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Artificial neural network-based estimation of the eyeball position using the magnetic contact lens sensing technique

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Abstract— **We have created an artificial neural network based approach for measuring eye movement using a magnetic contact lens sensing technique. The sensor array is based on using four magnetoresistive sensors. A two-layer feed-forward artificial neural network was used and an artificial eyeball model was made for the test. The neural network is trained with sample data obtained from nine spots. After training, we compared the position calculated from the developed system with the real one. The result shows that there is a good linear relationship between them. This indicates the developed system is capable of recording the position of the eyeball with a high degree of accuracy.**

I. Introduction

An innovative and new method for measuring the eye movement using the 'Magnetic Contact Lens Sensing Technique (MCLST)' [1] has been proposed. The MCLST technique is based on the reverse concept of the magnetic field search coil technique [2]. Magnetoresistitive sensors located at fixed position relative to the face detects the magnetic field intensity generated by the magnets attached to the contact lens. A significant potential advantage of this technique is that it does not require wires between the search coil in the contact lens and the signal processing instrument, and this allows the subject to be unencumbered. However, this method has had a couple of significant drawback: the wireless measurement is limited because of the connection for the data transmission. Also, in this method, assuming that there is a linear relationship between the angle of rotation and the output signal of the sensor, there has been a significant level of error in estimating the eyeball position. Therefore, it is necessary to develop an improved system that can increase the subject's mobility and an effective method for detecting the position of the eyeball with a high degree of reliability. In this paper, we present a method that allows us to accurately estimate the position of eyeball using an artificial neural network for the processing output signals from the sensor.

II. Methodology

A. Hardware Design

We implemented the sensor array by arranging four magnetoresistive sensors (HMC1052, Honeywell, USA) at 1.5 cm interval both horizontally and vertically. In order to provide high sensitivity status, the output signal is amplified through a differential amplifier which consists of two op-amps (TL084, Texas Instrument, USA) with a gain of about 600. The amplified signal is converted into a digital signal via an eight-channel analog-to-digital converter (ADC) chip (MCP3208, Microchip Technologies, USA). The digital signal is sent to a microcontroller that encodes the information and transfers it to the transmission unit. A Bluetooth® module (AIRCODE, Initium, Korea) was used for wireless data transmission to the computer. A sampling rate of at least 500Hz is needed to transmit data without aliasing error because the maximum frequency of eye movement is 200Hz. One sample includes eight channels of digital signal that consists of 16bits for a total of 128bits and this indicates that 64000 bits should be transmitted per second. The maximum transmission baud rate of the Bluetooth® module is 115200 bps, which covers the required sampling

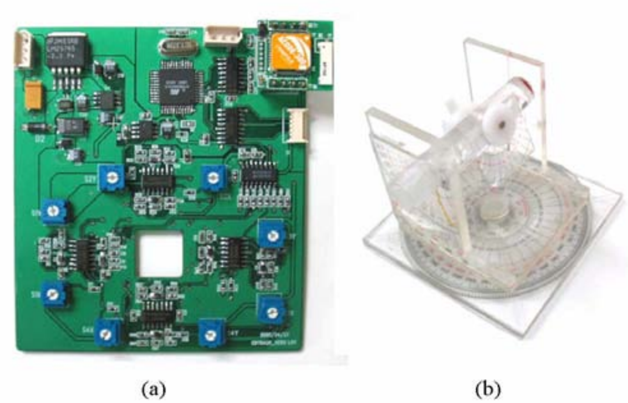

Fig.1. Developed hardware (a) sensor array board (b) artificial eyeball model

B. Artificial Neural Network Design

An artificial neural network can learn the characteristic of a non-linear, non-modeled system through training samples. A two-layered feed-forward backpropagation artificial neural network was used as shown in Fig2. The first layer of a hidden layer consists of nine neurons which have eight inputs corresponding to the number of sensor outputs. The output layer as a second layer has two neurons which are fed with the output of the hidden layer. Those two neurons' outputs present the horizontal and vertical angle of the eyeball rotation from the resting position.

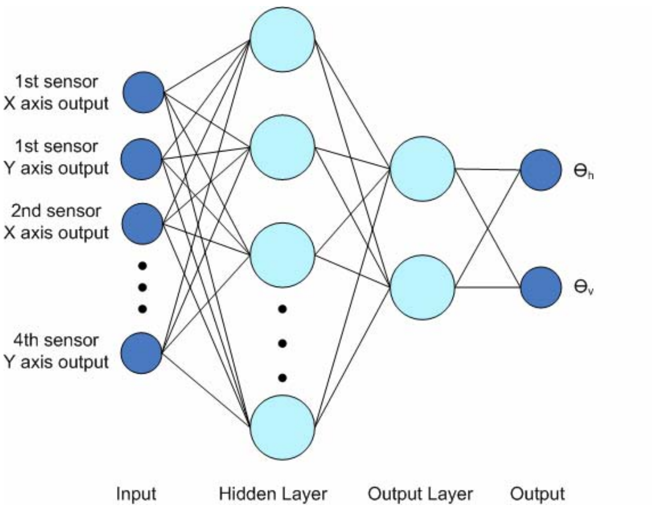

Fig.2. Neural network model for eyeball movement detection

C. *Feasibility Tests*

Feasibility tests to evaluate the performance of the proposed method were performed using an artificial eye model shown in Fig1-(b). The eyeball with a small magnet attached on it was made to rotate in both vertical and horizontal directions. In the first test, we obtained the sample data for training the network by measuring sensor outputs at the fixed nine points with the incremental rotation of -15°, 0°, and +15° in both vertical and horizontal directions. Using these measured data, the network parameters were adjusted to provide the desired results using the backpropagation learning algorithm. In the second test, we verified the accuracy of the trained networks for the vertical and horizontal rotation separately. While rotating the artificial eyeball vertically in the range of -20° to +20° with 2°increment, the vertical positions calculated by the network were compared with the real position of the artificial eyeball. Same test was performed for the horizontal eyeball movement. A least-square linear regression to model the relationship between the network outputs and real positions produced the following equation:

$$P_{Calculated} = A \times P_{Real} + B \quad (1)$$

where A is the slope of the fit and B the intercept. Finally, in the third test, we repeated accuracy verification experiment at 8 different positions which require both vertical and horizontal rotation simultaneously. The mean square error was calculated according to each specified position.

III. RESULT

As the result of the second test, Fig 3 shows that there exists a good linear relationship between the developed system outputs and the real positions throughout the whole rotation range. For the horizontal rotation, A is 1.046 and B is -0.1341, and for vertical rotation, it is 1.034 for A and 0.2040 for B.

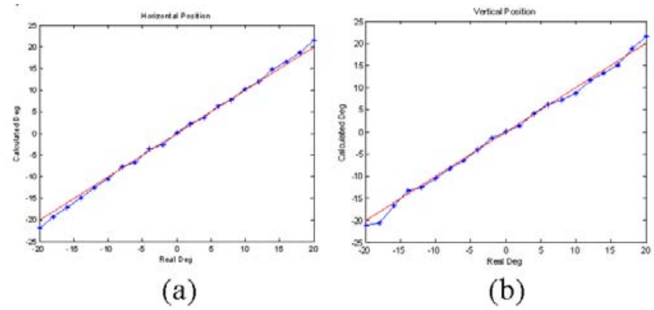

Fig.3. Linear regression of the system outputs vs real position in (a) horizontal and (b) vertical rotation

Fig. 4 shows the results of the third test where calculated positions from the trained neural network were compared with the real position for eight points with simultaneous rotations in the horizontal and vertical directions. The mean square errors of the horizontal and vertical positions are 0.1492° and 0.2344° respectively

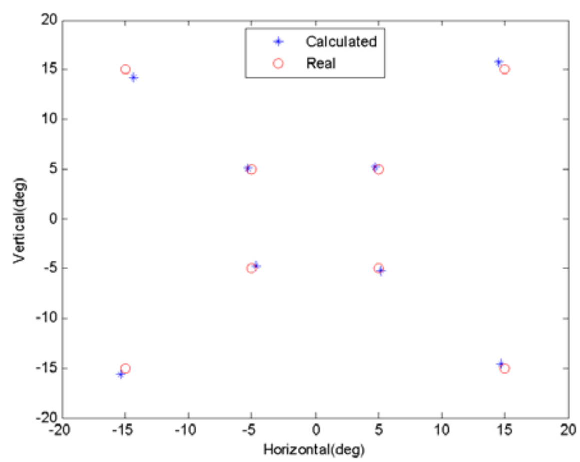

Fig.4. Results of the third test for eight positions with simultaneous rotations in both directions.

IV. DISCUSSION

The well-correlated fits with a slope of near one (horizontal: 1.046, vertical: 1.034) indicates that proposed system is capable of measuring the position of the eyeball with high accuracy over the entire visual field with a range of -20° by +20°. Considering that the mean square error is below 0.5, it is reasonable to conclude that the developed method can provide a high spatial (<<1°) accuracy. Further works are required to reduce the error at the positions with maximum rotational angle of near 20° or -20° as noticeable in Fig. 4.

V. CONCLUSION

An artificial neural network-based approach was proposed for improving estimation accuracy of the eyeball position using the magnetic contact lens sensing technique. The position estimated using this method fit linearly with the real position with a minimal error. Further research should be performed on the production of a clinically applicable contact lens with a magnet on it.

ACKNOWLEDGMENT

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