Sensors and Actuators A 247 (2016) 98–104

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

Tactile sensing for object identification based on hetero-core fiber optics

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ARTICLE INFO

Article history:
Received 15 February 2016
Received in revised form 12 May 2016
Accepted 29 May 2016
Available online 31 May 2016

Keywords:
Object identification
Optical fiber sensor
Hetero-core
Tactile sensor
Surface features detection
Physical characteristics detection

ABSTRACT

This paper describes a human-like tactile sensing method for object identification using a tactile sensor based on hetero-core fiber optics. The sensor performs for detecting tactile information in such ways both of gentle and heavy touch with the contact force applied ranging from 0.0 N to 5.3 N. The proposed method for object identification is intended to measure several types of tactile impressions such as surface features and physical characteristics in both scanning and pushing motions. It is found that the fabricated tactile sensor can detect surface features such as arranged bump dots and two types of textured fabrics by the sensor scanning on the surface. Moreover, it is confirmed that the sensor can measure the physical characteristics of touched materials, including the hardness in the range from 5° to 80° according to the Shore hardness A scale, as well as viscoelastic properties by assessing the temporal variation of the sensor response during stress relaxation.

1. Introduction

Human tactile sensing plays an important role for human-object interaction as one of the five fundamental senses. Tactile sensing receptors distributed on human skin can measure various features of touched objects, including magnitude of applied force, shape, texture, slip, and temperature. The tactile sense of fingertips is considerably more sensitive than other parts of body and thus useful for precisely identifying or manipulating objects [1]. Due to the versatility of the tactile sense, artificial techniques for imitating tactile functions have attracted attention among many robotic developers, and therefore have been developed into a sophisticated technology over the past four decades [2].

In recent years, tactile sensing technology has been introduced into complex applications such as humanoid robotics and biomedical usages with advanced robotics technology being developed, so that the requirements for the tactile sensing also becomes complicated in such applications [2].

Tactile sensors, for instance, help humanoid robots interpret objects around them via physical contact similar to human behavior. Unlike industrial use robots, humanoid robots are required in some cases to collaborate with humans in more complicated environments, where the body surface of robots containing tactile sensors may be subjected to temperature fluctuation, static electricity, sudden impact forces upon them. Therefore, tactile sensor elements should be robust to various disturbances [3].

Recent advances in robotic technology made available minimally invasive robotic surgery (MIRS) in practical use [4]. MIRS is a form of surgery intended to minimize the incision size (about 1 cm) on the body surface for reducing trauma, pain, and blood loss to patients, with providing higher precision and accuracy in repetitive motions compared to human surgeon [5]. There may be a problem that limited perceptions in indirect visual and tactile information will cause misrecognition of the position and depth of a target in body, hence the feedback systems for a surgeon should preferably be as detailed as human perception. As a tactile feedback system, compact tactile sensors should be applied to laparoscopic instruments, with having a good tolerance to blood invasion and unwanted mechanical stress [6]. Sadovnichy et al. [7,8] have developed a tactile sensor for intraoperative detection, which consists of 19 pressure sensors located at the end of a 10 mm diameter probe. The device measures pressure distribution applied by contacting tissues, moreover have practically proved its usability for measuring in-vivo tactile information. A tactile feedback system can be combined with magnetic resonance imaging techniques which are

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http://dx.doi.org/10.1016/j.sna.2016.05.032

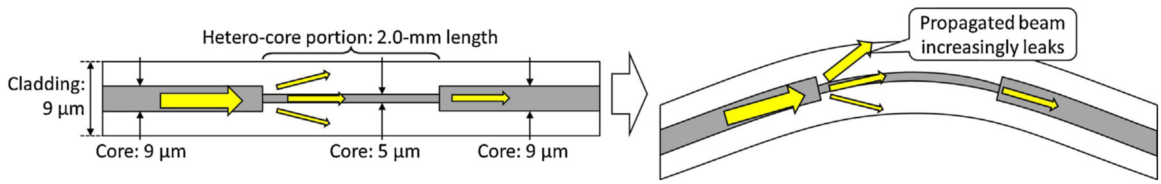

Fig. 1. Schematic view of a hetero-core fiber optic sensor being sensitive to gentle bending curvature at a hetero-core portion.

suitable for intraoperative image guidance, as the tactile feedback system is unaffected by magnetic field.

Conventional tactile sensors were developed based on resistive, capacitive, and piezoelectric sensing techniques, although these electrical techniques have some inherent issues because of temperature fluctuation, electro-magnetic interference and cross-talk effect caused by integrated wiring [9].

In contrast to such conventional ways of electrical sensing techniques, fiber optic sensors [4,5,10–19] for tactile sensing have been previously proposed as alternative methods because of the immunity to electro-magnetic interference, and their physical merits such as lightweight, thin size, and flexibility. In particular, fiber Bragg gratings (FBGs)-based strain sensors were often applied as tactile sensors [13–18]. FBG sensors measure longitudinal strain caused by physical contact on the glass fibers by observing resonant optical wavelength shifts, although they have to be temperature compensated.

Hetero-core fiber optic sensors have been developed as a breakthrough approach of fiber optic sensing with some attractive advantages including their high sensitivity to soft bending on a sensor portion, no need of temperature compensation, and the cost effective scheme [20]. In our studies [21–24], many applications have been so far proposed as practical pressure sensors.

In our previous works, a tactile sensor has been produced using a hetero-core fiber technique [25,26]. This tactile sensor is compact and facilitates integration into artificial fingertips or laparoscopic instruments. The report [25] described that the tactile sensor preliminarily can detect force and texture conditions, with an applied force ranging from 0.0 to 5.0 N, and a surface roughness height as large as 0.1 mm. It was also discussed in our work [26] that the sensor is able to detect surface roughness height ranging from 10 to 100 μm, and additionally was tried to obtain the hardness and viscoelastic nature for various touched objects.

In this study, an object identification method has been proposed in a way of human fingertip motions by introducing various experimental conditions and by more quantitative discussions. Object information can be classified into surface features and physical characteristics such as the hardness and viscoelastic properties, those of which are detected by means of scanning motion and pushing motion, respectively. From an experiment for surface feature detection, the contact sensitivity of the tactile sensor was found to be higher at the center of the sensor head, whereas reduced at the edges of the head but still sufficient to detect surface condition. Furthermore it can be also seen that the surface features of fabrics such as periodic patterns can be estimated from the changes in the optical loss. Another experiment for physical characteristic detection shows that the changes in the optical loss for the tactile sensor when pushing into materials can be used to extract tactile information of the hardness and viscoelastic properties of the materials.

2. A hetero-core tactile sensor

2.1. Structure of a hetero-core tactile sensor head

A hetero-core fiber optic tactile sensor contains a hetero-core fiber optic sensor, as discussed in [25] As illustrated in Fig. 1, the hetero-core fiber optic sensor consists of a single mode transmission fiber with a core diameter of 9 μm, and a hetero-core portion with a core diameter of 5 μm and with a length of 2.0 mm. The single mode transmission fiber was once cleaved so that the hetero-core portion can be inserted in the transmission fiber by fusion splicing by means of an automatic fusion splicer (FSM–100 M, Fujikura Ltd.). The 5-μm-core fiber was then fusion spliced to the end of 9-μm fiber and cleaved with leaving a length of 2 mm that is connected to another 9-μm transmission line. At boundaries between the transmission fiber and the hetero-core portion, propagating beam partially leaks into the cladding layer with the optical loss monotonically increasing with bending action around the hetero-core portion.

The hetero-core fiber optic sensor is housed in a tactile sensor head with dimensions of 5.0 mm × 5.0 mm × 3.6 mm, as shown in Fig. 2(a). Variation of the optical loss in the hetero-core fiber optic sensor is monitored using a photodiode (PD) and a light-emitting diode (LED) with the output wavelength of 1.31 μm coupled into the transmission line leading to the sensor. As illustrated in Fig. 2(b), a half-column plastic piece covers the hetero-core sensing region by means of three silicone rubber spacing segments placed on a flexible plastic film. The hetero-core portion is bent following a physical distortion of the plastic film which occurs via the off-line configuration of the three rubber spacers when the plastic column contacts an object. In this manner, the tactile sensor head measures the contact force from the optical loss response of the hetero-core fiber caused by the distortion of the plastic film.

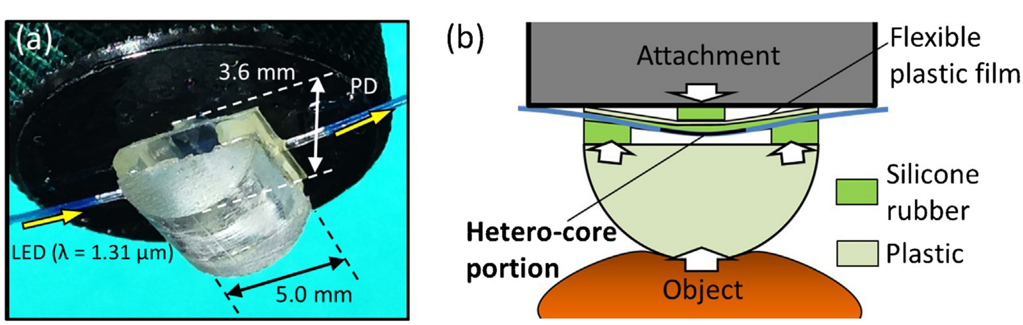

Fig. 2. (a) Appearance view of a hetero-core fiber optic tactile sensor head and (b) the mechanism of contact force detection.