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A Study on the Sensitivity of Illumination Source in the Geometerical Eye-Gaze Model

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ABSTRACT

Enhancement of computing ability of the smart phones the new use of the said device focus on the eye gaze estimation. The geometrical eye gaze estimation method measure the relation between camera, user's eye and smart device. The illumination source on smart device generate glint on capture pupil image of the user's eye. From the relation of glint and pupil center the eye gaze position is captured. Slight variation on light source position will drastically reduce the accuracy of the system. This research paper proposed a method to reduce the noise at light source position. The results shows significant performance and reduce the noise at light source location with 1 degree angular error.

KEYWORDS*:* Illumination Source, Noise reduction and eye gaze position.

1 INTRODUCTION

Both in Cognitive based experiments and Human machine interaction the eye gaze plays a pivtol role. Recently a new smart game designed with eye gaze estimation ability. In the human machine interaction the course can controlled through human eye gaze. This will increase the role of the human machined interface based technologies. Eye gaze systems broadly classified in two groups namely image based eye gaze estimation and geometrical based gaze estimation[1].The image based eye gaze estimation is based on mapping function namely polynomial function to define the relation between pupil image and the screen position. The major draw backs of such system with slight head movement the system performance reduced drastically. Second, geometric based gaze systems defines the mathematical relations between image feature, the visual axis of the eye, and a screen object. Goemeteric method is non-intrusive and head-free eye gaze estimation.

Most recent research work has focused on the relationship among image features with varying geometric models having many hardware combinations of one or more light sources and a camera [2]. In order to find that geometrical relationship the system required to estimate the subject dependent parameters namely, cornea center, cornea radius and gaze angles between pupil axis and visual axis. Many researcher has focused to estimated these subject dependent parameter by either varying geometrical relationship or increase the hardware to reduce the number of parameters. In some existing system used calibration procedure in order to measure accurately the subject dependent parameters. The method due to Guestrin et al. [2] used two illumination sources, a single camera, and nine calibration points in order to estimate the subject-dependent parameters. Hennessey et al. [3] demonstrate geometric gaze estimation with four calibration points. The algorithm due to Villanueva et al. [4] used a geometrical model with a single camera, single eye and a single point calibration and also demonstrated that regardless of how many camera or light sources are used, a calibration procedure is necessary for geometrical gaze estimation.

Recently, many researchers focus on calibration free gaze estimation. Nagamatsu et al. [5] used two cameras and two light sources in order to reconstruct the optical axis. The point of intersection between the optical axis and the screen was calculated. The midpoint of this intersection from the both eyes was used to reconstruct the point of gaze (POG). A method due to D. Model [6] used a stereo camera in order to reconstruct the optical axis without distance parameter estimation and the off set relations among visual and optical axes of both eyes are expressed by four angles. In order to determine this offset relation has used the assumption that the visual axis of both eyes converges to a single POG. N.Iqbal[7][8] shows the eye gaze estimation with smart hand held device having subject dependent parameter cornea center estimated through objective function and error reduced at image glint position . In most recent research work the main focus is to reduce noises at image glint position while assumed the other parameter should be measure correctly. Empricaly is observed that parameter still posses some measurement error which is quite

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sensitive to the point of gaze estimation. In this paper, we analyzed the noise at the light source postion. Section 2 is demonstrated the proposed algorithm. Section 3 and section 4 is about experiment setup / simulation results and conclusion respectively.

2. **ERROR REDUCTION MODEL**.

In order to reconstruct the eye gaze estimation and multistage system with many user dependent paprmeter need to be estimated. Slight variation in the illumination source will effect the estimation of gaze position. In geometrical gaze model, the illuminated rays generated from light sources $\mathbf{s}_i$ reflected from the user eye-cornea having cornea center **c** and the reflected ray passes through camera center **o** and display corresponding image position $\mathbf{u}_i$. Each light source with camera center **o**, and image position $\mathbf{u}_i$ defines a plane. Two planes, defines from two light sources having intersection line on which both **o** and **c** is located[7]. We expressed $\mathbf{w}_{ij}$ as th unit vector along the intersection line of the planes of two illumination sources namely $\mathbf{s}_i$ and $\mathbf{s}_j$ having the vector multiplication is defines as

$$\hat{\mathbf{w}}_{ij} = (\mathbf{s}_i \times \mathbf{u}_i) \times (\mathbf{s}_j \times \mathbf{u}_j), \quad \mathbf{w}_{ij} = \frac{\hat{\mathbf{w}}_{ij}}{\left\|\hat{\mathbf{w}}_{ij}\right\|} \qquad (1)$$

Where "$\times$" represent the cross product. In order to introduce the noise at light source position the light source $\mathbf{s}_i$ are expresses as spherical coordinates. Whose origin is attached to the camera center and z-axis is out of the camera. Single light source position is expressed in form azimuth angle ϕ and inclation agle φ. Having all light sources are on attached on the same plan as shown in Figure 1, therefore the inclination angle is same for all the light sources.

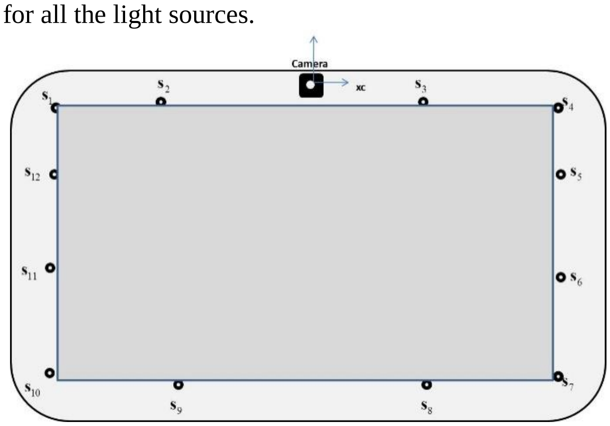

Figure 1. *Display screen and light source position on hand-held device*

Therefore error at X-axis ad Y-axis will affect the azimuth angle. In case of no noise at light sourced position the reconstruction of $\mathbf{w}_{ij}$ from different sources will be identical with average $\mathbf{w}_{av}$ which is defined as.

$$\hat{\mathbf{w}}_{av} = \frac{2}{N(N-1)} \sum_{i=1}^{N} \sum_{j>i}^{N} \mathbf{w}_{ij}, \quad \mathbf{w}_{av} = \frac{\hat{\mathbf{w}}_{av}}{\left\|\hat{\mathbf{w}}_{av}\right\|} \qquad (2)$$

Where N is the number of light sources. However noises at different light source produced corresponding $\mathbf{w}_{ij}$ which is not identical to $\mathbf{w}_{av}$. Also single light source produced reflections in both eye and generate two glints in corresponding images of the eye. Having noise at azimuth angle ϕ is minimized having the following cost function

$$f(\phi_i, \ldots\ldots\ldots, \phi_n) = \frac{1}{2} \sum_{k=L,R} \left(\sum_{i=1}^{n} \sum_{j>i}^{n} \left(\mathbf{w}_{av}^{(k)} - \mathbf{w}_{ij}^{(k)}\right)^T \left(\mathbf{w}_{av}^{(k)} - \mathbf{w}_{ij}^{(k)}\right) \right) \qquad (3)$$

Where L and R is the left and right eye respectively. We have correct noise at only one angle therefore one parameter for one light sources, therefore for n lights source system, n number of parameter are to be optimized. In order to apply gradient descent algorithm to optimize the parameters the gradient of cost function is calculated as.

$$\frac{\partial f}{\partial \phi_q} = \frac{1}{2}\sum_{k=L,R}\left(\sum_{i=1,i\neq q}^{n}\sum_{j>i}^{n}(\mathbf{w}_{av}^{(k)} - \mathbf{w}_{ij}^{(k)})^T\left(\left(\frac{2}{n(n-1)}\sum_{j=1,j\neq q}^{n}\frac{\partial \mathbf{w}_{qj}^{(k)}}{\partial \phi_q}\right) - \frac{\partial \mathbf{w}_{qi}^{(k)}}{\partial \phi_q}\right)\right) \qquad (4)$$

2.1. **Experimental Result**. We have done experiment to analyze the noise correction algorithm. We used multiple light source attached to smart hand-held device. A 2 mega pixel camera at 30 fps is center at the top of display screen. The distance between user and the device is about 200mm. The system parameter namely camera focal length and pixel size must be obtained from manufacture specification. One hundred independent realization of an additive zero-mean Gaussian noise with standard deviation between 1 to 5 mm were added to the each light source position in order to simulate the noise at light source position. The angular error between the true and the corrected light source position is calculated. The angular angle is show in Figure [2]

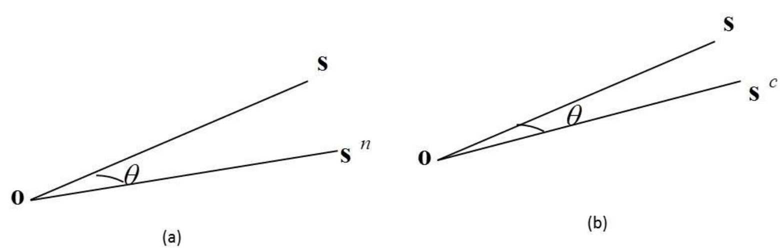

Figure 2. Angular error estimation. a) angle with noise b) angle after noise correction.

In the experiment, we consider eight light sources among twelve light sources. All the light sources has considered noise and then corrected the noise through proposed object function. The method reduced the 1 degree angular error approximately. The results exhibits some light sources reduce more error than others. In comparison light source location namely s7 reduced angular error more than light source location s5. The reason observed that light source location s5 is more parallel to camera x-plane than light source location s7.

TABLE I: Angular error on different light source position with-out-correction.

Light Position	Noise level				
	1 mm	2 mm	3 mm	4 mm	5 mm
S-5	$0.65° \pm 0.35°$	$1.20° \pm 0.64°$	$1.94° \pm 1.01°$	$2.44° \pm 1.16°$	$3.20° \pm 1.70°$
S-12	$0.60° \pm 0.27°$	$1.19° \pm 0.65°$	$1.93° \pm 0.98°$	$2.36° \pm 1.26°$	$3.17° \pm 1.78°$
S-6	$0.49° \pm 0.25°$	$0.97° \pm 0.52°$	$1.50° \pm 0.64°$	$2.08° \pm 0.96°$	$2.70° \pm 1.22°$
S-11	$0.51° \pm 0.25°$	$0.97° \pm 0.52°$	$1.41° \pm 0.74°$	$2.07° \pm 1.01°$	$2.61° \pm 1.24°$
S-8	$0.42° \pm 0.20°$	$0.93° \pm 0.53°$	$1.38° \pm 0.76°$	$1.78° \pm 0.95°$	$2.46° \pm 1.32°$
S-9	$0.46° \pm 0.25°$	$0.92° \pm 0.49°$	$1.26° \pm 0.69°$	$1.86° \pm 0.80°$	$2.11° \pm 1.14°$
S-10	$0.38° \pm 0.20°$	$0.73° \pm 0.37°$	$1.11° \pm 0.58°$	$1.40° \pm 0.70°$	$1.93° \pm 1.02°$
S-7	$0.35° \pm 0.20°$	$0.77° \pm 0.39°$	$1.09° \pm 0.51°$	$1.69° \pm 0.97°$	$1.83° \pm 0.99°$

During experiment, we have considered among eight light sources half of light source location is noise and rest half light source location is noiseless. The results exhibits high angular error reduction.

TABLE II: Angular error on different light source position after noise correction.

Light Position	Noise level				
	1 mm	2 mm	3 mm	4 mm	5 mm
S-5	$0.43° \pm 0.22°$	$0.86° \pm 0.52°$	$1.33° \pm 0.69°$	$1.73° \pm 1.10°$	$2.18° \pm 1.19°$
S-12	$0.47° \pm 0.24°$	$0.80° \pm 0.52°$	$1.33° \pm 0.78°$	$1.66° \pm 0.83°$	$2.41° \pm 1.41°$
S-6	$0.25° \pm 0.13°$	$0.54° \pm 0.35°$	$0.79° \pm 0.40°$	$1.04° \pm 0.60°$	$1.29° \pm 0.74°$
S-11	$0.27° \pm 0.14°$	$0.46° \pm 0.26°$	$0.77° \pm 0.40°$	$1.00° \pm 0.52°$	$1.36° \pm 0.67°$
S-8	$0.19° \pm 0.12°$	$0.41° \pm 0.23°$	$0.56° \pm 0.27°$	$0.75° \pm 0.45°$	$0.93° \pm 0.54°$
S-9	$0.19° \pm 0.11°$	$0.36° \pm 0.19°$	$0.55° \pm 0.27°$	$0.74° \pm 0.43°$	$0.93° \pm 0.48°$
S-10	$0.19° \pm 0.10°$	$0.34° \pm 0.18°$	$0.54° \pm 0.28°$	$0.72° \pm 0.41°$	$0.94° \pm 0.47°$
S-7	$0.18° \pm 0.10°$	$0.40° \pm 0.25°$	$0.55° \pm 0.28°$	$0.74° \pm 0.43°$	$0.91° \pm 0.53°$

3. **CONCLUSION**.

The proposed methodology is based on geometrical optical method using smart-phone/monitor screens for controlling and measuring the human eye position. In this paper, a new method was proposed to investigate the relation of noise at light source position. The Proposed algorithm used binocular eye and their reflection properties to reduced measure noise at light source position. The experiment setups for hand-held device were simulated the results shows significant improvement in the measurement of light source position. The algorithm is quite useful to automated the process of measuring light source and this will in turn increase the importance of gaze detection for the future human-machine interface development.

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