Development of an Electro-Optic Scanner for Potential Endoscope Application

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Technological advancements in endoscopy design are in current development due to the increased demand for minimally invasive medical procedures. One such advancement is reducing the overall size of the endoscope system while maintaining the resolution and field-of-view (FOV). Reduction of size results in less tissue damage and trauma during operation as well as faster recovery times for patients. Additionally, areas that are inaccessible by today's endoscope designs will be possible to examine. Current endoscopes use either a bundle of optical fibers (optical waveguides) and/or one or more cameras having an array of detectors to capture an image. Thus, the diameter of these devices employed for remote imaging cannot be reduced to smaller than the image size. Even if one ignores additional optical fibers used for illumination of a region of interest, the scope diameter is therefore limited by the individual pixel size of a camera or by the diameter of optical fibers used to acquire the image. Therefore, it is apparent to achieve scopes with less than 3 mm overall diameter using current technologies, resolution and/or FOV must be sacrificed by having fewer pixel elements. All commercially available scopes suffer from this fundamental tradeoff between high image quality and small size. More recently, our research has been working on developing a 2-D electro-optic scanner potentially be implemented for clinical endoscopic imaging application. The proposed optical device has several unique advantages. Electro-optical scanning offers a sensitive, facile, accurate, and superb quality method to capture images of physical and biological tissues. In addition, the minute physical size of the imaging system has a much needed advantage over conventional imaging systems. The proposed design is based on the fact that the propagation direction of a light beam can be changed when the index of refraction of an electro-optic medium is altered by the application of an external electric field. The basic design of the system consists of a thin film electro-optic polymer waveguide with built-in cascaded prisms structure for horizontal beam deflection and an electro-optic grating structure for vertical beam deflection. The cascaded prisms are combined with the electro-optic polymer to create a voltage-controlled horizontal beam deflection. A grating coupler, a structure that is commonly used as light coupling device for dielectric waveguide, is combined with the EO polymer to create the vertical controlled beam deflection. A collimated light beam coupled into the waveguide by a mechanical coupler via an optical fiber cascaded down these two deflection stages. When the beam exits, the emitted light beam is displaced along two orthogonal directions in a raster pattern. A photodetector array integrated in the same substrate captured the reflected intensity. The scanned imaged is then analyzed and reconstruct based on the received signal.

Designing an Optical Bendloss Sensor for Clinical ForcMeasurement

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For many clinicians, their effectiveness is dependent on the force they manually apply to their patients. However, current care strategies lack quantitative feedback making it difficult to provide consistent care over time and among several clinicians. We have developed a disposable force-sensing glove that provides real-time quantitative feedback in the clinical setting. To minimally affect a clinician's function, obtain maximal signal to noise in a medical environment, and maintain patient safety, a fiber optic sensor has been developed for this application. A disposable nitrile glove with embedded fiber optic force sensor has been developed and initially tested for clinical efficacy. The sensor's design is based on the bendloss properties of optical fiber whereby the attenuation of light through a fiber is related to the bending of that fiber through a series of corrugated teeth. The sensor is fabricated in two parts, sandwiching the fiber between alternating teeth. When force is applied across the sensor, the teeth engage the fiber and bend it along an elastic, repeating profile. the specific light attenuation is dependent on the amount of bending that the fiber experiences between the teeth and can be used to measure the load applied to the sensor. Fabricated at $10\times 8\times 1$ mm, the sensor achieves an appropriate clinical thickness and minimally affects normal clinical thickness and minimally affects normal clinical function. It provides real-time force feedback up to 90 lbs with 0.1 lb resolution. The sensitivity of the sensor follows an exponential relationship with strong agreement to theoretical calculations. Because the calibration curve is non-linear, the sensor is most sensitive at low forces allowing detection of extremely delicate forces such as the pulse from the carotid artery. Each glove is fabricated with a single sensor embedded in the fingertip or palm and a magnetic connector couples the glove with a non-disposable wrist cuff. The wrist cuff houses the power supply, light source, and photodetectors. The fibers are nonpermanently coupled to their respective sources and detectors completing the optical path from source, through the fiber and sensor, to the detector. The light intensity is then transmitted to the display module which calibrates and displays the force graphically in real-time. The display module records, summarizes, and stores the data from each clinical session allowing clinicians to collaborate on treatment protocols and provide consistent care over time. Initial results from current clinical trials with physical therapists at the University of Minnesota have indicated improved recovery time after surgery. Twenty-four ACL reconstruction patients have been monitored post-operation for five weeks and the experimental group treated with the glove has demonstrated significantly faster recovery to normal range of motion than the control group. It has been suggested that the quantification of patient evaluation allowed the clinicians to recommend adjustments to at-home stretching regimens, contributing to faster healing times. Similar clinical studies are planned for chiropractic care and other physical therapy procedures. This fiberoptic force sensing glove represents a new biomedical tool which can impact patient evaluation and care by providing clinicians with a quantified sense of touch.

