546 Journal of Electrical Engineering & Technology, Vol. 1, No. 4, pp. 546~549, 2006

Study of Neuron Operation using Controlled Chaotic Instabilities in Brillouin-Active Fiber Based Neural Networks

Yong K. Kim†, Do Geun Huh*, Kwan-Woong Kim* and C. Yu**

Abstract - In this paper the neuron operation based on Brillouin-active fiber in optical fiber is described. The inherent optical feedback by the backscattered stokes wave in optical fiber leads to instabilities in the form of optical chaos. Controlling of chaos induced transient instability in Brillouin-active fiber is implemented with Kerr nonlinearity having a non-instantaneous response in network systems. The controlling chaotic instabilities can lead to multistable periodic states; create optical logic 'on' or high level "1" or 'off, or low level "0". It is theoretically possible to apply the multi-stability regimes as an optical memory device for encoding and decoding series and complex data transmission in optical systems.

Keywords: Neural networks, Neuron operation, Nonlinearity, Optical fiber, Optical memory

1. Introduction

It is well known that optical fibers have potentials for various uses in the communications field. Research in the past and in recent years has focused on using optical fibers for sensor based neural network applications and hardware implementation; each fiber capable of reacting to measure and changes in its immediate environment [1, 2]. Current research has centered on combining fiber optic sensors and actuation materials to create a system that is capable of sensing, and controlling shape or orientation with respect to its environment, as a first step in creating a smart structure. Specifically, our research focuses on configuring and developing a stimulated Brillouin scattering (sBs) sensing system that behaves as a neural network, in order to acquire the ability to learn by experience, predict future reactions to environmental changes, and execute as prescribed.

A "possible" smart structure system would 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 sensor signal outputs, and the network outputs are the control signals for actuation controls. The true advantage of this "proposed" system for application to smart structures lies both in its capability to analyze complex sensor signal patterns and its speed in generating the appropriate control signal for the actuators. The key can be found in the implementation of a neuron operation based neural networks using sBs in optical fibers

2. SBS Based Neuron

Nonlinear effects in optical fibers, specifically stimulated Brillouin scattering, has emerged as a versatile tool for the design of active optical devices for all-optic in-line switching, channel selection, amplification and oscillation, as well as in optical sensing, and optical communications[3, 4, 5]. The backward nature of SBS scattered light, with a frequency shift equal to that of the laser induced acoustic wave in the fiber, has long been viewed as an ultimate intrinsic loss mechanism in long haul fibers [6, 7]. The very backscattering nature of this nonlinear process and the existence of a threshold provide potential optical device functions, such as optical switching arithmetic and neural functions.

An artificial neuron, used in neural network research, can be thought of as a device with multiple inputs and single or multiple outputs. The inputs to a neuron are weighted signals. The neuron adds the weighted signals, compares the result with a preset value, and activates if the sum exceeds threshold. 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 is illustrated in Fig. 1.

---

† Corresponding Author: Department of Electrical Electronics and Information Engineering, Wonkwang University, Korea. (ykim@wonkwang.ac.kr)

* Department of Electrical Electronics and Information Engineering, Wonkwang University, Korea.

** Department of Electrical Engineering, North Carolina State University, North Carolina 27410, USA

Received December 21, 2005 ; Accepted September 2, 2006

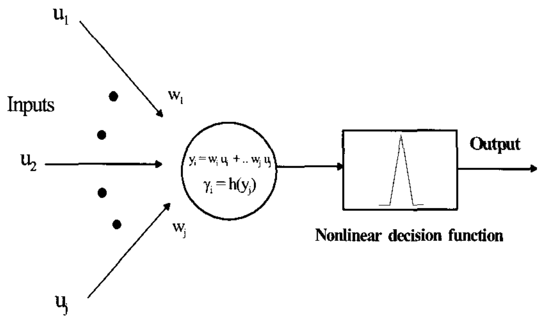


Fig. 1. A simplified multi-layered feedward neural network; the processing node between interconnects, where weighted sums are fed to a threshold decision-processing element.

The system through SBS mixing combines weighted signals to produce an output if the weighted sum exceeds the threshold. The threshold decision is made by an individual neuron in conjunction with weighted inputs from other neurons. A theoretical sBs based neural network, utilizing sBs threshold sensing with an embedded sensor were explained [8, 9].

3. SBS Threshold Logic

Since the Stokes shift is small, the wavelengths in each wave λp, λn, and λs are almost equal [9]. With these assumptions, the nonlinear coupled equation can be written as [8]

$$\frac{dI_p}{dz} = -\alpha I_p - g_B I_p I_s \tag{1}$$

$$-\frac{dI_s}{dz} = -\alpha I_s + g_B I_s I_p - g_B I_n Is \tag{2}$$

$$\frac{dI_n}{dz} = -\alpha I_n + g_B I_n Is \tag{3}$$

where I represents wave intensity of the pump "p", the backward Stokes wave "s" and the acoustic wave "n", and α and g_B are respectively the fiber attenuation coefficient and Brillouin gain coefficient for all the waves. In the basic optical neuron-type setup shown in Fig. 2, the input-output conditions of the waves are given as follows:

$$I_p(L) = I_p(0)e^{-\alpha L} \tag{4}$$

$$I_n(L) = I_n(0)e^{-\alpha L} \tag{5}$$

$$I_s(0) = I_s(L)e^{-\alpha L g_B L_{eff} \Delta I} \tag{6}$$

where $\Delta I = I_p(0) - I_n(0)$ and $I_p(0)$ is the pump transmission. If the net gain of the sensor signal is close to 0 dB, then $I_s(L) \approx I_s(0)$ so that $P_s(0) \approx P_s(L) << \alpha A_{eff}/g_b \le p_p(0)$, where we have used $I = p/A_{eff}$, in which $A_{eff} = \pi r^2$ is the effective cross sectional area of the fiber, and p is the power. The ratio $\beta = P_s(L)/P_s(0)$ is on the order of 0.01 or less. Using pump power level for 0 dB gain, we can estimate the pump power value,

$$p_s(L) = 0.001 p_n(0) \tag{7}$$

if $Ps = 1$ mw, the pump power $Pn(0)$ required will be 1W. The intensity level of each wave is set below the SBS threshold ($I_{th} = 21/gbL_{eff}$) in order to avoid the generation of backward Stokes from spontaneous scattering. The stokes gain versus total pump power difference $p_p(0) - p_n(0)$ is shown in Fig. 2. The gain can be converted to loss and vice versa, simply by changing the pump power levels. The output state of a neuron can be altered by changing one or both input pump intensities. The threshold of the neuron can be controlled by changing the power launched in the stokes signal as indicated in Fig. 2.

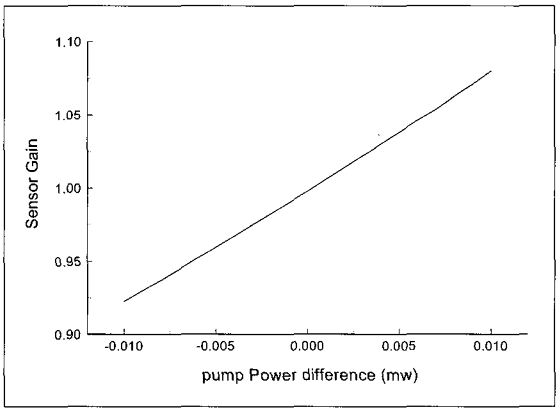


Fig. 2. Backward Stokes signal (vs) vs. pump power difference $p_p(0) - p_n(0)$

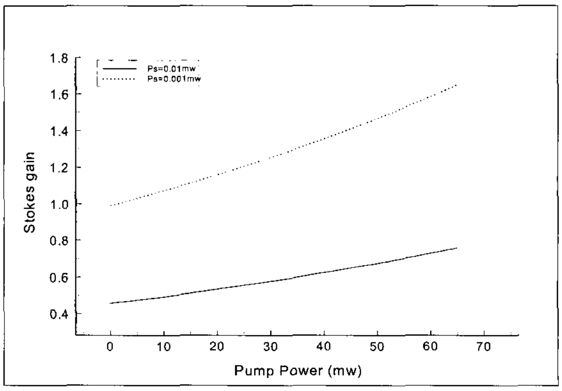


Fig. 3. Net gain of stokes signal as a function of pump power. The change in stokes power is reflected as change in the 0dB.

Assuming α = 0.2 *dB/km* at 1.03 μm and a fiber core diameter of $8\mu m$ by 3*M*. The net gain of stokes signal as a function of the pump power is shown in Fig. 3. It indicates a change in pump power as a change in the 0 *dB*(or 1.0) gain point. The threshold of the neuron can be controlled by changing the power launched in the Stokes signal. Thus different neurons can have different thresholds. For a single mode optical fiber, the threshold incident laser power required is on the order of 10 *mw* for 1*Km* fiber. Thus, the sensor power level should be ~10 *mw*, and the pump power level should be greater than 10 *mw*.

4. Controlling SBS Chaotic Instability

Conversion of SBS chaos induced instability to periodic effect is inspired by theory in nonlinear dynamics. The basic idea lies in the stabilization of unstable periodic orbits embedded within a chaotic attractor [8].

Since these orbits are very dense in such an attractor, a successful control may therefore serve as a generator of rich forms of periodic waves, thus turning the presence of chaos to advantage. The experimental setup for controlling SBS chaotic instability is illustrated in Fig. 4.

A stabilized *cw* probe laser was used as a pump source for low scattering losses in the fiber, yielding a ≈12 *GHz* Brillouin scattering shift. We use a fiber length of *LITESPEC-G-ZEANQ*. Detection is also achieved with *IR* Photodetector Set (New Focus and an amplifier with 20*ps* impulse response) connected to a *HP* Oscilloscope. The temporal repetition rate that corresponds to a pulse round-trip time in the fiber-ring is taken to be less than few *nsec.*

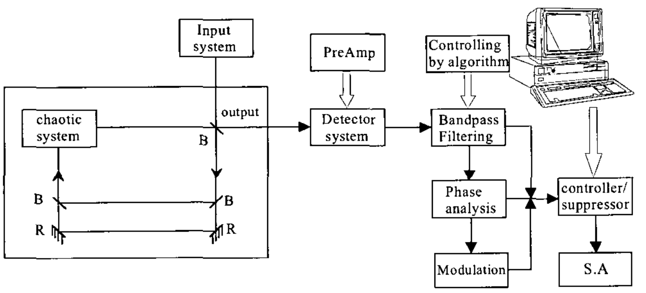


Fig. 4. Schematic diagram for controlling chaos induced instability in an optical fiber system. The optical implementation included a chaotic system conFig.d in a fiber ring. *R* is the mirror reflectivity and *B* is beam splitter.

The Brillouin pulse train amplitudes remain unstable, particularly just below pump threshold. When the observation is made using a long time scale (μsec */division*), the Brillouin output exhibits randomly distributed trains of periodic pulses. Partial stabilization of amplitude fluctuations is achieved as laser pump power approaches maximum value. These experimental features are shown in real time in Fig. 5 and Fig. 6.

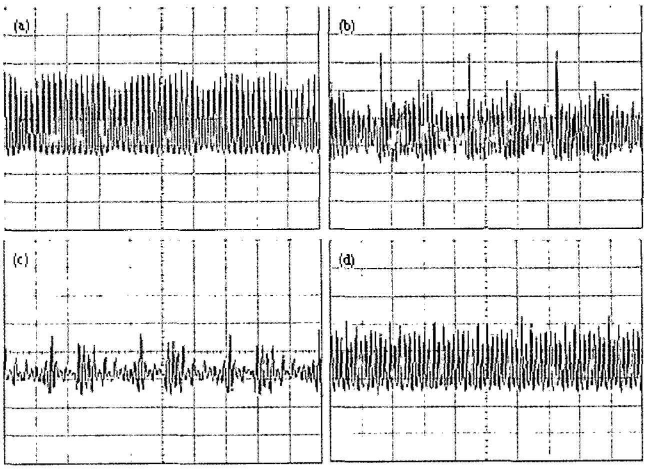


Fig. 5. Brillouin induced various instabilities in function of time (µsec/div) at threshold and above thresholds.

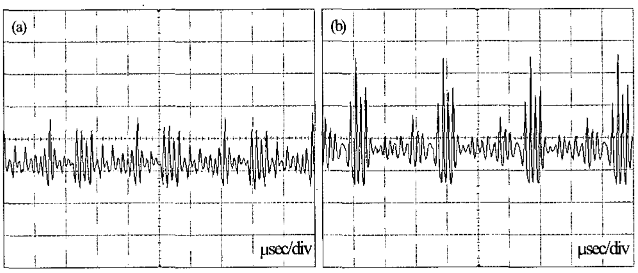


Fig. 6. Brillouin induced instabilities in function of time (µsec/div) at threshold (a) and high above threshold (b)

At low power, Brillouin instability can occur below SBS threshold. This is much lower than the power required for normal Brillouin process, involving single pump power. The temporal evolution immediately above threshold is periodic and at lower intensities can become chaotic. We propose to employ continuous optical feedback for control in which coherent interference of the chaotic optical signal with itself, when delayed, can achieve signal differencing for feedback. If suppressing by attractor proves to control chaos then, suppressing under natural chaos can be exploited as a means of sensing structural chaos. The examples of sequence of suppression are assigned by 'low level' and 'high level' states. Multi-stable periodic states, as shown in Fig. 7 (a) and (b), can lead to logic '0' or '1' and can in principle create large memory capacity as input bit streams in TDM network systems. Its implementation still requires significant engineering improvements, such as arriving at a spatial resolution that is comparable to the references or speckle, and suppression of its tendency to chaos.

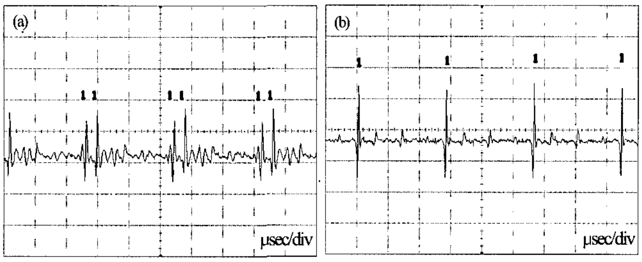


Fig. 7. Transiently controlled SBS chaos induced instabilities (µsec/div) at threshold (a) and high above threshold (b). The examples of sequence of suppression are assigned by '0' and '1' symbols.

5. Conclusions

We studied that the controlling of sBs in optical system based smart structures leads to neural networks with multistable periodic states, creating optical logic 1 or 0. It is theoretically possible to apply the multi-stability regimes as an optical memory device for encoding/decoding messages and complex data transmission in optical communications systems. It can also in principle create large memory capacity.

Acknowledgements

This work was financially supported by MOCIE(I-2004-0-074-0-00) through the EIRC program.

References

[1] Gregory D. Vanwiggeren, Roy, R, "Communication with Chaotic Lasers" SCIENCE. Vol. 279, pp.1198-1200, 1998

[2] Koyamada, Y., Sato, S., Nakamura, S., Sotobayashi, H., Chujo. W. "Simulating and Designing Brillouin Gain Spectrum in Single-Mode Fibers", *J. of Lightwave Tech.* Vol.22 *(2),* pp. 631-639, 2004.

[3] Bernini, R., Minardo, A., Zeni. L, "Stimulated Brillouin scattering frequency-domain analysis in a single-mode optical fiber for distributed sensing", *Optics Letters.* Vol.29(17), pp.1977-1979, 2004.

[4] Hotate, K., Sean, S., L, Ong., "Distributed Dynamic Strain Measurement Using a Correlation-Based Brillouin Sensing System" IEEE. Photonics Letters. Vol.15 (2), pp. 272-274, 2003.

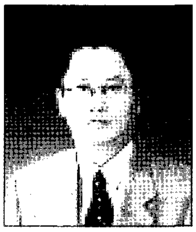
[5] Tanemura, T., Takyshima, Y., Kikuchi. K., "Narrowband optical filter, with a variable transmission spectrum, using stimulated Brillouin scattering in optical fiber", *Opt. Lett.* Vol.27 (17), pp.1552-1554, 2002.

[6] Cotter, D.,"Stimulated Brillouin scattering in Monomode Optical Fiber", *J. Opt. Com.* Vol. 4, pp. 10-19, 1983.

[7] Agrawal, G, P. *Nonlinear Fiber Optics, 3rd, Academic press*, London 2001.

[8] Tariq, S., Habib, M, K., "Neural operation using stimulated Brillouin scattering in optical fiber", *Opt. Eng.* Vol.37, pp. 1823-1826, 1989.

[9] Yong K. Kim, Jin S. Lee "Chaotic and Instability Effects of Brillouin-Active Fiber-Ring Sensor", *Trans. KIEE*, vol. 53C, No. 6, pp. 337-341, June 2004.



Yong K. Kim
He received his Ph.D. degree in Electrical Engineering at North Carolina State University. His research interests are fiber optics sensing, photorefractive fiber and crystal devices, and PLC Optical signal processing.

Do Geun Huh
He received his Ph.D. degree in Electronic Engineering, Kyung Hee University, Korea. He is currently a Professor in the Division of Electrical, Electronic, and Information Engineering, Wonkwang University. His interests are image processing and communication systems.

Kwan-Woong Kim
He received his B.S., M.S. and Ph. D degrees in Electronic Engineering from Chonbuk National University in 1996, 1998 and 2002, respectively. Now he is part of the faculty of the Division of Electrical Electronic & Information Engineering, Wonkwang University. His interests include traffic management and routing protocol in telecommunication networks and Quality of Service in wireless networks

C. Yu
Department of Electrical Engineering, North Carolina State University, USA