Implementation of Brillouin-Active for Low Threshold Optical Logic and Memory Based on Neural Networks

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Summary

We propose a novel application of sBs in embedded optical fibers as a building block for the implementation of optical neural net based on smart structures. By employing well established technology in fiber embedding in structures, and exploiting the ability of sBs as a highly versatile ambient sensor, and its nonlinear optical property of energy addition and subtraction to perform optical arithmetic, we predict the possible integration of sensing and actuation for smart structures. In this paper, the fiber based sBs neuron is explained based on neural network in smart structures. Optical arithmetic schemes are shown to demonstrate the simplicity of operation of these neurons.

Key words:

Optical Fiber Sensing, Neural Networks, Neuron, Nonlinear Optics

1. Introduction

Optical fibers based on neural networks application and hardware implementation have been extensively used in optical systems [1], [2]. Recent interest has been also focused on using optical fibers as sensors since fiber parameters are sensitive to the fiber immediate environment [3], [4]. Important advances have been made in reducing optical losses in fibers, so the light signal can propagate in long haul transmission without requiring inline amplifiers. Large input signals are required leading to nonlinear optical phenomenon in optical fibers, when signal power exceeds threshold. Specially, in the case of stimulated Brillouin scattering (sBs), part of the signal power is converted into reflected lightwave, traveling backwards towards the input of the fiber. The backward scattering nature of Brillouin scattering has long been viewed as an ultimate intrinsic loss mechanism in long haul fibers, since Brillouin threshold decreases with increasing effective fiber length. On the other hand, the very backscattering nature of this process and the existence of a threshold, provide potential optical device functions, such

as optical switching, channel selection, amplification, as

optical switching, channel selection, amplification, sensing, arithmetic and neural functions in optical signal processing, and neural network applications and hardware implement-tation. The theoretical and physical background of this nonlinear process has been well explained [5],[6]. The backward scattering scheme based on neural networks in optical fiber is shown in Figure 1.

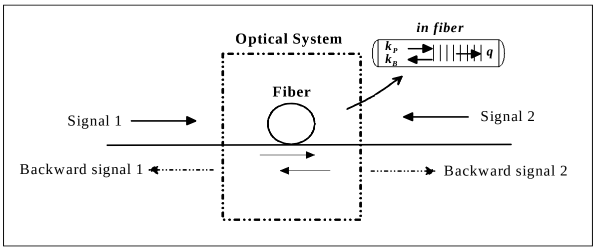

Fig. 1. Hardware implementation based Brillouin-active fiber with forward/backward propagation Stokes waves

Active device in optical systems generally require the employment of nonlinearity, and possibly feedback for increased device efficiency. The presence of nonlinearity together with intrinsic delayed feedback has been repeatedly demonstrated to lead to instabilities and optical chaos [7], [8]. This phenomenon has extensively investigated by us for its potential detrimental effect to the Brillouin fiber sensor [9], [10].

A smart structure can potentially implement a massively parallel computational architecture with its attendant reduction in processing time while managing the complexity of the system, i.e. the sensing/actuation grid. Our sBs network would learn the correct "algorithms" by example during training and have the ability to generalize to untrained inputs after training is completed. The inputs to the network are the fiber optic signal outputs, and the network outputs are the control signals for actuation controls. The true advantage of this system for application to smart structures lies both in its capability to analyze complex signal patterns and its speed in generating the appropriate control signal for the actuators. The key lies in

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the implementation of a neuron operation using sBs in optical fiber.

2. SBS Based Neuron

An artificial neuron, used in neural network research, can be thought of as a device with multiple inputs and single or multiple outputs in hardware implementations. The inputs to a neuron are weighted signals. The neuron adds the weighted signals, com-pares the result with a preset value, and activates if the sum exceeds threshold. Neuron-type operations can be performed by an optoelectronic system that uses sBs for the weighted summation required in a neuron. Weighting can be achieved by optical summation and subtraction, conveniently carried out in an optical fiber using sBs. Weighted additions and subtractions are needed in many situations. For example, a neuron performs weighted summation of the incoming signals. The performance of such a device will enhance if it operates optically. We propose to study a system that can perform the practical implementation of a Brillouin-active fiber for optical neural net, neural function by exploiting the acousto-optic nature of the sBs process [9],[10].

In the nonlinear optical phenomenon, the system's combined weighted signals also produce an output if the weighted sum is greater than the threshold. A typical neuron, based control signal with input and output systems, is illustrated in Figure 2.

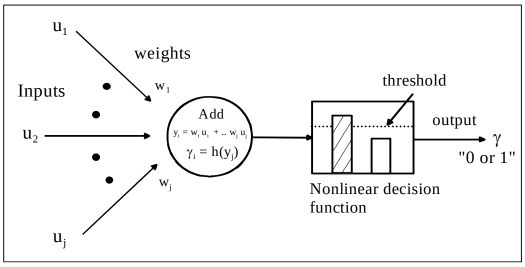


Fig. 2. A simplified multi-layered neural network. The networks have physical resemblance; optical fiber networks to nerve system and neural networks.

A theoretical sBs based neural network, utilizing sBs threshold sensing with an embedded sensor is shown in Figure 3. The arithmetic building block of energy addition and subtraction (normally difficult to perform), as in Fig.3, can conceivably be accomplished by the sBs process, which involves energy transfer between waves. Thus, if two waves at a frequency difference equal to the Stokes downshift of the fiber propagate in the fiber in opposite directions, then energy is "subtracted" from the higher frequency wave and "added" to the lower frequency wave. If three waves are present in a fiber with equal Stokes shifts, then the wave at the middle frequency will receive energy from the higher frequency wave and lose energy to the lower frequency wave. Practical implementation of this scheme calls for all the waves to be generated by the same laser, since the Brillouin shifts are typically very small.

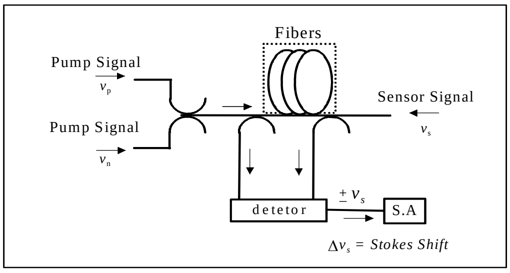


Fig. 3. SBS implementation of threshold logic with optical logic networks

3. SBS Logic Implementation

A practical implementation of theoretical neuron calls for all the waves to be generated by the same laser. We are very familiar with this method and a scheme is devised in Figure 4. A laser was used as the pump to the system through a coupler. An isolator is installed to prevent any reflected signal back into the laser cavity that may disrupt the performance of the laser. The pump wave travels through the long fiber to an embedded sensing fiber. If the pump signal launched into the fibers exceeds some critical threshold level, then sBs occurs. In this process, the input pump traveling through the fibers may be converted into a Stokes wave, shifted in frequency, and traveling backward towards the laser source.

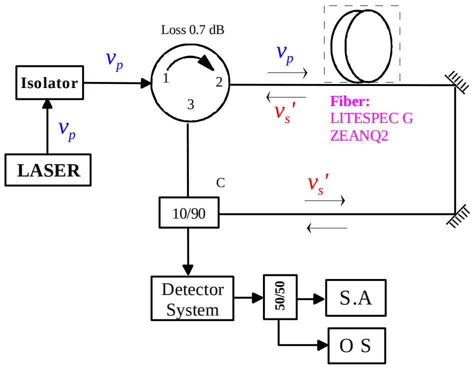


Fig.4. Practical Implementation sBs based threshold logic. Optical fibers are used as the medium for providing sBs gain to the stokes wave. Here $\nu_p > \nu_s > \nu_n$

Three identical fibers are used, two in the oscillator format, and one in the amplifier format. Fiber 1 is used to provide the v_s generated by the laser pump ν_p. The v_s wave is then used as a pump to generate ν_n in fiber 2. The residual v_s and ν_p proceed to fiber 3, where all three waves will mix. Since all three signals are present, the third fiber can be in the amplifier format. The sensor signal v_s wave will act as a stokes wave for ν_p and as a pump wave for ν_n, with ν_p - ν_s $=\Delta\nu_p$, and ν_s - ν_n $=\Delta\nu_p$, where $\Delta\nu_p$ is the Brillouin shift. The enhanced Stokes signal, and pump signal of the sBs oscillator fiber and other backwards signals due to the sensing fiber will be used for the multipoint threshold sensing technique in the sBs neural net. The 'sensed' signal will be viewed on a Spectrum Analyzer for comparison. This sensed signal energy can be added to and/or subtracted from the sensor wave by its interaction with v_p and v_n via sBs.

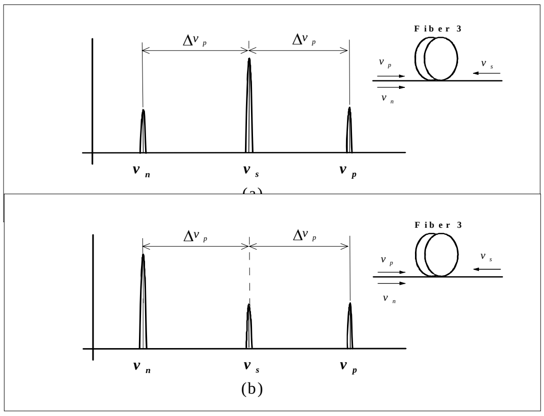
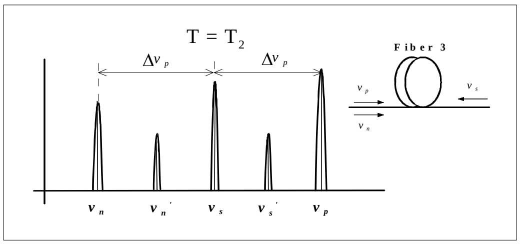


Fig. 5. (a); Addition = Energy from ν_p added to ν_s and (b); Subtraction = Energy from ν_s added to ν_n

In our implementation, the threshold of the device can be set to any suitable output power level of the "sensor" signal. We take the threshold to be reached when the sensor signal emerges from the fiber device with no net gain or loss (0dB gain). The sBs mechanism can also serve as input weight controller, since energy can be added or subtracted from the input signal. The sBs oscillator / amplification scheme without wave mixing is shown in Figure 5, where the Brillouin-shifted energies are $\Delta E_p = h\Delta\nu_p$, and $\Delta E_s = h\Delta\nu_s$. This energy can be added or subtracted from the sensor wave ν_s when it interacts with waves at ν_p and ν_n via sBs.

As an example in temperature sensing, the sensor system be at a temperature T_1, signal energy is subtracted from ν_p by ν_s and then subsequently added to ν_n. If the temperature is changed to a new value T_2, different from T_1, then the ν_p and ν_s waves will create new stokes signals shifted to frequencies ν_s' and ν_n'. Due to the presence of these new frequencies, ν_p and ν_s, and ν_s and ν_n, respectively, the arithmetic changes and no signal energy is added and/or subtracted as shown in Figure 6. The experimental result of a practical implementation for a SBS based neural networks shows two narrow single-frequency outputs. The Brillouin shifted output, which 'adds' signal energy (large-amplitude signal) and/or 'subtracts' signal energy (small signal), from the sensor wave through interaction (Δv_s) of v_p and v_n via SBS observed on the spectrum analyzer. For the case where the signals add, the Stokes signal is downshifted in frequency by approximately 12.9GHz to 12.8GHz, with the display centered at 12.85 GHz. Linewidth resolutions was better than 30 MHz.

Fig. 5. sBs Oscillator-Amplifier Amplification scheme, with the presence



of ν_s' and ν_n' between ν_p, ν_s, and ν_n, at fiber 3 when temperature is changed from T_1 to T_2

4. Conclusions

Embedded fiber sensors have been extensively deployed in structures normally as passive light conduits. However, Brillouin active fibers not only propagate light, but also provide device functions in the fiber. The ability of sBs to perform both sensing and optical arithmetic render such a scheme as the simplest building block for neural network based smart structures.

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