Optical Fibers on Medical Instrumentation:
A Review

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ABSTRACT

This paper provides a revision with the state-of-the-art related to the use of optical fiber sensors on medical instrumentation. Two types of optical fiber sensors are the focus of review: conventional optical fibers for communications and fiber Bragg gratings (FBGs).

Keywords: Communications, Conventional Optical Fibers, Fiber Bragg Gratings (FBGs), Medical Instrumentation, Optical Fiber Sensors

INTRODUCTION

It is not new that since 1970 after the proof of concept on using optical fibers for communications with acceptable losses (Keiser, 2011), the span of their use on other fields of science and common life didn't cease to occur (Bertrand *et al.,* 1996; Murtaza *et al.,* 1993; Khorsandi *et al*, 2012). The intrinsic nature on using light makes these components extremely reliable, even on automotive (Silva *et al.,* 2010) or within harsh environments (Silva *et al.,* 2011a). More recently, the use of optical fibers as sensing elements resulted on new and interesting applications (Rocha *et al.,* 2014). This is even more evident when looking the fact the optics being used trough the history on sensors (Yang *et al.,* 2012), light sources (Fang *et al.,* 2013), actuators (Zebentout *et al.,* 2013), displays (Cho *et al.,* 2013) and so on. Optical fibers ave proven to be very attractive for medical applications, due to their general characteristics, such as: reduced dimensions, reduced weight, chemical inertness and low loss (Baldini & Mignani, 2002). In the specific context of sensors, a wide variety of optical fiber sensors are available and can be divided into three categories: the external or extrinsic ones (Beard *et al.,* 1996) where the fiber simply drives the measured information to and from the transducer at a distant location, the intrinsic category (Boerkamp *et al.,* 2007) where the optical properties are sensitive to a given external stimulus (Grattan *et al.,* 2009; Gu *et al.,* 2006), and the hybrid category where the light is transferred over the optical fiber for conversion into electricity on a distant optical receiver (Yao *et al.,* 2003). Taking these ideas into account, the focus of this paper is the

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making of the review with the state-of-the art using optical fibers as sensing elements on medical instruments. The optical fiber types considered in this paper are the following: conventional optical fibers and fiber Bragg gratings (FBGs).

CONVENTIONAL OPTICAL FIBER SENSORS

Technology

An optical fiber by itself is not a sensor. A set of complementary technologies must be used in conjunction with optical fibers. Excluding few applications (Bilro *et al.,* 2011; Correia *et al.,* 2013; Morim, 2008) that belong to the category of intrinsic sensors, the optical fibers are often used exclusively as auxiliary elements for providing/collecting light into/from direct-in-contact sensorial structures (e.g., belonging to the extrinsic category). The optical detection can be provided by two ways: by direct transmission with an optical source aligned on a given extremity and the optical detector on the other extremity; and by reflection, with both the optical source and detectors are in the same extremity of the optical fiber. In this second approach, an optical circulator must be used to separate the generated and reflected optical beam into/from the optical source. The Figure 1 illustrates these two approaches. In the example (a), the light attenuates along the optical fiber, whereas in the example (b), the optical fiber is used as a simple light conduction element.

Curvature

It is a well known fact that the variation on the fiber's radius of curvature R result on losses L variation. Therefore, it is possible to establish a relation between the light intensity on an optical detector I_{RX} and its initial value in the optical source location I_{TX}. There are available an extensive number of works (both theoretical, empirical and combinations of them) with studies presenting closed form equations and charts, showing how the radius of curvature R affects the loss L. Few closed forms and charts can be found in the papers published by (Schermer *et al.,* 2007; Zendehnam *et al.,* 2010).

An interesting application of this concept is in the respiratory frequency measurement (Correia *et al.,* 2013; Morim, 2008). In fact, the thoracic expansion on a respiratory cycle can be

Figure 1. Concept illustration behind the (a) direct and (b) reflect detection