Color Imaging in Telemedicine
Current Trends & Future Needs

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Abstract

This paper will examine the many complex issues surrounding the effective use of color imaging as an integral part of telemedicine systems. This includes an overview of common color medical imaging techniques and the color needs of each as well as a discussion of global issues that contribute to the viability of this technology; thereby highlighting roles that imaging professionals can play to increase the value of color imaging technology in healthcare by ensuring that color applications in telemedicine benefit from optimal technical solutions.

Introduction

Broadly defined, telemedicine is the application of telecommunications and imaging technology to the practice of medicine. It links health care specialists with clinics, hospitals, primary physicians and patients in various locations for diagnosis, treatment, consultation, and education. In its most recognized form, telemedicine is used to provide medical services to underserved rural populations—but this isn't the whole story. Despite the recent broader discussions of telemedicine, it has actually existed for almost four decades—beginning with usage in the late 1950's to facilitate remote psychiatric consultations. Only recently has telemedicine and specifically the use of color imagery within telemedicine become viable for use within a broadly applied healthcare infrastructure. Table 1 lists a number of proposed application areas discussed in the recent medical literature.[1] Some medical visionaries expand upon this list to include such applications as surgery via *telepresence* which would incorporate robotics and a patient at a location distant from the physician holding a "virtual scalpel."[2]

The ability to capture and replay high quality calibrated and standardized color images in real-time is currently a reality, however, the usage of such technology in medical imaging applications, such as telemedicine, has been slow to gain acceptance. Reasons for this are varied, including a lack of research quantifying the levels of image information content needed for accurate remote diagnosis, an insufficient perspective on the true cost savings of such an endeavor, and medical training methods that have been slow to adopt color imaging as a viable medical tool. A lack of medical industry standardization for image capture, display and archiving also contributes to the problem. A few industry standards are just beginning to provide the framework needed for quality color medical imaging solutions but there is much work to be done. As is true in many application areas, relatively few vendors are making telemedicine products per se. However, huge advances are being made indirectly through the use of "off the rack" technology from analogous "enabling technologies" in the consumer and industrial markets.

It is important to remember that a healthcare infrastructure that uses telemedicine must accommodate the needs of different communities, and different medical specialties, realizing that not all technologies are available in all locations, nor are they necessarily required. Generalities tend to be drawn over what applications require the most capability—for example, Cardiology which currently tends to use composite still imagery is generally thought of as requiring lower bandwidth than Orthopedics which requires higher resolution for radiographic transmission. Interactive examination using live real-time video has even higher bandwidth requirements while medical education can require anywhere from moderate to high capability. However, as widespread telemedicine is just getting a foothold, it is important not to pigeonhole applications too tightly to permit practitioners to find new ways to explore and utilize this technology. For example, teledentistry has moved beyond the transmission of simple dental radiographs to include interactive video for patient consultation and remote diagnosis of dental and oral problems. Such growth and exploration of new ways to utilize electronic imaging technology can be beneficial to patients. Providers. must have the flexibility to further explore ways that this technology can continue to grow and to improve healthcare delivery.

There are currently many Telemedicine programs underway worldwide. In the U.S., these include relatively large programs in Texas, West Virginia, Virginia, Montana, and Georgia as well as a US Army Global project and a multifaceted effort by the Mayo Clinic. Many smaller regional programs are also being tested and new programs on a variety of scales are continuously being launched. These efforts have incorporated numerous types of data transmission technology and network topologies. Everything from POTS (the Plain Old Tele-

Table 1. Proposed application areas for telemedicine technology.

• Cardiology	• Dentistry
• Dermatology	• Electronic Medical Records
• Emergency Care/Triage	• Endocrinology
• Home Care	• Disability Management
• Medical Education	• Military & Remote Industrial
• Neurology/Neurosurgery	• OB/GYN
• Oncology	• Ophthalmology
• Pathology	• Pediatrics
• Psychiatry	• Radiology
• Sign-Language Communication	• Sports Medicine
• Surgery	• Urology
• Veterinary Medicine	

phone System), packet switched Data lines, other digital Services such as ISDN, T1 and T3, Ethernet, Fiberoptic, Ku or C band satellite and ATM (Asynchronous Transfer Mode) technology. A telecommunications signal protocol which delivers the highest rate of data transmission speed to date, ATM is currently being tested in metropolitan area networks[3]. A variety of local and wide-area networking is being tested with telemedicine systems of all sizes. As a result, and due to the varying teleservices that a given provider, such as a dentist, may need to provide to a patient, telecommunication service providers are examining strategies for increasing transmission rates and purchasing schemes to permit the acquisition of necessary bandwidth on an as-needed basis.

Cost benefit is, of course, a very real concern dictating the widespread use, acceptance and longevity of telemedicine. Studying the cost vs. benefits associated with telemedicine have prompted the Development of the National Information Infrastructure Testbed for Telemedicine.[4] Formed in 1993, the NIIT is a cooperative of companies, universities and government agencies, which has initially involved primary care and trauma physicians collaborating remotely via satellite and beta ATM technology. A principal aim of this group is to help facilitate a National Information Infrastructure that will use a host of transmission media, networks, information sources, and computing devices in diverse locales to deliver affordable, high quality access to healthcare to all. Other organizations, such as the American Telemedicine Association, have been created to help facilitate additional research and education in this area.[5]

The Emerging Role of Color

In medicine, the predominant imaging technology has been diagnostic radiology with its use of high resolution gray-scale imagery. However, this is changing and color is becoming more pervasive within the medical imaging domain. The current use of color in medical imaging falls into two categories:

(1) Video-based color (such as that utilized in endoscopy, surgery or in teleconferencing applications)
(2) Pseudo-color (used in text, graphics, telemetry (e.g. heart activity waveforms) and diagnostic images).

The viability of color as an integral part of telemedicine is just beginning to be re-examined within the medical imaging community. The arrival of electronic diagnostic modalities have actually enabled color to establish a presence in medical imaging and telemedicine. Prior to this, radiographic techniques and thus grayscale images were the primary imaging tool. Two prominent problems have been noted by the radiological community as boundaries to wide acceptance of color[6,7]: Firstly, full color displays are felt by many to distort the anatomical information present in gray-scale images. For example, visual borders between adjacent contrasting colors may be misinterpreted as indicative of real anatomic boundaries. Secondly, the acquisition, computation and archiving of full color images are felt to be more troublesome than traditional gray scale images.

However, there have been technological advances that have reignited the medical community's interest in color imagery. This has included exploration of new ways of color-encoding information as well as strides in imaging modalities. A number of color-based enhancement techniques have emerged in recent years. These include:

- **Enhanced Computed Tomography (CT)**
- **Magnetic Resonance (MR)**
- **Ultrasound** (Color Doppler)
- **Nuclear Medicine**—which includes techniques such as **SPECT**
- **Positron Emission Tomography (PET)**
- **Direct Imaging Techniques -** e.g. using conventional film and CCD cameras.

The color usage in these various techniques runs the gamut from pseudocoding to true color rendering. In **Enhanced CT**, which provides a 2-D mapping of X-ray attenuation coefficients, bony detail can be contrasted with major vessels. Color (hue) as well as relative brightness assist in the evaluation of image content. However, due to the composited nature of images generated, reconstruction artifacts can result, the effects of which can be lessened or heightened through choice of colors.

Magnetic Resonance images are based on the differential biophysical responses of human tissue and body structure to a magnetic field. Color enhanced MR utilizing a variety of color encoding schemes, can be used to augment this tissue detail.

In **Doppler imaging**, a technique is utilized in which a pulse echo is reflected off of various body systems. In the resultant image, brightness represents echo intensity while motion can be charted by correlating previous and subsequent echoes relative to one another. Normally, two primary colors indicate flow direction and the technique utilizes a mapping between these two colors and 6 bits of color information to distinguish the intermediate levels. In general, color information is displayed at half the gray scale resolution and gray scale image detail is essential.

In one of the more common types of **Nuclear Medicine**, cardiac thallium perfusion is used to examine variations in the working and resting heart from a variety of angles of view. Again, pseudocoding using limited color is generally applied. This is also true in **Positron Emission Tomography (PET)** which in cardiac applications enables examination of function, metabolism and blood flow using a variety of radio-tracers. Again, pseudocoding is utilized but many of the conventions adopted are different from those seen in other imaging modalities.

For the most part, all of the imaging techniques mentioned so far use color in a relatively limited way relying on pseudocoding or predetermined, limited palettes of color for image encoding. This is a sharp contrast to the type of real-color imagery that is utilized in photographic or CCD Camera based **Direct imaging**. Contrast dye-enhanced photography is used in a variety of applications—one most notably being ophthalmic images in which color content is used to make judgments about an underlying ocular condition. Another example of direct imaging is endoscopic applications where a color CCD camera inserted into the body attempts to capture true full color images in real time for the purpose of diagnosis and therapy. Not only is color important for the initial assessment of a condition but it is often important in the comparative judgments made over time to assess the progress of disease. The need for true accurate color rendition is obvious in such imaging applications. Despite the fact that CCD-based imagery is gaining wider use, as is the use of various electronic devices for image evaluation (CRT display, electronic printing, etc.), very little attention is currently paid to color standardization, control or management in hardware and software.

The inconsistent and relatively uncontrolled use of color between different techniques or even within a single modality must be considered seriously. The choice of colors and the overall scheme used in the construction of an image are generally left up to the operator/technician and there are a few typical conventions but most are loosely followed. This has tremendous impact on overall, consistent interpretability of images. The problem becomes even more complex in multimodality imaging where techniques are overlaid or fused to combine the strengths of individual imaging techniques - for example, the bony detail of a CT image and the soft tissue detail of MR can be used to better assess the effect of head trauma on the brain. Some earlier investigative work done in color-based MR imaging has helped set the stage for continued development and interest. Both hybrid color[8] and compositing[9] techniques have demonstrated enhanced appearance of tissue leading to more efficient and accurate interpretation of MR scans. Realize that a given diagnostic imaging technique does not necessarily lend itself to direct combination with all other techniques and it will be imperative to understand the level at which such interplay must be accommodated. However, a lack of medical industry standardization for image capture, display and archiving equipment also contributes significantly to the problem. Generally, in medical imaging applications, color specification is not objective. Colors are specified using device-dependent parameters—typically RGB, YIQ, or one of the user-based, "perceptual" systems such as HLS or HIS. In other computer-based imaging applications having a broad spectrum of color quality requirements, such as the graphic arts, the color imaging community has been working diligently to bring objective color specification, such as CIE-based definition and overall color management utility to imaging systems and to users. Similar work must be undertaken in the medical imaging arena to assure the cost-effective, accurate interchange, archiving, and interpretation of patient image information. The medical community must work in concert to help define levels of practitioner expectation, image acceptability criteria and related color user-interface requirements.

Industry standards are just beginning to provide the framework needed for quality color medical imaging solutions. As the use of computers proliferated into medical imaging through the 1970's, the American College of Radiology (ACR) and the National Electrical Manufacturer's Association (NEMA) formed a committee in 1983 to develop a standard which 1) aided in the communication of digital image content—regardless of manufacturer, 2) aided in the expansion of picture archiving and communication systems (PACS) used to link with other hospital information systems, and 3) facilitated the creation of diagnostic information data bases. The standard has evolved over time with the current designation "Digital Imaging and Communications in Medicine (DICOM) Version 3.0"[10]. This standard, which supports operation in networked environments, was developed in conjunction with the Health Level 7 (HL-7) protocols which are currently evolving for multilevel hospital data interchange and communication. Such standardization is a big step forward. Perhaps since color information has not been viewed as an essential part of medical imaging, the device-independent nature of this standard does not extend to color parameter specification. The only color models supported are device-dependent (e.g. HSV, RGB, and CMYK Palette Color) and there is no specification related to device calibration to enable optimal color performance or enable a level of matched performance between different devices. Given the multi-media nature of telemedicine and the interchangability of image capture and image processing devices, reliable, accurate color definition will require some form of device calibration and means of handling device-independent color specification. Such functionality will have to be transparent to the clinical users but may present new technical challenges to the device manufacturers and clinical engineers responsible for system development and diagnostic equipment maintenance.

Unresolved Issues

The truth is that electronic modalities have been enabling technologies for color in medical imaging Despite the fact that color is being used in a variety of diagnostic techniques, the fact remains that color is still not popular. Much of this is due to a lack of familiarity with or a lack of confidence in the additional enhancement that color can provide. A lot is not understood in this domain about the need for accurate color and the required limits on accuracy and color information content necessary for accurate diagnosis. As “off the shelf” technologies continue to pervade this application and as physicians become more computer literate there is a danger in assuming that imaging technology will simply deliver the requisite color control without some deliberate management effort.

There are other complex issues. For example what are the clinical expectations in terms of accuracy, reliability and overall utility of telemedicine. What is the true medical effectiveness? Research is needed in these areas. Due to limited equipment and monetary resources, there is a true challenge to find the best choices in terms of equipment and services to provide a distributed healthcare network to meet the needs of the public at large. Cost efficiency is a driving factor and one serious limitation to greater acceptance of telemedicine technology is the fact that the Health Care Financing Administration (HCFA) does not authorize reimbursements for broad telemedicine services. HCFA is currently studying the value of telemedicine and their current policy[11].

Legal issues loom very large in this application from a number of perspectives. This includes malpractice liability incurred from the interpretation of an image of inadequate content. What is the minimal diagnostic resolution in terms of various image parameters and the resultant quality of those images to make the most accurate diagnosis? Without a standard or recommendation defining requisite quality of images, physicians may have less confidence in an imaging technique or continuously overspecify image content/resolution, unnecessarily driving up costs. The regulation of physician conduct and licensing is administered on a state level. If telemedicine is involved when a poor outcome results, does it constitute malpractice? If there is a breakdown in telemedicine delivery, who is ultimately responsible, physician or data access provider? From a social perspective, how does telemedicine need to be configured and administered to assure universal access to all while assuring that the human element of medicine is not lost in the wake of technological progress?

Conclusion

This paper has attempted to provide a brief overview of the many complex issues surrounding the role of effective color imaging as an integral part of telemedicine systems. A discussion of the emerging use of color in state-of the art color medical imaging techniques as well as a brief perspective of other contributing issues such as medical effectiveness, economics and legal concerns that are driving policy decisions in this area are intended to provide the necessary background for the imaging scientist to understand their emerging role as a significant technical contributor. Imaging professionals should begin to realize the application of their expertise can indeed play an important role: impacting the quality of healthcare by designing, defining, and improving economic color-based telemedicine systems.

Telemedicine employs a wide array of technologies to meet the rigorous demands of numerous clinical applications. Its effectiveness has been demonstrated on a wide variety of scales and it is likely to have significant, beneficial, long-term as well as short-term effects on the delivery of healthcare on a wide, cost-effective basis. For example, telemedicine can help to reduce the costs and increase the quality of patient care in underserved areas such as rural and poor communities. The interest in and demands for telemedicine as a new facet of many other medical practices such as emergency medicine, general medicine, and cardiology, to name but a few, is on the rise. This brings a host of technical challenges into the telemedicine arena.

Color is important because it affects both the acceptance and utilization of telemedicine. This will directly and significantly impact the quality of healthcare. However, these changes will not happen overnight. To help facilitate the success of color in telemedicine, imaging professionals can aid in the standardization efforts for color image capture, video transmission, playback, and archiving. In addition, concerted efforts should be made to integrate such standardized color utility into the medical education community such as in virtual reality surgery simulators used in training. Currently, the effective utility of color imaging is not stressed during physician education. Therefore, the current generation of practitioners in the diagnostic medical imaging community believe color is of little intrinsic value. Realistically, it will take years for this branch of medical practice to fully embrace standardized color as a diagnostic dimension. However, real-time video surgery and teleconferencing applications are an ideal starting point to employ sound color methods that will gain the faith and trust of physicians. Through consistent, accurate, high quality color images and data representation. Teaching the power of color as an essential diagnostic dimension of medical images and a contributing factor to effective diagnosis will help sustain color-based imaging modalities and drive continued technical improvement.

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