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Invited Papers

Fiber optic sensor networks

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ABSTRACT

One of the main goals in fiber optic sensor technology is to multiplex together a high number of sensors in the same network in order to share expensive terminal equipment and develop a system including multiple measuring points. Different kind of multiplexing networks for fiber optic sensors will be described and compared here, including networks using optical amplification and lasing multiplexing systems. State of the art in multiplexed and distributed sensor networks is also shown, focused on robust, remote and distributed Brillouin networks.

1. Introduction

The cost of a single channel fiber optic sensor is relatively high. Fortunately, aggregation of the sensors results in their cost reduction, given that it would be possible to share either the source of light, system of detection, or, preferably, both. Furthermore, the most suitable transmission medium for the signals generated by the fiber sensors is also optical fiber, from which follows that all the advantages of the fiber-based networks are also directly applicable to the fiber optic sensor networks.

Multiplexing is the simultaneous transmission of two or more information channels along a common path. A fiber sensor system includes three main parts or subsystems: the sensing elements or transducers, the optical fiber channel and the optoelectronic unit [1]. Because the last subsystem uses to be the most expensive one, when is possible to multiplex a high number of sensing points in the same optical fiber network using a common optoelectronic unit, the cost per sensing element decreases.

Trends for the network implementation using sensor multiplexing are just as much, or even more widespread than those of the fiber transmission networks.

Multiplexing of optical fiber sensors is a concept that includes three basic tasks [2]

- Launching of optical signals with the correct power level, spectral distribution, polarization and modulation into the network.
- Detection of the portion of optical power codified or modulated by the sensor element, which is sent by means of transmission or reflection.
- Unique identification of the information corresponding to each sensor in the network, by means of proper addressing, polling and decoding.

Because of this, in the realization of the sensor networks it is possible to utilize the following: various modulation techniques of diverse parameters of the optical signal, different network topologies and simple or complex decoding methods of the received signal. And all of these as a function of the type of sensors multiplexed within the same network.

When designing a network, one should take into account the strong relationship that exists between all the factors mentioned above, together with the existing economic conditions; that would give rise to a most appropriate network. The cost of the network depends on many factors, and the dominant cost is usually application specific. In some applications, the cost of the fiber may be dominant, and a multiplexing scheme that provides the highest channel density per fiber will provide the lowest total cost. However, usually the cost of the electro-optics system dominates, and multiplexing approaches that provide the highest channel density per laser may be the lowest cost approach [3].

Thus, the mail goal of most fiber sensor networks, is to connect a number of sensors to a single reading unit. These sensors can be addressed either simultaneously or sequentially by using optical switches. No manual intervention should be necessary.

This paper highlights the main fiber optic sensor networks general concepts and characteristics and seeks to provide a state of the art of modern multiplexing sensor networks.

2. Fiber optic sensor networks: Basic concepts

In classifying optical fiber sensor networks, it is necessary to make a first subdivision between them:

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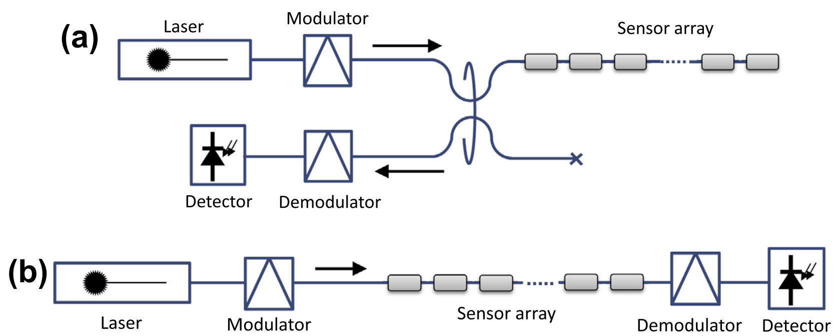

Fig. 1. Serial multiplexed sensors (a) reflective arrangement and (b) transmissive arrangement.

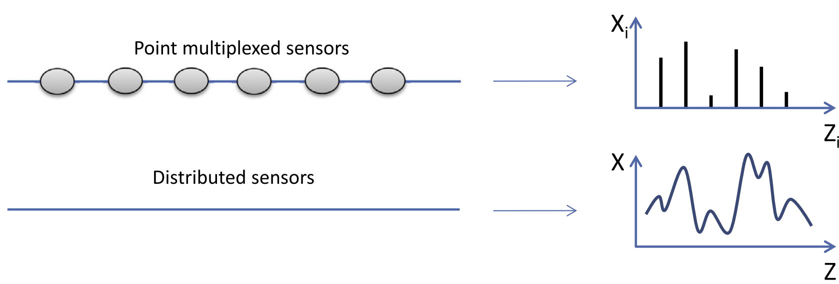

Fig. 2. Multiplexed and distributed sensors.

- Simple networks. Term which is applicable to the networks in which only one type of sensors is multiplexed.
- Hybrid networks, in which several types of sensors are multiplexed, or through which several types of signals circulate, as may be the case of superposed data and sensors signals in a local area network [4].

Further preliminary subdivisions that must be made in order to clearly define a network, and which is based on the type of sensors used are [5] (Fig. 1):

- Transmissive networks, based on transmissive sensors.
- Reflective networks, that use the reflected signal in each sensors and that usually result in fiber saving.

Finally, it is common to distinguish between point multiplexed sensors and distributed sensors, as shown in Fig. 2. In the distributed sensors there is only one sensing element, and the objective of the signal processing is to recover the measurand as a function of position along the sensing element. On the other hand the multiplexing of point sensors consists of processing the value of the measurand corresponding to each discrete sensing element.

It must be made clear that both types of sensors may coexist in the same network, resulting again in hybrid networks [6].

As far as the type of optical signal is concerned one can make an initial distinction between networks capable of multiplexing sensors by employing optical signal's phase for the information transmission (interferometric sensors networks), or ones that are based on codifying the intensity of light (by means of some multiplexing technique) which we will call the intensity sensor networks. It is precisely this classification which is utilized in most of the classical texts covering this topic [7,8].

One can see in Fig. 3 different multiplexing formats as a function of optical signal's varying parameter used for data representation.

There exist a number of diverse topologies for making sensors available in a network. They are divided into four basic

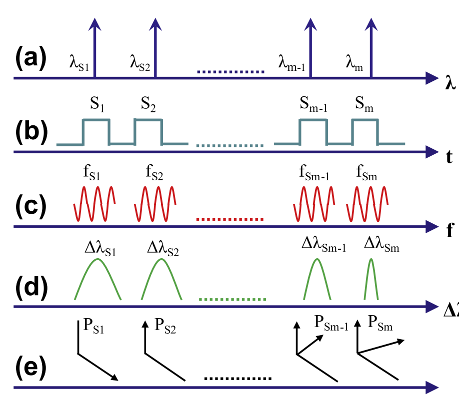

Fig. 3. Multiplexing formats for sensor networks.

configurations, shown in Figs. 4a and 4b; where each one in turn can be of a transmissive or reflective type. One important factor to have in mind in fiber optic networks in general and in the sensor ones in particular is the optimized value of the received signal level arriving from each of the sensors. A fiber optic transmission system always has available a range of optical power, such as the existing difference between the maximum level of signal that can be received by a detector without saturating and the corresponding minima for which the system will operate with the acceptable signal to noise ratio. Where in a star topology the choice of the splitting ratio is easy ($1/N$, where N is the number of sensors to be multiplexed), that of the bus architecture is a delicate subject [8]. In the usual case, where it is desirable that all the couplers have equal splitting ratio, the optimum value would still be $1/N$. On the other hand, the signal can be optimized by making each coupler to have a different coupling ratio. This last case, however, is not common and results on an increased cost and complexity of the network.

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