Electronic Monitoring of Head Position after Vitrectomy

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Abstract — **A developing electronic monitoring system is intended to help patients with maintaining an optimum head position during the recovery process after an ophthalmologic surgery procedure called *vitrectomy*. In the final phase of this operation a bubble of expansive gas (SF_6 or C_3F_8) is injected into the eye to push recovering parts of the retina together. Positioning the head correctly for a period of several days or even weeks is then crucial for achieving optimal treatment results.**

The designed head-mounted intelligent device continuously monitors the head position and immediately warns the patient whenever detected position is out of the desired boundaries set by the clinician. The position of the head is described by the angle of tilt in all axes. As a sensing element a 3D MEMS accelerometer is utilized. Digital signal processing is used for noise suppression, tilt angle calculation and for calibrating the sensor. Position data is stored into a built-in flash memory in regular intervals during the whole postoperative period. Each non-ideal head position occurrence is stored immediately regardless the sampling interval length.

As a part of postoperative examination procedures, position data can be downloaded to the host computer at the clinic, analyzed and confronted with the actual therapy results. Computer software for data acquisition and analysis is also a part of the system.

The proposed solution will improve results of vitreoretinal surgery procedures. The designed system is in fact a form of Holter monitoring combined with biofeedback and biotelemetry in postoperative head tilt monitoring.

Keywords — **head, tilt, monitoring, accelerometer, MEMS**

I. Introduction

Keeping patient's head in a certain position during the postoperative recovery period is often necessary for optimal results of the recovery process after complicated ophthalmological operations [4].

Presented paper is focused on a combination of a biofeedback and data logging system. A microcontroller driven intelligent sensor helping the patient in maintaining proper head position and computer software for remote controlling and data acquisition from the device are described in the following text.

A typical subject intended for post operative head tilt monitoring is a person recovering from retinal surgery. Patient's eye needs to be positioned in way that allows a bubble of expansive gas injected inside to push on the recovering parts of the retina.

The patient suffers from a distinctive swelling in the area of eyelids and orbit tissues and the postoperative eye is only minimally movable. This allows us to make no difference between the position of the head and the actual position of the patient's eye.

II. Basic principles

A. Tilt sensing with MEMS accelerometers

A method of tilt sensing with MEMS accelerometers was chosen. Tilt sensing using MEMS accelerometers is based on measuring static acceleration forces such as gravity. Position of the patient's head can be obtained from the angle of tilt in x and y axis against the ground reference as seen in fig. 1.

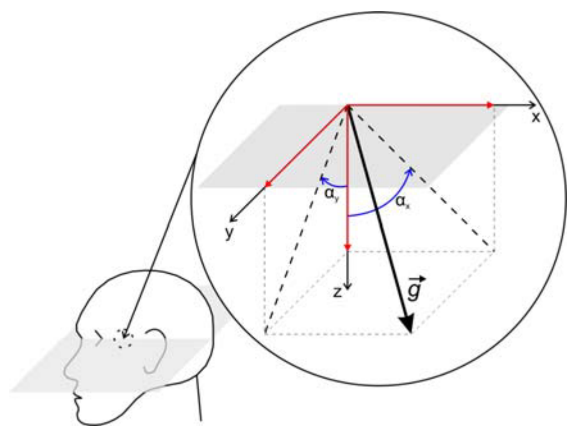

Fig. 1 Head tilt sensing with a triple axis accelerometer

Sensing by a triple axis accelerometer as seen in fig. 1 appears to be an efficient method. Using goniometric functions, the angles of tilt against the plane parallel to ground can be calculated from three measured components a_x, a_y and a_z of the acceleration force vector applied to the head.

J. Vander Sloten, P. Verdonck, M. Nyssen, J. Haueisen (Eds.): ECIFMBE 2008, IFMBE Proceedings 22, pp. 1758–1761, 2008

In case both static and dynamic accelerations are applied, these angles describe the direction of the resulting acceleration force vector, which only has the influence on the gas bubble position inside the post-operative eye.

Orthogonal coordinates of the acceleration force vector need to be converted into their angular representation useful in tilt angle monitoring.

Equation (1) is an example of computing α_x tilt angle. The resulting angle should fall within $<-\pi; +\pi>$ interval.

$$\begin{aligned} a_z > 0: &\quad \alpha_x = \arctan\left(\frac{a_x}{a_z}\right) \\ a_z < 0 \wedge a_x \geq 0: &\quad \alpha_x = \arctan\left(\frac{a_x}{a_z}\right) + \pi \\ a_z < 0 \wedge a_x < 0: &\quad \alpha_x = \arctan\left(\frac{a_x}{a_z}\right) - \pi \end{aligned} \tag{1}$$

Although the equation above represents a simple mathematic task, for an 8-bit microcontroller used in our design it may be very time consuming using standard C libraries. Methods for fast integer calculation of goniometric functions have to be used.

Fast integer computing of tilt angle was finally implemented using a method built around a 256-value per quadrant look-up table for *arctan* calculation.

B. Accelerometer offset error correction

When sensing static acceleration forces, MEMS accelerometers often introduce a slight offset error in one or more axes. We eliminate this error by calculating these offsets at the time of initial setup of the device and including them into further computations as offset correction constants. The method used for offset calculation is based on solution to the general equation of a sphere from 4 points on its surface. The principle is clearly illustrated in fig 2. Coordinates of four points (P_1 up to P_4) on the spherical surface are given by acceleration force vector components measured stepwise in four different positions of the sensor. Solving the equation of a sphere, we get the coordinates of the sphere center *C*, which are in fact the offset correction values x_0, y_0, z_0 for all three axes.

The main advantage of this method to a classical approach based on computing average values from minimum and maximum values in each axis is its ease of use in common practice. One does not need to search for limit values but simply puts the whole tilt sensing device in 4 or more different positions with different tilt angles.

Described procedure needs to be done at the time of production or when the accelerometer is being replaced.

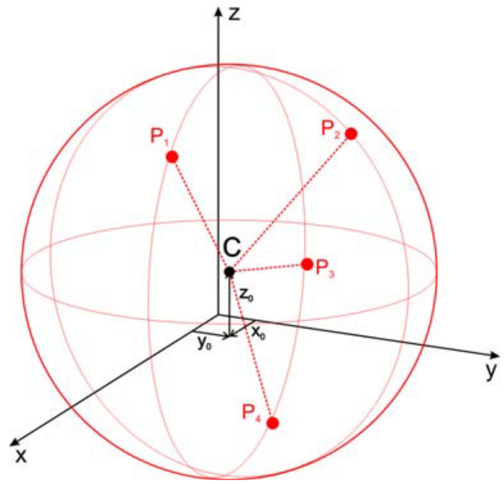

Fig. 2 Calculating accelerometer offset corrections with the equation of a sphere from 4 points.

III. Results

A. Hardware design

A complete block diagram of the prototype device can be seen in fig. 3. We are using AtMega16 microcontroller from Atmel or alternately HC908GZ32 from Freescale for initial testing. These microcontrollers support in-system programming and are optimized for high-level programming language development. Both contain 10-bit ADC for processing analog signals from accelerometers equipped with analog outputs. Currently we are experimenting with both analog and digital output accelerometers. The analog type used is ADXL330 triple axis MEMS accelerometer. The digital type used in experiments is LIS3LV02DL accelerometer with I^2C serial interface.

To reduce noise, averaging of the input signals is implemented in the firmware. This low-pass filtering also reduces number of possible false alarms caused by rapid movements or short-term deviations from the desired tilt angle. Achievable accuracy of angular measurements is approx. 1 degree, which is sufficient for clinical practice.

An acoustic transducer is used as a warning indicator in case the patient moves the head so its tilt is not within the preset desired range. This bio-feedback application helps the patient in maintaining the optimal head position that was determined by the ophthalmologist at the time of operation.

EEPROM memory integrated in the microcontroller is used for saving calibration data (maximum and minimum in every axis, allowed angles etc.) and basic settings. External FLASH memory is used for storing larger amounts of data obtained during regular head position measurements.

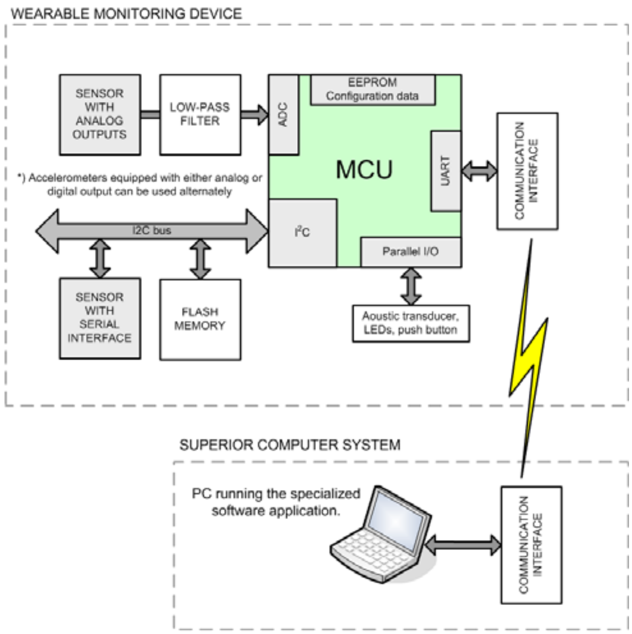

Fig. 3 A block diagram of the designed device

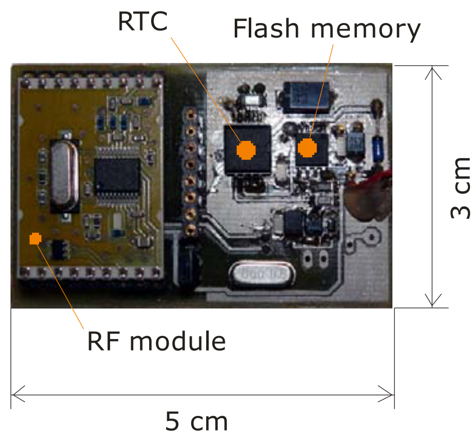

Fig. 4 Top side of the printed circuit board of a prototype device.

Accelerometer data is sampled every 5 seconds as the device regularly wakes up from its power saving mode. Position data are stored into external non-volatile memory every 5 minutes or immediately in case of deviation from the desired head position lasting longer than a defined amount of time. Each record in the memory contains a time stamp and position data.

A 3V lithium cell is used as a power supply. Thanks to power-saving mode of the MCU only a single battery is sufficient for powering the device during the whole monitoring period.

A photo of a prototype device is pictured in fig. 4 where communication module, real time clock (RTC) and external flash memory are visible. The microcontroller and accelerometer are placed on the other side of the board.

B. Communication interface

Our system is based on so-called thin client philosophy. That means the tasks performed by the wearable monitoring device are reduced to a minimum. Complicated tasks like sensor calibration or initial setup for a new patient have to be done in collaboration with the server – a computer application with graphic user interface. Therefore a communication interface is needed.

Currently we use both cable and wireless interfaces. So far serial cable, IrDa and ISM RF interface have been implemented.

C. Computer software

Computer software application is used for communicating with the device. It serves for two main purposes: it sets the monitoring parameters and acquires measured data from the device. A screenshot of the main window can be seen in fig. 5. The main window of the application is intended to serve as a quick setup interface.

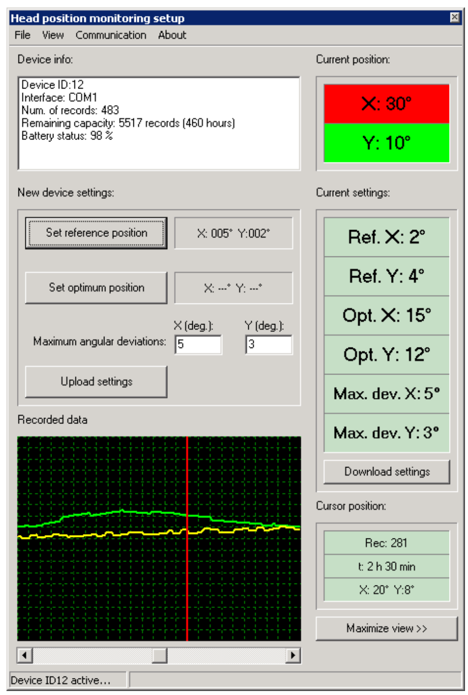

Fig. 5 A screenshot of a computer software application used for setting up the device and data acquisition.

The user is able to monitor actual measured angles of tilt. Current tilt angle of the sensor can be marked as the reference position or the optimal position that has to be maintained. After maximum angular deviations from the optimum are entered, configuration data can be sent to the monitoring device.

The graphical representation of measured data can work in two basic modes. In the off-line mode users can explore a set of measured values downloaded from a flash memory of a monitoring device. The real-time mode can be used for displaying a graph of currently received incoming data. The graphic view can be expanded to a more detailed full-screen window.

Acquired sets of measured data can be exported in CSV file format for further processing and analysis using software such as MS Excel or Matlab.

D. Field of application

Our efforts are aimed on developing a wearable electronic device (intelligent sensor) for post-operative head tilt monitoring that would improve the overall quality of the recovery process after complicated ophthalmologic operations.

Shortly after the operation, the patient is equipped with the monitoring device and desired angles of tilt are set by the clinician. During the post-operative recovery period, the device helps the patient in maintaining the desired head position. The position data are being stored regularly in the devices built-in flash memory.

During the recovery period the patient regularly visits the clinic for examinations. At the time of these visits, position data stored in the monitoring device can be downloaded to a personal computer equipped with proper communication interface and our software. The clinician is then able to analyze the overall success rate of proper head position maintaining and confront it with the actual findings and treatment progress.

IV. Conclusions

Eye surgeons from clinics performing vitreoretinal surgery find proper head positioning crucial for a successful result of the operative treatment. Currently there are discussions on how many days after the operation a head needs to be positioned [1] [2] [3].

Our developing system for post operative head tilt monitoring consists of two basic parts: a wearable intelligent tilt sensor capable of wireless data transfers and a personal computer equipped with communication interface and a special software application used for controlling the sensor and acquiring measured data.

Prototypes of both the monitoring device and computer software were successfully tested.

Remote controlling and data acquisition from the monitoring device is possible trough RF interface, IrDa or serial cable connection.

Achievable accuracy of tilt angle measurements using ADXL330 MEMS accelerometer with analog outputs is approx. 1 degree, which is sufficient for clinical practice. Future efforts will be focused on the overall mechanical design of the device. Recent research has been primarily focused on system functionality and electronic hardware.

Acknowledgment

The work is supported by Czech Science Foundation project No. 102/08/1373.

References

1. Cullen R. Macular hole surgery: helpful tips for preoperative planning and postoperative face-down positioning. J. Ophthal. Nursing. Technol., 1998, 17, s. 179-181.
2. Dahl A., Stöppler M. Retinal Detachment Causes, Symptoms, Signs, Treatment and Risks. MedicineNet.com. Online: <www.medicinenet.com/retinal_detachment/article.htm>. 2007
3. Jacobs P. M. Vitreous loss during cataract surgery: prevention and optimal management. Eye. Online: <http://www.nature.com/ eye/journal>. Feb. 2008
4. Vitreous–retina–macula consultants of New York. Vitrectomy. Online: < http://www.vrmny.com/pe/ vitrectomy.html >. New York, 2006

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