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Real-time measurement of multipoint hetero-core fiber optic binary sensors based on optical pulse loss change

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ABSTRACT

Hetero-core fiber optic sensors can transmit sensing and communication signals on a single fiber optic transmission line and have numerous advantages for environmental information monitoring such as home security. Moreover, these sensors are cost effective due to their temperature independence and light-intensity-based measurements. We have previously developed a hetero-core fiber optic binary sensor that can be connected in series to detect the number of doors and windows that are opened or closed. In this paper, we propose an improved method for using hetero-core fiber optic binary sensors that are connected in series, which are referred to as binary switches. A unique pulse loss change enables the states of the connected switches to be identified. As a result, the total optical loss in the transmission line is reduced. Therefore, the number of binary switches connected in series can be increased on a single transmission line. The unique pulse loss peaks can be controlled by the action of a flat spring and by adjusting the position of the flat spring inside the binary switch module. Typical pulse peaks of each binary switch are from 0.13 to 0.75 dB in the positive direction and from −0.47 to −0.03 dB in the negative direction, while the typical insertion loss is from 2.23 to 2.61 dB, depending on the position of the hetero-core segment within the binary switch module. The connection of two binary switches in series is successfully demonstrated for monitoring the optical loss change on a single transmission line. The results of the present study show that the number of binary switches connected in series can be increased significantly on a single transmission line.

1. Introduction

Recently, the demand for security and monitoring systems for elderly individuals who require care has increased as the number of crimes involving private homes and elderly people living alone has increased. These systems can obtain information on the presence of individuals, for example, by monitoring the opening and closing of doors and windows to track the entering and leaving of rooms in the intelligent environment. Conventional monitoring systems that employ electromagnetic devices include cameras and proximity sensors. However, cameras can evoke feelings of discomfort from those being monitored, and proximity sensors tend to be adversely affected by electromagnetic interference. Therefore, such conventional monitoring systems are problematic for private spaces, hospitals and nursing homes. In such cases, multipoint sensors without cameras that have electromagnetic induction resistance are desirable alternatives.

Fiber optic sensors have several advantageous characteristics, such as electromagnetic induction resistance and ease of use under adverse environmental conditions. In addition, the sensors are flexible and light weight. Fiber optic sensors have been adopted as structural health monitoring systems [1,2]; in particular, fiber Bragg grating (FBG) sensors [1–5] have been extensively developed to detect minute strain by measuring wavelength shifts with a diffraction grating in the core of an optical fiber. FBG sensors have the ability to be connected in series on a single transmission line using wavelength division multiplexing [4]. However, FBG sensors have shortcomings such as temperature dependence [5]. As a result, their cost effectiveness is limited by the need to compensate for temperature fluctuation.

Multipoint sensing schemes based on optical intensity measurements with an optical time domain reflectometer (OTDR) or Brillouin optical time domain reflectometer (BOTDR) have also been proposed [6,7]. OTDR requires several minutes to determine the optical loss by integrating the strength of the returning pulses as a function of time, because OTDR measure weak backward Rayleigh scattering. Although BOTDR has better distance resolution than OTDR (a few centimeters versus a few meters, respectively), BOTDR is affected by the temperature dependence of Brillouin scattering.

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Consequently, a new multipoint sensing scheme using transmitted light is required.

In contrast of conventional fiber sensors, the hetero-core fiber optic sensors [8–11] that we have developed, which measure optical loss caused by bending of their hetero-core segments, have several advantages. The first is temperature independence [8], and the second is cost effectiveness due to their simple fabrication and light-intensity-based measurements. Using this hetero-core fiber optic sensor, we have developed a strain sensor [9] and a wearable motion capture sensor [10] for use in smart structures. A multipoint sensing scheme with hetero-core fiber optic sensors that use OTDR has also been proposed [9]. However, to conduct multipoint measurements in real time on the order of a few tens of hertz, a sensing scheme that measures transmitted intensity without time averaging is necessary. Focusing on the time differentiation in the optical loss of the hetero-core fiber sensors, a multipoint sensing scheme has been proposed that identifies the sensors connected on a single fiber transmission line [11]. In this method, however, the optical loss from the working sensors on the transmission line accumulates, and thus the number of the sensors connected in series on a single transmission line is limited to the detectable range of the measuring instruments for optical loss.

In this report, we propose an improved method for measuring the pulse loss change of hetero-core fiber optic sensors connected in series, which restricts the sensor information to binary form, for example, whether doors and windows are opened or closed. A unique optical loss peak enables the connected sensors system to identify the states of the sensor without accumulating optical loss, and as a result, the total optical loss in the transmission line is reduced. As a result, this allows the number of sensor connected in series to be increased on a single transmission line. This sensor can detect whether a button is pushed (ON) or released (OFF) by measuring optical loss. Thus, we can regard this binary sensor as an optical binary switch. We tested the improved method to adjust the sensitivity of the hetero-core fiber optic binary sensors in multipoint sensing, and demonstrated two binary sensors connected in series on a single transmission line. This work presents the concept that the monitoring system for security to break-in through the doors and windows in home could be constructed by means of hetero-core fiber optic sensors in series and a single transmission fiber line, which is used for the internet communication, in real-time such as a few tens Hz.

2. Binary switch module

2.1. Hetero-core fiber optic sensor

Fig. 1 shows the internal structure of the hetero-core fiber optic sensor and the newly developed binary switch module. The hetero-core fiber optic switch consists of an optical fiber transmission line and an inserted hetero-core segment with a length as short as a few millimeters that was inserted by fusion splicing. The fiber transmission line and the inserted fiber have core diameters of 9 μm and 5 μm, respectively, as shown in Fig. 1. The length of the inserted fiber used in the present experiment is approximately 1–2 mm. The transmitted light is lost as leakage due to the different core sizes. At the spliced interface between fibers with different core diameters, transmitted beam partially leaks into the cladding layer. The bending curvature, whose radius is in the range of several 10 cm to 10 mm, changes the angle of spliced interface, as a result, induces the light leakage and radiation loss at the fiber with the core of 5 μm in diameter due to the smaller core diameter than the transmission fiber line.

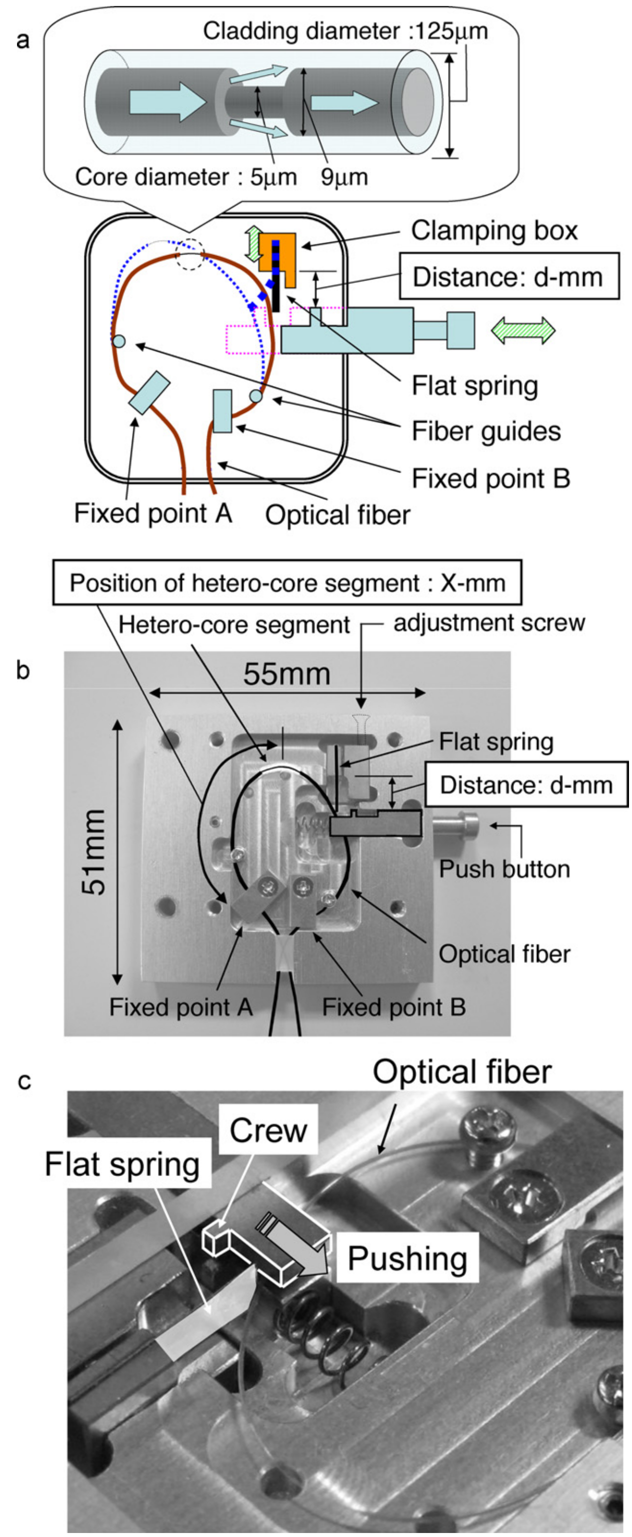

Fig. 1. Hetero-core fiber optic binary sensor; (a) schematics of sensor module and optical fiber; (b) photographs of sensor module and (c) an oblique perspective view of the arrangement of the flat spring, crew and fiber line.

In our previous work, it was found that the optical loss of the hetero-core fiber optic sensing element increases monotonically as the hetero-core segment was bent. Inserting the hetero-core segment into the transmission line decreases the overall signal by less than 1 dB when unbent, which is an extremely small loss.