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An optimal placement of FBG sensor network based on probability model

Xiaosu Yi, Jia Liu*, Xiangyu Ye, Song Lin

School of Instrument Science and Optic-electronics Engineering, Beihang University, Beijing 100191, China

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ABSTRACT

Optimal placement of sensor network determine the performance and cost of sensor network, and sensor range is a key factor of optimal placement. Unlike the traditional sensor, FBG sensor have different detecting probe length in difference angles, due to the sensitivity of FBG in axial direction is much better than the other directions. Sensor layout angle is not discussed in previous studies about FBG sensor network. The layout angle of sensor considered in placement can greatly impact the performance of FBG sensor network. The paper propose a detective model for FBG sensor which fit it is feature based on probability model, and verified the correctness of it by experiment, then particle swarm optimization is used for optimize the placement of FBG sensor network. Finally, the paper compare this optimization result with method which not consider the layout angle of sensor, and that indicates the performance of sensor network is greatly improved by add the layout angle to placement.

1. Introduction

In recent years, smart material and structure and structural health monitoring (SHM) have developed rapidly and have been more and more used in aerospace, space station health monitoring, bridge dams health monitoring, undersea fiber optic cable maintenance and other aspects. Development in these areas led to many studies in optimal sensor placement and sensor performance [1,2]. In order to be able to play the sensor's maximum performance for meeting the high utilization and at the same time to control costs, there is a strong need to select appropriate sensor and to arrange the sensor rationally in line with its own characteristics. Due to the many advantages of Fiber Bragg Grating (FBG) sensor, a growing body of research and applications tend to use FBG sensor. But the research on FBG sensitive range is not combined with its application. The paper attempts to explore the sensitive range of the FBG sensor, and propose a optimal placement for FBG sensor network fitting with the feature of FBG sensor, in order to achieve the purpose of rational use of sensor resources, optimizing the performance of sensor network.

2. FBG sensor

FBG sensor has the incomparable advantages that other sensors hard to achieve: information of the sensor is encoding with wavelength, which is not subject to the fluctuations of the light source power and connection or coupling loss. System is very easy to continuous making many gratings which are lightweight and soft in one fiber. Combination of time division multiplexing and wavelength division multiplexing technology, FBG is suitable as a distributed sensor buried in the internal materials and structures or placement on the surface, to achieve multi-point detection of temperature, pressure and strain [3–7].

Now various studies tend to consider the sensitive range of sensor as a circular [8–11], but for FBG sensor, however, it is the unique character of axial direction sensitive that determines the Bragg wavelength shift (BWS), induced by same stress on different directions of FBG sensor, is generally different, which means that its sensitive range is not a standard round shape, while there may be an oval or other shapes.

The relationship between FBG BWS and axial strain is expression by Eq. (1):

$$\Delta\lambda_{BS} = \lambda_B(1 - \rho_\alpha)\Delta\varepsilon \tag{1}$$

where ρ_α is the elastic-optic coefficient of the fiber, generally determined by type (2).

$$\rho_\alpha = \left(\frac{n^2}{2}\right)[\rho_{12} - \nu(\rho_{11} - \rho_{12})] \tag{2}$$

where ρ_{11} and ρ_{12} are components of the photo-elastic tensor, ν is the Poisson coefficient. ρ_α can be measured by experiment. Meory [12], Rao [13] et al. have done experimental measurements in this area. Because acceleration, ultrasound, power and other physical quantities can be converted to strain measurement, types (1) and (2) are equally applicable in the measurement of these parameters.

* Corresponding author.
E-mail address: keith_l@126.com (J. Liu).

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For the convenience of describe, this paper define axial represents the direction along the fiber, and vertical represents the direction perpendicular to the fiber.

Generally speaking, vertical stress acting on FBG makes grating pitch change, and the value of the pitch changing is linear with regard to BWS; transversal stress acting on the FBG makes the micro-changes of fiber diameter, resulting the trace changing of light propagation, but this change is usually negligible compared to the fiber effective refractive index and grating pitch changes.

3. FBG sensor model

Sensing range (coverage) is a measurement of the detection probability of the target area. This is a key factor of the sensor networks. It impacts on the target area monitoring of sensor networks directly. For sensor network coverage, it must set a sensor detection model first, which will be the basis of coverage. In general, the sensor detection model consists of the Boolean model and the Probability model, etc. More realistic sensor detection models can be found in the work by Zou and Chakrabarty [14]. In the Boolean model, sensor detection range is a circle where sensor is at the center, and the radius is the sensor detection length. The probe is controlled only in this round range, i.e. monitoring objective detected by the sensor of a probability of 1 when it is within this round range, and when it is outside this round range, the probability to detect it is 0. In practical applications, the probability of target being monitored by the sensor is not a constant but a varied value depending on the distance between target and the sensor, physical characteristics of sensor and material, the number of sensors around the target, as well as various other dynamic factors.

The probability of a target detected by sensor changes exponentially with the distance of the target to the sensor, i.e. if the distance between target and sensor is d, then the probability of sensor detected this target is $P = \exp(-\alpha d)$ [8,9,15]. The parameter α can be used as a measure of the quality of sensor performance and the decay rate of detection probability decreased with distance. α can be calculated when sensor and material is selected. Obviously, when the monitored target and the sensor overlap, the detection probability is 1. Monitored target distance sensor the closer, the greater the probability of the sensor detects it. A threshold m can be set, when the probability of sensor detecting a target is larger than that, it consider this target is detected, saying that the target point is covered by the sensor. Otherwise, the point cannot be covered by the sensor. The value of m selected affects the accuracy of targeting in the practical application. A description of the model is shown in Fig. 1.

Assume that the sensor is arranged at the point i, while the target at point j, P_{ij} represents the probability of this target be detected.

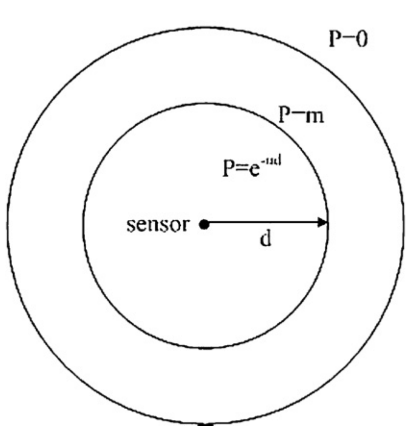

Fig. 1. Sensor detection model.

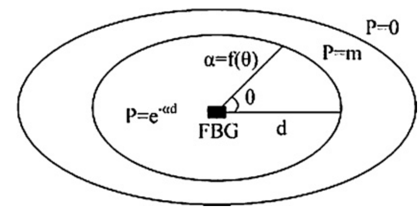

Fig. 2. FBG sensor detection model.

When this probability is smaller than m, consider it as 0. The sensor detection probability should satisfy the following relations (3):

$$P_{ij} = \begin{cases} \exp(-\alpha d), \exp(-\alpha d) \geq m \\ 0, \text{others} \end{cases} \qquad (3)$$

When same force acting on different direction of FBG sensor, the value of BWS in axial is greater than vertical because of the axial sensitivity of FBG. Thus it is required to consider the layout of the sensor direction for FBG sensor placement. Thence the layout of location and angle of sensor are all needed to consider in placement. Due to the axial sensitivity of FBG sensor, type (3) needs to add an auxiliary condition of θ, where θ represents the angle from sensor axial to detecting direction. Different values of θ corresponding to different values of α. There is also a probability to believe that θ and α satisfy a certain functional relationship. A description of this model is shown in Fig. 2 .

When the functional relationship between θ and α is obtained, substituted it into type (3), the probability of a FBG sensor layout at point i to detect a target layout at point j is P_{ij}; Assuming the number of sensors layout in detecting area is N, the co-probability of point j be detected by all N sensors is:

$$P_j = 1 - \prod_{i=1}^{K} (1 - P_{ij}) \qquad (4)$$

Assuming M signal sources in arranged in detecting area, then average probability of all sources be detected by sensor network is:

$$P_A = \frac{\left(\sum_{j=1}^{M} P_j\right)}{M} \qquad (5)$$

The average miss probability is:

$$P_{AM} = 1 - P_A \qquad (6)$$

Thence the purpose of optimal placement is maximum the type (5), that is minimum the type (6). Type (5) is the optimal criterion of optimal placement.

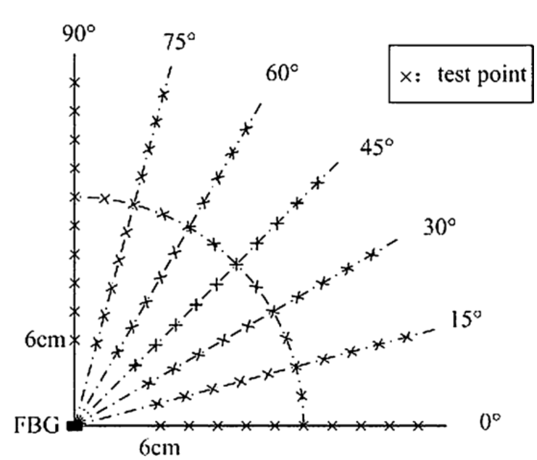

Fig. 3. Test points and test angles.