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EyeSim - II: An Ophthalmic Response simulator

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Abstract: The practical natures of topics in the field of ophthalmology are very much dependent either on the availability of patients or virtual reality simulators in that scenario. Though there are varieties of virtual reality simulators EyeSim is the only electronic simulator developed in 2004 at Flinders University School of Computer Science, Engineering, and Mathematics. There is no other physical simulator reported in the field. So the thesis here in provides the detailed design, implementation and testing done on EyeSim, an ophthalmic response simulator, that can be used to teach medical students how to examine impairments of the three cranial efferent nerves (Oculomotor, Trochlear and Abducens nerve). The CMUcam4 camera, the four servos, the iris PCBs and the controller work together in a coordinated fashion so as to realize object tracking, eye movement and pupillary responseTaking Nelson’s EyeSim as a bench mark, the new EyeSim utilizes easy but reliable concepts for object tracking, eye movement and pupillary response. It is shown that both the controller and the control program are capable of handling all input output requirements. Testing EyeSim, it successfully replicates the three cranial nerve lesions and hence EyeSim could be manufactured to augment the teaching and learning process in the field of ophthalmology.
Keywords: Cranial nerve lesion, EyeSim,Ocular motility, Ophthalmology, Simulator

I. INTRODUCTION

Defined by the Free Medical Dictionary, ophthalmology is “the branch of medicine that deals with the anatomy, functions, pathology, and treatment of the eye” [38]. Being somewhat an asymmetric globe [16], the eye is anatomically composed of different parts: eyelids and lacrimal apparatus, eyeball and its refractive media, optic nerves, ocular muscles and orbital vasculatures [28].

During ocular impairment, ophthalmologists examine the eye in order to investigate the root cause of the pathology. Cranial nerve lesions, as one of the pathologies, are elicited through identifiable symptoms. Efficient examination of these pathologies requires a skill which can be acquired through scrutinized training or education. In order to create synergy between knowledge and skill, teaching facilities should combine both theory and practice. In view of this, virtual reality simulators are common in medical education though physical simulators are superior in conveying realism [30, 34].

This paper presents the design and construction of EyeSim, an electronic physical simulator that could be used in the field of ophthalmology. It begins by looking in to the brief conceptual overviews of the human ocular system followed by explanation of current practices of ophthalmic examination. After dictating the pathologies of the eye, the paper examines the existing simulators in the field of Ophthalmology. It highlights the objectives of the paper progressing through the design intent. It also elucidates the possible outcomes and future directions. Finally it concludes that with possible future developments such as the addition of pathologies and the inclusion of eyelids, eyelashes and a face-like cover it is highly probable that EyeSim could be manufactured and incorporated as a teaching aid in the field of ophthalmology.

II. BRIEF BACKGROUND HUMAN OCULAR SYSTEM

The human ocular system is a complex system [37] roughly composed of eyelids and lacrimal apparatus, eyeball and its refractive media, optic nerves, ocular muscles and orbital vasculatures [28].

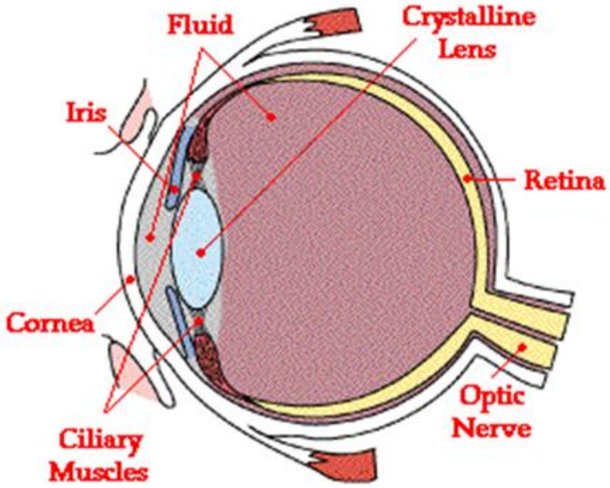

Figure 1: Basic anatomy of the human eye [37]

Among the nerves that supply the eye, the three cranial afferent nerves: cranial nerve II - optic nerve, cranial nerve V1- ophthalmic nerve and cranial nerve V2 - maxillary nerve, and the three cranial efferent nerves: cranial nerve III - Oculomotor, cranial nerve IV - Trochlear and cranial nerve VI - Abducent nerve[11, 27, 5] are a prime concern for the design and development of ophthalmic simulators.

Action potential from the efferent cranial nerve fibers is utilized to control movement of the eye through the use of three sets of extra-ocular muscles; levatorpalpebraesuperioris, four recti and two obliques, which operate either in synergistic, agonistic or antagonistic fashion [28, 5, 12]. Generally speaking all possible eye movements are classified into three categories: Ductions - movement of each eye considered separately, Versions - movement of both eyes in the same direction and Vergences- movement of both eyes in the opposite direction [27]. All these eye movements are intended to fixate the image of interest at the center of retina (fovea) so that it can be taken to the higher processing center [24].

III. OPHTHALMIC EXAMINATION: CURRENT PRACTICES

According to Wikipedia, the eye movement or ocular motility is defined as “voluntary or involuntary movement of the eyes, helping in acquiring, fixating and tracking visual stimuli” [17]. Hence eye movement is essential for proper vision and is the focal point of the paper.

Though there are varieties of ophthalmic examinations, two are relevant to the project. The first method, the extra-ocular muscle test, involves a practitioner holding an object at a distance of 10 to 14 inches away from the patient while the patient's head is still and examining the ability of the patient’s eye to track the object. In the second method, the internal ocular muscles test, the visual field is tested by moving an object back and forth from 40 cm to 10 cm from the patient’s nose while a small light is illuminated on one of the pupils so as to inspect the response of the two pupils due to direct reflex on the illuminated eye and consensual reflex on the non-illuminated eye. The sympathetic nerves dilate the pupils if the surrounding area is dark while the bright light response of the pupils (the pupils will be constricted for a bright light) is mediated by parasympathetic nerves. The Oculomotor nerve supplies both sympathetic nerves and parasympathetic nerves of the eye [6, 39].

IV. PATHOLOGY OF THE OCULAR SYSTEM

Though ocular pathology covers a wide range of conditions, the loss of the three cranial nerves (Oculomotor nerve lesion: loss of adduction, elevation and depression, dilation of the pupil and ptosis (droop) of the eyelid; Trochlear nerve lesion: loss of depression and abduction; and Abducense nerve lesion: loss of abduction), nystagmus and strabismus are the most common [6, 26, 36, 39].

Figure 2: A complete failure of the left eye to move laterally due to paralysis of the lateral rectus supplied by VI nerve [39]

V. SIMULATORS IN THE FIELD OF OPHTHALMOLOGY

Current teaching practices in the field of ophthalmology are mainly reliant on theory. The practical natures of the topics are very much dependent either on the availability of patients or on virtual reality simulators. Though there are varieties of virtual reality simulators [21] like Eyesi [19] and Eyesi2 [22], physical simulators are the most comprehensive [34]. At the Flinders University of South Australia, a number of collaborative works have been done between the School of Medicine and the School of Computer Science, Engineering, and Mathematics to meet the increased demand for a small scale ophthalmological simulator and the EyeSim was developed in 2004 [30] with the aim of equilibrating experience gained by a novice and maximum possible patient care in the field of ophthalmology. No other electronic (physical) simulator is reported in the field.

VI. OBJECTIVE

The objective of the research was to design and develop a standalone ophthalmic response simulator that can be used to teach medical students how to examine lesions of the eyes particularly impairments of the three cranial efferent nerves (Oculomotor, Trochlear and Abducens nerve).

VII. DESIGN

The ultimate aim of the paper was to replicate real life situations of patients with cranial nerve lesions (Oculomotor, Trochlear and Abducens nerve lesions); therefore, real time object tracking, coordinated eye movements and pupillary response are fundamental.

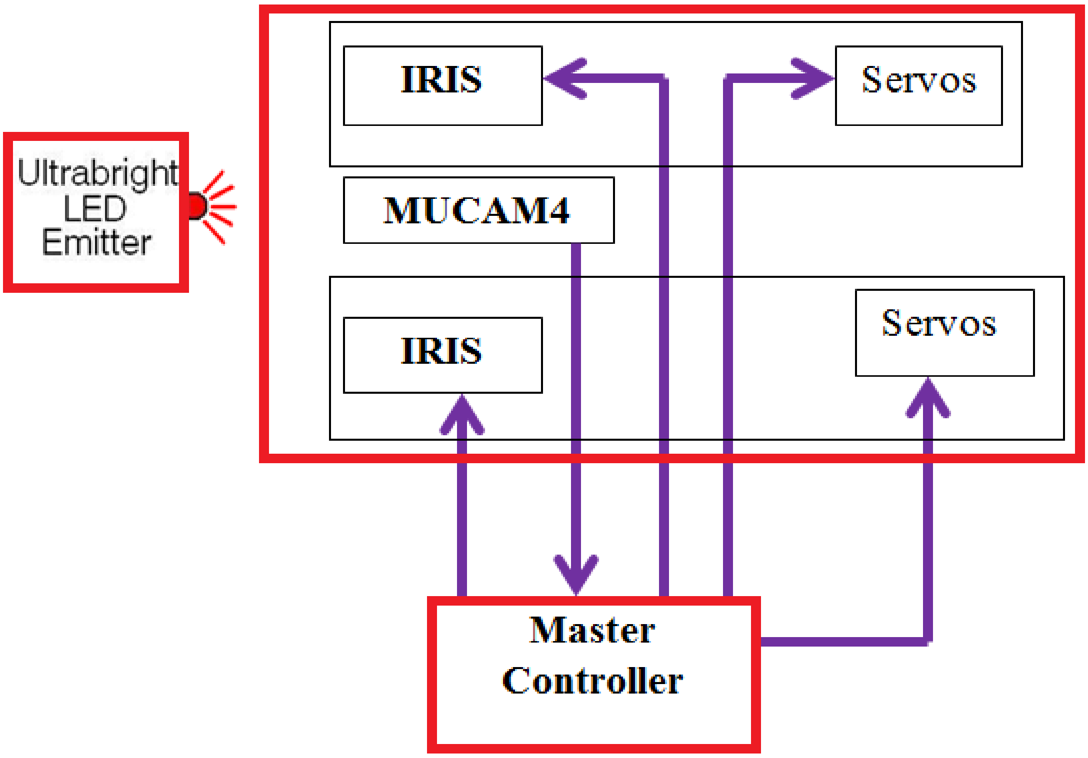

Figure 3: EyeSim block diagram

Object tracking & Eye Movement: The position of a torch is detected by a CMUcam4 camera mounted between the two eyes. The CMUcam4 on board DSPcamera tracks the position of a red LED inside the torch and send the X and Y centroid of the torch to the controller via serial port. Afterwards the controller determines where to move the two eyes based on initial position of the eyes and the feedback from the CMUcam4 camera. Then the four servos (two servos per eye) mounted on the eyeball armature propel the two eyes towards the new position so as to keep the emitter centered.

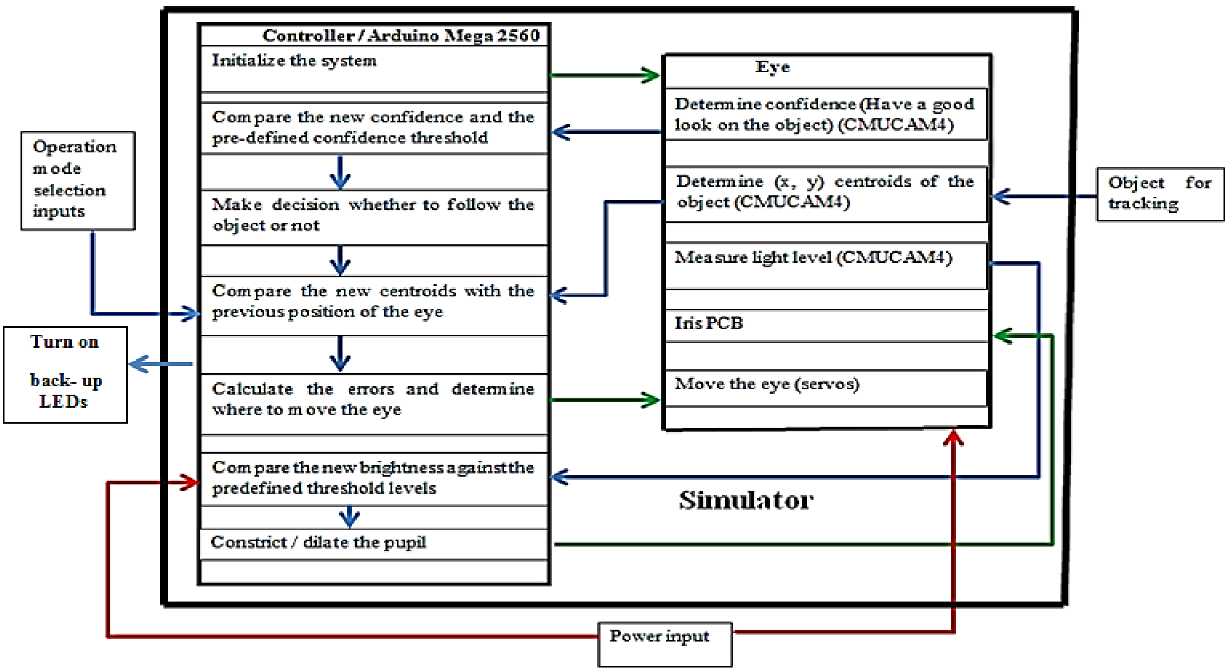

Figure 4: Working principle of EyeSim for object tracking

Pupillary response: Depending on the intensity of light falling on the CMUcam4 camera, a proportional pixel volume is generated by the CMUcam4 and fed to the controller through serial port. The controller then controls illumination of the circular rings of LEDs from which the iris is made up of.

VIII. RESULTS

As can be seen in the Fig.5 below, EyeSim is stand-alone and portable and runs from a 12V DC adaptor. The CMUcam4 on board DSP camera is used for object tracking. Using a simple one pass algorithm, the CMUcam4 camera has the ability to locate the centroids of the light source and send these to the controller via serial port. Additionally, the pixel volume method is used for pupillary response instead of the light dependent resistor of the previous version.

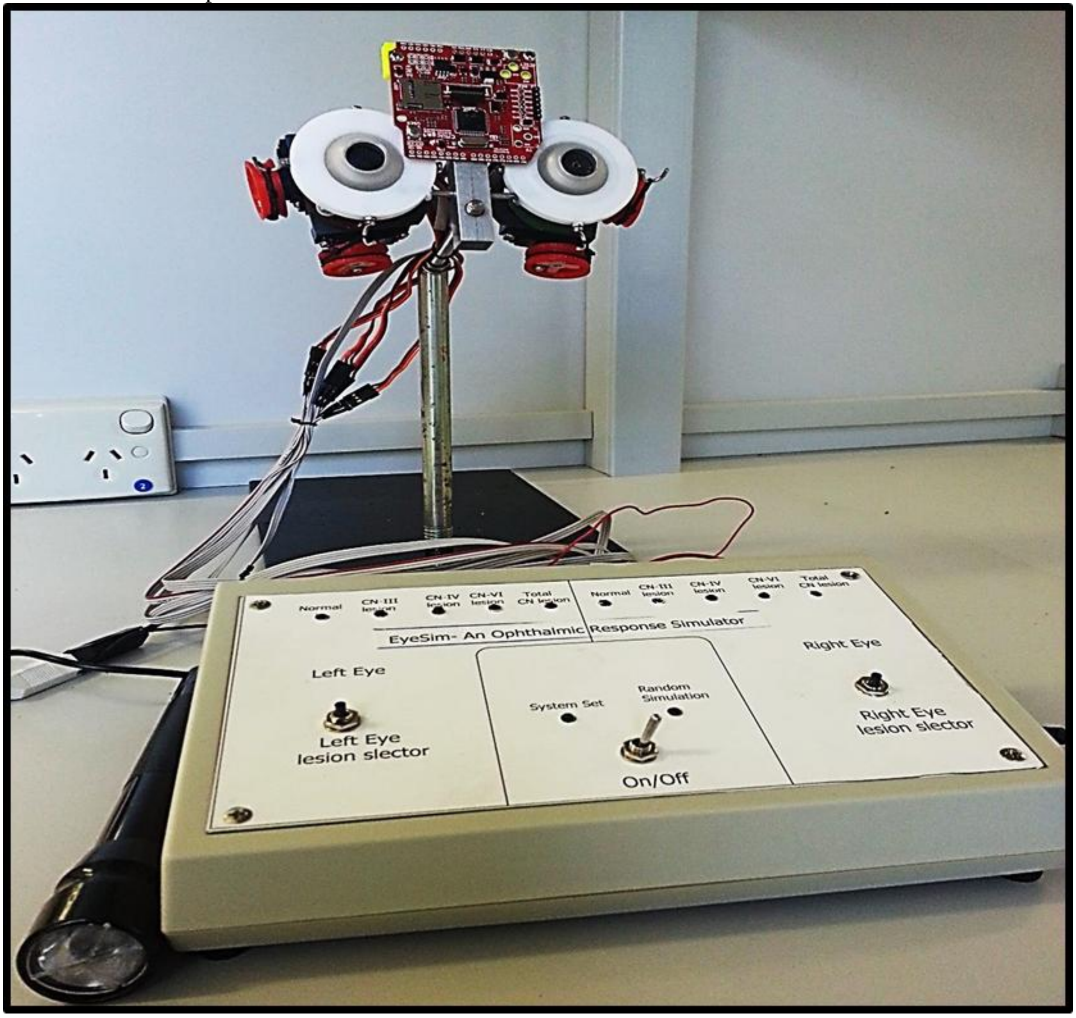

Figure 5: EyeSim Final Prototype

As the core objective of the research, the EyeSim is capable of following an object and successfully replicates the three cranial nerve lesions (CN-III, CN-IV and CN-VI); conjugate movement as well as independent eye movement is also achieved.

Broadly speaking, there are two simulation modes of EyeSim. In one of the operation modes, the practitioner or the trainee already knows the type of lesion he/she is going to mimic. The second mode of operation is random simulation, when the user has no idea but the built-in feedback mechanism of the simulator is responsible for telling the novice what type of lesions he/she has been simulating. To choose the simulation mode, the user chooses the type of lesion or random simulation for both eyes using two lesion selector toggle switches found on the front panel of the control box.

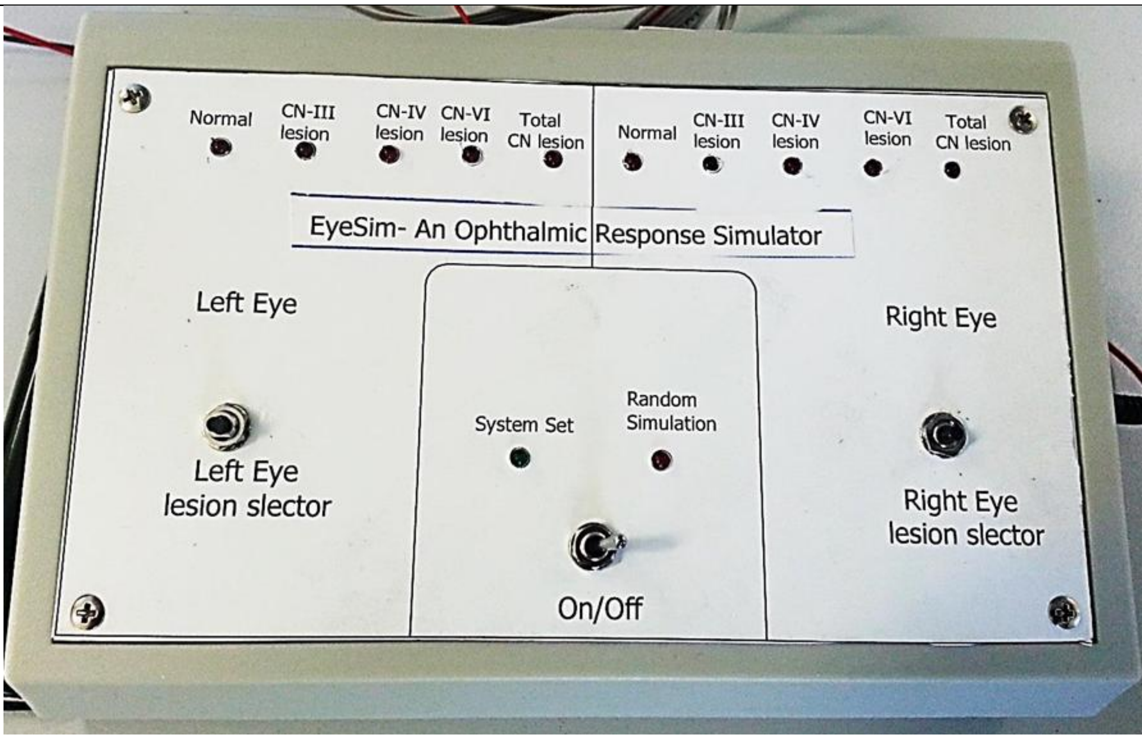

Figure 6: EyeSim Control panel

IX. FUTURE DIRECTIONS

The objective of this project was to replicate lesions of the three cranial nerves (CN-III, CN-IV and CN-VI). It has been clearly shown that EyeSim successfully replicates the three cranial nerve lesions. So the same concept can be used to expand the emulating capability of EyeSim by considering effects of impairments of Cranial Nerve V1, Cranial Nerve V2 and Cranial Nerve VII on human eye motility. With its capability of simulating the possible cranial nerve lesions, the realism of EyeSim as a teaching aid could be enhanced if eyelids and face-like cosmetics were incorporated in the design.

X. CONCLUSION

During ocular impairment, ophthalmologists examine the eye so as to investigate the root cause of the pathology. Cranial nerve lesions are one of the causes and are elicited through identifiable symptoms. Efficient examination of these pathologies requires a skill which can be acquired through scrutinized training or education. In order to create synergy between knowledge and skill teaching facilities should combine both theory and practice. In view of this, EyeSim, an ophthalmic response simulator, was designed, implemented and tested.

Having decided on a standalone simulator, the major issue was to choose either SPIN or C to write the control program which entirely depends on the choice of microcontroller. Because the CMUcam4 camera was already approved for object tracking, the first available option was to use the propeller microcontroller of the CMUcam4. Even if the complete SPIN program had been written by the end of June, assuming the CMUcam4 could handle all input-output requirements, it was realized that all the memory space would have been used up which would have made further programming and refinement difficult. So the Arduino Mega 2560 microcontroller was chosen due to its greater space for programming, familiar programming language (C), and ease of compatibility with CMUcam4 camera.

As the core part of the paper, the hardware comprised Arduino Mega 2560, CMUcam4, 2 iris PCBs, 4 digital servos and a custom-made control PCB which was designed and manufactured to power up all electronic components and provide the necessary signal input-output headers. Because the original iris PCBs was found faulty, a new 4 layer iris PCB was designed and manufactured.

To sum up, using Nelson’s EyeSim as a bench mark, a stand-alone, portable simulator has been developed which utilizes easy but reliable concepts for object tracking, ocular motility and pupillary response. Written in C, the control programs is capable of handling all input output requirements. Moreover test results of the EyeSim prototype showed that EyeSim successfully replicates lesions of the three cranial efferent nerves (Oculomotor, Trochlear and Abducens nerve). With possible future developments of EyeSim such as the addition of pathologies and the inclusion of eyelids, eyelashes and a face-like cover it is highly probable that EyeSim could be manufactured and incorporated as a teaching aid in the field of ophthalmology.

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