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

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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. A Fiber Optic Biosensor is modeled and a strain attenuation linear response is obtained. Artificial Neural Networks are viewed here as parallel computational models, with varying degrees of complexity, comprised of densely interconnected adaptive processing units.

Keywords- Aritificial 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.

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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 upto 10^{-6} Kg mm.

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

$$\beta_p - \beta_q = 2\pi/(/\backslash) \qquad (1)$$

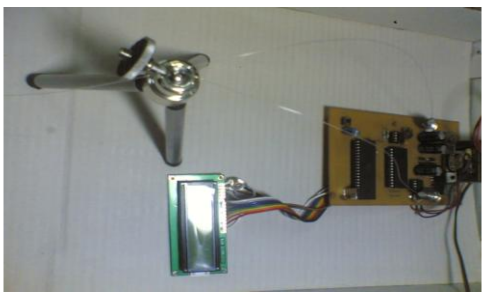
where β_p and β_q represent modal propagation constants, then power transfer will occur from pth to qth mode. If qth mode happens to be a radiation mode, this transfer of power will result in a net transmission loss of the guided modes [8]. From theory of coupled modes, it can be shown that for the case 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

$$/\backslash cr = \pi\alpha/(\sqrt{\Delta}) = (\sqrt{\pi}.a.n1)/N.A. \qquad (2)$$

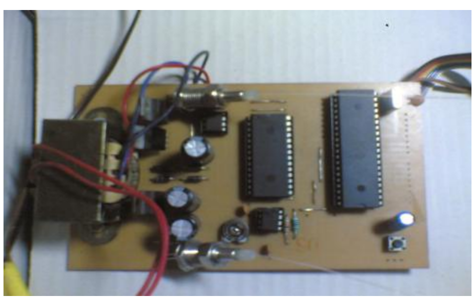
where α is profile index of fiber, Δ relative indices difference, a radius of fiber core, n1 refractive index of fiber core, NA the numerical aperture.

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.



(a)



(b)

Fig. 1. Data acquisition system for biosensor (different views)

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 microbend 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.

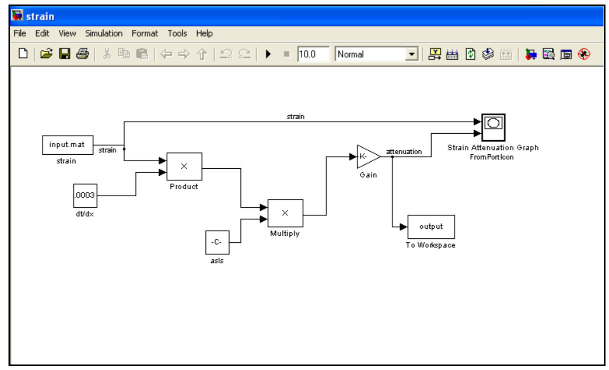


Fig. 2. Simulink model of Fiber Optic biosensor

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

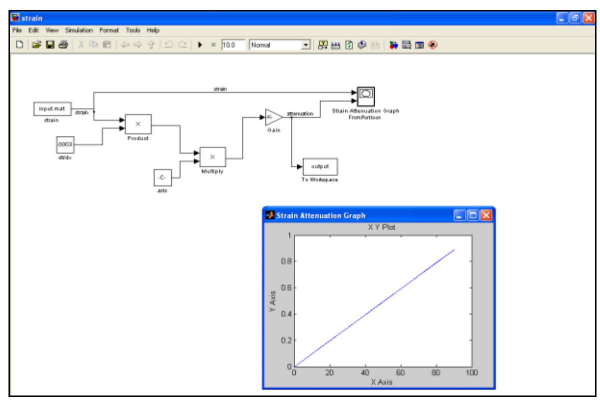


Fig. 3. Response of model of biosensor; Strain

(x-axis) versus attenuation(y-axis) response

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.

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