Measurement of Eye and Head Position in Neurological Practice

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Abstract— **The base of this work is an analysis and design of specialized glasses usaging the basic available parts and makings with the goal to create an experimental machinery with a possibility of eye movement research. The aim of this work was to describe a „Design and Construction of Specialized Glasses for Neurology Investigation". The motivation for this work is to implement a system usaging primary 2D and 3D HMD (Head-Mounted Display) projection displays for eye stimulation. The result is a set of experimental models describing specialized glasses which are used to verify the proposed solution of eye movement and for measurement of the dynamic position of the head in 3D space. Modified Starburst algorithm for recognition centre pupil and calibrated scene for repeated measurement were used to detect eye movements. Created specialized projection displays for neurology investigation can perform measurements in different luminous conditions (method based on both infra red and a visible light spectrum) and stimulation with measurement of the dynamic position of the head based on programmed software.**

Keywords— **HMD, eye measurement, head measurement, videooculography, eye tracker, head posture**

I. Introduction

The measurement of eye position is an important investigative tool in the understanding of a human vestibular system. As well, the measurement of head position could contribute to diagnosis of vestibular system. These relations have not been systematically studied and the both measurement methods have been separately examined.

Monitoring eye movements and their imaging plotting have a long tradition in the medical practice. It is used as a diagnostic tool in neurology and psychology. More information about used methods of eye measurement can be found in [1], [2] and [3]. We measure eye movements using a VOG (videooculography) method that is based on the principle of scanning eye using a set of video cameras and consequently, this data is post-processed to a different result in IR (infra red) or visible light spectrum (e.g. nystagmogram, fixing the eye to the projected area et al.).

First possibility is to scan the eye moving using the IR spectrum created by a LED (light emitting diode) diode with a wavelength approximately λ = 880 - 940 nm. Looking to the eye we can see its elements – outer filamentous layer with title sclera, further is cornea, iris and eye pupilla [4]. The VOG method in the IR spectrum detects the pupil using an appropriate light that makes it completely black. Advantage of this method is a relatively easy pupil detection and a well known directive light, most often using an IR LED diode. Disadvantage and limitation is a need to make measurements without access of visible light, i.e. in conditions that do not correspond with patient's real situation.

Eye analysis in the visible light spectrum is far more complicated. The method is called passive, because the eye is scanned in the visible light spectrum due to the diffused visible light. The method without the IR supplementary light will not be only safer for the patient (undesirably warms up the eye), but also much more preferable, because does not necessarily needs to suppress background light. Detection can be done due to the sclera and iris interface. Disadvantage of these methods is the uncontrolled lighting from scattered sources, considerable luminous artefacts and high computational power. Also accuracy of these methods is rather poor, because in contrast to the pupil of the eye that is over measuring time visible, the interface between sclera and iris is often hidden.

II. Background and related works

Horizontal and vertical eye movements can be measured from an image of the eye by detecting the edges of the pupil (iris) and fitting an ellipse them. The video system PAL (NTSC) record video with frequency 50 Hz (60 Hz) non - interlace. In the medical practice were documentary eye movements with frequency approximately 200 – 250 Hz. These movements present angular change approximately 400 – 450°/s. These video systems are too slow for capture images of the eye movements, e.g. torsion iris description. The main analysis of eye movements is obtaining centre of the pupil or the iris. The torsion measurement needs high quality iris description. We used the detection method which search for the interface points between the pupil and the iris or between the iris and the sclera. The points are base on the mathematical function (e.g. circle or ellipse). We used algorithm RANSAC (Random Sample Consensus) [5] for higher accuracy. It is an iterative method to estimate parameters of a mathematical model from a set of observed data which contains outliers.

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In many cases, the head position can be small and hard to be observed. Despite the fact that an accurate method for measuring the head position and the eye position could contribute to diagnosis of vestibular system, this issue has not been systematically studied [13].

III. Problem solution

A. Eye movement analysis

We applied modified Starburst [5, 6] algorithm [9], which we used in the IR spectrum or in the visible spectrum. Goal of our solution is using eye movements' detection [7] in comparison with the stimulation scene. The scene can be showing on the LCD screen or through the special HMD display unit in 2D or 3D space. Thanks the special 3D HMD projection displays [9] we used Starburst algorithm for measuring in the IR spectrum and appropriate LED diode to illumination the eye. The method is called active, because the eye is scanned in the infra red light spectrum. Goal of the eye movements' measurement is location the centre of the pupil area. We used a new system based on finding the outline pupil of the eye. The system and algorithm was the first time published on Iowa University in 2006 [9] and the name of the project is Starburst [5]. Method finding the margins of the pupil (IR spectrum) or the iris (visible spectrum) along limits quantity of the rays. The rays are visible on Fig. 3. The starting point shoots the rays to generate candidate pupil points. The candidate pupil points shoot rays back towards the start point to detect more candidate pupil points. This two-stage detection method takes advantage of the elliptical profile of the pupil contour to preferentially detect features on the pupil contour.

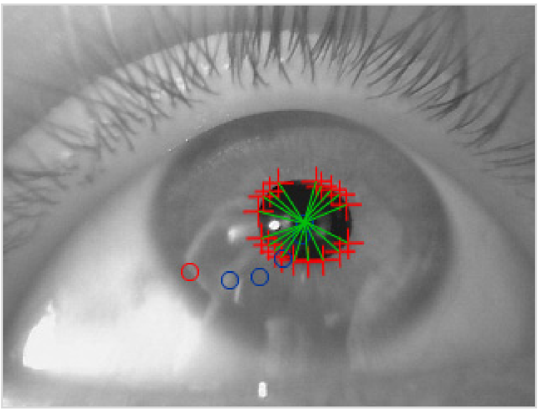

Fig. 1 Location of the pupil center with the rays

The blue circle (Fig. 1) shows the centre of the pupil after the second iteration (and after the next iteration) includes determine points. The Fig. 1 show red and blue circles quickly converge to the actual centre of the pupil. The iteration was stopped when the detected centre of the new points turn less than d = 10 pixels. Thanks to exponential calculation is error of the pupil centre about ± 10 pixels whole circle bearing and it is important from found points' fit resulting ellipse. At the end, we can find centre of the pupil from the resulting ellipse.

There are more possible methods how we can put together resulting ellipse. We chose method [9] Random Sample Consensus (RANSAC [10]) to solving the problem with large error points. The method RANSAC is efficient technique for completion model in the presence of large, but unknown percentage outlines in sample measurement. In our case are all internal found points' probable points that correspond with outline of the pupil. RANSAC algorithm was used to estimate parameters of the mathematical model from a set of observed data which contains outliers. On the basis of the MATLAB documentation we used optimal mathematical model to create the ellipse - *Nelder-Mead's* algorithm. The final result of the RANSAC algorithm and the *Nelder-Mead* ellipse model is on Fig. 2.

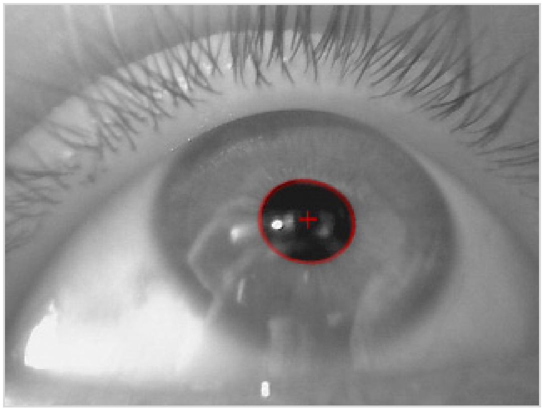

Fig. 2 Use the RANSAC and the Nelder-Mead algorithm together

B. Head position measurement

The headtracker in the eMagin Z800 3DVisor® personal display can measure head position in the 3D space. For the acquisition of the head motion we programmed software FBMI SPH in C# language based on Z800 3DVisor® SDK 2.2. The SW (software) retrieves position of the head from the build-in headtracker through the USB connection and save the measured results in to the CSV (comma-separated values) file. The result of measurement can be representing graphically as a graph of the head position (Fig. 3). The first measured values ware used as initial, i.e. zero and ware used as correction for all subsequent values. Head position was measured with precision of 1.0º in three planes (rotation -yaw, flexion-pitch and inclination-roll).

The main result is that the accuracy of the method alone is in eights of degree per the ten measurements. This is the dynamic error thanks the low-cost headtracker which has long stabilize time after the previous measurement.

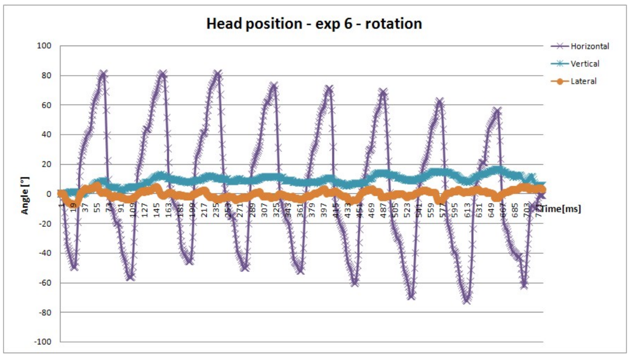

Fig. 3 Rotation of a patient's head for the X-, Y-, Z- axis

C. *Displays units - specialized glasses*

We made the first type of projection displays (Fig. 4), which used PAL cameras, supplementary IR LED diode, projection displays, control appliance, video capture appliance and laptop computer with appropriate software equipment.

For the eye stimulation we used commercial HMD system Z800 3DVisor® from eMagin Company or LCD monitor. The HMD displays eMagin Z800 3DVisor's integrated headtracker uses MEMS (micro-electro-mechanical system) accelerometers and gyroscopes to detect motion. The headtracker features three gyroscopes, one each for the X-, Y-, and Z-axis. In addition, the headtracker contains corresponding compasses and accelerometers to ensure performance over varying forms of motion. We used the headtracker for the measurement of head position. The Z800 3DVisor® is the personal display system to combine two OLED (organic light-emitting diode) micro displays with stereovision 3D capabilities. Stereo vision refers to the human ability to see in three dimensions and most often refers to depth perception (the ability to determine the approximate distance of objects). Stereovision 3D provides this experience by delivering two distinct images simultaneously on two separate screens, one for each eye. The Z800 3DVisor® personal display is used to stimulate the eye in 2D or 3D space. The position of eye and the position of head can be recorded simultaneously by the video camera and integrated headtracker to the laptop.

We found during the measurement problematic parts which were necessary solve for the next biomedical tests. The problems ware to be with weight, sharp edges on the semi-permeable mirrors and minimal place between personal display Z800 3DVisor® and the eyes. Another problem was measuring with the glasses.

On the previous base type we made the new projection displays, which allowed trace projection on the LCD monitor or the projection screen in visible spectrum. We used the special projection displays (Fig. 5) to control principle function and detection algorithm. Detection algorithm can measure the eye position and the scene position. The video files of positions are merging into the date file. The second version of projection displays has lower weight, does not contain any sharp edges and include the cameras, which are connect by the help of USB (Universal Serial Bus) interface and does not usaging any special recorder. Power supply is solving over the USB port. We used record software TVideoGrabber. The software TVideoGrabber can set capture parameters (30 FPS – Frames Per Second, 640 x 480 pixels, RGB24, data format AVI). We used for the synchronization between two cameras external flash from photographic apparatus (In the future we will use the TVideoGrabber component with more threads. The threads will start record from several video sources at the same time).

Fig. 4 Displays units - specialized glasses with eMagin 3DVisor®

The next type of our projection displays is designated for measuring in the IR spectrum. The third projection displays using the IR USB cameras which record eye movements. The type of this projection displays must using cameras which are support scan the eye movements in the IR spectrum because lighting is already poor. This type of projection displays combines a unique system for measuring eye movements and head position with 2D or 3D stimulation.

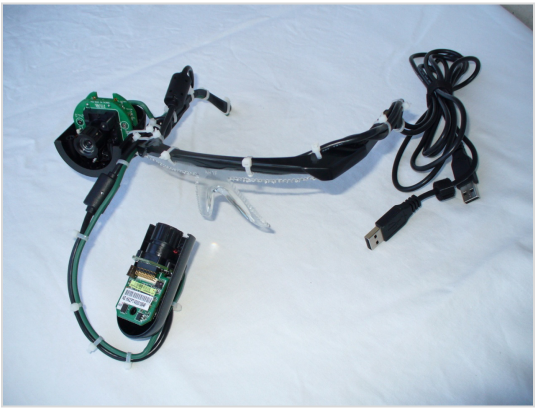

Fig. 5 The eye tracker unit with the measurement cameras

The specialized glasses - projection displays for neurology investigation can be using without the LCD monitor thanks build-in HMD 3D projections displays eMagin Z800 3DVisor® and can by using as a mobile system. We usaging experimental machinery for monitoring eye movements with different luminous conditions (in the visible spectrum or in the IR spectrum) or using different stimulation sources (e.g. record eye movements at specific activities - „eye Holter", long time eye movements record, 2D and 3D stimulation et al.).

IV. Conclusions

We designed the specialized projection displays for neurology investigation which can perform measurement in the different luminous conditions and stimulations with measurement of the dynamic position of the head. The solution combines the unique system for measurement of the eye movements and the head posture in the 3D space with 2D or 3D eye stimulation. We come to the conclusion that is possible joining together of the two important and closely related methods for the measurement of the human vestibular system. A result of this study is a recommendation to use the video cameras with higher frequency (approximately 200 Hz) for the measurement of eye movements and the headtracker with lesser dynamic error (less than 0.3°/s) for the measurement of head position. The whole accuracy of the method could be this way markedly increased.

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