A Temperature Compensated Optical Fibre Bending Sensor for Physiological Measurement

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ABSTRACT

The light attenuation measurement of a plastic optical fibre sensor based on a referenced intensity modulation technique with respect to different input voltage level and room temperature has been investigated. The results show that light attenuation at the sensor output and reference output are dependent on the source (LED) drive current and temperature, but the output ratio is small and tolerable for this application. This is significant for bending monitoring applications using optical fibre sensor based on intensity modulation, providing a more reliable technique based on power and temperature compensation.

Keywords: Optical fibre bending sensor, divided beam intensity referencing, temperature compensation

1. INTRODUCTION

In the application of spine bending assessment, three different types of sensors have been implemented, namely hand-held, non-contact and skin-mounted devices. Some practical device examples for hand-held devices are flexible ruler, tape measures, goniometer and spinal mouse. Although these types of devices are easy to handle and low in cost, continuous monitoring of the human spine movement seems to be unrealistic using this method. For non-contact devices, measurement is achieved using a set of components being located at a distance away from the human body such as detectors with good spatial resolution e.g., CCD camera, rasterstereography and digital video fluoroscopy. These methods have high accuracy in reading, but the systems are relatively high in cost, require a special room to operate effectively and continuous measurement could lead to a complex software and hardware integration. Moreover, there is a potential risk and side effect associated with the excessive radiation exposure on human skin in the case of fluoroscopy.

To practically provide a reliable device for spine bending assessment over a period of time suitable for clinical assessment, the skin-mounted type is considered to be a good candidate. Some examples of the skin-mounted devices designed for human spine monitoring are based on the use of ultrasonic sensor, electromagnetic sensor and optical fibre sensor. In the case of the ultrasonic-based and electromagnetic-based bending sensor, the transmitter and the receiver are placed directly along the spinal column and mounted on the human back. As the components for the transmitter and/or the receiver are relatively bulky in size, the movement of the patient under study becomes disrupted and so affects the natural bending of the spine.

In the case of optical fibre sensor, the physical diameter of a fibre varies between $37 \mu m$ and $0.98 \ mm$ depending on the fibre being used. Due to the small size of the fibre, it is possible to develop a sensor which is lightweight and more comfortable for patients to wear. An additional advantage is, as the optical fibre sensor detection scheme is based on the modulation of the lightwave properties such as intensity, wavelength and frequency (time), it is immune to external electromagnetic interference. This characteristic is important such that it makes the optical fibre sensor suitable for magnetic resonance imaging (MRI) environment. The sensor of this investigation is based on a $1 \ mm$ diameter plastic optical fibre whose diameter including the protective jacket is $2.5 \ mm$.

1.1 Bending measurement using optical fibre sensor

The use of optical fibre sensors for bending application based on wavelength modulation technique have been reported, e.g. using long period fibre grating, tilted fibre Bragg grating and special optical fibre. However, these approaches require special interrogation instruments to measure the wavelength shift, e.g. optical spectrum analyzer.

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The compensated intensity modulation technique using optical fibre provides a low cost clinical alternative to these more expensive methods. To increase the sensitivity of the fibre, the fibre needs to be modified accordingly. For example, in the study of Tseng et al.,\textsuperscript{10} the fibre was placed on a V-groove for mechanical support before manually side polished to increase the sensitivity of the fibre to detect curvature. Another way to apply plastic optical fibre for bending application was to use a tooth-like fibre side called ‘sensitive zone’ at several segments along the fibre cable\textsuperscript{11}. The bending sensitivity of the fiber was theoretically estimated from the angle and height of the teeth. Besides that, there has also been a technique to remove small segments of the fibre at a predetermined length and depth manually using a razor blade\textsuperscript{12}. In these areas along the fibre, the intensity of the output signal changes according to the magnitude and direction of the fibre bending. This technique has been implemented as a wearable sensor to monitor human body posture\textsuperscript{13}.

However, the inherent problem associated with intensity modulation techniques for optical fibre sensors is that several factors can alter the output light intensity level. Any disturbances at the optical fibre cable such as unwanted fibre bending, the gap between the fibre cable end tips and the light source as well as an external light coupling via the polished area can lead to a significant difference of the light intensity, rendering a drift in the bending measurement. In addition, there is also a potential fluctuation of the light intensity of the source due to surrounding temperature\textsuperscript{14}, inconsistent forward current and performance degradation over time\textsuperscript{15}.

2. SENSOR CONFIGURATION FOR THIS INVESTIGATION

2.1 Compensation method for intensity modulation.

In order to neutralize the drift and fluctuation effects on the output measurement of the intensity modulated sensor, a compensation approach has been adopted into the bending sensor of this investigation. Several possible approaches have been previously investigated for various applications using optical fibre sensor\textsuperscript{16} including twin receiving fibres (transmission and reflective modes), twin reflective mode, 2D reflective sensing probe and dual wavelength input fibre. Among the compensation types mentioned above, it has been experimentally established that the most suitable option for the sensor of this investigation is the dual wavelength input fibre. However, as the minimum available size of the beam splitter currently on the market is 12.7 mm in diameter (e.g. Dichroic mirror and visible splitter, Thorslab), the overall size of the sensor would be too thick and it becomes rigid for bending movement. Therefore, a different configuration has been implemented by using an aluminum film to provide a reflective surface intended for referencing signal\textsuperscript{17}.

2.2 Optical fibre bending sensor based on fibre tilt angle loss measurement

The sensor configuration of this investigation comprises two light transmitting modules, namely the source with reference fibres in one part and the active sensor fibre in the second part. Both fibres were inserted separately in two modified PTFE rods of 2 cm length. A small piece silver mylar tape with a centered hole of 1 mm in diameter was attached to the end of the source/reference part as shown in figure 1. On the second part, the PTFE rod end tip was tapered so that a small portion of this rod can fit into the hole in the first rod. Both first and second parts were bound to each other using a silicone rubber tube (inner diameter of 5 mm). The angle of the sensor is measured and cross-checked against a conventional goniometer (Prestige Medical) whose accuracy is limited to 1° as presented in previous publication\textsuperscript{16}. Therefore, all measurements value in this investigation are limited to this value.

![Figure 1. Illustration of optical fibre bending sensor under investigation.](image)

In order to achieve the low cost in overall sensor development, the light source used was a green LED (IF-E93) with a peak wavelength at 530 nm and spectral bandwidth of 50 nm. At the detection side, two identical photodiodes were used (SFH-250V) for each of the reference and sensor output fibres. Respective amplification and filtering circuits have been included to establish the sensor measurements and the block diagram of the experiment is presented in figure 2.
3. RESULTS AND ANALYSIS

To study the effect of the LED input driver voltage (proportional to forward current) and the temperature on the output intensity at the sensor and reference fibres, a normalized light intensity was presented. This is the value referred to the most possible intensity of the LED provided by the drive circuit. In the first measurement, the input to the LED driver circuit was increased in increment of 0.2 V starting from 2.8 V to 5.2 V under a maintained temperature of 17 ± 0.5 °C. For temperature response measurement, the output voltage was recorded at each increment of 5 °C starting from a temperature of 15 °C until 60 °C with a fixed input drive voltage of 4.5 V.

Figure 3 shows that the light intensity in each channel increased by about 14% for a 0.4 V change of input voltage. This relation is equally applicable to both output intensities measured for the sensor and reference fibres. The increment in temperature results in a lower level of output intensity as shown in figure 4. For sensor fibre output, the light intensity decreased by 5% for each 15 °C increment in temperature. This is slightly different for the reference fibre where the same 5% reduction of light intensity only resulted with 20 °C of rises in temperature. For temperature compensation purpose, it was possible to employ a feedback control system to increase the LED input voltage and consequently compensate for a decrease in the light output with the increasing temperature.

The compensation technique was implemented by means of divided beam system. As the light source of the sensor and reference fibres was shared, any intensity variation related to the source was automatically reduced. As shown in figure 3 and figure 4, the differences between the maximum and minimum intensity for individual output were as large as 64% for input driver voltage and 14% for temperature effects. With the compensation technique using the beam divided system, the intensity variation was minimized to as low as 3.6% for both input supply and temperature effects. The output ratio drift for a two hour measurement is presented in figure 5. It shows that the drift output ratio was maintained at or below 0.25% from the nominal value of 1.1625 during that measurement. The bending assessment of the sensor configuration was presented in our previous publication", giving a sensitivity of 0.0136/1° and an accuracy of 0.24° (± 0.12°) of bending, thus making it suitable to be considered as a continuous bending sensor in the clinical environment.
4. CONCLUSION

The effect of the input driver voltage (current) and the temperature on the output intensity at the sensor and reference fibres have been investigated. It was shown that the output intensity increased with the increment of input voltage, but it decreased with the increment in temperature. In order to minimize the intensity variation from the temperature and the input driver voltage changes, the compensation technique based on divided beam system method for intensity referencing was implemented. An assessment of the noise and drift in the optical fibre sensor has shown a maximum drift in the ratio value of 0.25% of the nominal value (1.1625) over a two hour period. This indicates that the optical bending sensor using this configuration may be capable of highly accurate and stable measurement being of the typical value 0.24° (± 0.12° ) over the same measurement period.

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