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Measuring Eye Gaze Convergent Distance within Immersive Virtual Environments

Mihai Duguleană*, Adrian Nedelcu, Florin Bărbuceanu

Universitatea Transilvania Brașov, B-dul Eroilor nr.29, Brașov 500036, Romania

Abstract

Within applications conducted in immersive virtual environments such as CAVE, eye gaze convergent distance (also called focal distance) is an important parameter used in several fields such as telepresence, virtual scenes depth perception, HRI, and others. By knowing the object that is focused by the operator, various interaction interfaces may be developed. This paper focuses on measuring with precision the convergent distance from an operator working inside an immersive virtual environment, to the gazed virtual object. Measurement errors are handled by an error filtration algorithm. The study concludes with proposing a method of selecting gazed virtual objects using proximity selection.

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Keywords: eye gaze; convergent distance; focal distance; CAVE; virtual environments

1. Introduction

Eye movements, gaze direction and gaze point dynamics interpretation are powerful tool in terms of transferring information in a non-verbal manner. Especially physically impaired persons, but also elderly persons, can exhibit locomotor deficiencies which prevent them from performing daily life activities, peculiar to their homely environment [1]. Eye tracking can help in these situations.

Eye tracking in virtual environments has received considerable attention from many related researchers over the last years. I.e., Murray [2] used an avatar to reproduce the movements of an operator as he relates to multiple objects in front of him. Subjects had the task to indicate the objects on which operator was focused, based on avatar gestures. If the person's avatar reproduced head movement, subjects were able to correctly estimate the average

* Corresponding author. Tel.: +40726385701; fax: +40 268 410525.
E-mail address: mihai.duguleana@unitbv.ro

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number of 1.8 items out of 9. If the avatar also reproduced eye movements, subjects estimated correctly on average 8.8 out of 9 items, which emphasizes the significant contribution of eye movements to non-verbal communication. Head movement was correlated with eye movement in other studies, which try to measure the gaze orientation [3].

Other researchers deal with subjects that are much closer to the one presented in this paper - they focus on measuring the gaze distance. By knowing the focal length, the feeling of immersion within the virtual environment can be increased, i.e. by blurring the clarity of the details that are given outside the vicinity of the gazed object [4].

In the case of stereoscopic viewing systems based on projection images on a flat surface, virtual objects can be seen closer or further from the projection screen with respect to the user. The parallax distance is the distance between the optical axes determined by the points of projection of the eyes measured on the projection screen. When objects are projected in front of the screen, the parallax is negative; when they are projected behind the screen, the parallax is positive. When projected objects are designed to be right on the projection screen, the parallax is zero. A head mounted tracking device such as ASL H6-HS-BN (see Fig. 1a) can determine, based on the parallax distance, the convergent distance of the eyes, which is basically the distance at which the operator is gazing [5].

The main purpose of most eye tracking studies in VR is to achieve some form of interaction interface that would help the operator in performing more complex tasks or performing common tasks much faster [6, 7, 8].

This paper is organized as follows. In section 2, the experimental setup and the measurement details are given. In section 3, the process of determining the convergent distance is presented. The error filtration algorithm is proposed in section 4. The variation of the convergent distance in relationship with the convergent angle of the operator's eyes is presented in section 5. In section 6 it is determined the proximate volume of the gazed virtual object. Finally, the experimental results of this study are summarized in the last section.

2. Experimental setup

Trying to measure the convergent distance implies the concurrent use of 4 different components: the stereoscopy 3D graphic component, the eye tracking component, the head movement component and the data acquisition component [9, 10]. The first component is handled by a CAVE (Cave Automatic Virtual Environment) with 3 projection screens. The images displayed on the front screen by horizontal/vertical polarization. The operator wears a pair of special glasses which produce the 3D effect. The eye tracking component is handled by the eye tracker device mounted on subject's head. Head movement is assessed using ArtTrack system (see passive markers in Fig. 1a).

The virtual scene designed to assess the precision of measurement consists nine objects arranged in a matrix of three rows and three columns, each element being placed at a distance of 30cm from neighboring objects. The task of the operator was to look at each element for about one second, in a certain order that is preset from left to right and top to bottom. Matrix objects are successively placed at a distance of 0.1, 0.5, 1, 1.5 and 2 meters from the user.

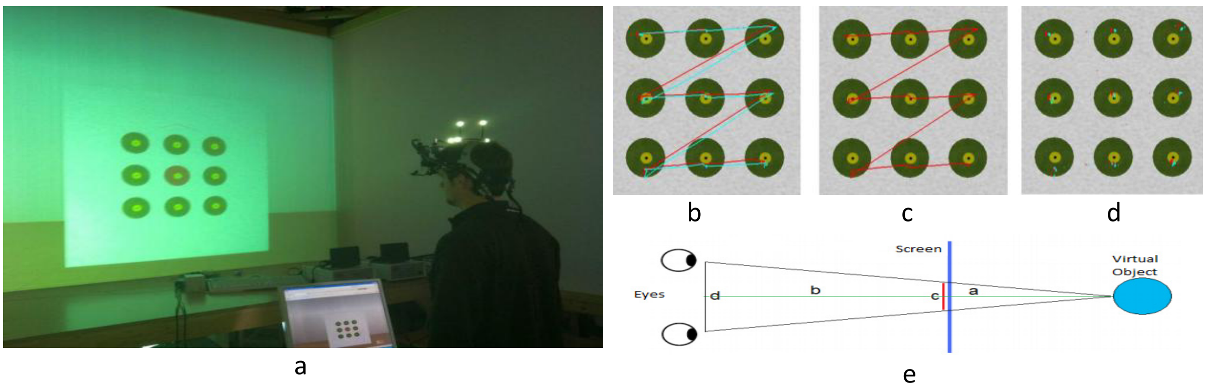

Fig. 1. (a) Experimental setup, (b) the two trajectories corresponding left and right eyes; (c) the trajectory obtained from mediating the first 2 trajectories; (d) fixation points(e) Convergent distance.

In Fig. 1(b),1(c),1(d) can be seen a set of records of eye movements, fixations determined by superimposing the recorded trajectories of both eyes over the matrix of nine objects in the order specified above. You can see a gap between the trajectories corresponding to the two eyes. In the ideal case of infinitely precise determination of the sight of both eyes, the two trajectories would overlap. The gap between the two paths means that gazing point is located as measured either behind or in front of the object viewed. A path closer to the real trajectory of the eye movement can be obtained by mediating the two trajectories corresponding left and right eyes. The most accurate measurements are those in which fixations are located within the yellow circles, but their incidence is about 30% (from experiment).

3. Measuring the eye gaze convergent distance

The measuring experiment was conducted with a sample of 4 subjects. The convergent distance can be calculated by the formula (see Fig. 1e):

$$D = a + b, \text{ where } a = (b*c)/d \quad (1)$$

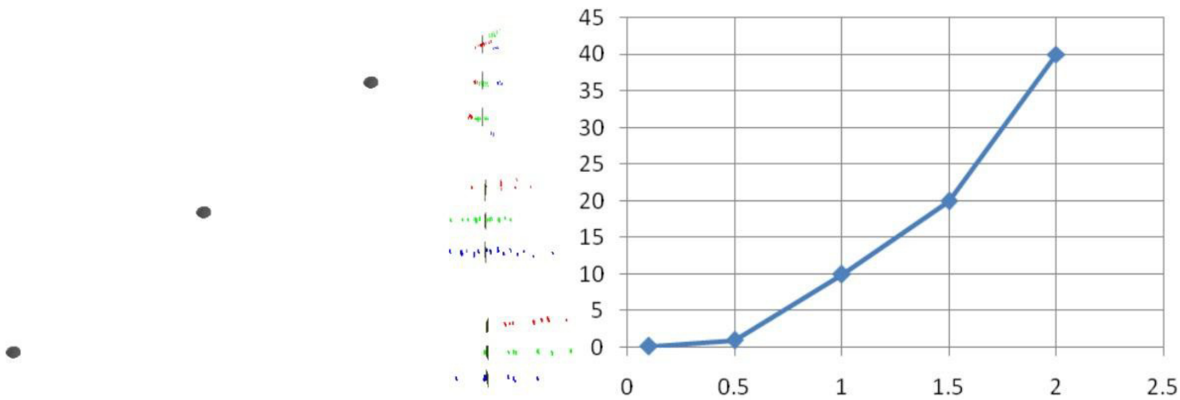

Fig. 2. (a) Fixation points for 0.5, 1 and 1.5m. (b) The variation of convergent distance with respect to the distance between the operator and the object.

In Fig. 2(a), each color of the fixation points represents a column from the matrix. The figure illustrates the fixation points from all subjects recorded at 0.5, 1 and 1.5m. As expected, the convergent distance between 2 successive fixation points is directly proportional with the distance between the operator and the object. The graph presented in Fig. 2(b) illustrates exactly this variation, for all 5 measured distances. At 0.1m from the user, the convergent distance between two consecutive points is calculated as average at 6mm. If the location of the matrix is at a distance of 0.5m from the user, the convergent distance between two consecutive points of the same fixation is 3cm, 5 times higher than previously. At 1m, the corresponding distance is about 10cm, at 1.5m - 20cm and at 2m, 40 cm.

Another observation is fixation count, which inversely proportional with the convergent distance (Fig. 3), because the change of the eye convergence angle is higher when the operator is closer to the objects, in comparison with the case where the objects are further. Also, as eye sight converges at closer distances, the eye movement requires muscles that control eye rotations to perform additional moves, which may cause extra shakes. Another good factor that causes a higher fixation count at closer convergent distances is the eyes focusing process. Close objects are difficult to focus and eye orientation variations may appear while performing it. At greater distances, even if the focusing process is not complete, it doesn't imply extra eye orientation movements.

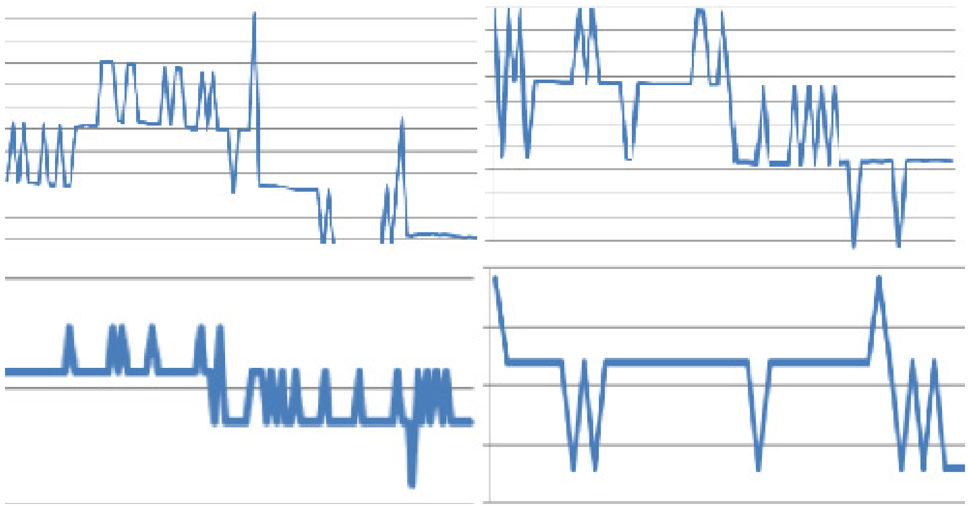

Fig. 3. Fixation count for 0.5, 1, 1.5 and 2m (top-left to bottom-right) – one spike equals one fixation.

4. Error filtering

A fixation point must be extracted from the set of points, which should be gravity center, as well as an area like a three-dimensional shape in which the gazed object is most likely to fit. To find the center of the set of fixation points, it is sufficient to mediate the coordinates of all points that belong to that set. The center of gravity can be considered as the fixation closest to the actual location of center point. As it may be noticed, targets 3, 6 and 9 corresponding to the right column of the object are placed at a higher distance from the center point. This may be related to the left-to-right reading ability of all our subjects, as well as to our experimental paradigm which also specifies this gaze order. Another conclusion is that the last part of the object is less important than the first and the middle part.

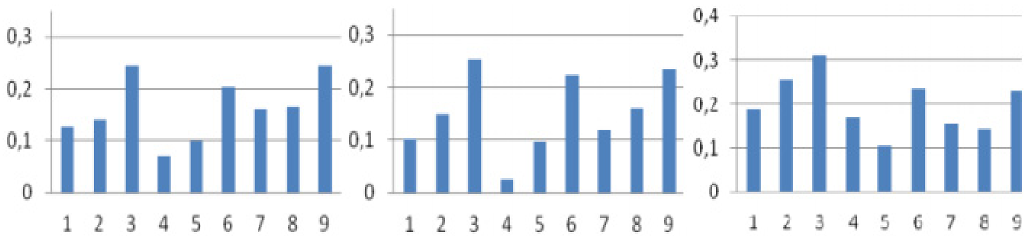

Fig. 4. Distance from each of the 9 targets to the calculated center point, in the cases of 0.5, 1 and 1.5m.

As seen from Fig. 4, targets 4 and 5 are closest to the center. Much more important, the variation between the errors measure in the 0.5, 1 and 1.5 cases is very small. For error filtering, a real time evaluation algorithm was used. The data received from the eye tracker is analyzed in batches of 10 recordings each. This algorithm has the advantage of maintaining the raw saccadic eye movement characteristic, unlike other filtering methods like the one based on convolution product. The error paradigm is described in Fig. 5a.

The filtering algorithm maintains a buffer which stores data while continuously processing the information from detection and filtering block. Actual filtering is done by comparing the most recent record with the last processed record. If the difference between these is less than 1% of their value as a module, and the difference between the last processed record and the one before it is more than 30%, then this "out of the ordinary" entry is considered an error. Error correction is done by assigning the error with the last processed record's value. The result for filtering the input from case 1m is presented in Fig. 5b.

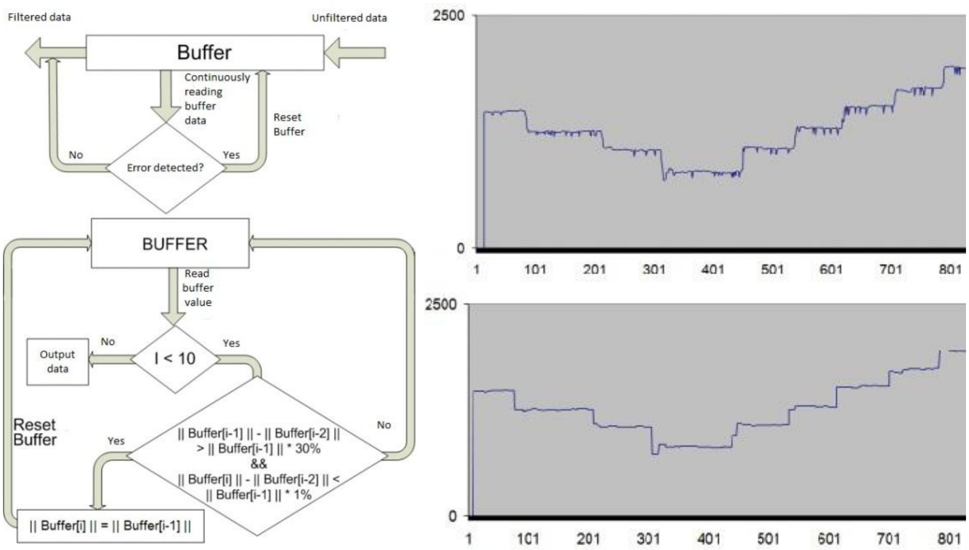

Fig. 5. (a). Error filtering algorithm, (b) Filtering the input from distance 1m .

5. Convergence angle

It is well known that the convergence angle variation decreases in the same proportion with the convergent distance [11]. The convergence angle is greater for closer objects, and smaller to object located further. This explains the decreased ability of assessing the distance between two objects beyond a certain distance from the observer. From this limit, depth perception should be assessed with other parameters related to the perception of two-dimensional images.

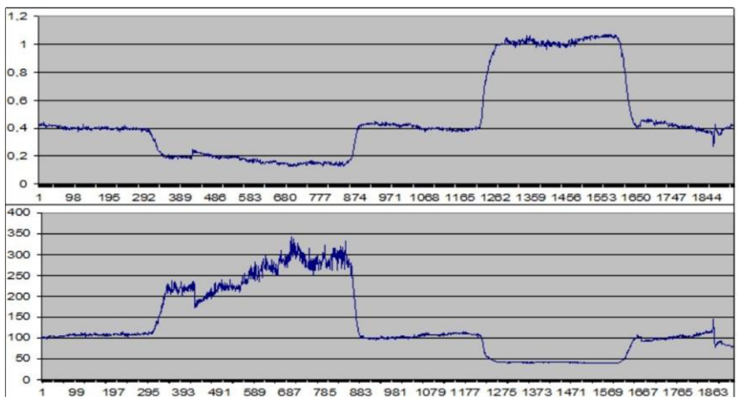

Fig. 6. Convergence angle and distance variation for 1m.

In Fig. 6 and 7 it is presented the correspondence between the gazed object and the convergence angle. In Fig. 6, the operator is located at 1m from the projection screen, while in Fig. 7, the operator is located at 4m from the projection screen. The first values recorded on the graphs are the ones that correspond with a convergent distance equal with operator's distance from the screen. As it can be seen, the convergence angle in the second case has a very small value (approx. 0.5), which leads to the conclusion that measuring with precision the convergent distance can be done if the operator sits within a distance limit of 1m from the projection screen.

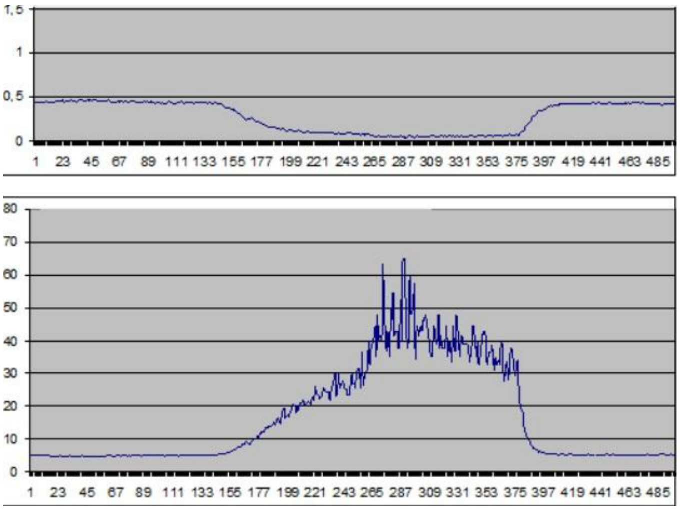

Fig. 7. Convergence angle and distance variation for 4m.

6. Selecting gazed virtual objects using proximity selection

In order to verify the results reached earlier and to confirm the conclusions obtained, a test was performed. This test consisted of placing five objects within the immersive environment, three on the same direction with the operator. Correct selection of the object desired by the operator depends on a reliable detection of the focal distance. The sets of fixation points obtained in the test are shown in Fig. 8.

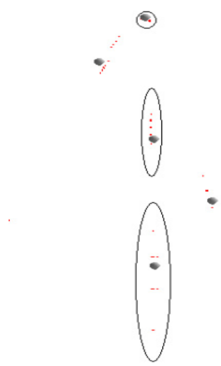

Fig. 8. Selecting 3 virtual objects placed on the same axis with the user. View from above.

At small distances, the condensation of these points can be observed. At larger distances, the sets spread on bigger areas. The gravity center from each set of fixation points is sufficiently close to the actual location of the object concerned. The volume shape of an eye fixations which is close to an object can be approximated as an ellipsoid with large radius given by $(N\text{-}1)*d_{fixation\ step}/2$, and small radius $d_{fixation}*tg(\theta)$,where N is the number of sets, $d_{fixation\ step}$ step – the distance between 2 consecutive sets and $d_{fixation}$, the distance from the operator to the mediated coordinate of all the fixation points sets of a certain virtual object.

7. Conclusion

The study proposes a new method of precision measurement of the focal distance within immersive virtual environments, using an eye tracking head mounted device. It is concluded that convergent distances between 0.5 and 1.5 meters are measured with an acceptable error. The proposed error filtration algorithm produces much smoother results in comparison with the convolution method.

From the angle data measured, it is concluded that the best position of the operator is within the 1m distance limit from the projection screen.

Determining the shape and the size of the convergence sets of fixation points is important, as human-computer interaction often requires this type of knowledge, in both virtual and real environments.

For future work, we plan to improve the filtration algorithm even more, by adding a new block which will refer to an artificial learning algorithm, meant to firstly analyze the pattern of fixations produced by the user and then, in the second phase, to predict a selection even before the user actually selects the virtual object.

Acknowledgements

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