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Improvements on a Fast Algorithm for Real Time Eye Movement Quantification

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Abstract – **An equipment to support the medical diagnosis and the studies of human balance in real time is being developed. This equipment is based on a recent technique which quantifies the movement of the eyes based on digital image processing. During the development of the equipment, modifications to the original algorithm were applied to improve its performance, since a faster camera is being used. The purpose of this work is to show the improvements applied to this fast algorithm. These improvements are intended to decrease even more the processing time.**

Keywords – Digital Image Processing, Human Balance, Eye Tracking

I. Introduction

An equipment is under development to support the clinical diagnosis and to study the disorders that affect the human balance. This equipment measures the response of the vestibular system (inner ear), which is responsible for the detection of head movements. The vestibular system is composed by three semicircular canals that can be individually stimulated by selective head movements, which generate compensatory eye movements through the vestibulo-ocular reflex [1], [2]. The objective of this equipment is to quantify the compensatory eye movements and then display them on the computer screen.

This equipment is based on a recent technique [3], which quantifies the translation movement of the eyes based on digital image processing. This technique uses a system to acquire images of the eyes and a fast algorithm for real time eye movement quantification. The suggested acquisition system is composed by goggle cameras that are affixed on the head, blocking the incidence of external light. The suggested algorithm that quantifies eye movements first segments the pupil from background calculating the threshold level with the histogram. The next part is to enclose the pupil with four tangent lines (two vertical and two horizontal) around the pupil, forming a rectangle. The center of the rectangle is assumed to be the center of the pupil.

There is a third compensatory movement that causes the rotation of the eye.

The original algorithm was adapted to increase processing speed of the images, leaving more time for the second algorithm to quantify the eye rotation. Modern computers are being used, what already decreases the processing time, but the modifications on the algorithm decrease even more the time. This paper describes the modifications implemented to build this equipment.

II. Materials

A personal computer composed by a Intel® Pentium® 4 2400MHz and 512Mb of RAM where used for the tests. The operational system running was a Ubuntu Linux version 5.10.

The algorithm was compiled with GCC version 4.0.

A graphic library, called ImageMagick [4], were used to create the images for the tests.

A Matrox Metor II was used to digitalize the images from the cameras in real time.

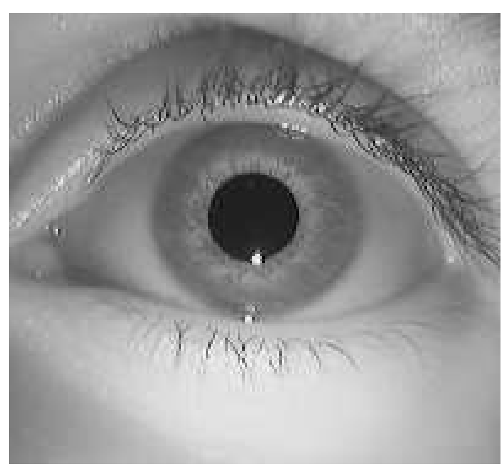

Fig. 1. Image acquired by the acquisition system and digitilalized by the frame grabber

An acquisition system was designed and built to acquire images of the eyes, under IR ilumination, blocking the incidence of any external light. This system was built with goggles, a pair of CCD cameras and infrared LEDs.

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Fig. 2. Image of the acquisition system.

III. Methodology

Two performance improvements were made in the original algorithm.

A. Performance Improvements for the Approaching Lines

The first performance improvement changes the way that the approaching lines reach the pupil.

Initially only two perpendicular lines are used for approaching the pupil, one horizontal and another vertical. When both cross the pupil, four lines are then used to find the tangents.

The two lines start in the middle of the image, each one dividing it in two halves. If the line does not cross the pupil, the line starts stepping around the middle one, in other words, the line starts moving within each half of the image at a time in steps of 10 pixels (Fig. 3).

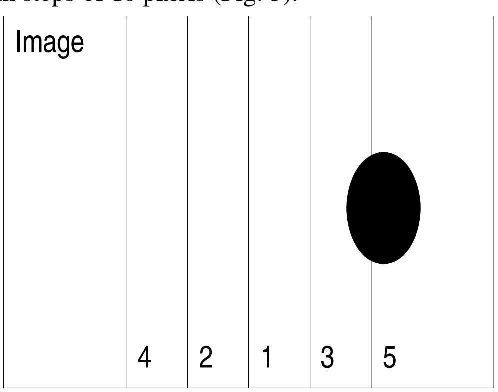

Fig. 3. Scan line in action. The scan line starts in 1 and then moves to 2, 3, 4... scanning each side of the image until it crosses the pupil.

When the line crosses the pupil, "crossing at least 10 pixels with gray levels below the pupil threshold"[1], it stops and records its location.

The second stage starts at this point. From the line that crosses the pupil, two parallel lines move in direction to the borders in steps of 10 pixels until they leaves the pupil. Backward steps are performed on each line to ensure that they are inside the pupil near to the borders.

The third stage that begins: the parallel lines move in steps of one pixel until they are tangent to the pupil. The rectangle formed is then used to calculate the center of the pupil[5].

B. Performance Improvements Based on Last Frame

The second performance improvement uses the information of the last frame to process the next [6].

When the next frame arrives, the two initial perpendicular lines are drawn over the pupil center coordinate of the last frame (Fig. 4). If the line crosses the pupil, the second and third stage mentioned before are applied; otherwise, two more lines are tested around the first with steps of 10 pixels. If none of the three lines cross the pupil, the algorithm falls back to the first stage, searching the pupil from center to borders.

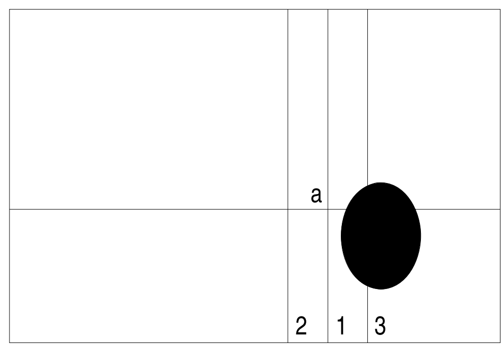

Fig. 4. Second improvement. The two initial lines mentioned before are drawn over the coordinate of the pupil center of the last frame (a). If one of the lines does not cross the pupil, other two are moved in the order indicated by the numbers.

C. Validation

Three tests were used to validate the improvements achieved by the algorithm.

The first test evaluates the ability of the algorithm to find the center in random generated circles that represent the pupil with the reflex artifacts.

A black circle is placed over a known center representing the pupil, a second circle clearly is drawn concentric to the first, under it, representing the iris. Then two small white circles are placed over the first circle region to simulate the reflexes. This image is then blurred to smooth the edges (Fig. 5).

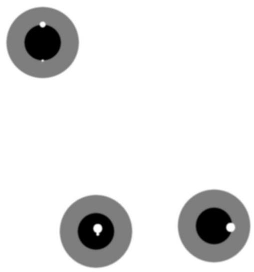

Fig. 5. Example of four test images used in the first test. The reflexes assumes different positions always inside the pupil.

The second test generates a synthetic movement of the eye and quantifies it. The movement follows two sinusoids, one in the vertical direction with two periods and the other in horizontal direction with three periods.

The third test evaluates the performance comparing the time spent by each algorithm to quantify the synthetic movement of the second test.

IV. Results

The two improvements were compared to the original algorithm.

In the first test, 317 circles were generated and each algorithm processed it. The final result is shown in TABLE I.

TABLE I
Comparison of the three algorithm in the first test.

	Algorithm		
	Original	**Center improvement**	**Frame improvement**
hits	316	316	316
misses	1	1	1
total	317	317	317

A *hit* is considered when the center calculated coincides with the real center or when it coincides with one of its four neighbors. A *miss* is considered when the center calculated does not match the hit criteria.

The unique miss happened because of a big reflex artifact on a border of the pupil. The center calculated in this frame was dislocated just 2 pixels from the center.

The second test checked the ability of the algorithm to quantify synthetic eye movement of each algorithm. The result of the three algorithm are shown in Fig. 6.

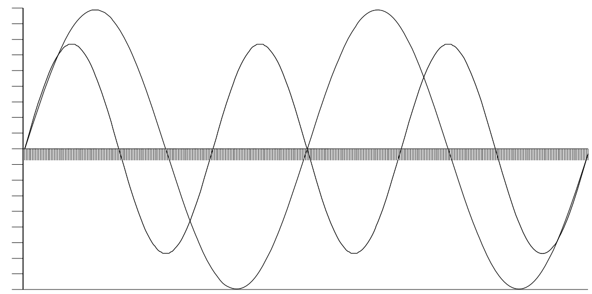

Fig. 6. Results of the quantification of a synthetic eye movement by the three algorithms. The movement was compose by 2 horizontal sinusoids and 3 vertical sinusoids. The quantification of each movement match perfectly on each algorithm.

The result of the quantification of the two movements by each algorithm matched perfectly. The result of the quantification is the same for the three algorithms.

The last test evaluated the performance in seconds of each algorithm to quantify the images of the second test composed by 360 images. The results are in TABLE II.

TABLE II
Comparison of the performances of each algorithm

	Algorithms		
	Original	**Center Optimization**	**Frame Optimization**
time per frame	0.89 ms	0.62 ms	0.51 ms
percentage	0%	30%	42.7%

The changes applied to the original algorithm generate an improvement of 42% in time.

V. Conclusions

The first test proved that the modifications in the algorithm did not alter the final result of the pupil center calculation. The images generated were processed by the three algorithms and all obtained the same center.

The second test proved that the improvements did not affect the quantification of the movement of the eyes generated synthetically. The three algorithms perfectly matched their results as shown in Fig. 6.

The performance test proved that these small modifications in the original algorithm can reduce the processing time in 42%.

With these results, it is possible to use faster cameras and still have enough time to test rotational movement quantification algorithms with harder heuristics.

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