Simulation Approach towards Eye Prosthesis with Clinical Comparisons of Original Human Vision Capture Procedure

ABSTRACT: This paper is based on the glimpse of modeling of a prosthetic eye by incorporating clinical study of a human eye and by attempting a proper interfacing technique between a prosthetic or artificial eye and human brain intelligence via integrated control approaches and with the help of simulation aspects. Specific result analysis has been carried out by generating an appropriate transfer function of linear concept. After the generation of transfer function model, the simulation approach is incorporated via stability analysis for designing of the prosthetic eye. Moreover, an attempt is taken on furnishing the hardware implementation of producing an ideal prosthetic eye which tends to be a pre-innovative work in the varied field of prosthesis and artificial intelligence.

Keywords: robotic vision, prosthetic eye, eyeball movement, prosthetic eye modeling, prosthetic eye simulation, prosthetic eye stability.

I. INTRODUCTION

The vision, an essential aspect of living being, bears one significantly important communication for completeness of the information about a system and its study or analysis. Any object, unless viewed, cannot be inferred properly, as the vision enables the grasping of various information of an object regarding dimension, color asthenia etc. As we feel, for viewing any object for purpose of gathering intelligence, eyeball automatically gets directed to capture the intelligent message as governed by the brain. This message is subsequently processed by the brain and brain in turn initiates the functionality of the concerned neuron-motor for the associated movement of various parts and sub parts to have the completeness towards the study and analysis of any object getting viewed. Now-a-days, the prosthetic eye is one of the recent and fascinating areas to recapitulate human vision power. Lot of researches have been carried out on developing the prosthetic or robotic eye and its significant applications in various fields. A comparative training and learning procedure for gathering useful information for drawing the virtual reality of robotic vision is shown in this work [1]. The methodologies of examining and comparing various simulation approaches for rendering a visual scene and the related virtual–reality apparatus involved for this examinations for generating a perceptual and psychophysical aspects of prosthetic vision is shown in this paper [2]. The necessity, functioning and testing of a retinal electronic prosthesis for generating artificial work is very efficiently shown in this work [3]. A stereo-based vision system framework where aspects of top-down and bottom-up approaches for demonstrating how the system can be utilized for robotic object grasping is another research work in the field of robotic vision [4]. The accomplishment of a task frame to model, implement and execute three-dimensional (3D) robotic tasks, for force control and visual serving, in an uncalibrated workspace for robotic eye via integrated control approaches is shown in this paper[5]. These are few recent and past research works on robotic eye. A precise study of human vision capture procedure, the clinical analysis of an eyeball movement, the schematic block diagram representation for furnishing the robotic vision from human vision, the integrated control analogy and its stability analysis for the designing of a prosthetic eye is shown chronologically in this paper.

II. HUMAN VISION CAPTURE PROCEDURE

All visual information that the human mind receives is processed by a part of the brain known as visual cortex. The visual cortex is part of the
outermost layer of the brain [6], and is located at the
dorsal pole of the occipital lobe, more simply put, at
the lower rear part of the brain. The visual cortex
obtains its information via projections that extend all
the way through the brain from the eyeballs. The
projections first pass through a stopover point in the
middle of the brain, an almond like lump known as
the Lateral Geniculate Nucleus (LGN);

There from they are projected to the visual cortex
for processing. It is classified into five areas, labelled
V1, V2, V3, V4, and MT, which on occasion is
referred to as V5. V1 is sometimes called primary visual cortex or area 17. The other visual areas are
referred to as extrastriate cortex. V1 is one of the
most extensively studied and understood areas of the
human brain. V1 is an approximately 2mm thick
layer of brain with an area of about index card.
Because it is scrunched up, its volume is only a few
cubic centimeters. The neurons in V1 are organized
on both the local and global levels, with horizontal
and vertical organization schemes. Relevant variables
to be abstracted from the raw sensory data include
color, shape, size, motion, orientation, and others
which are more subtle. The parallelized nature of
computation in the human brain means that there are
certain cells that are activated by the presence of
color A, others activated by color B, and so on.

III. CLINICAL STUDY OF EYE BALL MOVEMENT

The human eyeball movement in different
directions is controlled by six different sensitive eye
muscles which are as follows: Medial rectus (MR),
lateral rectus (LR), superior rectus (SR), inferior
rectus (IR), superior oblique (SO) and inferior
oblique (IO) are pointed. All the above six muscles
are playing an important role in moving our eyeball.
The medial rectus (MR) moves the eye inward, and
toward the nose (adduction). The lateral rectus moves
the eye outward, away from the nose (abduction).
Superior rectus (SR) basically helps to move eye upward and inward (adduction) and also it helps to rotate top of the eye toward the nose. The
primary act of inferior rectus (IR) muscles is to
move the eye downwards which occurs during
depression and moves the eye inward (adduction).
Likewise the superior rectos (SR) it contributes in rotating the top of the eye away from the nose. Superior oblique (SO) primarily
rotates the top of the eye toward the nose, secondarily moves the eye downward, thirdly moves the eye outward. Lastly the interior oblique (IO) basically acts to rotate the top of the eye away from the nose
(extortion) as well as it helps to move our eye upward and outward direction which means elevation and abduction.

A. Different position of human eyeball movement:
The different position of human eye ball movement represents to determine the probable path of momentum [8][9]. In this consecutive sequence of eyeball movement (Fig:3) visualize the boundary of maximum flexible path of human eye ball movement. The elliptical boundary path generated by the retina of human eye is like this figure.

Figure 1: Visual information cached visual cortex
through LGN (Lateral Geniculate Nucleus).

Figure 2: Different Muscle controls the human eyeball movement.

Figure 3: Different position of human eye ball movement.
B. Spiral curve fitting of human eyeball movement:
The spiral curve fitting and family of ellipses introduced to define the human eyeball movement. The human eyeball rotated in an elliptic path to detect all the objects in its 3 degree of freedom. Applying the spiral equation the all the point (position) will be identified in continuous path which covering the regions of lens movement zone. The Fig: 4a to Fig: 4d define the different spiral equations, all the equation express the continuous path in a spiral to determine any point or position of the lease.

Figure 4: Different spiral equation.
The Archimedean spiral approach approximated here to determine the lens position in the region of effective movement area of lens, introducing this fitting spiral curve general equation.
The spiral curve fitting equation is:
\[ r = a + b \theta^{1/x} \]  
Here, \( x \) is any integer number, \( r \) is the radius vector, \( \theta \) is the angle (positive or negative) and \( a \) & \( b \) are only two parameters (real numbers). The parameter value of \( a \) denotes the turn the eyeball as much as possible towards the center and parameter value of \( b \) controls the distance between successive turnings. As \( b \) tends to zero, it is expected the most probable path of the eyeball that will cover the whole region of our lens movement. Applying MAT Lab 6.5 the generalized equation is simulated and the curve is determined shown in Figure 5.

Figure 5: Simulation of generalized Spiral equation.

Applying spiral equation, it’s possible to determine the all point of the eye movement coverage area. Changing the value of arbitrary constant \( a, b \) the different spiral is to be obtained.

IV. APPROACH TOWARDS ROBOTICS VISION FROM HUMAN VISION

The Figure 6 shows a block diagram of normal human vision [7]. When a person wants to view an object, the brain causes the mussels to rotate the eyes central line towards the object. The image form the object passes through the eyes lens to the retina, sending impulses back to the brain, closing the loop.

Figure 6: Control block representation of normal human vision.

Figure 7 shows the prosthetic eye system [7]. The brain attempts to view the object by pointing the poorly functioning eye along some angle. A prosthetic eye orients a camera along the same angle as the eye.

Figure 7: Control block representation of prosthetic vision.
The image from the objects enters into the camera and it is then routed to some components that elicit response in the brain, closing the feedback loop of feedback control system. Figure 8 shows the construction of a prosthetic eye [7]. The part of a special pair of glasses is used to create the artificial optical portion that is the portion of the system having the eyes pointing angle as an input, while the camera angle is the output as shows in Figure 8. As the brain causes the eye to rotate, a mirror rotates via...
gimbals, deflecting an infrared (IR) beam towards the eyes lens, with resulting impact on

Figure 8: Construction of the Prosthetic Eye.

the electronic retinal detector. The retinal detector as electrode array makes its position to determine the visual object, micro-motor acting here to project the object. As in natural phenomena the optical muscles work to move the eyeball. That is implemented there. As the mirror gimbals in the correct direction, the detector accepts more input until IR level equaling that of the reference IR beam is reached. The mirror links to the camera so that the camera follows the eyes angle, creating artificial vision. The electrode array movement bounded by a oval shape and object position is located in brain to view it. The micro-motor acts to move the electrode as per the brain signal.

V. CONTROL ANALOGY OF ROBOTICS EYE SYSTEM

Figure 9 represents the prosthetic eye control loop dynamics. The compensation technique considered with the gimbaled mirror is represented in Figure 10 whose extended part is shown in Figure 11.

Figure 9: Prosthetic eye control loop dynamics.

Figure 10: Simulated Prosthetic eye control loop dynamics.

Figure 11: Component selection of prosthetic eye control loop.

To design the compensator $G_c(s)$ and gimbaled mirror $G_p(s)$, it needs to think about the properties of normal vision of this electronic eye. For example, the eye should be able to change focus from one object to another object, without any steady state angular positioning error. Thus there should be a steady state step error. Similarly, the eye should be able to scan a scene or tracing of moving object with smooth response. That property will follow if the prosthetic eye provides zero steady state ramp error. $G_c(s)$ and $G_p(s)$ both have a pole at $s=0$ as in Figure 11; then the steady state properties are assured so that the control loop is clearly supported.

$$T(s) = \frac{G_c(s)G_p(s)}{1 + G_c(s)G_p(s)}$$

(2)

$$T(s) = \frac{Kb(s+a)}{s^3 + bs^2 + kbs + kba}$$

(3)

The values for $K$, $a$ and $b$ needed to be selected from the closed loop transfer function. Suppose, it requires the eye to refocus with a step response that achieves approximated zero step error in less than one second. Choose the dominant closed-loop poles as three time constant equal 0.6s, then one time constant is 0.2, requiring the pole to be in terms of $a$ and b. There
are two other closed-loop poles. One should nearly cancel the closed loop zero at \(-a\). Choose \(-1.01a\) for the closed loop pole, while the other should be well to the left at, perhaps \(-50\). To find \(K\), \(a\) and \(b\), equate

\[
\left( s + 1.01a \right) \left( s + 5 \right) \left( s + 50 \right) = s^3 + \left( 1.01a + 55 \right) s^2 + \left( 55.5a + 250 \right) s + 252.5a
\]

\[
= s^3 + bs^2 + kbs + kba
\]

There are 3 equations

\[
Kba = 252.5a
\]

\[
K_a = 5555a + 250
\]

\[
b = 1.01a + 55
\]

Solving (5), (6) and (7), we get the values as follows,

\(a = 0.045\), \(b = 55.04545\), \(k = 4.587\)

Now, the generated transfer function is

\[
T(s) = \frac{252.5 \left( s + 0.045 \right)}{\left( s^3 + 55.04545s^2 + 252.5s + 11.3625 \right)}
\]

\(\text{VII. CONCLUSION}\)

Artificial or prosthetic human organs can be classified into three general types: Internal Organs, Sense Organs and External organs. Though research work is going on rapidly on each of these types, it is very difficult to facilitate proper interpretation and designing of Sense organs. Human Eye is one of the important sense organ which is a very challenging and growing research area in the field of prosthesis. In this paper, the mathematical and simulation approaches for efficient modeling of a prosthetic human eye has been carried out. Further, from the appropriate control model development of the prosthetic eye an effective performance study has been furnished. In our future works, the practical approaches for generating a hardware implementation of a prosthetic eye will be carried out regarding to the performance and stability analysis for a prosthetic eye.

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REFERENCES


