Vestibulo Ocular Reflex Analysis while Using a Virtual Reality Headset

Geovanny Palomino-Roldan
Department of Electrical Engineering,
Bioelectronics
CINVESTAV
Mexico City, Mexico
gpalominor@cinvestav.mx

Ernesto Suaste-Gomez
Department of Electrical Engineering,
Bioelectronics
CINVESTAV
Mexico City, Mexico
esuaste@cinvestav.mx

***Abstract*—The analysis of human reflexes has been very useful for the study of human behavior. Specifically, the Vestibulo-Ocular Reflex (VOR) has been studied to solve problems related to posture, gait, balance, and human movement in areas such as aviation medicine, rehabilitation and even in marketing. On the other hand, virtual reality (VR) has been used as a teaching method and for the development of therapies. There are studies that have focused on the alterations that a subject experience when using these technologies as a VR headset. Some reports have analyzed the VOR before and / or after the use of these technologies, but not during the use of them. The goal of this work is to analyze the VOR through its gains while the subject is immersed in a VR scenario. For this, we use a mini-camera and sensors to detect the movements of the head and the eye. The tests consisted of inducing VOR in the subject while experiencing a VR immersion. Knowing the moment in which the VOR was induced and through a statistical analysis of the gains obtained, we were able to demonstrate that the VOR was successfully recorded while using a virtual reality headset.**

Keywords—Vestibulo-ocular reflex, virtual reality, human behavior.

I. Introduction

The eyes movements are coordinated according to the head movements, when a subject fixes his/her gaze on a point and moves his/her head horizontally, vertically, laterally, longitudinally, or angularly there is a compensatory movement that rotates the eye in the opposite direction to the movement of the head, but with the same magnitude to keep the gaze fixed on the point of attention. This reflex is known as the vestibulo-ocular reflex (VOR). [1,2]

In areas such as aviation medicine, disorientation in flight is a pathology that is based on physiological mechanisms. One way to induce vestibular responses for the study of this pathology is through the natural head movements and the VOR. [3, 4]

Virtual reality (VR) is based on a set of technologies that allow the development of a three-dimensional scenario using computational methods to imitate space and movement, creating a similarity between physical reality. [5]

The use of VR has also been proposed as a rehabilitation method for cases such as Ménière's disease [6] and the effects of its use on posture control have also been studied. [7]

Modifications to the VOR have been analyzed before and after the use of a VR headset. In these studies, it was found that the VOR gain decreased after the use of a VR headset. [5]

Comparative studies between virtual reality and physical reality have been carried out where head movements have been analyzed and they have concluded that in virtual reality subjects tend to move their heads more times than in physical reality. [8]

Among other applications of VR related to VOR, protocols based on the use of VR have been developed to improve VOR, postural control in patients with vestibular impairment. [9]

The use of a VR headset as well as the sensors and computational techniques used to achieve the sensation of a 3D scene can affect vestibular and visual signals [10,11], these alterations can affect the responses of some reflex such as VOR.

Our contribution in this work is to analyze the gains of the VOR recorded during the use of a VR headset to be able to determine whether the records correspond to this reflex.

II. Methodology

To analyze the VOR, it was necessary to implement a technique that would allow recording the head movements and the eye movements while using the VR headset. A mini-camera was placed in front of the subject's eye to record eye movements, stimulating the opposite eye with the VR scene. This mini-camera was placed on the VR headset and a sensor (accelerometer + gyroscope) was placed on the headset to record head movements.

The mini-camera used was ZZCP with a resolution of 1920x1080 pixels and a capacity to record 30 frames per second. Its power supply is 5V. It has a rechargeable battery via USB

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and supports a micro memory of up to 32 GB. It works with an AVI video format.

The MPU6050 sensor was used for the detection of head movements, this sensor is composed of a 3-aixs accelerometer and 3-axis gyroscope values combined that allows to record the displacement in the three planes. It has a built-in 16-bit ADC that provides high precision. Its power supply is in the range of 3 - 5 V. Data acquisition was performed using its I2C serial communication protocol.

Fig. 1 shows the position of the sensors for recording movements in the final VR headset used for the tests.

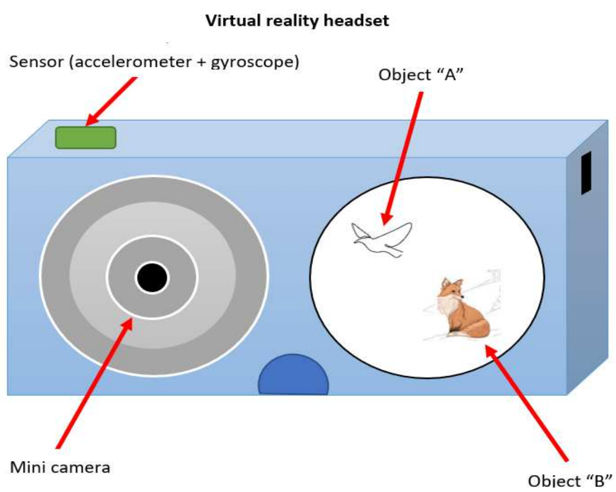

Fig. 1. Virtual reality headset and position of sensors for testing.

Fig. 2 shows the virtual reality headset used to carry out the tests.

Fig. 2. Virtual Reality headset.

Through image processing it was possible to obtain the position of the eye and thus be able to graphically represent the displacement of the eye and the head. Image processing was done with an interface developed in LabVIEW. This processing consisted of a color extraction to generate a template, that is, to select the pupil that was our region of interest. This template was stored and mounted to the grayscale full video to track and store the position of eye movements. [12]

Records of head and eye movements were synchronized by analyzing the audio and image video. First, the mini-camera began to record and then the sensors began to record. A sound was emitted as well as a light signal that allowed the start and end of the test to be identified through audio and image processing.

A. Tests

Three healthy subjects between 30 and 35 years old, one woman and two men, participated in the reported tests. It was decided to start the tests with healthy subjects, without a medical history of loss of balance or visual weakness to have a reference point regarding the responses that we should obtain when inducing VOR, that is, gains close to 1 (±10%).

To carry out the tests, the subject was asked to remain seated. The VR headset was placed on the subject where a VR scenario was projected with two objects (A and B). The first instruction that the subject had to follow was to keep his gaze on object "A" and then the subject was instructed to look in the direction of object "B". After gazing at object "B", the subject was asked to move his/her head from left to right three times without losing gaze of object "B". This to induce the VOR. Finally, the subject had to return his/her gaze to object "A" to finish the test.

The recorded responses were obtained and the gains in each test were analyzed considering that the VOR gain is the change in the angle of the eye between the angle of the head. If this gain is close to 1 it means that the VOR had been registered. [13]

III. RESULTS

Even though the tests induced the VOR in the horizontal plane due to the movement of the head from left to right, it was decided to analyze the VOR in both, horizontal and vertical plane to detect the variations that were experienced during the test. Fig. 3 and Fig. 4 showed the response obtained in the horizontal and vertical plane while the subject performed the test.

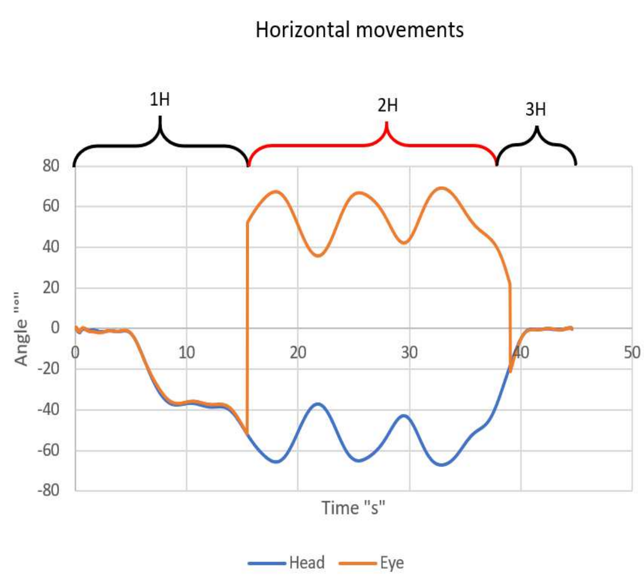

Fig. 3. Horizontal movemens.

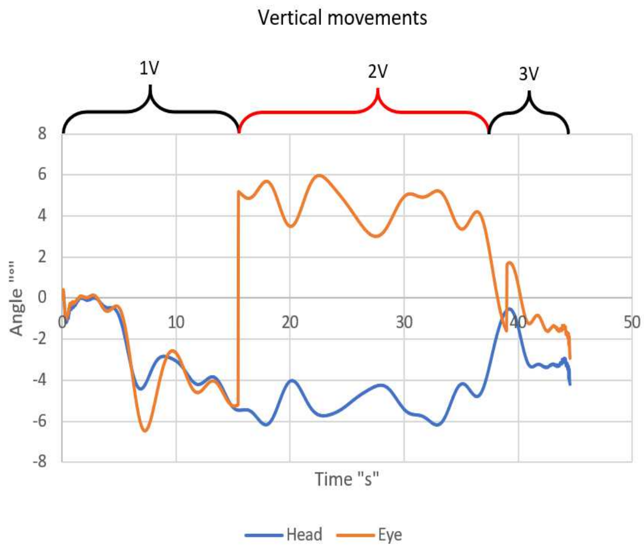

Fig. 4. Vertical movemens.

In the above figures it is possible to visualize the complete register of the head and eye movements in both, horizontal and vertical plane. In the case of Fig. 3, where horizontal movements are visualized, three segments were identified as 1H, 2H and 3H.

Segment 1H corresponds to the beginning of the test, where the subject was asked to keep his/her gaze fixed on object "A" without movements in the head, therefore, movements in this segment coincide until segment 2H begins.

Segment 2H corresponds to horizontal VOR, that is, when the subject was asked to keep his gaze fixed on object "B" by moving his/her head from left to right three times. In the graph the repetition of the movements three times is observed in the three peaks recorded during this segment.

It is necessary to indicate that in the change from segment 1H to 2H an almost vertical register is observed that corresponds to the change of gaze from object "A" to object "B". Because this movement was very fast, this very marked change in the direction of eye movements occurs, which also happens at the end of the VOR recording, in the change from segment 2H to 3H.

Finally, segment 3H corresponds to the moment in which the subject kept his/her gaze fixed on object "A" without moving his/her head to end the test. So, the eye and head movements perform a similar trajectory.

Fig. 4 shows three segments labeled as 1V, 2V, and 3V. These segments correspond to the same responses described above, but in the vertical plane.

In the 2V segment that corresponds to the vertical VOR, it is observed that the response does not present the same amplitude as in the case of the 2H segment, this because the test induced the horizontal VOR only. To rule out or confirm the presence of the VOR in the 2H (horizontal VOR) and 2V (vertical VOR) segments, the gains were obtained.

In segment 2H, an average gain of 1.0144 was found and in segment 2V the average gain was 0.8671, which can be determined that only in the horizontal plane was the VOR registered as expected by the type of tests developed.

Due to the amount of data obtained in segments 2H and 2V, it was decided to carry out a more detailed analysis using a box plot to graphically represent the data considering the outliers, quartiles, and the median of the gains. Three cases of three different subjects were analyzed to make a multiple box plot.

Fig. 5 shows the box plot of the gains from horizontal movements.

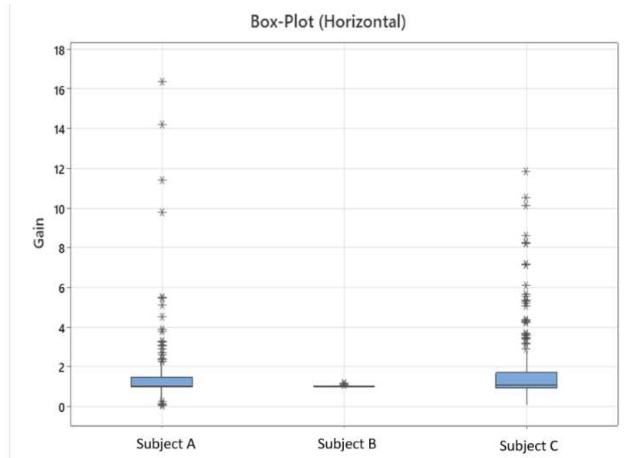

Fig. 5. Box Plot - Horizontal movemnts.

Table 1 shows the statistics data extracted from the horizontal records.

TABLE I. STATISTICS (HORIZONTAL GAIN)

Variable	N	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Subject A	383	1.4135	0.0780	1.5256	0.0305	0.9729	1.0354	1.4787	16.3604
Subject B	707	1.0144	0.00141	0.0376	0.9621	0.9927	1.0142	1.0254	1.1868
Subject C	331	1.5807	0.0883	1.6063	0.0539	0.9365	1.0879	1.7075	11.8530

Fig. 6 shows the box plot of the gains from vertical movements.

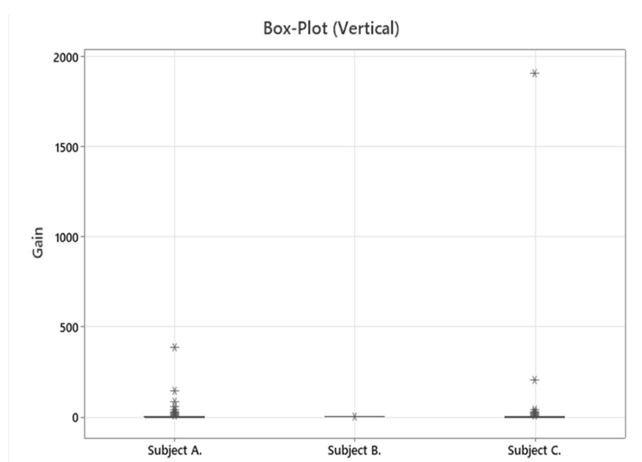

Fig. 6. Box Plot - Vertical movemnts.

Table 2 shows the statistics data extracted from the vertical records.

TABLE II. STATISTICS (VERTICAL GAIN)

Variable	N	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Subject A.	383	4.03	1.11	21.73	0.00	0.35	1.42	2.32	383.99
Subject B.	707	0.86715	0.00731	0.19431	0.01584	0.82265	0.86971	0.91019	2.61891
Subject C.	331	8.28	5.78	105.18	0.01	0.51	1.07	2.06	1904.48

In Table 1, it is observed that only the mean of subject B is close to 1, so, there is no doubt that it corresponds to the horizontal VOR. However, for subjects A and C the standard deviation is greater than for subject B, which indicates that the data dispersion is greater. This can be seen in Fig. 5, which corresponds to the box plot of horizontal movements, where an asterisk "*" represents the extreme cases that were detected during the analysis. For both subjects, these cases are greater than in the records of subject B.

On the other hand, the median in the three cases tends to values close to 1 and considering that the maximums for subjects A and C are significant, this causes the mean not to be close to 1. This does not mean that the horizontal VOR was not detected in both cases since the distribution of the data is close to the gain of 1. Extreme cases could be due to distractions in the subjects or involuntary rapid movements of the eyes or head.

In Fig. 6, which corresponds to the box plot of the vertical movements, it seems that the average gain in the three cases is close to 1. However, if we look at Table 2, we can verify that in none of the cases is the gain close to 1. Due to the extreme cases that were recorded, the distribution of the data is not observed in detail in the box plot. However, in Table 2, according to the quartiles Q1 and Q3, the range where most of the recorded data oscillates is observed and we can see that in all three cases the dispersion of the data is greater than in the horizontal movements.

According to the statistical data presented, it is concluded that the vertical VOR was not registered, because the tests carried out only included movements from left to right to induce the horizontal VOR and not from top to bottom to induce the vertical VOR.

IV. DISCUSSION

VOR registration and analysis using statistical techniques to rule out or confirm its presence while using a VR headset is possible. Different methods for the analysis of the records obtained can be applied to determine the presence of the VOR. These methods of analysis must be established according to the amount of data and the types of tests developed.

At first glance it seems that the movements recorded in Fig. 3 and Fig. 4 corresponded to the VOR, however, using the gains for the statistical analysis carried out, it was possible to determine if the records corresponded to the VOR.

In Fig. 6, which corresponds to the box plot of the vertical movements, it was not possible to determine whether the gain corresponded to the VOR, however, with the help of complementary data, such as the case in Table 2, the presence of vertical VOR was ruled out.

Using the interval plot, it is also possible to observe in greater detail the distribution of the data to determine the presence of the VOR. Fig. 7 shows the interval plot of the gains in the horizontal plane and Fig. 8 shows the interval plot in the vertical plane.

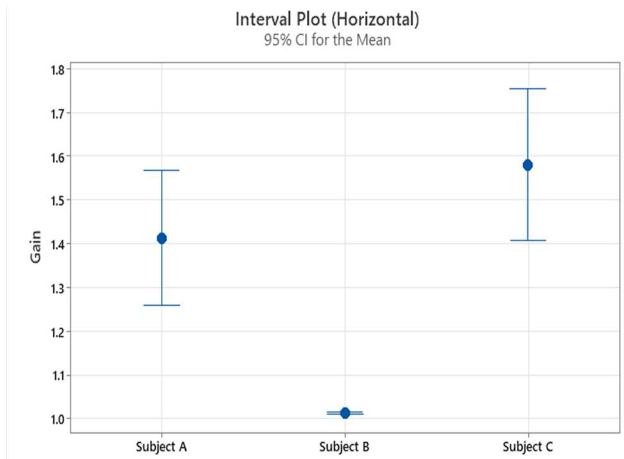

Fig. 7. Interval Plot - Horizontal movemnts.

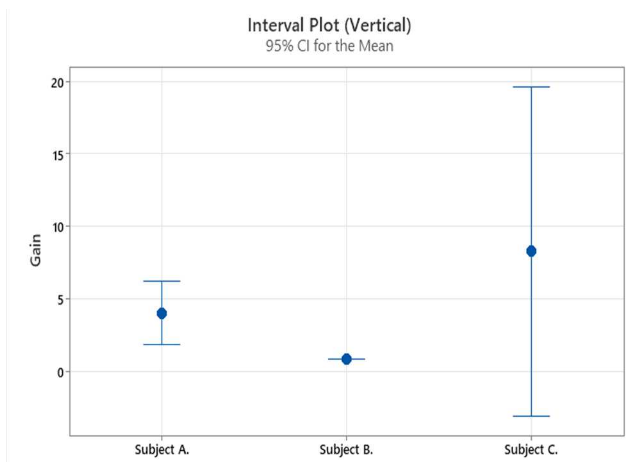

Fig. 8. Interval Plot – Vertical movemnts.

In Fig. 7 and Fig. 8 the distribution of the data is observed, however, the extreme cases that are contemplated in the box plot must be considered.

According to the statistical data presented, it is concluded that the vertical VOR was not registered, because the tests carried out only included movements from left to right to induce the horizontal VOR and not from top to bottom to induce the vertical VOR.

Specifically, Fig. 7 shows values close to one, which is not the case in Fig. 8 where the dispersion of the data is greater and the gain in two of the three cases is not close to one.

V. Conclusion

With these VOR records while using a VR headset it is possible to develop a wide variety of applications focused on areas such as biomedicine, rehabilitation, teaching and even the study of human-machine interaction with new technologies.

The analysis and recording are not limited to the response of the horizontal VOR, however, by the type of tests the vertical VOR was not induced.

The methodology used as well as the analysis developed to confirm the presence of the VOR while using a VR headset can be used for other types of reflexes such as saccades and even to detect problems associated with posture, gait, or neck affectations.

Finally, our contribution was to present a proposal for VOR analysis while using a VR headset, since tests for VOR analysis before and after exposure to a VR scenario have been performed but not during the use of these technologies.

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