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A Wireless Measurement System for Three-dimensional Ocular Movement Using the Magnetic Contact Lens Sensing Technique

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Abstract— **A new and innovative method to measure the eye movement in a wireless manner was proposed. We verified the feasibility of our idea by fabrication and performance test of a prototype system. The prototype system consisted of a contact lens with a ring-shaped thin magnet, and eyeglasses frame-shaped PCB with analog/digital signal processing circuitry as well as four magnetoresistive sensors. This new method based on the magnetic contact lens sensing technique (MCLST) is expected to overcome all the disadvantages of the existing techniques.**

Keywords—**eye movement measurement, magnetic contact lens sensing technique, magnetoresistive sensors**

I. INTRODUCTION

Several methods for *in situ* measurement and analysis of the eye movements have been developed. An electrooculogram (EOG)-based technique, an videooculogram(VOG)-based technique, and the magnetic field search coil technique (MFSCT)[1] are among the clinically applicable methods with partial success.

The EOG-based method is a relatively widely-known approach and based upon the fact that the rotation of an eye ball as an electric dipole produces detectable changes in electrical potential distribution on the skin surrounding eyes. This method provides a relatively good resolution for horizontal eye movement. But disadvantages of this method include difficulties in calibration as well as obtaining vertical movement signal in good quality.

The VOG-based technique is a new approach using a video recording system. In the VOG system, a video camera records the images of eye ball movement. Then, a specialized computer program analyzes the eye ball movement through digital image processing techniques based on the relative distortion of the pupil image at a given time referenced to the starting time. This is the most non-invasive method among all the introduced methods so far. However, its temporal resolution is limited to the video recording system's frame rate and it loses the target image during an eye blink.

In 1963, Robinson[2] introduced a highly accurate detection system for eye movement. The MFSCT provides a higher sampling rate and is minimally influenced by an eye blink. Under the magnetic field generated by a big external coil, the search coil attached to a contact lens can detect the change of induced current according to the rotation of the eye ball. Assuming that there is no relative motions between the eye ball and the contact lens, projection area of the search coil for given magnetic field is changed as the eye ball rotates. In spite of this clearness of the detection process, the wire connection between amplifier and the search coil provides not only restriction on degree of freedom of the experiment, but also system failure due to its fragility.

In this paper, we proposed an innovative and new method to measure the eye movement in a wireless manner so that we can provide both unhindered eye movement and system ruggedness. Our main idea is based upon the reverse of the MFSCT's detection principle. That is, a small permanent magnet attached on the contact lens surface generates magnetic field and magnetic sensors located at the fixed position relative to the face detects the time-varying magnetic field intensity according to the eye ball movement. This new method of the magnetic contact lens sensing technique(MCLST) is expected to overcome all the disadvantages of the existing techniques including inconveniences and limitation of the MFSCT. The main purpose of this preliminary paper was to fabricate a prototype device of our new MCLST system and to perform a feasibility test.

II. METHODOLOGY

The prototype device consists of two parts; a contact lens with a magnet on it, magnetic field intensity detector on a eyeglasses frame-shape printed circuit board(PCB) with a signal processing unit. Fig. 1. shows a schematic drawing of the prototype device with a block diagram of the signal processing unit.

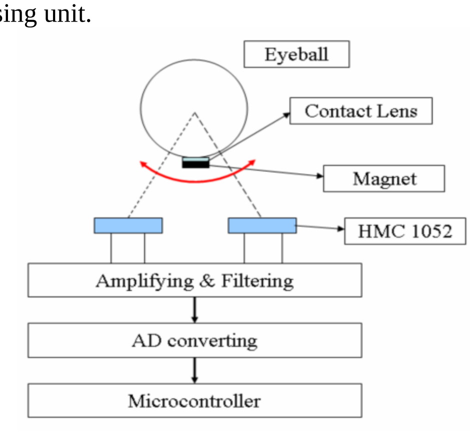

Fig. 1. Schematic drawing of the developed MCLT system

1) Contact Lens with a magnet

A fully swelled contact lens (Acuve-2 disposable contact lens, Johnson & Johnson, USA) was put on a mold which has same surface's curvature of the contact lens. Then a ring-shaped thin rubber magnet was glued to the contact lens at the coaxial position. The fabricated contact lens is shown in Fig, 2 with the in-house built tracking model which was used for performance test.

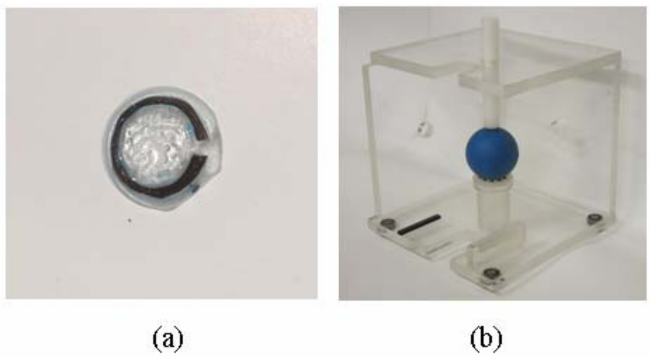

Fig. 2. Pictures of (a) contact lens with a magnet, and (b) in-house made tracking model of an eye ball to which the contact lens is attached.

2) Magnetic field intensity sensors

Total two magnetoresistive sensors (HMC 1052, Honeywell, USA) were assemble on an eyeglasses frame-shaped PCB which contains amplifiers and subsequent signal processing circuitry(Fig. 3). This scheme of close location of the sensors and electronic circuitry in one PCB provides high gain amplification for an extremely weak signal with high fidelity. A microcontroller-based (AVR, Atmel, USA) control unit performs analog-to-digital conversion and signal transmission to a PC for post-processing of the acquired signal.

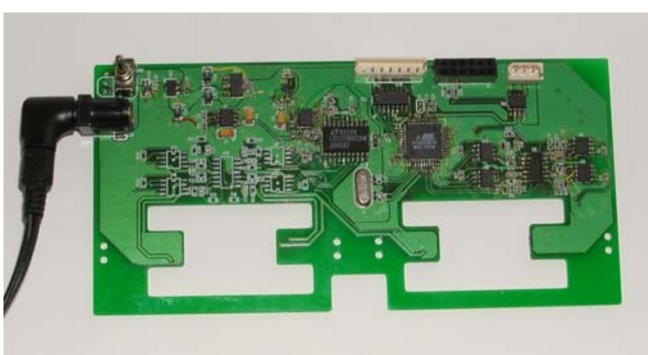

Fig. 3. Eyeglasses frame-shaped PCB for magnetic field sensors and signal processing unit.

3) Feasibility Tests : The contact lens with a magnet was attached to the surface of the eye ball in the tracking model. Then, rotating the eye ball in various directions, we recorded the output signals of the signal processing unit. In order to examine the effect of eye blink, a thick(~1mm) paper was inserted in the gap between the eye ball and the sensor.

III. RESULTS

Fig. 4 shows a typical result of the feasibility test. Two sensors located at the opposite site produced out of phase signal variation as expected. The peak to peak range of the final signal output is about 1.2V under the reasonable range of rotational angle (<20°). Due to the asymmetry in the sensor's relative position to magnet, sensitivities, and corresponding amplifier gain, the absolute amplitude of two tracings are different.

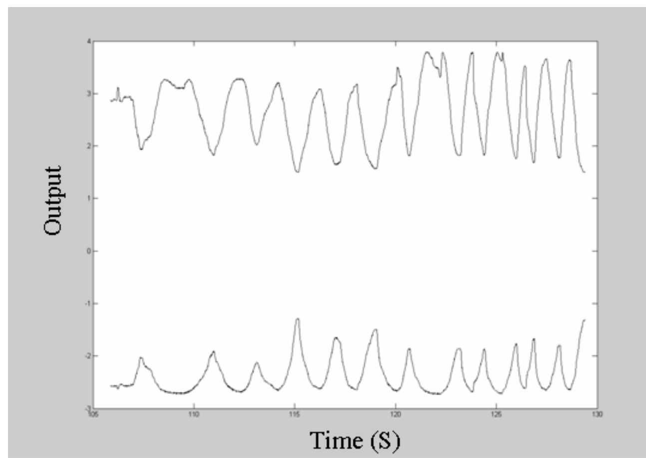

Fig. 4. Output signal from two magnetoresistive sensors when rotating the eyeball from left and to right, then from right to left. The Upper signal comes from right sensor and lower signal from left sensor.

The effect of the intervening paper on the signal output was negligible as shown in Fig. 5 where the difference between two signal outputs is unnoticeable.

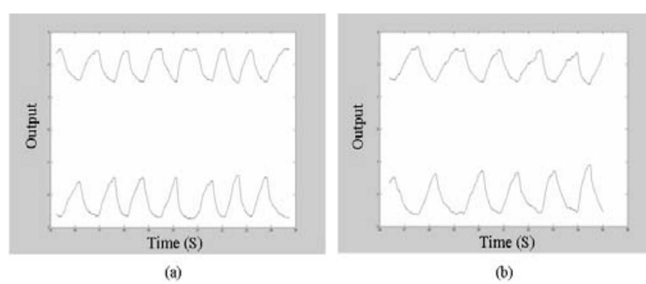

Fig. 5. Signal outputs (a) without any intervention and (b) with a intervening paper between the eye ball and magnetic sensors.

IV. DISCUSSION & CONCLUSIONS

A new and innovative method to measure the eye movement in a wireless manner so that we can provide both unhindered eye movement and system ruggedness was proposed and the feasibility of our idea was verified by fabrication and performance test of the prototype system.

The prototype system consisted of a contact lens with a ring-shaped thin magnet, and eyeglasses frame-shaped PCB with analog/digital signal processing circuitry as well as two magnetoresistive sensors. In feasibility tests, the developed system was applied to the in-house built tracking model and the output signals represented the eye ball movement in a very reproducible manner. The influence of the eyelid during an eye blink was also found to be negligible. This new method of the magnetic contact lens sensing technique(MCLST) is expected to overcome all the disadvantages of the existing techniques. Further researches and development will be performed on the fabrication of a clinically applicable contact lens with a magnet, effective calibration method, and radio-frequency telecommunication linkage between the sensor PCB and the PC for post-processing.

V. ACKNOWLEDGEMENT

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VI. REFERENCES

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