Color Imaging in Endoscopy
Perspectives and New Directions

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Abstract

The authors discuss new methods and tools developed to implement quality color rendition into endoscopic video systems. Limitations of currently used fiber optic and CCD color technology as implemented in conjunction with state-of-the-art video endoscopy equipment will be reviewed. A perspective will be provided on pertinent color and appearance attributes as well as the evolving needs and expectations of the clinical domain.

Introduction

Spiraling costs have led to recent critical review of preventative healthcare practices and to scrutiny of the cost-effectiveness of diagnostic and treatment procedures used by the healthcare community. Endoscopy offers a minimally invasive approach to more precise diagnosis and treatment of numerous conditions throughout the human body, including the gastrointestinal, respiratory, auditory and musculoskeletal systems, to name just a few.[1] In particular, with colorectal cancer as the second leading cause of cancer deaths in the United States, the use of gastrointestinal endoscopy as both a diagnostic and therapeutic tool is increasing. The ability to directly visualize the gastrointestinal tract using real-time color imagery permits examination and treatment of high-risk cancer sites, without major surgery or additional costly procedures. The ramifications of this both in terms of healthcare dollars and patient well-being means that continuous improvement is warranted. As a result, it has been the focus of much clinical as well as technical research and development.

Physicians' diagnosis and treatment decisions are based on what is observed through the endoscope. The level of these decisions is such that image quality, particularly color quality, is of growing concern. There are other salient issues to bear in mind. Consider that these still and moving images upon capture must be recorded, replayed, relayed in real-time to remote sites and economically archived. Such multimedia capability has far reaching potential to revolutionize the documentation of patient records, physician consultation, and in the teaching and continuing education of physicians and other clinical personnel.

Basics of Endoscopic Systems

Endoscopes have evolved significantly since their inception in the early 1800's with the first video endoscope (VE) system being introduced in 1983. Soon after, there was documented concern over the VE system's ability to faithfully reproduce colors[2]. After all, what is accurate? It is difficult to know for certain the actual color appearance of the interior of the body. The only method by which most physicians have received a direct view of various body systems is through invasive surgery, however, disruption of blood flow and exposure to air can cause marked changes in the appearance of tissue and organ systems. There are also variations in surgical environments (e.g. lighting) that influence perception.

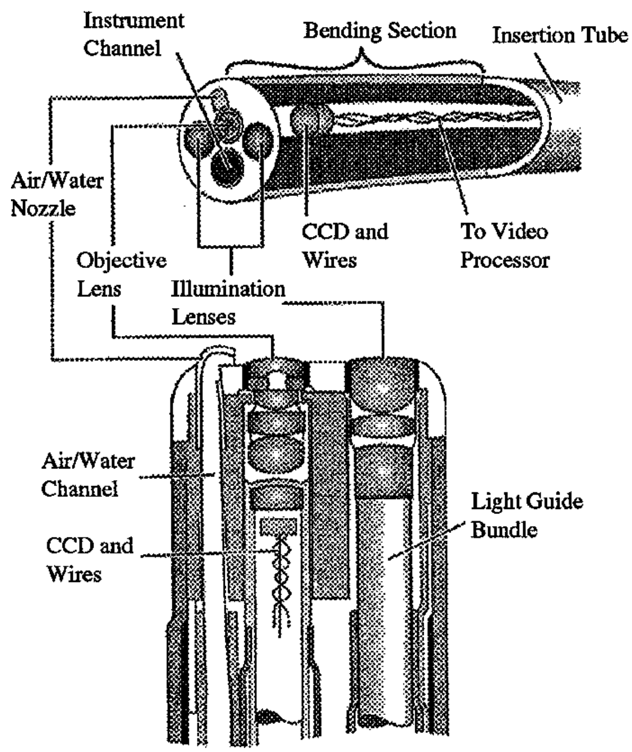

Figure 1. Cutaway and cross-sectional views of the distal tip of a typical direct video colonoscope

State-of-the-art video endoscopic systems combine medical instrumentation with electronic video equipment to form a highly specialized imaging system. In the most common technique, *direct* systems have an endoscope which incorporates an image sensing device in the tip, such as a CCD, and directly generates video signals.

Systems which utilize a camera at the eyepiece of the endoscope's handheld control thus generating electronic signals from an image returned through a fiber optic cable are referred to as *indirect*. The basic video principles of both are quite similar, however, this review will focus on the technology of direct systems. A diagram of a typical direct colonoscope is illustrated in Figure 1. Note that it is a highly sophisticated instrument which in addition to imaging and illumination capability incorporates means of facilitating instrument usage (e.g. biopsy) and insufflation/irrigation (injection of gas/water).

There are two types of CCD technology used in direct gastrointestinal endoscopic systems. Most systems utilize *RGB Sequencing*, incorporating a rotating color filter wheel comprised of Red, Green and Blue filters. The second technique utilizes *Mosaic Color Filtering*, in which a CCD array is augmented using an arrangement of color filter elements. In both systems, light reflected within the body utilizing a xenon illuminant is filtered, passed to the CCD array and then processed.

Despite the fact that most endoscopes are quite similar in design, there are a number of differences among various models in terms of their performance. The most obvious is the human factors of each – some systems are easier to use than others. The field of view of systems can differ markedly due to differences in the design of the optical assembly, and there are many other examples.

To meet a variety of clinical needs, video endoscopic systems are generally configured in one of three ways:

1. Basic live imaging system (no peripherals)
2. System 1 with documentation capability (VCR, video printer)
3. System 2 with additional computer capability (for data and schedule management)

Each system permits direct manipulation of some system controls, including monitor color settings. There are also limited manufacturer-specific calibration routines, however, in many clinical settings these are not followed.

Color Imaging and Domain Considerations

The primary thrust in medical video imaging technology advancements is focused on improved image and color quality. Overall, there are still questions about the minimum resolution requirements necessary for proper diagnosis. In terms of appearance, note that obtaining good color is not simply a reflective measurement problem. For example some portions of the gastrointestinal tract are translucent and thus transmit color of underlying structure. Vakil[3], et. al. have also cited the diagnostic importance of texture – realistic imagery and textural details such as tissue irregularity or mottled appearance. It is essential to distinguish observed normal color changes from a host of subtle color and textural variations that result from pathology beneath the organ surface such as increased blood flow or tumor growth. The transmission characteristics of the fiber optic bundles of the endoscope impart their own effects on the overall perceived image.

The design of fiber optic and lens assemblies cause significant attenuation of the illumination and changes in the overall spectral quality of the illuminant. Marked color shifts are common. Many physicians have been trained using more traditional fiber optic endoscope systems and (unfortunately or not) their interpretations and color preferences have been set using such a baseline. So much so that many practitioners will alter the appearance of their video-based devices to more closely conform to the results expected when using simpler fiber optic systems, which generally impart a yellow cast. However, individual color preferences vary widely, resulting in even greater differences in overall color rendition and appearance of endoscopic images. Today's VE systems permit users to directly manipulate device controls, including monitor color settings. This creates a very real problem when archiving images for use at a later time or by numerous practitioners since it is often impossible to separate preferential color variation from that of an underlying condition.

One of the first studies of the performance of color endoscopes by Knyrim, et. al.[4] (1987) describes marked variations in color reproduction capability of a number of direct VE systems, despite extensive set-up calibration provided by the manufacturers. Significant variations in hue, saturation, and grayscale reproduction of manufacturer-supplied color test charts are noted. In a 1992 study by Seidlitz, et. al.[5] a similar study was undertaken which demonstrated noticeable variation between (VE) systems' ability to render target levels of saturation, with no system able to accurately reproduce the saturation of all of the test gamut colors. In both studies, the acceptability or goodness of color rendition is primarily subjective. Chromaticity diagrams are used to illustrate the direction and magnitude of color shifts. In neither study is there a complete description of color measurement set-up, so its contribution to overall error is unknown. Inadequate system characterization and processor optimization are likely contributors but calibration and measurement related errors cannot be ruled out.

In a recent (1994) study[1], three VE systems were evaluated for both white-balance capability as well as reproduction of a number of Munsell sample chips of similar colors to those found in the body, namely reds (glossy) and skin tones (both glossy and matte). VE systems are generally sold as calibrated entities and do not provide the user with extensive means to effect continuous calibration. No attempt was made to characterize the individual peripherals within any system. The proprietary software used in each does not permit examination of color information as it is being processed. As a result, color reproduction capability was essentially a comparison of input samples to output display and among output displays.

White balance evaluation was, by necessity, somewhat qualitative. The white balance function of most VE systems is pre-set at the factory and cannot be adjusted by the user. To determine performance level, a Kodak 90% reflectance card was imaged and color output evaluated using a vectorscope, which is an instrument that demodulates the video signal, permitting evaluation of hue and saturation. One VE system exhibited a noticeable green tint that the manufacturer described as normal due to system enhancements which were designed to more faithfully render clinical colors. The other two systems showed reasonable white balance, one being the only system with user white balance control. An additional white balance procedure was repeated for this system using three samples from the Macbeth ColorChecker™ chart (yellow, sky blue and moderate red). A second vectorscope evaluation indicated effective compensation when "calibrating" using each of the chromatic test colors. In terms of color target reproduction, rendition was not noticeably poor, however, preliminary evaluation of the data indicates that none of the Munsell target colors were reproduced exactly in any of the systems and there were noticeable hue shifts in rendition of most of the color chips. As one would expect, each monitor had different maximum luminance capability, effecting the overall relative lightness of samples. The overall magnitude of differences between colors was generally discernible when viewed on each monitor but observed hue shifts varied depending on both the color being imaged and the endoscope/processor/ monitor combination being utilized. This is a new concern for the clinical engineer and practitioner, who take advantage of the physical interchangeability of system parts to better manage hospital testing facilities. It is also a clear indication of a need for better standardization.

In addition to these noted color rendering concerns there are other appearance related effects that have been considered. G*eometric (barrel) distortion* caused by the wide-angle lens of the endoscope is well documented and, in general, is not deemed troublesome by practitioners since most seem able to visually compensate. However, such distortions can contribute to miscalculation of the relative size of growths which can in turn impact clinical procedure time. The effect that this distortion has on uniform color rendering has not been formally studied to this point. Another effect, *motion blur*, results when movement occurs during the endoscopic procedure−most typically during irrigation. Water passing through the imaging area will often cause a rainbow-like distortion or streaking on the image, particularly in systems utilizing RGB Sequencing technology. This effect passes quickly but if it occurs during moments of still image capture, may require recapture of a higher quality image. The glossy interior of the body often contributes to *blooming*, which results when specularly reflected illuminant light floods a portion of the image area, resulting in white glare. A similar effect can also be observed in some systems when utilizing lasers during surgical procedures.

All of the aforementioned appearance effects, to one extent or another, are compensated for by the expert-user physician. There are still many questions regarding the interdependence of these effects and the overall impact that they have on system color performance.

The Future

What is tomorrow's role for video endoscopic technology and the related data and issues that it generates? There have been no documented cases of misdiagnosis due to poor image quality of endoscopic systems, however, this should not breed complacency. There have been anecdotal reports of prolonged, delayed and conversion to open surgical procedure due to a lack of system management and command of video imaging-related technology in the clinical setting. More consistent and accurate color rendition would permit the practitioner to exercise subjective color judgment exclusively for the diagnosis of disease rather than expending great effort compensating for device-related color artifacts. All of the systems in each of the aforementioned studies utilize proprietary image processing techniques and encoding schemes. It is a primary reason for the limited objective color performance evaluations to date. New technology on the horizon includes 3-D endoscopic video systems (using 2 CCD-arrays), which will lend additional capability and complexity.

As the use of VE systems continues to grow, there will be a need for education of appropriate healthcare personnel (e.g. clinical engineer, physician) regarding the importance of color attributes and their control in medical imaging. There is ongoing work to improve VE systems to address this and a host of other concerns. The desired interchangeability of system components and the overall multi-media nature of data capture, annotation, and archiving points to a very real need for standardization of equipment, procedures, terminology, and data encoding/decoding. The multimedia nature of VE systems lends itself to use of additional color imaging peripherals, such as printers, which also points to a need for imaging system component characterization, color data interchange and management. The authors are researching optimal methods and tools to accomplish consistent and acceptable color rendition with today's VE systems. In corroboration with clinical researchers, the authors are also investigating the clinical value and practicality of color-related standards for endoscopic imaging.

Information management and the flexibility and power that multimedia brings to the clinical setting also raises a host of different concerns. From a technical point of view, it is now possible to obtain extensive medical imaging information. How should such information be encoded, compressed, archived, and what is adequate? Too much? What is the ultimate diagnostic resolution? The electronic availability of such information raises numerous ethical questions, as well. With the ability to obtain and archive medical records electronically come new concerns about confidentiality of patient medical records. What level of information should be available and to whom? These are all questions that are being asked within the healthcare industry today and that imaging professionals should be poised to help answer. Readers are encouraged to communicate their experiences and concerns to the authors on these and related matters.

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