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Noise of Eye Movement Detection by Videooculography

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Introduction

Today, several ways of tracking the direction of eye-gaze exist. None of these techniques are perfect and devised for all situations. The main requirements for eye trackers are to offer a high accuracy and large dynamic range. Accuracy is limited by the cumulative effects of nonlinearity, distortion, noise and other sources of error. The search coil method is one of the few methods that satisfy requirements. But this technique requires putting the lens with coil on the eye, which can pose unacceptable risk. Using lens it is a need of anesthesia.

Our task is to create algorithms for gaze tracking using video-method. The investigation of eye tracking accuracy using synthetic images [1] shows that video method has a good accuracy (measurement errors less than 1 arc minute in low noise conditions). During the analysis of real experiments it was noticed that artifacts don't allow to achieve good accuracy. The aim of this study is to propose pupil contour filtering algorithms for noise reducing.

Pupil contour filtrating algorithms

The pupil is the largest dark area in the image of eye and is distinguished from surrounding iris by brightness threshold value. Pupil edge points are obtained scanning the image in horizontal and vertical directions. In low noise conditions without artifacts, these points directly belong to pupil edge.

To exclude points that clearly do not belong to the pupil edge we used two distinct filtering methods: line and circle filtering.

Points obtained by averaging coordinates in each scanned line [1], can be represented as a vertical line using line approximation or Hough transform [2]. Hough transform method is widely used in computer vision for the detection of regular curves such as lines, circles, ellipses. The accuracy of Hough transform is limited by the accumulator it uses in parametric space. Since we have to achieve a high accuracy this method is not useful. But the Hough transform can be used for the pupil contour filtering. As shown in figure 1 line obtained by Hough transform resides exactly on points belonging to the same line unlike the line approximation result.

For the pupil contour line filtering points that clearly don't belong to the line given by Hough transform are excluded for the further line approximation.

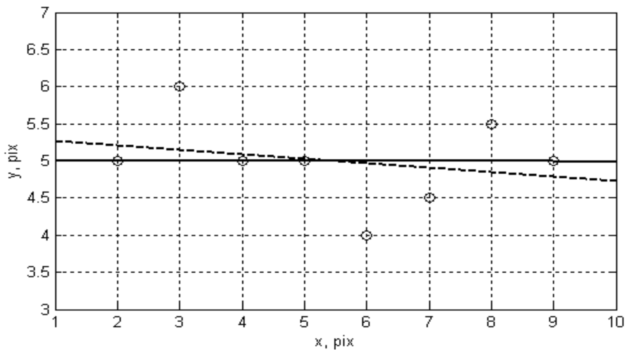

Fig. 1. Points represented as a line using Hough transform ('—') and line approximation ('- -')

Analogue filtering is executed for the points obtained after scanning the image in vertical direction.

In pupil contour circle filtering points, obtained by horizontal and vertical scanning, are approximated by the circle. Circle center coordinates x_0, y_0 and radius R are computed. If the distance from the individual points (x_i, y_i) to the fitted circle are greater than:

$$\left|\sqrt{(x_i - x_0)^2 + (y_i - y_0)^2} - R\right| > d\ , \qquad (1)$$

these points are excluded. During the analysis it was noticed, that circle approximation method fails in a high noise conditions. So a filtering also fails. In order to prevent such situations, points in such frames are represented by the circle using Hough transform [2].

To compare noise level given by different analysis algorithms researchers use rms value [3]. But the rms value is useful to specify the noise if the signal fluctuates about the constant value. If in the area of interest are two or more such constants, rms value will not characterize the true system noise. Other way to compare algorithms is to use low pass filter. But low pass filter deforms time diagrams of eye movement results. The resulting noise level will be larger, than it actually is.

We propose a novel algorithm performance parameter, which doesn't have shortcomings mentioned above. Algorithm performance parameter is computed using the equation:

$$N = \sqrt{N_x^{\ 2} + N_y^{\ 2}}\ , \qquad (2)$$

where:

$$N_x = \frac{\sum_{i=1}^{n-1}(x_i - x_{i+1})^2}{n-1}\ , \qquad (3)$$

$$N_y = \frac{\sum_{i=1}^{n-1}(y_i - y_{i+1})^2}{n-1}\ , \qquad (4)$$

n – number of frames,
x,y – the resulting horizontal and vertical coordinates.

Pixel resolution

The pixel of the image can be represented either in 8-bit or in 10-bit resolution. 8-bit resolution in gray-scale image gives values from 0 to 255, while 10-bit – from 0 to 1023. To store image width 8-bit we need 1 byte per pixel, and width 10-bit – 2 bytes per pixel (4 bits wasted).

The experiments where subject tries to fixate eyes steadily were done using 10-bit pixel resolution. The sequences of frames were converted to 8bit pixel format.

Results

Each sequence was analyzed with fourth different pupil center detection methods:

1) coordinates averaging [1];
2) circle approximation [1];
3) coordinates averaging with Hough line filtering;
4) coordinates averaging with circle filtering.

Algorithm performance parameter was calculated in the fixation intervals. This parameter depends on both the stability of fixation and the noise of used pupil center detection algorithm. Since the analysis was made for the same fixation intervals, the results provide a direct comparison of algorithms.

Figures 2,3 and 4 show performance parameter of algorithms calculated in different fixation intervals. The left most bar represents coordinates averaging algorithm, second – circle approximation, third - coordinates averaging with Hough line filtering, and the right most bar - coordinates averaging with circle filtering.

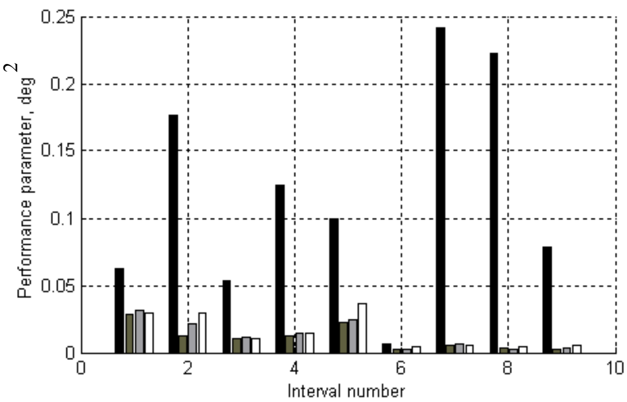

Fig. 2. Performance parameter of horizontal movements

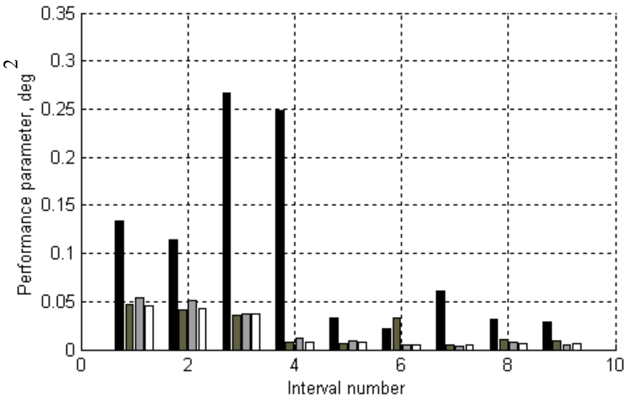

Fig. 3. Performance parameter of vertical movements

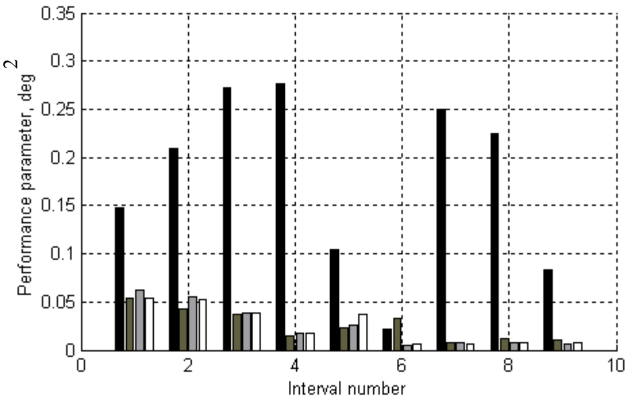

Fig. 4. Total performance parameter

The analysis results of the 7 – th fixation interval is shown in figure 5 for the coordinates averaging algorithm and in figure 6 for the coordinates averaging with circle filtering.

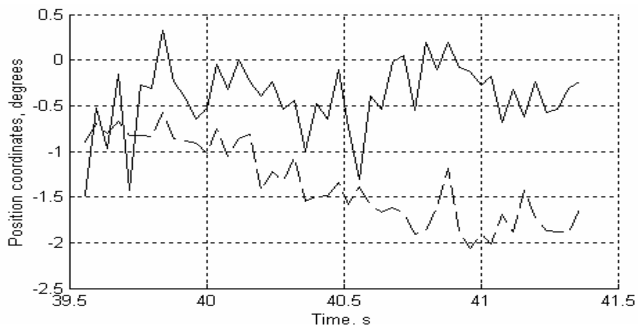

Fig. 5. Coordinates averaging results. '—' – horizontal position; '--' – vertical position

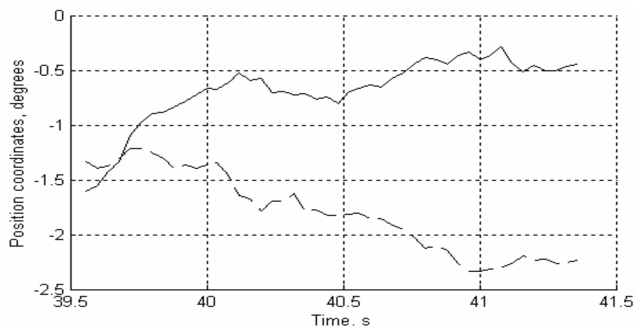

Fig. 6. Coordinates averaging width circle filtering results. '—' – horizontal position; '--' – vertical position

To compare the differences between algorithms the one way analysis of variance for total performance parameter was done. The results are summarized in table 1.

Table 1. One way analysis of variance results

Compared algorithms	F	p
1,2,3,4	21,72	$7,36*10^{-8}$
1,2	23,79	0,0002
2,3,4	0,01	0,995

Circle approximation method fails to locate pupil center in high noise conditions. The performance parameter is shown in figure 7 for fixation intervals, where circle approximation algorithm fails.

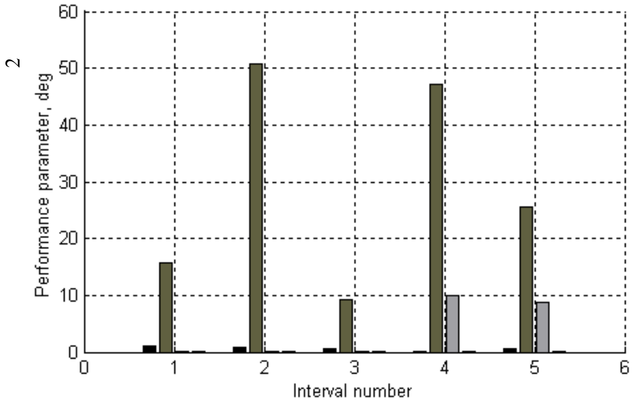

Fig. 7. Performance parameter of intervals where circle approximation algorithm fail

Detected eye movements of the 5-th fixation interval by circle approximation algorithm shown in figure 8, by coordinates averaging with circle filtering – in figure 9.

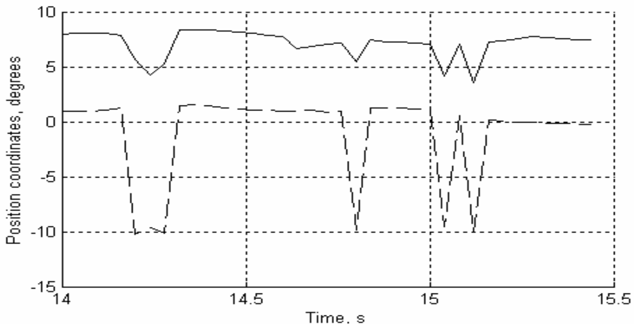

Fig. 8. results. '—' – horizontal position; '--' – vertical position

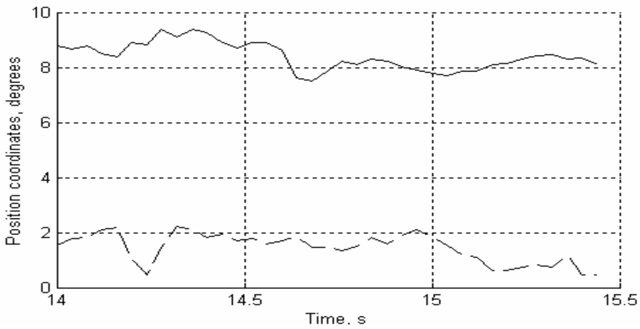

Fig. 9. results. '—' – horizontal position; '--' – vertical position

The total performance parameter was calculated in the same fixation interval for the 8 bit and 10 bit encoding (Fig. 10). Black bars represent 8 bit encoding, white bars – 10 bit.

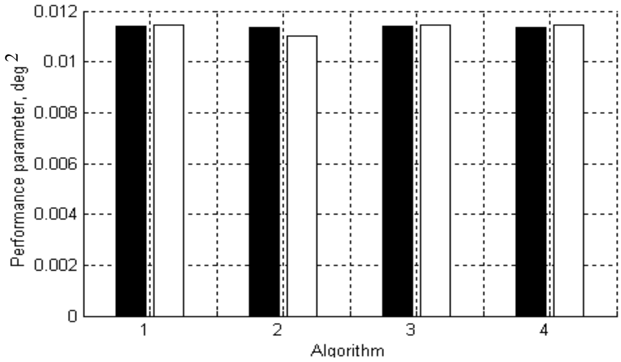

Fig. 10. Total performance parameter of 8-bit and 10-bit pixel format

To compare the differences of encoding, student test was performed. Table 2 shows the probability that the null hypothesis (the means of two samples are equal) can't be rejected at the significance level $\alpha = 0{,}05$.

Table 2. Probability of null hypothesis

Algorithm	Probability
1 - Coordinates averaging	0,9855
2 – Circle approximation	0,8201
3 - Coordinates averaging width Hough line filtering	0,9758
4 - Coordinates averaging width circle filtering	0,9289

Discussion

Analysis of results shows that coordinates averaging method has the highest noise level. The difference of performance parameter is not significant for circle approximation, coordinates averaging width Hough line filtering and coordinates averaging width circle filtering algorithms. But in high noise level conditions circle approximation fails to locate pupil center (Fig. 7).

There is no significance difference between 8-bit and 10-bit pixel format (Fig. 10). While 10-bit format requires two times more memory than 8-bit, it is better to use 8-bit pixel format.

Conclusions

The noise of pupil center detection methods width various pupil contour filtrating algorithms was investigated. Coordinates averaging method combined width pupil contour filtrating algorithms have advantages over circle approximation method. Increasing pixel resolution from 8-bit to 10-bit has no influence to noise level.

Acknowledgement

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References

1. **Ramanauskas N. Daunys G.** The investigation of eye tracking accuracy using synthetic images // Electronics and Electrical Engineering. –2003. – Nr. 4 (46). P. 17–20.
2. **Fisher R.** Hough Transform. – 2000. http://www.dai.ed.ac.uk/ HIPR2/hough.htm.
3. **Clarke A. H., Ditterich J.** Using high frame–rate CMOS sensors for three–dimensional eye tracking // Behavior Research methods, Instruments & Computers. – 2002. – No. 34 (4). – P. 549–640.

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N. Ramanauskas, G. Daunys. Triukšmai videookulografiniu metodu matuojant akių judesius // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2004. – Nr. 6(55). – P. 25-28.

Buvo ištirti vyzdžio centro nustatymo algoritmų triukšmai. Pasiūlytas naujas parametras, apibūdinantis algoritmų triukšmus. Šis parametras geriau atspindi algoritmų triukšmus nei eksperimentinis standartinis nuokrypis ar žemojo dažnio filtras. Pasiūlyti ir ištirti du vyzdžio kontūro taškų filtravimo algoritmai: filtravimas tiese ir apskritimu. Koordinačių vidurkinimo algoritmas yra pats nestabiliausias. Kombinuojant šį algoritmą su vyzdžio kontūro taškų filtravimo algoritmais, sumažinamas triukšmų lygis. Aproksimacijos apskritimu algoritmas negali nustatyti vyzdžio centro, triukšmų lygiui viršijus kritinę vertę. Nustatyta, kad pikselio formatas (8 ar 10 bitų) neturi įtakos triukšmų lygiui. Il. 10, bibl. 3 (anglų kalba; santraukos lietuvių, anglų ir rusų k.).

N. Ramanauskas, G. Daunys. Noise of Eye Movement Detection by Videooculography // Electronics and Electrical Engineering. – Kaunas: Technologija, 2004. – No. 6(55). – P. 25-28.

The noise of pupil center detection algorithms used in videoculography was investigated. Proposed a novel performance parameter, which characterize the noise of algorithms. This parameter characterize true algorithm noise better than root mean squared (rms) value or low pass filter. Investigated pupil contour filtering algorithms: line and circle filtering. Coordinates averaging algorithm has a highest noise level. Combination of this algorithm and pupil contour filtering algorithms reduces noise level. Circle approximation algorithm fails to locate pupil center in high noise conditions. The pixel resolution (8-bit or 10-bit) doesn't have a influence to noise level. Ill. 10, bibl. 3 (in English; summaries in Lithuanian, English, Russian).

Н. Раманаускас, Г. Даунис. Шум видеоокулографического метода измерения движения глаз // Электроника и электротехника. – Каунас: Технология, 2004. – № 6(55). – С. 25-28.

Был исследован шум алгоритмов, используемых в видеоокулографическом методе для определения центра зрачка глаза. Предложен новый параметр, характеризующий шум алгоритмов. Этот параметр характеризует шум алгоритмов точнее чем среднее квадратическое отклонение или использованые низкочастотного фильтра. Исследованы алгоритмы для фильтрации контура зрачка глаза: фильтрация по линии и по окружности. Алгоритм усреднения координат имеет наибольшый уровень шума. Комбинация этого алгоритма с алгоритмами фильтрации контура зрачка глаза уменьшает уровень шума. Алгоритм аппроксимации точек окружностью менее устойчив для определения центра зрачка глаза при критическом уровне шума. Кодирование пикселя (8 или 10 битов) не влияет на уровень шума. Ил. 10, библ. 3 (на английском языке; рефераты на литовском, английском и русском яз.).