Effect of Neurons on the Performance of Microbend Optical Biosensor
Preeti Singh, Dr. H. M. Rai, Zile Singh

Abstract—Osteoporosis is a very severe disease of bones. It leads to an increased risk of fracture. Existing biosensors need improvement to detect the early onset of osteoporosis. Fiber Optic microbend biosensor is being developed to achieve such an improvement. Microbend sensors are based on Microbend induced excess transmission loss of an optical fiber. Artificial Neural Networks (ANN) were a key development in the field of machine learning. They were inspired by biological findings relating to the behavior of the brain as a network of units called neurons. The basics of these neurons have been utilized to analyze the performance of ANN based simulink model in terms of mean square error (mse). The best validation performance in terms of mse is 0.044938 for one neuron. The percentage accuracy of the designed biosensor is obtained as 94%.

Index terms—Artificial Neural Network, Biosensor, Epochs, Micobend, Neuron, Osteoporosis.

I. INTRODUCTION
Osteoporosis is a very severe disease of bones. It leads to an increased risk of fracture. It is affecting a mass population and increasing day by day the cause may be one or the other. In osteoporosis the bone mineral density (BMD) is reduced, bone microarchitecture is deteriorating, and the amount and variety of proteins in bone is altered. Work has been carried out towards the realization of a flexible, implantable sensor array for measuring surface strain on live bones [1]. Several methods to monitor the bone fracture healing process have been developed. Measuring the strain in an internal plate over times makes it possible using magneto elastic strain sensor [2]. Microbend sensors are based on Microbend induced excess transmission loss of an optical fiber to detect/measure displacement, pressure, strain, temperature etc. If a portion of fiber is deformed, the fiber would exhibit excess light loss [3],[4]. Such perturbation of fiber axis results in redistribution of guided power between modes of the fiber and also coupling of the fiber from one mode/mode group to another. The use of Supercomputers in orthopedic biomechanics research has been reported focus being on functional adaptation of bones [5].

Neural networks process information in a similar way the human brain does. Artificial Neural Networks were a key development in the field of machine learning. They were inspired by biological findings relating to the behavior of the brain as a network of units called neurons. The human brain is estimated to have around 10 billion neurons each connected on average to 10,000 other neurons. Each neuron receives signals through synapses that control the effects of the signal on the neuron. These synaptic connections are believed to play a key role in the behavior of the brain. Neural networks learn by example.

II. METHODS AND MATERIALS
Neural networks is composed of a large number of highly interconnected processing elements (neurons) working in parallel to solve a specific problem.

Fig 1: Basic Components of a Neuron
The fundamental building block in an Artificial Neural Network is the mathematical model of a neuron as shown in fig 1. The three basic components of the (artificial) neuron are:

1. The synapses or connecting links that provide weights, \( w_j \), to the input values, \( x_j \) for \( j = 1, \ldots, m \);
2. An adder that sums the weighted input values to compute the input to the activation function where, \( w_0 \) is called the bias (not to be confused with statistical bias in prediction or estimation) is a numerical value associated with the neuron. It is convenient to think of the bias as the weight for an input \( x_0 \) whose value is always equal to one, so that
3. An activation function \( g \) (also called a squashing function) that maps \( v \) to \( g(v) \) the output value of the neuron. This function is a monotone function.

MATLAB has been used for simulation work. The ANN based test bench has been developed for optimization of fiber-optic biosensor for strain measurement in ortho applications using MATLAB and then subsequently iterations have been performed to analyze the performance of the simulink model by considering the concept of neurons.
III. RESULTS AND DISCUSSION

Strain on bones can be measured more accurately with the improvement in biosensors. Such an improvement is being achieved with the design of fiber optic microbend biosensor model shown in fig 2 "to be published" [6]. A simulink model is being designed on the basis of system modeled shown in the fig 3. A strain vs. attenuation linear graph is obtained by tuning the modeled system.

![Fig 2: Photograph Of Biosensor Used For Taking The Readings](image)

![Fig 3: Simulink Model of Biosensor](image)

A simulation of Artificial Neural Network based biosensor has been carried out using the concept of neurons on the basis of which the performance of the system is being analyzed. Analysis is being made with one neuron.

**Fig 4: Neural Network Training Tool Showing With One Neuron Showing Various Parameters of Progress**

Fig 4 shows the neural network training tool depicting the various sections of ANN simulation process i.e. neural network system, algorithms, progress and plots. Performance evaluation is made in terms of mean square error (mse).

**Fig 5: Number of Epochs vs. Training State Parameters**

ANN based biosensor in the present research, is considered in terms of one neuron of neural network. Number of iterations (epochs) are being carried out. It has been observed that the number of iterations carried out for one neuron based neural network is 13.
The respective values of gradient, \( \mu \) and validation check in the training state in 13 epochs are 7.0472e-005; 1e-010 and 6 respectively are shown in fig 5. The performance of the system is analyzed in terms of number of epochs versus mse as shown in fig 6. The graph is showing trends of trained, validation and test data in terms of epochs versus mse. It is clear that with the increase in number of epochs the mse decreases for all trained, validation and test data with slight difference in the slope. The best validation performance in terms of mse is obtained as 0.573. With further iterations it is reduced to 0.044938 at epoch 7. On the basis of parametric performance the percentage accuracy of the neural network based biosensor for one neuron system comes out to be 94%.

IV. CONCLUSION

The model of photometric microbend biosensor is designed to improve the performance of biosensor. Such improvement is analysed with Artificial Neural Network on the basis of neurons of the network. The trained, validated and test data is analyzed as number of epochs vs. mean square error (mse). The maximum mse at initial iterations is obtained as 0.573. With further iterations it is reduced to 0.044938 at epoch 7 i.e. the best validation performance in terms of mse. The percentage accuracy of the ANN based photometric strain biosensor trained using one neuron comes out to be 94%. The ANN based microbend biosensor shall be further analyzed by varying the number of neurons for better performance.

REFERENCES


AUTHOR BIOGRAPHY

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Development of Optical Biosensor Based on Microbending Technique

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Abstract—In orthopedic treatments, measuring the strain makes it possible to monitor the bone fracture healing process. With the recent development of biosensors, it is now possible to monitor the strain on the bones. For this purpose a number of biosensors have been proposed. However, not much work has been done in the field of photometric sensors. Micro bend sensors are based on micro bend induced excess transmission loss of an optical fiber to detect/measure displacement, pressure, strain, temperature etc. A Fiber Optic Biosensor is modeled.

Keywords - Attenuation, bones, fiber optic biosensor, linear, micro bend, strain.

I INTRODUCTION

Bones have a natural and physiological ability to regenerate themselves. After a fracture, bone cells temporary proliferate at the fracture site to form a reparative tissue. During the healing process, the fractured bone is subjected to various treatments. Bone loss, new bone breakage and improper healing are complications that sometimes arise. In order to anticipate such failures, proper monitoring is required [1]. With the recent development of biosensors it is now possible to monitor the strain of the bones. For this purpose a number of biosensors have been proposed. These are mechanically robust micro fabricated strain gauges for use on bones, micro scale sensors for bone surface strain measurement and polyimide based single walled carbon nanonets flexible strain sensor for bone [2],[3],[4],[5]. Most of the researches have focused on using electrical transducers for measurement of strain but not much work has been done in the field of photometric sensors. The photometric sensors have the advantage of being chemically inert. They do not cause thrombosis. Moreover these are light flexible and EMI/RFI immune. Also such biosensors are electrically inert reducing the fear of patients in terms of shocks etc. With the improvement in biosensor for measuring the strain on bones it will be possible to more accurately detect the onset of osteoporosis.

Micro bend sensors are based on micro bend induced excess transmission loss of an optical fiber to detect/measure displacement, pressure, strain, temperature etc. If a portion of fiber is deformed, the fiber would exhibit excess light loss [6],[7],[8]. Such perturbation of fiber axis results in redistribution of guided power between modes of the fiber and also coupling of the fiber from one mode/mode group to another. Also, Artificial Neural Networks are viewed here as parallel computational models, with varying degrees of complexity, comprised of densely interconnected adaptive processing units.

II METHODS AND MATERIALS

Intensity modulation induced by microbending loss in multimode fibers can be utilized as a transduction mechanism for detecting environmental changes. In ray description due to sharp bends in the fiber, there will be some light rays falling at the core cladding interface at an angle less than the critical angle, thus preventing their total internal reflection. These rays will thus be lost from the guiding structure. As the fiber is bent more and more sharply, so more and more number of rays will thus be lost and at a certain bend radius defined by the fiber geometrical characteristics, the bend loss becomes very steeply dependant on bend radius and the micro bend sensor takes advantage of this very fact. Such sensors can be made very sensitive being capable of measuring displacement down to 10-3 microns and strains to 10-7 and pressure up to 10-6 kg/mm².
If the spatial wavelength of periodic deformation satisfies the following phase matching condition between pair of modes,

$$\beta_p - \beta_q = \frac{2\pi}{\lambda_o}$$  \hspace{1cm} (1)

where $\beta_p$ and $\beta_q$ represent modal propagation constants,

then power transfer will occur from $p$th path to $q$th mode. If $q$th mode happens to be a radiation mode, then this transfer of power will result in a net transmission loss of the guided modes. From theory of coupled modes, it can be shown that for the case of step index fiber of core radius 'a', core index $n$. The relative core cladding difference, required to induce heavy transfer of power from highest order guided modes to radiation modes will be given by the expression

$$\lambda_{cr} = \frac{c}{\sqrt{\Delta}} = \frac{\sqrt{n_1^2 - n_s^2}}{N.A.}$$  \hspace{1cm} (2)

Where $\Delta = \text{Relative indices difference}$,

$a = \text{Radius of fiber core}$,

$n_1 = \text{Refractive index of fiber core}$,

$N.A. = \text{Numerical Aperture}$.

III RESULTS AND DISCUSSION

A data acquisition system has been modeled in VIET Lab of P.U Chandigarh. It comprises of various major units viz. Fiber Optical Receiver, biosensor, and Analog to digital converter. It is shown in Fig. 1.

![Fig. 2. Simulink model of Fiber Optic biosensor](image-url)

Fig. 2. Simulink model of Fiber Optic biosensor

In the measuring unit the Fiber Optic Receiver converts the light intensity from the optical fiber coming from the biosensor fixed at the SMA connector into an electrical signal. This signal is then amplified. The amplified signal is then given to filter circuit. The filter conditions the signal to be input to the Analog to Digital Converter (ADC). The ADC converts the Analog signal into Digital signal. Digital signal is given to the microcontroller for analysis.

The software has been implemented in native MCS51 assembly language. It is kept compact and modular. Separate routines have implemented to initialize the system, handshake with the ADC for multiplexing. The results are acquired and displayed. Due to micro bend compensation, suitable corrections from a lookup table are applied to the results. A strain gage conventional sensor has also been attached along with this fiber optic biosensor for calibration and checking the accuracy of this sensor.
The verification of the data collected was performed by theoretical modeling. The model was constructed in simulink for this purpose. It is shown in Fig. 2. In the present simulink model with the change in the strength of strain the respective attenuation is being measured.

IV CONCLUSION

In the present research, it is proposed that with the improvement in biosensor for measuring the strain on bones it will be possible to detect more accurately various failures during the fracture healing process. For such an improvement a model of fiber optic biosensor is developed. The accuracy of the said sensor is checked with the aid of conventional strain gauge sensor. On the basis of the system developed a simulink model is designed. The present simulink model will be further tuned to get the strain vs. attenuation linear response by optimizing various parameters from the collected data.

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BIOGRAPHIES

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Modeling of Fiber Optic Biosensor to Measure Strain on Bones for Detecting Onset of Osteoporosis

Preeti, Dr. H.M. Rai

Abstract - Osteoporosis is a disease of bones that leads to an increased risk of fracture. With the recent development of biosensors it is now possible to monitor the strain on the bones. For this purpose a number of biosensors have been proposed but not much work has been done in the field of photometric sensors. Microbend sensors are based on microbend induced excess transmission loss of an optical fiber to detect/measure displacement, pressure, strain, temperature etc. An FBG is deformed, the fiber would exhibit excess light loss (5),[6],[7]. Such perturbation of fiber axis results in redistribution of guided power between modes of the fiber and also coupling of the fiber from one mode/mode group to another. Also, Artificial Neural Networks are viewed here as parallel computational models, with varying degrees of complexity, comprised of densely interconnected adaptive processing units.

Keywords - Artificial Neural Network, attenuation, fiber optic biosensor, linear, micro bend, Osteoporosis, strain.

1 INTRODUCTION

The importance of bone quality has long been recognized by orthopedic clinicians and radiographers to account for damage accumulation and predict susceptibility to fractures. Osteoporosis is a disease of bones that leads to an increased risk of fracture. In osteoporosis the bone mineral density (BMD) is reduced, bone microarchitecture is deteriorating, and the amount and variety of proteins in bone is altered. With the recent development of biosensors it is now possible to monitor the strain on the bones. For this purpose a number of biosensors have been proposed e.g. mechanically robust microfabricated strain gauges for use on bones, microscale sensors for bone surface strain measurement and polyimide based single walled carbon nanonets flexible strain sensor for bone [1],[2],[3],[4]. Most of the researches have focused on using electrical transducers for measurement of strain but not much work has been done in the field of photometric sensors. The photometric sensors have the advantage of being chemically inert and do not cause thrombosis. Moreover these are light flexible and EMI/RFI immune. With the improvement in biosensor for measuring the strain on bones it will be possible to more accurately detect the onset of osteoporosis.

Microbend sensors are based on microbend induced excess transmission loss of an optical fiber to detect/measure displacement, pressure, strain, temperature etc. If a portion of fiber is deformed, the fiber would exhibit excess light loss [5],[6],[7]. Such perturbation of fiber axis results in redistribution of guided power between modes of the fiber and also coupling of the fiber from one mode/mode group to another. Also, Artificial Neural Networks are viewed here as parallel computational models, with varying degrees of complexity, comprised of densely interconnected adaptive processing units.

2 METHODS AND MATERIALS

In ray description due to sharp bends in the fiber, there will be some light rays falling at the core cladding interface at an angle less than the critical angle, thus preventing their total internal reflection. These rays will thus be lost from the guiding structure. As the fiber is bent more and more sharply, so more and more number of rays will thus be lost and at a certain bend radius defined by the fiber geometrical characteristics, the bend loss becomes very steeply dependant on bend radius and the microbend sensor takes advantage of this very fact. Such sensors can be made very sensitive being capable of measuring displacement down to $10^{-3}$ microns and strains to $10^{-7}$ and pressure up to $10^{4}$ Kg mm.

If $\lambda$, the spatial wavelength of periodic deformation, satisfies the following phase matching condition between pair of modes,

$$\beta_P - \beta_q = 2\pi/(\lambda)$$

(1)

where $\beta_P$ and $\beta_q$ represent modal propagation constants, then power transfer will occur from pth to qth mode. If qth
mode happens to be a radiation mode, this transfer of power will result in a net transmission loss of the guided modes [8]. From theory of coupled modes, it can be shown that for the case of step-index fiber of core radius ‘a’, core index n, and relative core-cladding difference, required to induce heavy transfer of power from highest order guided modes to radiation modes will be given by the expression

\[ \frac{\Delta r}{r} = \frac{\Delta (n_1)}{a} = \frac{1}{2} \frac{2}{N.A.} \]

where \( \alpha \) is profile index of fiber, \( \Delta \) relative indices difference, \( a \) radius of fiber core, \( n_1 \) refractive index of fiber core, NA the numerical aperture.

3 Results and Discussion

A data acquisition system has been modeled comprising of various major units viz. Fiber Optical Receiver, biosensor, and Analog to digital converter as shown in Fig. 1.

![Fig. 1. Data acquisition system for biosensor (different views)](image)

In the measuring unit the Fiber Optic Receiver converts the light intensity from the optical fiber coming from the biosensor fixed at the SMA connector into an electrical signal. This signal is then amplified and given to filter circuit which conditions the signal to be input to the Analog to digital converter (ADC). The ADC converts the analog signal into digital which is given to the microcontroller to be analyzed.

The software has been implemented in native MCS51 assembly language keeping it compact and modular. Separate routines have implemented to initialize the system, handshake with the ADC for multiplexing and acquire and display the results after suitable correction due to micro bend compensation from a lookup table. A strain gage conventional sensor has also been attached along with this fiber optic biosensor for calibration and checking the accuracy of this sensor.

![Fig. 2. Simulink model of Fiber Optic biosensor](image)

The verification of the data collected was performed by theoretical modeling. The Fig. 2 above shows the model constructed in simulink for this purpose.

![Fig. 3. Response of model of biosensor; Strain (x-axis) versus attenuation (y-axis) response](image)

The simulink model was then finetuned by changing the values of gain of the preamplifiers to get a linear response. Fig. 3 shows the linear response of the system i.e. with the change in the strength of strain the respective attenuation is being measured and the present simulink model is tuned to get the strain vs. attenuation linear response.

4 Conclusion

Osteoporosis being a very severe disease of bones leading to an increased risk of fracture and affecting a mass...
population is increasing day by day the cause may be one or the other. With the improvement in biosensor for measuring the strain on bones it will be possible to more accurately detect the onset of osteoporosis. For such an improvement a model of fiber optic biosensor is designed. The accuracy of the said sensor is checked with the aid of conventional strain gauge sensor. On the basis of the system modeled a simulink model is designed and the strain versus attenuation is further linearised using the data collected. The accuracy of the present simulink model of Fiber Optic Biosensor shall be further improved using Artificial Neural Network.

5 REFERENCES


