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Elimination of Head Shifts in Videooculography

N. Ramanauskas, G. Daunys
Department of Electronics, Šiauliai University,
Vilnius str. 141, LT– 76353 Šiauliai, Lithuania, e-mail: n.ramanauskas@tf.su.lt

Introduction

Human computer interaction (HCI) systems with multi-modal interfaces use text, speech, lip reading, eye tracking, face recognition and tracking, gesture and handwriting recognition to interpret user intent in a user interface environment. In a vision-based user interface, people can interact with computers by pointing with their eyes [1]. The direction of eye gaze expresses the intent of user. This can be used for people with disabilities, which cannot move a mouse or press a key on keyboard as in command-based user interfaces. Therefore, the eye gaze of the disabled person can be used as an input modality for controlling the applications.

Today, video-oculography (VOG) is the most suitable eye tracking method in HCI. The physical layout of eye trackers differs in intrusive. Fixed (head is stabilized using chin rest or bite bar) and head mounted (eye tracker fixed to head) systems are more intrusive than remote systems (eye tracker typically fixed relative to display). In remote systems computer user works in the most natural conditions. However, such systems require more complex algorithms, because there is a need of head movement compensation.

The aim of this study is to compare head movements elimination methods.

Elimination of head movements

To provide point of intent measurement, either the head must be fixed so that the eye's position relative to head and point of intent coincide, or multiple ocular features must be measured in order to disambiguate head movement from eye rotation. One set of such features are coordinates of pupil center, depending on eye rotation and head movement. The other one is corneal reflection or eye inner corner coordinates, depending only on head movements [2].

Corneal reflections are known as the Purkinje reflections, or Purkinje images. The first Purkinje image is the reflection from the front surface of the cornea, second – reflection from rear surface of the cornea, third – reflection from the front surface of the lens, fourth – reflection from the rear surface of the lens. The 1st Purkinje image (Fig. 1) has a highest intensity, so it can be easily tracked.

Horizontal coordinates of pupil center x_p and corneal reflection center x_c can be written as:

$$\begin{cases} x_p = R \cdot \sin\varphi + x_h, \\ x_c = r \cdot \sin\varphi + x_h, \end{cases} \tag{1}$$

where x_h – horizontal coordinate of the head, φ – rotation of the eye, R – radius of eye ball, r – radius of corneal curvature. This and further formulas (2-3) are identical for vertical coordinate.

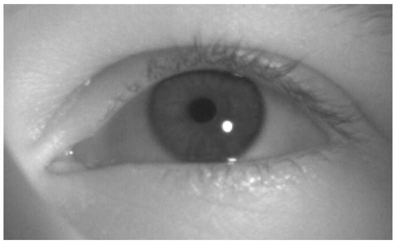

Fig. 1. Video frame with 1st Purkinje image

The difference between pupil and corneal reflection coordinates

$$x_p - x_c = (R - r) \cdot \sin\varphi \tag{2}$$

is directly proportional to the sine of eye rotation and doesn't depend on head movements. By using this value, the system becomes independent to head movements.

The head movements can be calculated using following equation:

$$x_h = \frac{x_c \cdot k - x_p}{k - 1}, \tag{3}$$

where coefficient $k = R / r$ is obtained from experimental data, using least squares method (pupil center coordinates fitted to corneal reflection coordinates).

The corneal reflection is distinguished from the surrounding iris by brightness threshold value. The center of corneal reflection is determined using two distinct methods: coordinates averaging [3] and center of mass [4].

Center of mass method allows to compute the center of 1st Purkinje image, located with accuracy of one pixel, using following equations:

$$x_0 = \frac{\sum_{i=1}^{n} B_i \cdot x_i}{\sum_{i=1}^{n} B_i}, \tag{4}$$

$$y_0 = \frac{\sum_{i=1}^{n} B_i \cdot y_i}{\sum_{i=1}^{n} B_i}, \qquad (5)$$

where ($x_i \;\; y_i$) – coordinates of i-th pixel, B_i – brightness value of i-th pixel.

For the coordinates averaging method, after scanning in horizontal and vertical directions [3], it is desirable to locate the edge of corneal reflection with subpixel accuracy. In the transit region between iris and corneal reflection pixel brightness is fitted to polynomial function versus coordinate. The transit region is narrow, especially in small resolution frames. So, the brightness in that region changes not so monotonically like in the transit region between iris and pupil. This limits the polynomial order and may cause some additional errors. Fig. 2 illustrates the fitting procedure after scanning in horizontal direction.

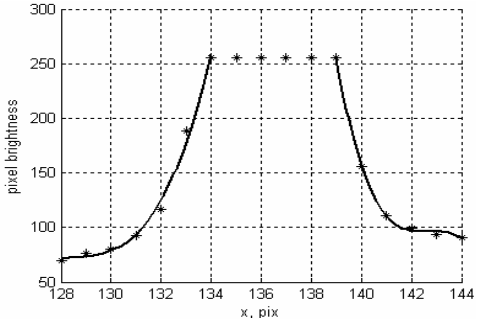

Fig. 2. Pixel brightness fitted to polynomial function

To track the inner corner of eye, the normalized correlation coefficient was chosen [5]. The algorithm decides which 20 by 20 pixels subimage is closest to the previous selected square. It examines 400 20 by 20 trial square subimages around the location of the previous selected square. The algorithm calculates the normalized correlation coefficient *r(s,t)* for the selected subimage *s* from the previous frame with each trial subimage *t* in the current frame:

$$r(s,t) = \left(n \cdot \sum_{i=1}^{n} s(x_i, y_i) \cdot t(x_i, y_i) - \right.$$
$$\left. - \sum_{i=1}^{n} s(x_i, y_i) \cdot \sum_{i=1}^{n} t(x_i, y_i) \right) \cdot \frac{1}{\sigma_s \cdot \sigma_t}, \qquad (6)$$

where n is the number of pixels in the subimage, and

$$\begin{cases} \sigma_s = \sqrt{n \cdot \sum_{i=1}^{n} s(x_i, y_i)^2 - (\sum_{i=1}^{n} s(x_i, y_i))^2}, \\ \sigma_t = \sqrt{n \cdot \sum_{i=1}^{n} t(x_i, y_i)^2 - (\sum_{i=1}^{n} t(x_i, y_i))^2}. \end{cases} \qquad (7)$$

The trial subimage with the highest normalized correlation coefficient in the current frame is selected. The normalized correlation coefficient of trial subimages is shown on Fig. 3.

To achieve subpixel accuracy, normalized correlation coefficient is fitted to polynomial function versus coordinate in the region of maximum. The fitting is evaluated in both horizontal and vertical directions. The fitting and calculation procedure in horizontal direction are shown on Fig. 4. Fitted polynomial roots are computed at the level 0.9 max(r). Average of these roots is assumed as corresponding trial subimage with subpixel accuracy.

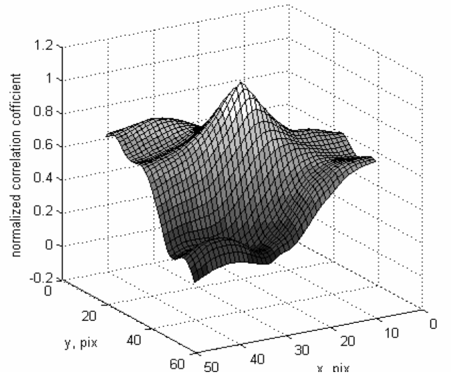

Fig. 3. Normalized correlation coefficient of trial subimages

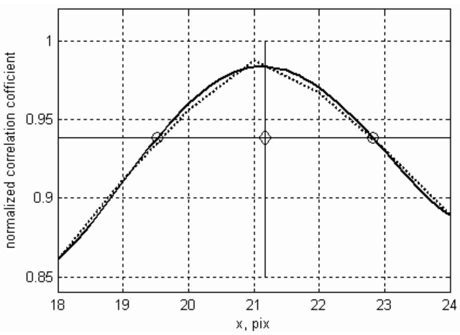

Fig. 4. Polynomial fitting. (--) - initial curve; (—) – approximated curve; (o) – polynomial roots; (◊) – center coordinate

Results

The experimental video sequences were recorded with VOG eye tracking system, developed in our laboratory. The camera's frame rate was set to 100 frames per second. The subject eye was illuminated by infrared light.

Each video sequence was analyzed with the same pupil center detection method (coordinates averaging). Obtained data contains both: actual pupil center coordinate plus head movements. Elimination of head movements was done using three different methods:

1) corneal reflection tracking with coordinates averaging;
2) corneal reflection tracking with center of mass;
3) eye inner corner tracking with normalized correlation coefficient.

The comparison of corneal reflection tracking by coordinates averaging and center of mass methods can be made by Fig. 5a). There are represented results in vertical direction. As we can see, center of mass method has a higher noise level.

Calculated head movements in the same interval, by formula (3), are shown on Fig. 5 b). As we can expect, noisy corneal reflection results, gives more noisy head movements.

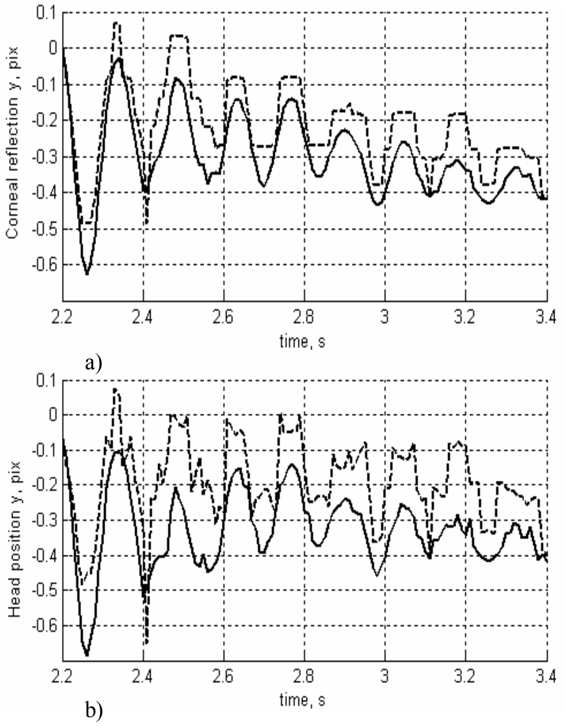

Fig. 5. a) Vertical position of corneal reflection. b) Calculated vertical head position; (—) – coordinates averaging method, (--) – center of mass

It was noticed, what during a saccade, head movements, calculated from corneal reflection, don't represent actual ones. Such situation is shown in Fig. 6. Head position coordinate moves to opposite side than saccade, while head position, obtained from normalized correlations coefficient, remains unchanged.

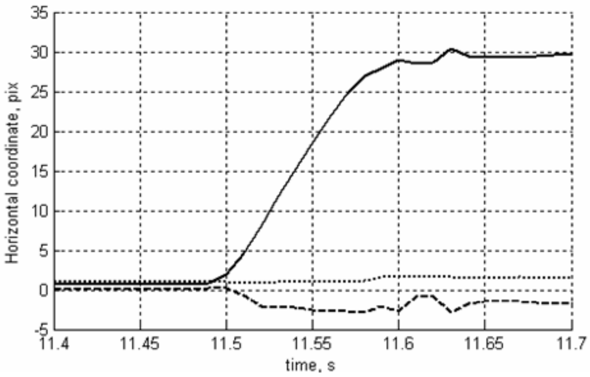

Fig. 6. Horizontal pupil center and head position. (--) – calculated from corneal reflection; (···) – normalized correlation coefficient; (—) – pupil center

During the analysis of video frames, it was also noticed, that horizontal head movements, calculated by normalized correlation coefficient, in some cases repeats the vertical ones (Fig. 7). The reason of that is low-pitched slope of normalized correlation coefficient in horizontal direction (Fig. 8).

After head movement's elimination, using different methods, the resulting eye rotations in vertical plane are shown on Fig. 9 a) and b). The initial pupil center coordinate is shown in dotted line in both figures.

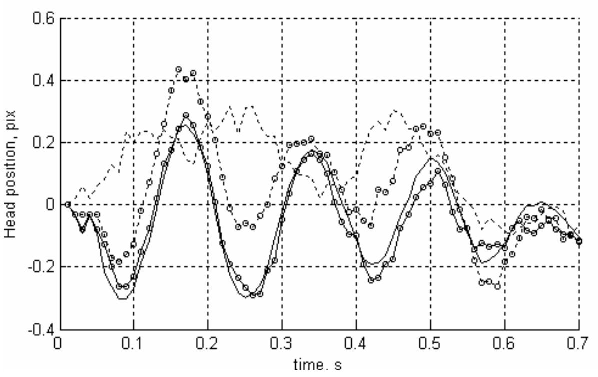

Fig. 7. Head position. Horizontal: (--) – calculated from corneal reflection, (--o--) – normalized correlation coefficient. Vertical: (—) – calculated from corneal reflection, (—o—) – normalized correlation coefficient

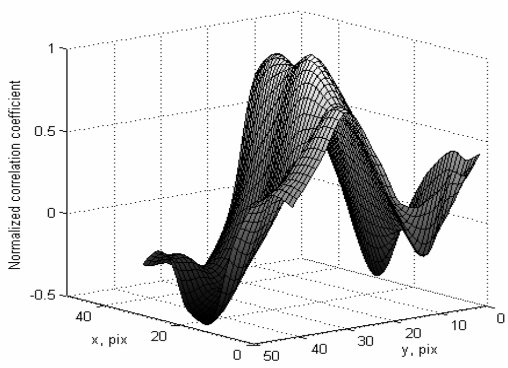

Fig. 8. Normalized correlation coefficient. Low-pitched slope in horizontal direction

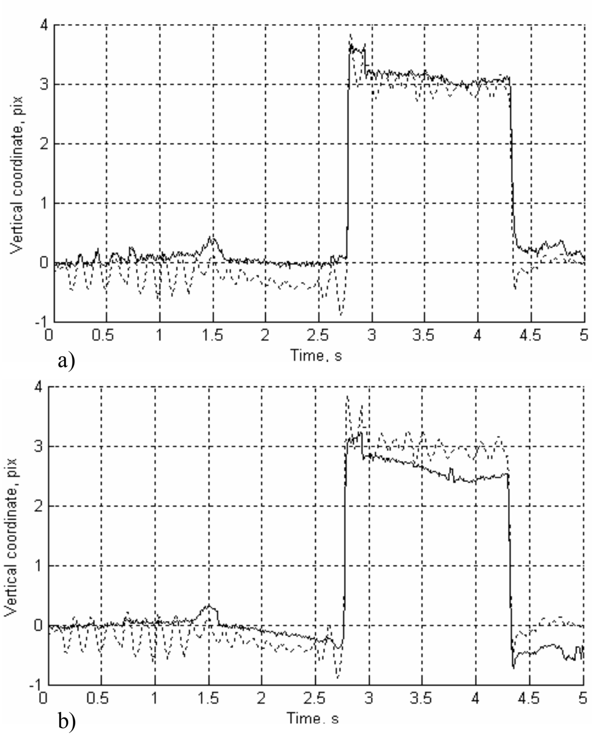

Fig. 9. The resulting eye rotation. (--) – pupil center; (—) – after head movement elimination: a) corneal reflection with coordinates averaging, b) eye inner corner

Discussion

The analysis of results shows that head coordinates' changes obtained from corneal reflection shifts by center of mass method have a higher noise level than using coordinates averaging. Resulting eye rotation, where head compensation was done using center of mass method, will also be nosiest.

The range over witch the direction of gaze can be tracked using corneal reflection is limited ±12°-15°. Further eye movement will render the 1st Purkinje image outside the spherical part of cornea.

Tracking the eye's inner corner, correlation coefficient of trial subimages must have sharp slopes in horizontal and vertical directions. In other way, results will not represent actual ones. Sharp slopes can be achieved by determining a suitable initial subimage, containing characteristic features.

The noise of evaluated eye gaze is greater than for detecting pupil center in image, independent of method used for head movement elimination. For clinical applications, where the accuracy is important, it is better to use a head mounted system.

Conclusions

The methods of head movement elimination from eye rotation were investigated. It was obtained that no one of examined methods is acceptable in all situations. This suggests that the combination of them must be further research direction.

Acknowledgement

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References

1. **Jacob. R.** The use of eye movements in human-computer interaction techniques: What you look at is what you get // ACM Transactions on Information Systems. – 1991. – V. 9, No. 3. – P. 152–169.
2. **Tian Y., Kanade T.., Cohn J.** Dual-state parametric eye tracking // 4th IEEE International Conference on Automatic Face and Gesture Recognition March 26-30, 2000, Grenoble, France. – 2000. – P. 110–115.
3. **Ramanauskas N., Daunys G.** The investigation of eye tracking accuracy using synthetic images // Elektronika ir elektrotechnika . –2003. – Nr. 4 (46). – P. 17–20.
4. **Mulligan J.** Image Processing for Improved Eye-Tracking Accuracy // Behavior Research Methods, Instruments, & Computers. – 1997. Vol. 29, No. 1. – P. 54–65.
5. **Betke M., Gips J., Fleming P.** The Camera Mouse: Visual Tracking of Body Features to Provide Computer Access for People With Severe Disabilities // IEEE Transactions on Rehabilitation Engineering. –2002. – V. 10, No. 1. – P.1–10.

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N. Ramanauskas, G. Daunys. Galvos poslinkių eliminavimas matuojant akių judesius videookulografiniu metodu // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2005. – Nr. 8(64). – P. 69–72.

Videookulografija yra akių judesių matavimo metodas, labiausiai tinkantis žmogaus ir kompiuterio sąveikai. Nuotolinėse žiūros linijos registravimo sistemose reikia eliminuoti galvos judesius. Šiame darbe buvo ištirti keli galvos judesių eliminavimo metodai. Vienas iš taikytų metodų – normuoto koreliacijos koeficiento metodas, taikomas galvos judesiams matuoti „CameraMouse“ sistemoje ir leidžiantis pasiekti subpikselinį tikslumą. Kiti tirti metodai: ragenos atšvaito koordinačių vidurkinimo ir masių centro metodai. Žiūros linijos registravimo triukšmas yra didesnis negu nustatant vyzdžio centro koordinates. Tai galioja, taikant visus tirtus galvos judesių eliminavimo metodus. Nė vienas iš tirtų metodų nėra visiškai priimtinas visais atvejais. Tikėtina, kad geriausia būtų kombinuoti kelis metodus. Il. 9, bibl. 5 (anglų kalba; santraukos lietuvių, anglų ir rusų k.).

N. Ramanauskas, G. Daunys. Elimination of Head Shifts in Videooculography // Electronics and Electrical Engineering. - Kaunas: Technologija, 2005. – No. 8(64). – P. 69–72.

Video-oculography (VOG) is the most suitable eye tracking method in Human Computer Interaction. In remote systems to provide point of regard measurement, head movement elimination must be done. During this study, the head movement elimination methods were investigated. One of them is used in “CameraMouse” system head tracking algorithm, utilizing normalized correlation coefficient, which allows to achieve subpixel accuracy. The noise of evaluated eye gaze is greater than initial pupil center, independent of method used for head movement elimination. No one of examined methods is ideal and acceptable for all situations. Only the combination of them could give better results..Ill. 9, bibl. 5 (in English; summaries in Lithuanian, English, Russian).

Н. Раманаускас, Г. Даунис. Исключение движений головы в видеоокулографии // Электроника и электротехника. – Каунас: Технология, 2005. – № 8(64). – С. 69–72.

Видеоокулография – эта метод измерения движений глаз, наиболее подходящий для применения в интерфейсах человек-компьютер. В системах дистанционного измерения нужно исключить движения головы. В настоящей работе было исследовано несколько методов исключения движений головы. Один из примененных методов – это метод нормированного коэффициента корреляции, нашедший применение в системе “CameraMouse” и позволяющий достигнуть субпиксельную точность. Шум при определении взгляда всегда больше начального шума для координат центра зрачка независимо от примененного метода для исключения движений головы. Ни один метод не подходит для всех ситуаций. Возможный путь решения проблемы – комбинация нескольких методов. Ил. 9, библ. 5 (на английском языке, рефераты на литовском, английском и русском яз.).