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Live Demonstration: Gaze Following System for Noninvasively Testing Electronic Contact Lens

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***Abstract* — This demonstration presents a gaze following system for facilitating the experiments with a contact lens. An animatronic eye model that can follow the user's gaze in real-time was developed. The hardware and software design are introduced in this work. This system can assist the development of electronic contact lens by providing an intermedia for noninvasively conducting the experiment before the product is safe for human experiments. The self-developed contact lens can be worn on the eye model instead of an animal/human eye. The eye model can perform the same eye movement as the user in real-time without any physical contact. This allowed to indirectly collect experimental human data and to evaluate the performance of the contact lens, which is helpful to reduce time and cost of contact lens experiment.**

Keywords— gaze following system, electronic contact lens, eye gesture control, human-machine interaction

I. INTRODUCTION

In recent years, the breakthrough in flexible electronics, wireless power transfer and communication further boost the possibility of the electronic contact lens. Electronic contact lens is fast becoming an important package for wearable electronics because of its superiority in mobility [1]. It has been proved itself as a strong candidate for future wearable technology with a wide range of applications such as health monitoring and human-machine interaction[2].

However, a problem raised in the experiment of homemade contact lens is that the rigorous safety evaluation is necessary before the experiment on the human body since the human eye is considered as a fragile tissue [3]. Potential discomfort and risk issues that are scrutinised by human experiment authorities. On the other hand, the primary prototypes in the lab are difficult to meet the human experiment standard before two or three iterations. This problem hugely slows down the development of electronic contact lens and increases the cost of the experiment.

The solutions used in recent researches include in vitro experiment and animal experiment [1, 4]. The in vitro experiment creates the measured target, for example the concentration of glucose, in vitro and test the output of the contact lens [5]. In this kind of experiment, the contact lens acts like a normal electrical component within a realistic environment, which can assess some aspects of its performance. The animal experiments, that are controversial, costly and require official permission, can provide a human-like eye environment for validating the contact lens' capability in testing the physiological parameter of the human body such as intraocular pressure [6]. Nevertheless, both above-mentioned solutions are incapable of mimicking the eye movement of a human user, which leads to the slow progress in the application of the human-machine interface.

In order to facilitate the experiment of self-fabricated contact lens especially for human-machine interaction, this paper proposed a Gaze Following System (GFS) where the human eye movement is mapped into an animatronic eye model in real-time via video processing and gaze tracking algorithm. The electronic contact lens under testing condition will be worn on the animatronic eye model instead of human or animal eye. The eye model will follow the movement of the user whose eye movement are recorded by a camera. The duplicated eye movement of the model driven by two servo motors will make a very similar eye vibration to the contact lens for the experiment without any risk for the human body. The GFS is well-suited for the early prototype experiments of self-fabricated contact lens, especially when a self-defined eye movement pattern is required to be generated to the contact lens. For example, a smart contact lens measuring eye gesture command needs to access the eye movement as a wearable device [7]. Therefore, using GFS, the experiment can be conducted without this procedure. This is beneficial for reducing the cost for primary generation and improving the success rate of the final product.

II. SYSTEM DEVELOPMENT

A. Hardware design

As shown in Fig. 1(a), the construction of the animatronic eye model includes an OEMI-7 eye model and a 3D printed eyeball holder. The OEMI-7, designed by Ocular Instruments, is a high-quality eye model consists of anterior chamber, crystalline lens and natural surface. Most of the details of eye are available on the model for research purpose. In addition, there are two servo motors behind the eye model providing the horizontal and vertical degree of freedom. The complete model is shown in Fig. 1(a) and (b).

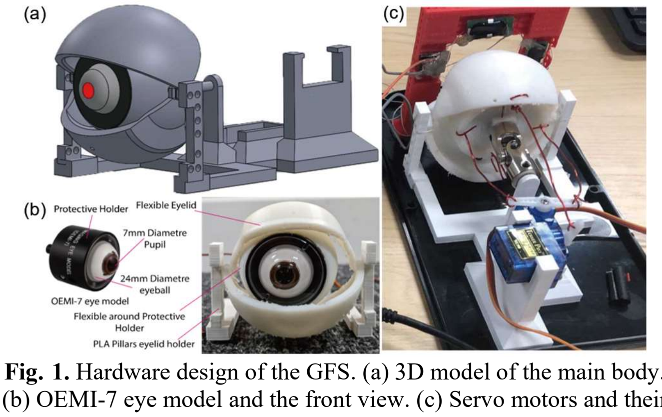

Fig. 1. Hardware design of the GFS. (a) 3D model of the main body. (b) OEMI-7 eye model and the front view. (c) Servo motors and their connection to the eye model.

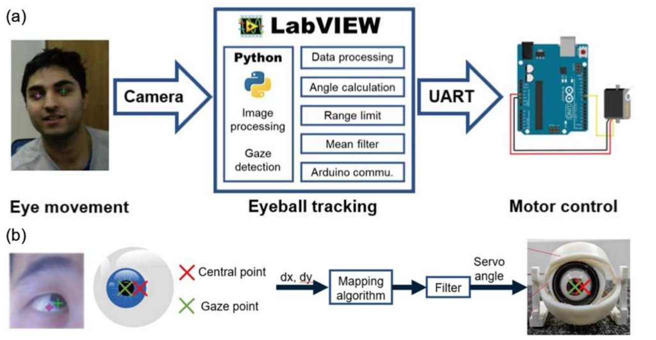

Fig. 2. Software design. (a) Overall schematic of the software. (b) Gaze mapping algorithm.

B. *Software design*

The software was developed to capture the eye movement by image processing and then map the coordinate into the angle of servo motors. The overall design is illustrated in Fig, 2(a). First of all, the video of the user is captured by a webcam. In our LabVIEW program, a gaze tracking Python code based on the open source eye tracking program [8] is employed to analyse the image. The two coordinates, pupil point and central point, are taken into consideration. Using these two points we can calculate the relative position instead of absolute position for eye movement mapping (see Fig. 2(b)), followed by a range limit algorithm and mean filter to make sure the output is in the range of servo motor and remove the noise. This algorithm can be described as follows:

$$\alpha_n = \frac{1}{L+1}\sum_{i=n-L}^{n}\left(\frac{(d_i-d_{lower})(M_{upper}-M_{lower})}{d_{upper}-d_{lower}}+M_{lower}\right) \qquad (1)$$

where d_n denotes the n^{th} d_x or d_y, α_n denots n^{th} angle output for horizontal or vertical motor (corresponding to d_x or d_y), L determines the length of mean filter, $d_{lower/upper}$ and $M_{lower/upper}$ are the movement range of pupil and motor respectively which are measured values once the system is developed. Finally, the two α will be sent to a microcontroller through UART communication for driving the motors.

C. *Performance*

As shown in Fig. 3, the GFS system demonstrates that it can follow the user's eye movement in real-time with negligible millisecond delay. Following this, a self-developed contact lens with a magnate embedded was placed on the eye

Fig. 3. Real-time gaze tracking using GFS.

model. Three magnetic sensors were mounted on a frame corresponding to a glass frame in real application. When a user is moving their eyes in front of the camera, the eye model is also moving accordingly and the signal of the changes in the magnetic field is captured by the magnetic sensors. The eye movement pattern can be extracted by a signal processing algorithm. Here, three eye commands were defined: 'look up', 'look left' and 'look right'. In addition, a simplified Tetris game was developed for demonstration [9]. A user can control the blocks in the Tetris game by moving their eye in front of a camera. The actual signal used to interact with the game was collected from the magnetic sensors that were added to the GFS system. In our trial, most of the user can finish the Tetris game within 2 mins.

III. VISITOR EXPERIMENT

The visitor will interact with a Tetris game on the screen by moving their eyeball according to the three pre-defined eye gesture commands. They will be required to fill in one line of square blocks and in order to complete the game. While the visitor is moving their eyeball, the same movement can be observed on the eye model of the GFS system. Besides, the signal of three magnetic sensors can also be seen on the screen. Everything will happen in real-time. In this demo, the visitor will understand how the GFS works, how it can facilitate the development of novel contact lens and the role of GFS in such an experiment.

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