A Neural Network Approach to Monitor Intraocular Pressure for Glaucoma Diagnosis

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***Abstract*- A nanoarray-enhanced, Fabry-Perot intraocular pressure (IOP) sensor has been recently fabricated for implantation in the eye for glaucoma diagnosis [1]. This work involves the development of an algorithm to process reflectivity data from the sensor collected via remote optical readout under pressure conditions observed in glaucoma patients. The method involves pressure extraction using a neural network approach based on prominent optical spectra characteristics. With the sensor in a pressure chamber, a correlation coefficient of 0.9994 was obtained between the measured and neural network extracted pressure with a run time of less than 30 s, demonstrating the accuracy and efficiency of the algorithm.**

BACKGROUND

A nanoarray-enhanced, Fabry-Perot sensor (Fig. 1) has been developed [1] whose membrane deformation depends on IOP. This deformation is found by measuring the optical spectrum of the sensor. However, as no analytical method exists to determine the IOP from the optical spectrum, a numerical method (Fig. 2) is developed here to extract the pressure from arbitrary optical data. Optical data was collected from the sensor when tested in a pressurized water chamber, ex-vivo rabbit eyes, and in-vivo rabbit eyes. Neural networks have been successful for optical signal processing [3], making them an attractive tool for extracting IOP from collected optical data.

METHODS

A. *Preprocessing*

A typical optical spectrum from the sensor is shown in Fig. 4a. For analysis, the high wavelength regions are removed due to large noise amplitude. Then the remaining data is low pass filtered to remove noise to leave clear, prominent peaks.

B. *Optomechanical Modeling*

The optomechanical model consists of two steps. First, a model was developed to determine the air gap between the sensor's silicon nitride membrane and its silicon base given an IOP. Then, a standard Fabry-Perot model was used to generate a theoretical reflectivity spectrum based on the air gap values. To validate the mechanical model used, the air gap profile was modeled in COMSOL and a close match was found between the analytical large deflection model [2], COMSOL results, and experiment (Fig 3).

C. *Spectral Feature Recognition*

The clearest features of the experimental optical spectrum are its extrema (Fig 4a). Thus, peaks and valleys with sufficient prominence were found in both the experimental and theoretically generated spectra (Fig 4b). Our peak detection method identified 93.66% (340/363) of extrema when analyzing water chamber data and 79.14 % (110/139) of extrema when analyzing ex-vivo data. The peak and valley lines shown in Fig. 4b enable comparison between experiment and theory.

D. *Neural Network Pressure Extraction*

A 10 node feed forward neural network was created and trained using SCG backpropagation. Several noisy theoretical spectra were created for each pressure between 0 and 40 mmHg. Then the wavelength positions of the 2 central peaks and valleys were found for each of the theoretical spectra and for an experimental input spectrum. The theoretical extrema data was used to train the network while the experimental data was fed in for classification. The network outputs correlation values (Fig. 5a) between the input experimental data and the theoretical data for 0 to 40 mmHg. A weighted sum of these correlation values with their corresponding pressures is used to calculate the estimated pressure. Fig. 5b compares the estimated and theoretical pressures.

RESULTS

An average error of 0.8544 mmHg (stdev 0.6274) was obtained between the network simulated and theoretical pressure values for the water chamber data, demonstrating the algorithm reliability. Investigation is ongoing for data from the sensor implanted in in-vivo and ex-vivo rabbit eyes.

REFERENCES

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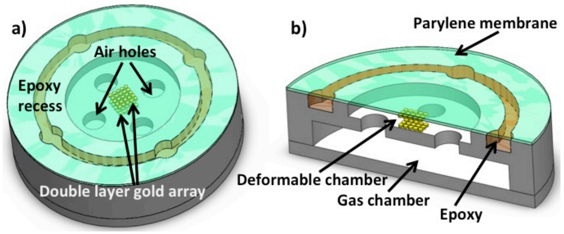

Figure 1: a) 3 dimensional representation of IOP sensor (340µm radius, 0.34µm Si_3N_4 membrane layer thickness, and 50µm x 50µm nano-dot array). b) Cross sectional view with initial air gap of 7.3µm

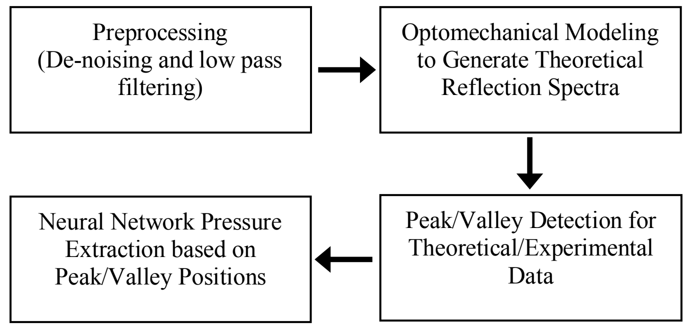

Figure 2: Block diagram of entire system algorithm

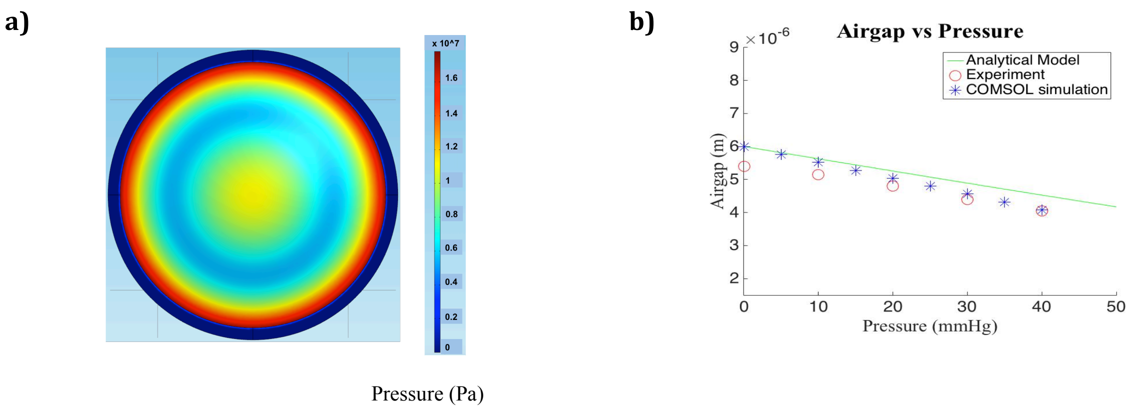

Figure 3: a) COMSOL model of parylene membrane deformation (Pressure profile shown). b) Air gap vs. Pressure for large membrane deflection analytical model, experimental data, and COMSOL simulation.

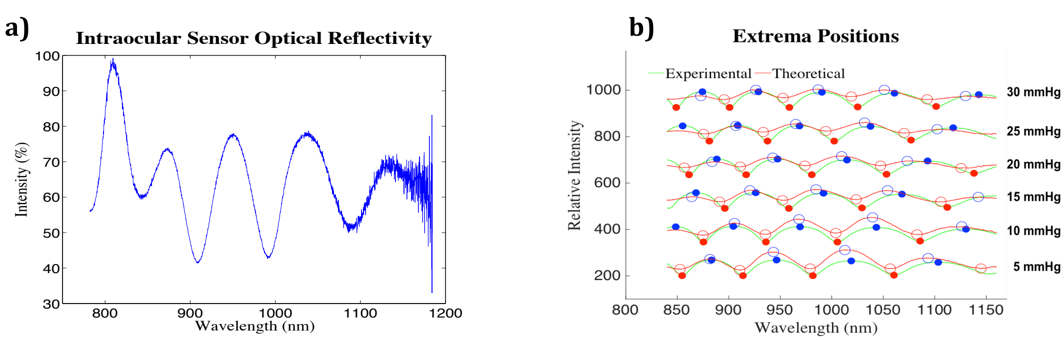

Figure 4: a) Raw optical spectrum from sensor b) Prominent peaks (blue) and valleys (red) of optical spectra collected at 5 mmHg to 30 mmHg in 5 mmHg intervals. Peaks and valleys shift linearly with pressure to form experimental (open circles) and theoretical (closed circles) peak/valley lines.

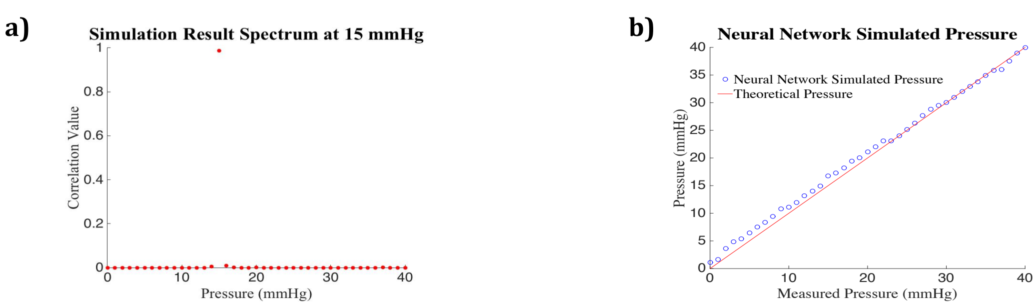

Figure 5: a) Correlation values when a 15 mmHg experimental spectrum is fed into the network. b) Neural network simulated pressure based on correlation values and theoretical pressure values [0 - 40 mmHg].