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An Optical Control System Based on Received Intensities from an Optical Sensor

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Abstract
Optical fiber sensors have attained lots of attention due to its light weight, small volume, and high precision. The optical sensors can measure a variety of physical quantities, such as temperature, pressure, strain, etc. However, some optical sensor systems require wavelength measuring instrument which is difficult for precise alignment, sensitive to mechanical impact, and large volume to install. An optical sensor system is proposed, which does not require an optical wavelength analyzing instrument. The proposed system stores the intensity for each wavelength of an optical source to eliminate the wavelength analyzing instrument. The optical intensity data can be used to identify the corresponding wavelength, because each wavelength of an optical source has different intensity. In the proposed system, wavelengths incident on detectors are identified using received intensities through wavelength vs. intensity table on the control unit. The wavelength which is converted from the intensity received by the detector in our system reflects the current physical quantity state. Base on the state estimated by the wavelength, the proposed system can control the physical quantity to the desired value. The proposed system is extended to limit a physical quantity variation within a pre-determined range employing a high pass filter and a low pass filter, and monitoring the intensities on detectors in the system. An optical control algorithm for the proposed system is suggested. The proposed system is simple to align, resistant to exterior impact, and easy to maintain in real applications.

Keywords: optical sensor, optical intensity, wavelength, spectrum, system control.

INTRODUCTION

Optical sensors have attracted lots of attention due to their advantages over other sensors such as high sensitivity, easy shape modification, light weight, low cost, and so on. The optical sensors find many application areas due to their capabilities to measure a broad range of physical quantities, like temperature, pressure, strain, refractive index, magnetic field, etc.[1-3] An optical sensor system can keep track of the physical quantity state by monitoring optical variations in intensity, polarization, phase, or wavelength as a measurement factor. For optical sensor systems which use optical wavelengths as a measurement factor, the optical sensor system consists of an optical source, an optical sensor, and a spectrum analyzing instrument. The optical source can be monochromatic or broadband, and of low or high power, depending on applications.[4-6] For the optical sensor, optical waveguide and optical fiber devices have been realized to quantify optical phase, intensity, or wavelength as a measuring factor.[7,8] Optical fiber sensor technology have evolved to be able to fabricate a variety of complicated fiber sensors and have substituted the optical waveguide sensors in most areas due to its light weight and easy installation.[9,10] Among fiber sensors, fiber Bragg grating (FBG) sensor is one of the commonly used optical sensors owing to its high precision and easy adaptability to various measurement environments. The wavelength analyzing instrument estimates optical wavelength changes due to temperature, pressure, or strain, etc. The spectrum analyzing instrument can be made by a tunable filter, an optical grating, or line detector, which are difficult for precise alignment, sensitive to mechanical impact, and relatively large volume to be mounted on an optical system.

In this paper, an optical sensor system is proposed without optical wavelength analyzing instrument which is difficult to align, complicated to maintain, and easily affected by exterior impacts. To eliminate the optical wavelength measuring instrument, the optical source spectrum is investigated. The proposed system stores the optical intensities for different wavelengths of the optical source on a control unit. The incoming wavelength on detectors from an optical sensor, such as an FBG filter, which reflects the current physical quantity state and shows any variation in the measurand, is identified through the wavelength vs. intensity table on the control unit. By removing the wavelength analyzing instrument, the proposed system is simple to align, immune to environmental impact, and cost effective to realize. The proposed system can control physical quantities such as temperature, pressure strain, etc., based on the measured current physical quantity state which is obtained through converting the incident intensity on a detector to the corresponding wavelength. The proposed principle can further realize a system which can restrict physical quantities within a pre-determined range by dividing the control region into two, three, or four regions according to control requirements.

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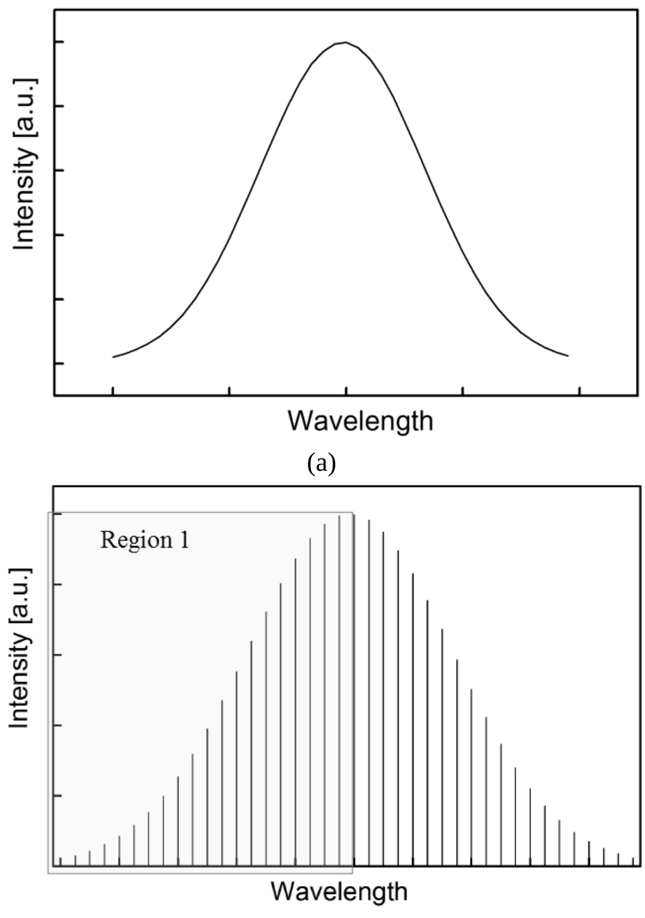
PRINCIPLE OF THE PROPOSED SYSTEM

An optical sensor system is proposed, which does not employ a wavelength measuring instrument. In the proposed system, the control unit stores optical wavelength spectrum of the optical source in the system and identify the received wavelength with the intensity incident on a photodetector. Let's assume the optical spectrum of the source as a Gaussian shape in this paper as shown in Figure 1(a). The intensity for each wavelength of the optical source is stored on the control unit, as shown Figure 1(b). When only half of the wavelength region of the optical source is used which is indicated as Region 1 in Figure 1(b) or the other region, the wavelength incident on the detector can be identified by its intensity, because each wavelength has a different intensity. That is, for the case that the physical quantity variation is restricted in Region 1 of Figure 1(b), or the other region, the proposed system can identify the received wavelength without a wavelength measuring instrument which is difficult for high precision alignment, sensitive to mechanical disturbance, and hard to manage. In the case that the received intensity is between two adjacent intensities, Figure 2, the wavelength can be calculated by interpolation method. The following equation give the wavelength corresponding to the intensity P_x.



(a)

(b)

Figure 1: Optical source spectrum (a) continuous wavelength (b) discrete wavelength (a box is drawn to describe the proposed system) he strategic planning process

$$\lambda_x = \lambda_n + \frac{\lambda_{n+1} - \lambda_n}{P_{n+1} - P_n}(P_x - P_n)$$

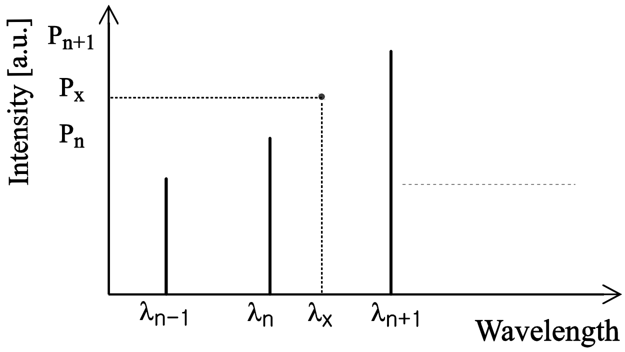


Figure 2: Wavelength calculation using interpolation

OPTICAL CONTROL SYSTEM WITHOUT WAVELENGTH ANALYZING INSTRUMENT

The proposed principle can be applied to optical sensor system in which an optical wavelength, indicating the current physical quantity such as temperature, pressure, or strain in the measurement area, is extracted by the optical filter, incident on the detector in the control unit, and identified by the intensity through the table of wavelength vs. intensity in the control unit. Figure 3 shows the proposed system which can identify the wavelength without a wavelength measuring instrument. In the proposed system, the reflective filter in Figure 3, of which

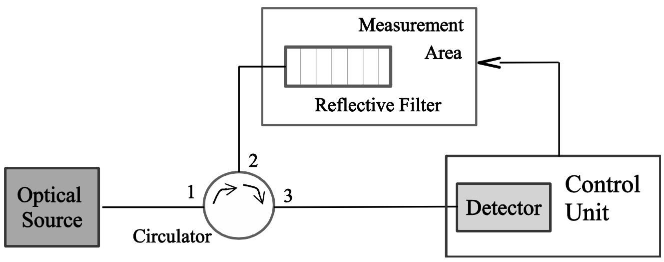


Figure 3: Proposed sensor system with wavelength identification method by intensity on photodetector

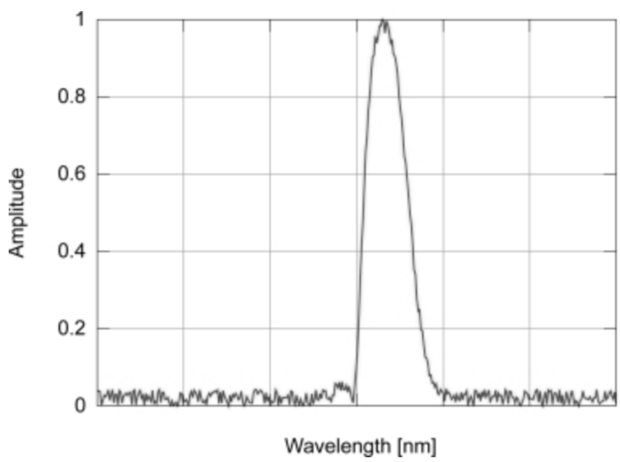


Figure 4: Optical spectrum of an FBG filter

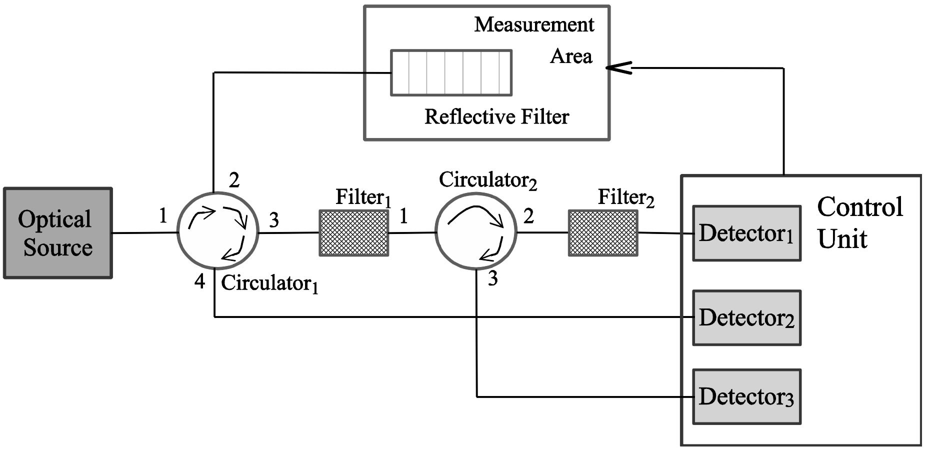
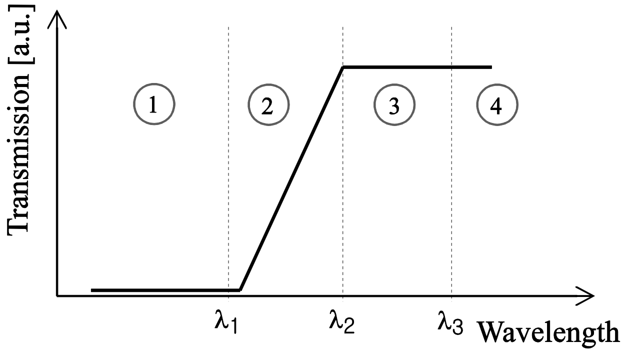
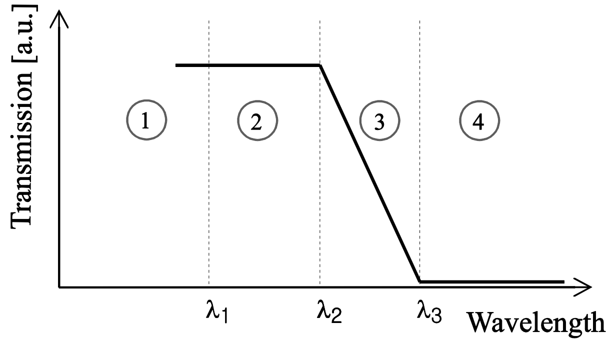


Figure 5: Extended proposed system to restrict a physical quantity state within a certain range

wavelength spectrum is shown in Figure 4, indicates the state of the physical quantity in the measurement area by reflecting the corresponding wavelength of the physical quantity state to the port 2 of the circulator which is a unidirectional device. The control unit receives the reflected beam traveling from the port 3 of the circulator on the detector, identifies the wavelength of the received beam based on the wavelength vs. intensity table of the optical source in the system wich is stored in the control unit, and adjusts the physical quantity in the measurement area based on the current physical quantity state which is estimated by the identified optical wavelength. The proposed sensor system can be exteneded to limit the variation of a physical quantity within a certain range by implementing the system of Figure 5. $Filter_1$ and $filter_2$ in Figure 5 are a high pass filter, Figure 6 (a), and a low pass filter, Figure 6 (b), respectively. Let's assume the case that a certain physical quantity should be restricted within the range of ② and ③ in Figure 6. That is, regions of ① and ④ are out of desired regions for the physical quantity. For the case that the wavelength of the beam reflected by the reflective filter in the measurement area in Figure 5 is a small wavelength in the range of ① in Figure 6 (a) and (b), the beam with the small wavelength is reflected by the high pass $filter_1$ and is incident on $detector_2$ after passing through the $circulator_1$. For a beam with a large wavelength which is in the range of ④ in Figure 6, the beam passes the high pass filter of $filter_1$ and is reflected by the $filter_2$ and travels to the $detector_3$ through the circulator②. By monitoring the intensities of each $detector_2$ and $detector_3$, the system can determine whether the physical quantity state is in the desired phycal range or not. In the case of the beam of which wavelength is in region of ② or ③ which is the derised region for the physical quantity state, a part of the beam is reflected by the $filter_1$ and incident on $detector_2$, and the other part passes the $filter_1$. For the beam passing the $filter_1$, a part of the beam is reflected by the $filter_2$ and propagates to the $detector_3$, and the other part of it passes the $filter_2$ and travels to the $detector_1$. At the optimal physical quantity which corresponds to the wavelength of λ_2 in Figure 6, the $detector_1$ has the largest intensity. By monitoring the received power by three detectors in the proposed system of Figure 5, the system can keep track of the physical quantity state and manipulate to restrict the physical quantity within a pre-determined range. Figure 7 shows the suggested optical control algorithm for the proposed system which dictates appropriate measures after comparing three intensities, I_1, I_2 and I_3 of three detectors, $detector_1$, $detector_2$ and $detector_3$, respectively in Figure 5. For the case in which intensity I_1 is the largest among three intensities and the intensity I_2 is



(a)



(b)

Figure 6: Optical high pass and low pass filters (a) high pass filter (b) low pass filter

approximately equal to the intensity I_3, the system should keep the current control status. When intensity I_2 is the largest, the physical quantity should be controlled to move the current optical wavelength to larger wavelength. In the case that the $detector_3$ receives the largest intensity, the sytem controls the physical quantity state to shift the current optical wavelength to smaller wavelength.

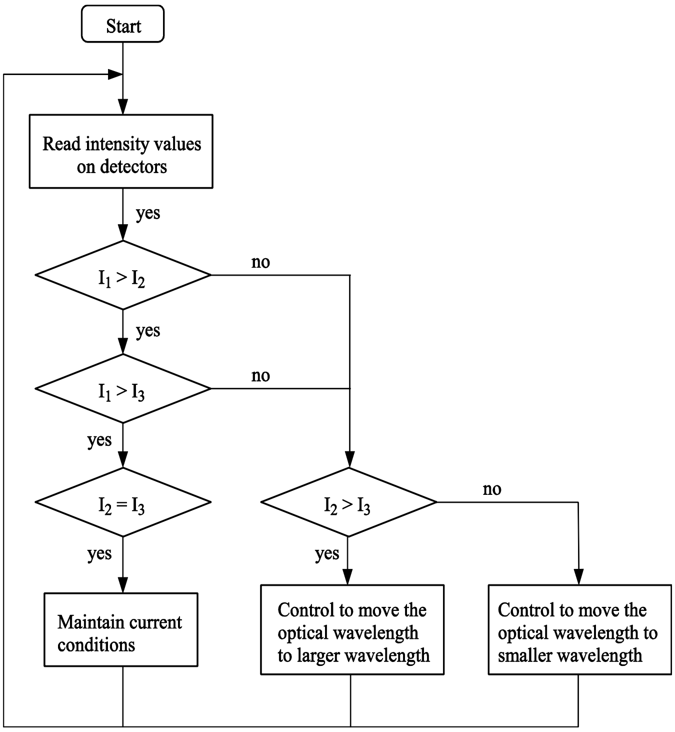


Figure 7: Control algorithm for the proposed system (I_1, I_2 and I_3 are intensities of the $detector_1$, $detector_2$ and $detector_3$, respectively, in Figure 5.)

CONCLUSION

An optical sensor system is proposed, which does not require an optical wavelength analyzing instrument. Taking advantage of optical source wavelength characteristic that a different wavelength has a different intensity in an optical source, the proposed system eliminates the wavelength analyzing instrument in our proposed system by storing the intensity for each wavelength of the optical source in the control unit. Wavelengths incident on detectors are identified by wavelength vs. intensity table in the control unit. The proposed system is extended to restrict a physical quantity state within a certain range by employing two filters, high pass and low pass filters, in the proposed system in which the physical quantity can be adjusted by monitoring the intensities of the three detectors. For the proposed system, an optical control algorithm is suggested to limit a physical quantity within a pre-determined range. The proposed system can be applied to real control systems because it is simple to align, resistant to exterior impact, and easy to maintain.

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