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Eye Tracking Simulation for a Magnetic-based Contact Lens System

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Abstract— **In this paper, we present a modelling of an eye motion tracking system. The system consists of an moving magnet and three static magnetic sensors, which implies the magnet embedded in a contact lens and sensors fixed on the spectacles in the application scenario. When the eye is moving, the changing relative position between sensors and magnet will result in different sensory outputs that encodes eye movement information. The simulation of eye movements and corresponding magnetic fields was carried out in MATLAB MathWorks software. After collecting the sensory output, artificial neural network was used to decode the signal and classify the direction of gaze. The gaze was classified with 9 or 17 regions, three levels of noise and 5 positions of the sensors. Each test was run on the same conditions and was repeated 10 times for repeatability. It was found that 3 sensors together achieved the best accuracy for noisy signals with 96.1% and 93.7% for mid and high noise, respectively. The 17-label variant showed below 90% for both mid and high level noise, proving to be not suitable for the application. The lens misplacement causes a lot of issues and requires further investigation to lower its impact on the results. This could be fixed by introducing a calibration step. For all of the configurations, usually, the confusion occurred on the neighbouring classes. This could be due to poor design of the classes, where borders of the regions do not overlap, and cause a sudden change. Based on this simulation, better tracking method can be derived.**

Keywords—eye movement, tracking, tunnel magnetoresistance, matlab, neural networks

I. INTRODUCTION

Originally, contact lenses were used to aid, or in some cases treat vision impairment. Nowadays, thanks to the advancement in technology eye contacts can contain microelectronics and many types of sensors [1]–[3], to detect biomarkers and provide medical assistance [4]. They can also be used for eye tracking, which became an essential factor in neurophysiological, behavioural [5] and psychophysical [6] evaluation. On top of that tracing the eyeball movements can be used to control assistive devices for people with impaired mobility (e.g. wheelchair) or for researching sleep disorders.

In this article, a simulation of an eye motion tracking system is presented as an alternative solution to a camera or electrooculogram. The system consists of an N42 Neodymium magnet embedded in a contact lens, tracked with tunnel magnetoresistance (TMR) sensors embedded in spectacles. The setup does not require head stabilization and the contact lens will not need any power supply or telemetry for data transfer. Previous experimental set-up of this system was classified with only 3 directions of gaze with a threshold classifier [7].

II. METHODS I - SIMULATION

A simulation of the system was created in MATLAB MathWorks software. The eye was plotted as a perfect sphere for simplification. The magnet was based 25° above the iris and the sensor was plotted 2.5 cm away from the eye on the eyebrow level, in 3 positions – Left, Centre and Right. The simulation plot is shown in Fig. 1. The randomly generated movements were coded in such a way that the simulated eye does not exceed the real eye limits. The eye rotation is limited by the muscles and cannot rotate more than 25° upwards, 30° downwards and 35° sideways. The eye motion was categorized in the regions of the gaze. Two sets of classes were produced, one with 9 labels and the other with 17. The general regions of both variants can be seen in Fig. 2.

The signal was generated based on the position of the magnet relative to the sensor. The sensor readings were simulated with simplified equations [8]. The equations]were using the specifications of the N42 Neodymium magnet, with diameter and thickness of 1 millimeter (mm). The signal was used in units of pico-Tesla (pT) and consisted of 3 channels – Bx, By and Bz, the magnetic field in all three orientations.

III. METHODS II - CLASSIFICATION

The classification was done with a feed-forward Neural Network with 1 hidden layer. The number of nodes of the hidden layer depended on the number of input and output nodes. For each set-up, total 19996 samples were available for training. The first layer of the network was always the last 5

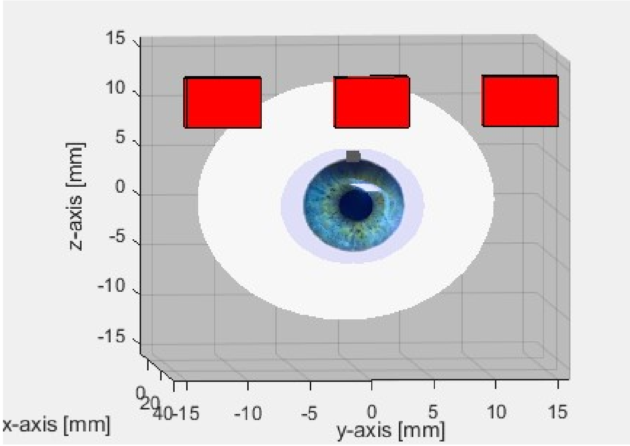
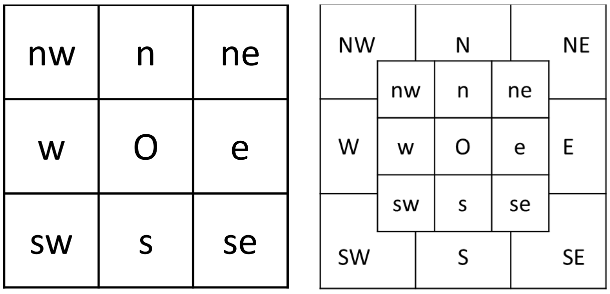


Fig. 1 Simulation plot. 3 TMR sensors are highlighted in red, the light blue, transparent semi-sphere indicates the lens, and grey cylindrical shape above the iris is the magnet.



a) 9 labels *b) 17 labels*

Fig. 2 Label regions, based on direction of the gaze. Position around the center of the eye is labelled with typical compass annotations.

samples of the signal, whereas the last layer consisted of the class indicator. In total 30 configurations were run and each one was repeated 10 times to get an average. The main variables were the position and number of sensors and 3 levels of noise. The sensors options included 1 sensor on the left, right or center, 2 sensors, one on the left and other on the right and all 3 sensors. The noise levels included no noise and two levels of white gaussian noise of approx. 10 µW and 3 µW added to the signal. Next variable tested was the number of the categories for the signal to be classified in. Those were either 9 or 17 regions. At the end it was investigated in how much the accuracy would deteriorate if someone put the lens incorrectly (slightly tilted – 5° or 10° rotation along the axial direction of the pupil).

IV. RESULTS AND DISCUSSION

First, the best position of the sensors was tested, with a 9-label variant and all 3 levels of noise. It was found the highest accuracy for the clean signal was spread among three methods, where all of them achieved above 99%. Those configurations include left and right sensors together and each of them separately. However, for the noisy signal, the highest accuracy was achieved with all 3 sensors, as expected. The accuracy for the signal with mid noise was just above 96% for 3 sensors and 2 sensors on the sides. This means that to classify the signal with 3µW of white gaussian noise, the addition of the third sensor in the middle does not make any significant difference. For the high level of noise, on the other hand, the best configuration turned out to be the 3 sensors, resulting in 93.7%. Then, more specific 17 labels were tested with the best set-up of sensors and all levels of noise and the accuracy dropped around 7% for each noise level compared to the 9 labels. The analysis of the results suggests that the proposed method of the neural network with the classification of selected regions is not suitable for high-resolution applications. Lastly, the effect of the incorrectly placed lens was investigated with 9 labels and the accuracy was found to drop significantly for a 5° rotation. The selection of the most relevant results is shown in Table 1.

Table 1 The selection of most relevant results.

Tilt	Labels	Sensors	Accuracy		
			Zero Noise	**Mid-Level Noise**	**High-Level Noise**
0°	9	1 side sensor	99.2 %	94.5 %	90.2 %
0°	9	2 sensors	99.2 %	96.2 %	92.6 %
0°	9	3 sensors	98.4 %	96.1 %	93.7 %
0°	17	3 sensors	92.0 %	89.2 %	85.4 %
5°	9	3 sensors	82.1 %	80.2 %	75.0 %
10°	9	3 sensors	67.1 %	63.5 %	53.5 %

V. CONCLUSIONS

This project provides a validation of the idea of eye tracking with magnets embedded in a soft contact lens. This tracking method cannot be compared to video-based tracking, as it does not follow the gaze on the screen but distinguishes in 9 directions of the gaze. It can be used only for specific applications, for example to aid people with impaired mobility. The applications could include driving a wheelchair or handling a software, which could control a smart home. The configuration with all 3 sensors together achieved the highest accuracy of 93.7% for the signal with high noise. With 2 sensors on the sides, the 92.6 % accuracy was still satisfactory. Then it was investigated if more precise directions of the gaze could be distinguished and 17 labels were tested under the same conditions as before. It was found that the overall accuracy was approximately 7% lower than with 9 labels. The results for the signal with no, mid and high noises were 92.0%, 89.2% and 85.4%, respectively. It was also investigated that, if someone wore the lens up to 5° off the centerline, it would result in a drastic decrease of accuracy, where is dropped below 80% for high noise. Whereas, with the rotation of about 10°, the accuracy would drop below 70% for all levels of noise, including clean signal. This could be fixed by introducing a calibration step, which is not yet developed. However, based on this simulation, a better tracking method can be derived.

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