Continuous Intraocular Pressure Monitoring Systems

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Abstract

It is known that intraocular pressure (IOP) is a key factor in the development of glaucoma, disease which could lead to blindness or eyeball loss. Present techniques are not able to measure IOP in a continuous way, capability which could be extremely helpful in diagnosing and preventing this disease. Implantable devices based on telemetric systems seem to be the most feasible technique to reach this goal. This paper summarizes some research work in this field. Firstly, two types of implantable sensors are evaluated by means of a functional simulation set up. One of them is based on magnetic effects whereas the other is based on resonant effects. Both are compared and, finally, a system based on the resonant sensor for capturing, processing and storing the signal is shown and evaluated.

Introduction

High values of intraocular pressure (IOP) are supposed to be the main cause, although not the only one, of glaucoma. This disease is known to cause blindness or even the loss of the eye. At present, the measurement of this magnitude is performed by means of an apparatus called tonometer which exerts a little push on the eyeball and measures its reaction force. This procedure is only possible in medical centres so the continuous time measurement is nowadays impossible. Continuous monitoring of IOP is very desirable for medical diagnosis and research because it is known the great range of variability of the IOP during the day and as a function of the patient’s activity [1],[2],[3].

In order to reach this goal, a solution based on an implantable device in combination with a telemetric system has been adopted [4]. The implant contains a pressure sensor. The telemetric system must be capable of extracting the pressure information of the implant without wires. In both solutions presented here the telemetric system captures the information with a coil whose magnetic field lines are perturbed by the implanted device. The coil is embedded in an eyeglass frame. Figure 1 shows the location of the implantable device.

Figure 1. Eye anatomy. A. Eyeball. B. Orbit bones. C. Eye muscles. D. Optic nerve. E. IOP pressure sensor. F. Glasses with reception system.
In addition, the system must contain an electronic subsystem whose functions are capturing, processing and storing the pressure signal. The architecture of the electronic subsystem is subordinated to the type of sensor chosen, so this paper begins with the evaluation and comparison of two approaches for the sensor.

**Magnetic sensor**

This sensor is made of a material whose magnetic permittivity changes with the applied pressure. In this manner, as the sensor perturbs the magnetic field lines, the changes in pressure produce changes in the impedance of the glass coil.

A simplified functional set up was used to evaluate the performance of this type of sensor. Several ferrite disks with different thicknesses were placed at 1cm from a circular coil which simulated the eyeglass coil. Different thicknesses simulate variations in magnetic permittivity as a consequence of the pressure. The new values of resistance and inductance of this coil versus frequency were obtained by an impedance analyzer (HP4190A) and the results are shown in Fig. 2. The variations are small but not negligible. However, the strong dependence of the impedance variation with the distance between the sensing coil and the sensor is the main obstacle for adopting this method to measure IOP.

![Figure 2](image.png)

*Figure 2. Variations of impedance for several ferrite disks at 1 cm from the sensing coil.*

**Resonant sensor**

The pressure sensor is a capacitive sensor. This capacitance is placed in parallel with a coil magnetically coupled to the eyeglass coil. The real part of the impedance of the external coil has a resonant peak at the resonance frequency of the LC pressure sensor. Hence, by measuring this frequency we are able to obtain directly the capacitance value and the IOP. In Fig. 3 it is shown the functional diagram of this approach.
The resonant frequency is independent of the distance between the external coil and the sensor implanted. This distance reduces the coupling and increases the bandwidth of the resonance, reducing the accuracy of the measurement. Figure 4 shows the real part of the impedance of the coil with an LC circuit placed at several distances illustrating these facts.

**Design of the electronic system for the resonant sensor**

The electronic system used in the resonant sensor performs a frequency sweep between the maximum and minimum frequency of resonance of the LC circuit, extracts the real part of the impedance for each frequency and makes a maximum search of this magnitude inside the range of frequencies swept. Besides, the system processes the signal to minimize noise effects and stores the signal in a removable memory.

This set of functions is accomplished by two subcircuits: one analog and the other one digital. The analog part is made of a sinusoidal oscillator whose frequency is controlled by the digital circuitry, a voltage to current converter (OTA), an analog multiplier and a low pass filter, as shown in Fig. 5. The oscillator frequency is swept and its voltage converted to a current by the OTA. This current flows through the external eyeglass coil and the resulting voltage is multiplied by the voltage of the oscillator. A low pass filter extracts a signal proportional to the real part of the impedance of the external coil.
The digital circuit (Fig. 6) converts to digital the output of the analog part with an A/D converter. The frequency of the oscillator is controlled by means of a D/A converter. A frequency meter measures the oscillator frequency in a continuous way. The core of the digital circuitry is a microcontroller with the necessary software to perform all this tasks, including the storage of the data in a removable memory.

![Figure 6. Digital subcircuit](image)

This circuit has been tested and preliminary results are shown in Table 1. The resonance frequency measured by the prototype is compared with the frequency measured by the impedance analyzer. The last column represents the difference between the two measurements divided by the frequency measured by the impedance analyzer. The error is below 1%, enough for an accurate measurement of the IOP.

<table>
<thead>
<tr>
<th>C(pF)</th>
<th>( f_{\text{resonance}}(\text{MHz})_{\text{HP4190A}} )</th>
<th>( f_{\text{resonance}}(\text{MHz})_{\text{prototype}} )</th>
<th>Relative error (%)</th>
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<tr>
<td>430</td>
<td>10.837</td>
<td>10.836</td>
<td>0.001</td>
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<tr>
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<td>10.261</td>
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<td>9.8591</td>
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<td>9.341</td>
<td>0.06</td>
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<td>0.07</td>
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<td>8.764</td>
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<tr>
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<td>9.127</td>
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<tr>
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REFERENCES


