

Panoramic endoscopy

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ABSTRACT

The limited field of view available with conventional endoscopes has restricted the extent to which a full assessment of an abnormality and its anatomical relationship to surrounding structures may be made. The purpose of this research is to design a prototype system of a new endoscope that allows for an increased field of view to be obtained when compared to traditional endoscopes. The design of the system utilizes a panoramic annular lens (PAL) to obtain an image of the 360 degrees surrounding the optical axis of the lens. PALs have been characterized and evaluated on a larger scale in previous work performed in our laboratory. In the development of a prototype panoramic endoscope, research has been performed in the design of an optical train utilizing a miniaturized PAL and in its integration with fiber optics to obtain a panoramic view of the interior of a cylindrical pipe. The annular image obtained with this system has been linearized using customized software routines to obtain a more conventional view.

1.0 INTRODUCTION

Endoscopic exploration within the human body has had a substantial effect on improving diagnostics and the treatment of disease. This technology has allowed the physician to glance within the human body and observe its structure and function from without. The limited field of view available with conventional endoscopes, however, restricts the surgeons ability to evaluate an abnormality and its anatomical relationship to surrounding structures.

The orientation of the lens of conventional rigid endoscopes may be directed at an angle from the long axis of the telescope, ranging from 0 to 120 degrees, with a conical viewing field ranging from approximately 60 to 120 degrees. The fixed lens orientation requires rotation of the endoscope and multiple lenses to be employed during a procedure to obtain numerous spot views *in vivo*. This constraint often translates to increased procedure time, patient discomfort, and possible patient risk. Efforts to increase the field of view with flexible scopes require flexing of the scope tip within the restricted confines of the human body. This procedure, however, limits the visual capability of the flexible scope to spot views.

Current methods of documenting the endoscopists visual impressions include verbal descriptions, drawings, spot photographs, and videotape recordings. Many of these methods are subject to interpreter variability and lack in detail. Videotape recordings are most informative but require considerable review time and result in a bulky storage media.

A need exists to integrate conventional endoscopy with optics capable of permitting an increased field of view to be obtained with a large depth of focus, while minimizing the distortion of the image. The purpose of this research is to develop a prototype panoramic endoscope. The system utilizes a panoramic annular lens (PAL) to obtain an image of the 360 degrees surrounding the optical axis of the lens, in addition to a finite degree of simultaneous forward and retrograde viewing. Customized image processing routines allowing linearization and storage of the annular image are demonstrated.

2.0 SYSTEM DESIGN

2.1 Panoramic annular lens

The PAL is a single element lens with spherical surfaces that form an internal image of its surroundings. The virtual image formed within the PAL is transferred by a collector lens to a sensor array to capture the image. The depth of focus of a PAL extends from the surface of the lens out to infinity, thereby eliminating the need to focus. The image formed within the PAL is a two-dimensional representation of the three-dimensional surface. The result is a flat annular image of the entire 360 degrees surrounding the optical axis of the lens. The mapping of the annular image is unique. All parallel rays are focused to a single point, unlike the traditional perspective technique in which parallel lines with different directions are focused to different points on a line (the horizon).

The field of view available with the PAL along with the annular image produced by the lens is depicted in Figure 1. The angle α describes the region surrounding the optical axis of the lens that may be imaged. In this figure it is illustrated that the region available for viewing truly encompasses the 360 degrees surrounding the optical axis of the lens, in addition to some degree above and below the horizontal axis. The region defined by β is not used for viewing. In the design of the lens, it is desirable to maximize α and minimize β . The width of the annulus is directly related to the cylindrical field of view available. Each concentric ring in the image plane corresponds to a panoramic view recorded at a constant angle measured from the optical axis.¹ Note that since the central portion of the lens is not used to form the image, utilization of this region for special imaging or therapeutic purposes renders further possibilities.

Analytical and experimental work has been performed in previous investigations, sponsored by NASA, to demonstrate and evaluate the critical components of a PAL imaging system on a large scale (38 mm outer diameter lens size). These systems have been used to make holo-interferometric and speckle photographic recordings,² and the potential for profiling cavities using radial metrology has been demonstrated.³⁻⁵ Examination of the PAL images obtained from a large scale prototype showed satisfactory performance of the device for visual inspection. Evaluation of these prototypes revealed that they have a field of view that extends from approximately -20 degrees behind the lens to approximately 25 degrees in front of the lens ($\alpha = 45^\circ$, $\beta = 65^\circ$). It was observed in these studies that the large viewing angle, α , resulted in increased illumination required to capture the image with a CCD camera having a PAL/collector lens system compared to the same camera equipped with only a collector lens. Customized software, PAL^{view}, has been developed and subsequently refined to segment and linearize the image obtained through a PAL, resulting in a more conventional view.

2.2 Prototype panoramic endoscope

In the development of a prototype panoramic endoscope, a panoramic annular lens and a collector lens have been integrated with a fiber optic imaging bundle and a CCD camera to obtain a panoramic view of the interior of a cavity. The design of the optical train incorporates a 6.3 mm diameter PAL and a 6.25 mm achromat lens, having a focal length of 12.5 mm. The optics were packaged in an opaque acrylic mount and attached at the distal end of a 5 mm fiber optic imaging bundle as shown in Figure 2. A 38 mm lens was used to image the proximal end of the fiber bundle onto a CCD sensing array.

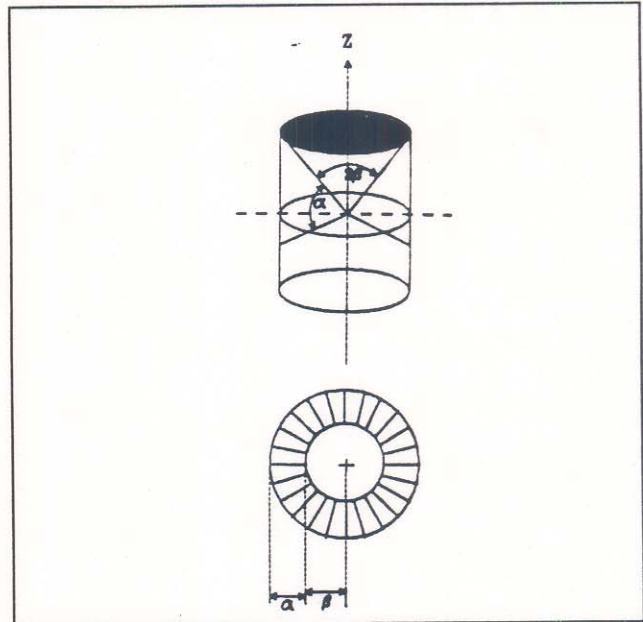


Figure 1. The relationship between the field of view of the PAL and the annular image.

To illustrate the annular image obtained with the probe, a pattern was wrapped about the circumference of a cylindrical pipe. The prototype was then positioned along the axis of the pipe and images were acquired. An external source of illumination was used. The probe, cylindrical pipe, and illumination source are depicted in Figure 3. The annular image obtained is shown in Figure 4. Software developed in our laboratory, PAL^{view}, was used to segment and linearize the annular image. The result of applying the linearization algorithm to one of the quadrants of the PAL image to obtain a more traditional view is illustrated in Figure 5.

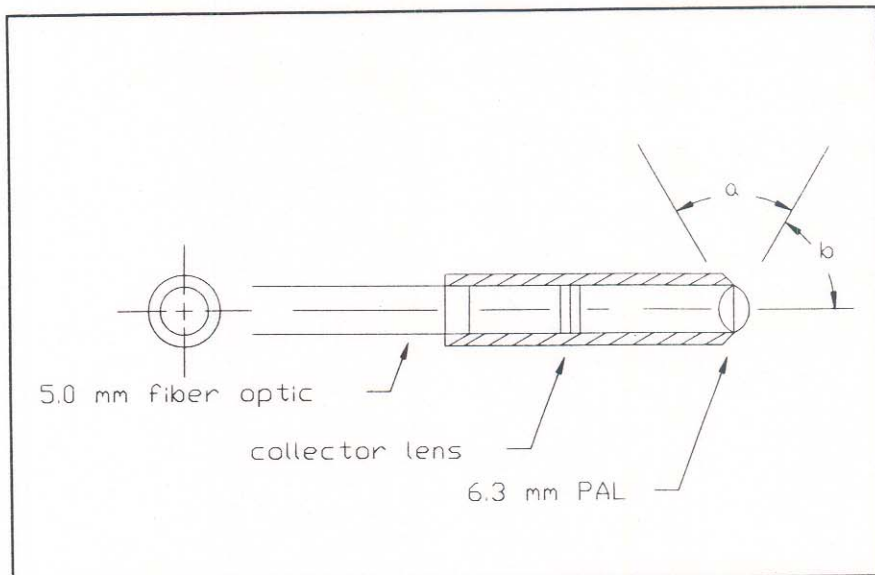


Figure 2. A schematic of the components of a prototype panoramic endoscope.

Several characteristics of the optical system and the resulting image were noted. The field of view available with this lens was found to be characterized by $\alpha = 90$ degrees and $\beta = 45$, as depicted in Figure 2. As in previous investigations, it was observed that the large viewing angle, α , coupled with the low transmissive properties of the PAL, resulted in increased illumination required to capture the image with a CCD camera having a PAL/collector lens system compared to the same camera equipped with only a collector lens.

3.0 DISCUSSION

As demonstrated in this study, inherent in a panoramic annular lens is the ability to view panoramically at an angle in the forward direction while simultaneously viewing at a posterior angle. Thus, a significant advantage of a panoramic endoscope is its ability to view many structures at multiple angles simultaneously. A panoramic endoscope has the potential to allow abnormalities and their relative position in a cavity or tubular structure to be determined. This advantage is a natural result of the increased field of view inherent in the proposed system and has important implications for cavity mapping such as bladder mapping.

A satisfactory image has been obtained with the prototype in this initial study suggesting to the investigators that the

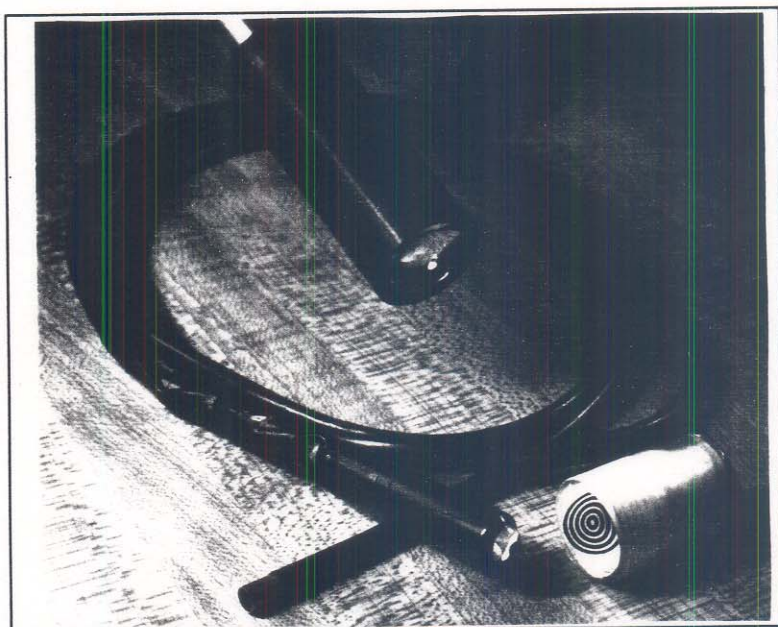


Figure 3. The probe positioned within a cylindrical pipe that is illuminated externally.

development of a panoramic endoscope is a viable objective. For successful application of a PAL for visual inspection, however, a detailed knowledge of its optical properties should be obtained. This research is planned for future investigations. The information will be acquired by using ray tracing techniques and the design parameters of the PAL. Since the characteristics of the sensing array are generally fixed, the only flexibility available to compensate for aberrations in the system occurs in the design of the collector lens. A standard lens design program will be used to determine suitable characteristics for a matching collector lens to optimize the overall performance of the system.

In addition to examining the optical characteristics of the lens system, several other considerations must be addressed in the next phase of this research to insure successful development of a panoramic endoscope. These areas include the illumination system and the image acquisition system. As illustrated in Figure 3, illumination by discrete external sources was not uniform about the circumference of the pipe. Characteristics including biocompatibility, sterilization, and the effects of employing the scope in an external media other than air also need to be addressed in the design.

4.0 CONCLUSIONS

The advantages of an increased field of view with a panoramic endoscope are harmonious with the needs of conventional endoscopy. In addition, the ability to view a large angular extent within a cavity, suggests the potential for a panoramic endoscope to be ideally developed as a global mapping system within the body. The ramifications of panoramic endoscopy are extensive, ranging from early diagnosis of cancer, improved understanding of pathological as well as biological processes, to the assessment of the local response to therapeutic treatment. Possible areas of utilization of this system may be extended to traditional engineering applications, ranging from the inspection of fuel lines in a rocket engine, potentially eliminating the need to break down the system, to the inspection of cooling lines in a nuclear power plant.

Combining a panoramic endoscope with conventional documentation scenarios, such as a video hardcopier, provides the surgeon with an extensive amount of information of the region of concern in one compact view. A hardcopy of the flat panoramic image could easily be interpreted by the physician and included in the patient's file. In addition, customized image processing routines could be used to produce a linearization of the annular image to facilitate viewing.

5.0 ACKNOWLEDGEMENTS

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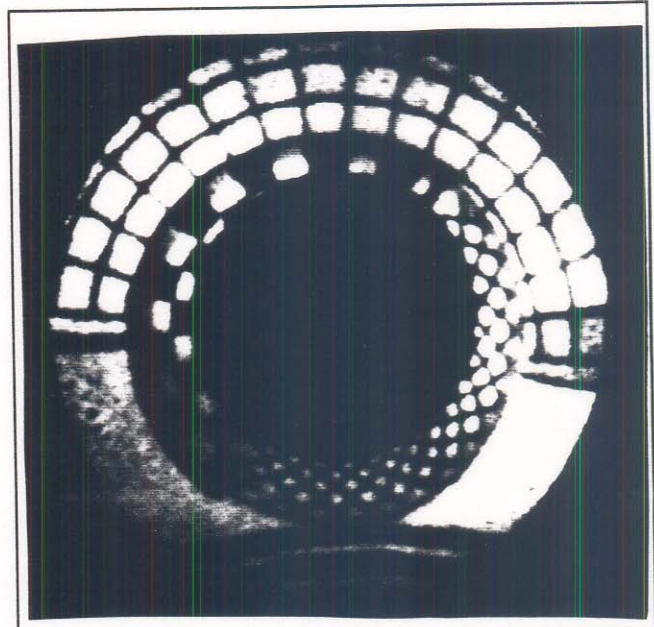


Figure 4. The annular image obtained when the prototype is positioned along the axis of a cylindrical pipe.

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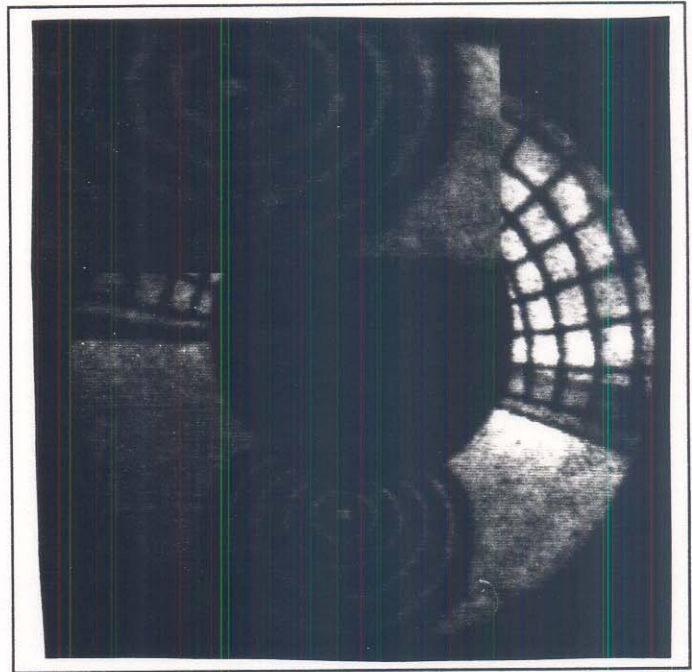


Figure 5. An annular image and a linearized view of a quadrant of the image.