrating on the physical evaluation of high-resolution CRT displays as well as on the physical evaluation of digital mammography systems.



Elizabeth Krupinski

Dr. Krupinski received her BA from Cornell University in 1984 and her PhD in Experimental Psychology from Temple University in 1992. She completed her early training at the University of Pennsylvania in the Department of Radiology. She is currently a Research Associate Professor in the Departments of Radiology and Psychology at the University of Arizona and has been the Director of Evaluation & Assessment for the Arizona Telemedicine Program since 1997. Her main interests are in medical image perception, diagnostic decision-making strategies, human factors/ergonomics in the medical environment, and observer performance issues in radiology and telemedicine. A number of her studies have used eye-tracking technology to study the ways that clinicians interact with digitally displayed information. She is currently President of The Medical Image Perception Society.