Prototype of a no Invasive Rehabilitation System to Training Impairing Vision Problem caused by Amblyopia in Early Children

Simena Dinas [1], Javier Ferney Castillo García [2], Juan Camilo Castro Rizo [2], Juan Pablo Moreno Garzón [2], Santiago Falla Navia [2]

[1] *Universidad de San Buenaventura, Carrera 122 #6-65, Valle del Cauca, Cali, Colombia*
[2] *Universidad Santiago de Cali, Cl. 5 #No. 62 -00, Valle del Cauca, Cali, Colombia*

Abstract

This study presents a prototype of a no invasive system based on vision and tracking to training amblyopia for early, which demonstrates a good response for near and far localization, rotation and translation and white and dark skin tones. The system consists of a camera to identify the pupils, a microcontroller to send the data from camera to PC, Wi-Fi and Bluetooth connection for the data transmission and an OLED display to visualize the object for tracking. Additionally, a software processing the video information and calculating the results of identification and the tracking of pupils.

Keywords

Amblyopia Disease, Amblyopia Training, Eye Rehabilitation, Non-Invasiveness, Stereovision Problem, Visual Impairment

1. Introduction

American Academy of Ophthalmology referred low vision to patients with less than 20/30 in visual acuity, which require rehabilitation services to avoid loss vision and to increase the quality of life and independence [1]. The International Classification of Diseases as the inability to see and classified in 2018 the visual impairment in two categories: distance vision impairment and near vision impairment. The impact of visual impairment in low- and middle-income regions is four times higher than high-income regions, it means, for each visual impairment person in a high-income region there are only four with the same problem in a low- or middle-income region.

Additionally, the experience of people with visual impairment affects health, economics and personal factors in different levels [2]. Firstly, on one hand, in health system, the availability for promotion, prevention, diagnosis, and treatment is important. The prevention and early diagnosis allows to starting an early treatment and reduce the possibilities of blindness. On the other hand, the rehabilitation allows using the assistive products as glasses and treatment and reducing the risk of disability, increasing the easy and early access to school and work. Secondly, the economic factor, it disease affects mainly low- and middle-income regions where there are a negative combination: the cost of rehabilitation is higher and the productivity of the patient is lower than high-income regions.

Finally, in personal terms, the social interaction or acceptability and space interaction or accessibility help visual impairment people to be able to matching in the society. Even though mobility, information,

[1] 6th workshop on ICTC for improving patients rehabilitation research techniques. Rehab 2022, Teruel, Spain
EMAIL: sdinas@usbcali.edu.co (S. Dinas); javier.castillo00@usc.edu.co (J. F. Castillo García); juan.castro17@usc.edu.co (J. C. Castro Rizo); juan.moreno15@usc.edu.co (J. P. Moreno Garzón); santiago.falla01@usc.edu.co (S. Falla Navia)
ORCID: 0000-0003-3771-152X (S. Dinas); 0000-0002-0630-3198 (J. F. Castillo García)

and building construction have improve, there are accessibility problems and a person with visual impairment have a higher possibility to suffer a fracture or fall. Additionally, social isolation, low productivity, anxiety, depression, cosmetic distress, low self-esteem and visual disorientation [1].

Summarizing, it is important the availably of care services, the social acceptability and the spaces accessibility to increase the life quality of people according to the goal 3.8 (achieve universal health coverage) of the Sustainable Development Goals –SDG [3]. According to World Health Organization (WHO), 2.2 billion of people have near or distance visual impairment and blindness, however, 1 billion could have been prevented or is been addressed a treatment [2, 4]. Amblyopia, usually called laze aye is a visual-neurological disorder started in early childhood due to the immature development of cortical visual that, consequently reduces the visual acuity, affects the stereovision and pattern recognition, decrease the sensibility to motion and contrast [5]. This disorder can happened in one or both eyes and it can be generated by several ophthalmic condition as strabismus, uncorrected reflexive errors and central axis visual obstruction, among others. For vision, brain and sight work together, this closed relation affects the amblyopia in both senses due to the sight sense stimuli is close related to the brain.

The immature development of virtual cortex send to the visual cortex unsharp images that the brain cannot process correctly; as a result, the brain suppresses the unsharp image because the brain cannot work with both images, then, the continuous suppression produce weakness in the eye, then it works worse in the time and become an amblyopic eye [5, 6]. However, the rehabilitation in early years has a higher probability of improve or eliminate the condition [7, 8]. The prevalence of amblyopia worldwide is between 1% and 5% approximately. Recently WHO estimated that there was 19 millions of children between zero and 15 years with visual impairment, of which 12 million suffer amblyopia and uncorrected reflective errors. In contrast, Hashemi in [9] showed highest prevalence of amblyopia in European countries. Three etiologies divide the amblyopia [5]: strabismus, refractive errors, and structural or deprivation problems. Strabismus or crossed eyes happened when, sometimes, both eyes drift into different directions losing the alignment. This is the most common etiology, the brain rely on the image of one eye and suppressed the image of the other eye, producing amblyopia. Refractive errors is related to the way that the light pass through the eye. This is the second most common etiology, it deals with the clarity of the images, it is divided into Nearsightedness or myopia, which is relate to the problem to seeing far away; Farsightedness or hyperopia, which is relate to the problem to seeing up close and Astigmatism, which is relate to the problem to have a curved cornea. Finally, deprivation or structural problem happens when there are problems in the eye structure.

The main structural problems that produce amblyopia are: a) Cataracts is the opacity in the lens, which produce cloudy and blurry vision. b) Astigmatism is a common imperfection, which is caused by the eye impair curvature of the cornea and cause cloudy and blurry vision. c) Droopy eyelid is a muscular disease of the eye and throat, which may occur for nerve damage, aging or medical disorder. It can affect the vision development and produces amblyopia. In addition, d) Scar on the cornea is opacity or irregularity in the cornea, which can limit the ability to focusing on the light accurately. For format testing of amblyopia, visual field testing can be performed including fundus photography, optical coherence tomography (OCT), and an electrorethinogram (ERG) [5]. The treatment of amblyopia depend on the etiology causes [5], however, the most common are patching or optical penalization. Patching is related to occluding one eye to force the other to work, sometimes the occlude eye is the better; sometimes both eyes are occlude alternately. Optical penalization works as an ophthalmic medicine to force a paralysis of the muscle for accommodation. Additionally there are exercises to force the motion of the eye. The treatment is highly responsive in early children, but after seven years, the response to treatment decreases [7, 10].

Orthoptic is the branch of the eye science dedicated to detecting, diagnosing, and treating defects on eye motion to correcting binocular vision. An orthoptic professional have the training to rehabilitate a patient focused on neuro-ophthalmology and pediatrics.

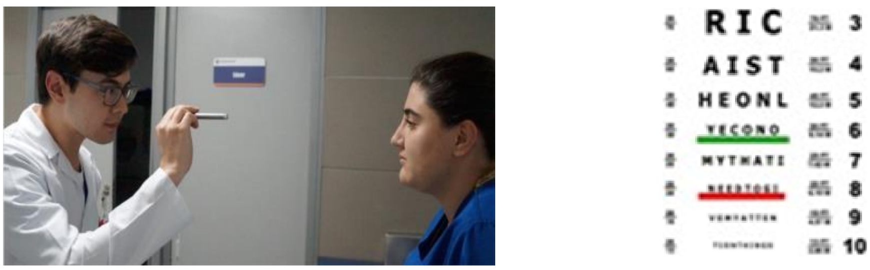
Strabismus amblyopia is a common type of visual impairment caused by unilateral and constant separation of the eyes [10]. For normal eyes, there are a separation angle closed to zero; however, for children diagnosed with this kind of amblyopia the angle of separation of the eyes changes and tends to increase without exercising as patching. However, the angle helps to identifying the problem but it does not depend on the severity of the problem.

In this document, there are a proposal of a prototype to exercise the eyes with inward or outward deviation.

2. State of Art

Several authors have worked on diagnosing and training of amblyopic eye, the most common solutions are based on smartphones [11], virtual reality [12-15] and 3D technology [16]. Cheng et al. [11] proposed EyeTurn, a smartphone application to diagnosis the eye misalignment by untrained nurses in schools. The problem with smartphones is the economic cost, the dependence of the children to the technology and the exposure to social interaction. In contrast, solutions for amblyopia focused on training [12], serious games [13, 14]] and quantification are based on virtual reality, which has high impact in ergonomics and fatigue for children. Finally the proposal with 3D is related to the training the stereovision [16]. Both smartphones and virtual reality use expensive devices, even though smartphones are common, they have to rely on children interaction.

In medicine there are different tests that identify ocular alignment, among them is the Hirschberg light reflex test (see figure 1.a). This test identifies ocular alignment by calculating the reflection of a flashlight on the pupils. The position of the light is approximately 66 cm from the eyes; if the reflection is centered, the eyes are aligned. If the reflection is near the nasal region of one eye, there is anisotropy, commonly referred to as deviated or "amputated" eyes. If the reflex is near the temporal region for one eye, there is an isotropy, commonly referred to as inwardly ocular deviation or "crossed eyes". In addition, the diagnosis includes identification of visual acuity lines by using a standard ETDRS (Early Treatment Diabetic Retinopathy Study) chart [18], as depicted in Figure 1.b.



(a) (b)

Figure 1: (a) Hirschberg light reflex test and (b) Standard ETDRS (Early Treatment Diabetic Retinopathy Study) chart. Taken from *Pautas para el examen oftalmológico. Enfoque para el estudiante de medicina y el médico general*, by Ríos. J, Bettin. L, et al. via DOI (https://doi.org/10.11144/Javeriana.umed58-2.ofta).

There is also a serious game prototype for eye training based on gaze tracking using an infrared sensor. An exergame based on a serious game mechanics that helps to strengthen the eye muscles by means of object tracking exercises where the gaze of the user is taken as a reference. The system was adjusted with a computer and an infrared sensor, with which the user interacts through the user interface of the developed program. The user interface of the developed program. The validation of the application was validated by means of a survey of people who spend several hours a day in front of the computer and from the Health and the Occupational Health office of the UMNG [17].

3. System Design

Following the description of the hardware and software constructed for identification and exercising eyes with amblyopia.

3.1. Processing: Integrated Microcontroller

The ESP32 CAM is a complete, independent and integrated microcontroller module that combines three important elements: a) the connectivity by using Wi-Fi and Bluetooth b) the image capture by using an integrated video camera and c) the storage by using a microSD slot. The Arduino platform was used because its flexibility, open-source option and easy to use. The advantages of Arduino include the possibility of both to connect several input and outputs devices and to programming in Windows, MacOS and GNU/Linux. For communicating the PC with the Arduino was used the converter module USB Uart CP102, which use the USB port and is compatible with Arduino, PIC, Atmel AVR, ESP8266, ESP32, among others.

1.1.1 *Connectivity: Wi-Fi and Bluetooth.* The connectivity module allows the image transmission from the camera to the PC in real time.

1.1.2 *Image Capture: Camera Integrated.* The integrated camera as a video captures the eye in real time to identifying the pupils. The camera uses the connectivity with Wi-Fi to send the video for processing to a local server.

1.1.3 *Storage: MicroSD.* The microSD is a storage device used to save information of the video and the results.

1.1.4 *Visualization: OLED screen*. The OLED screen project and circle to evaluate the tracking of the eyes for the prototype.

Figure 4 illustrates the technologies involved in the development of the prototype and the tasks involved in its operation, which details are explained in section 3.2.

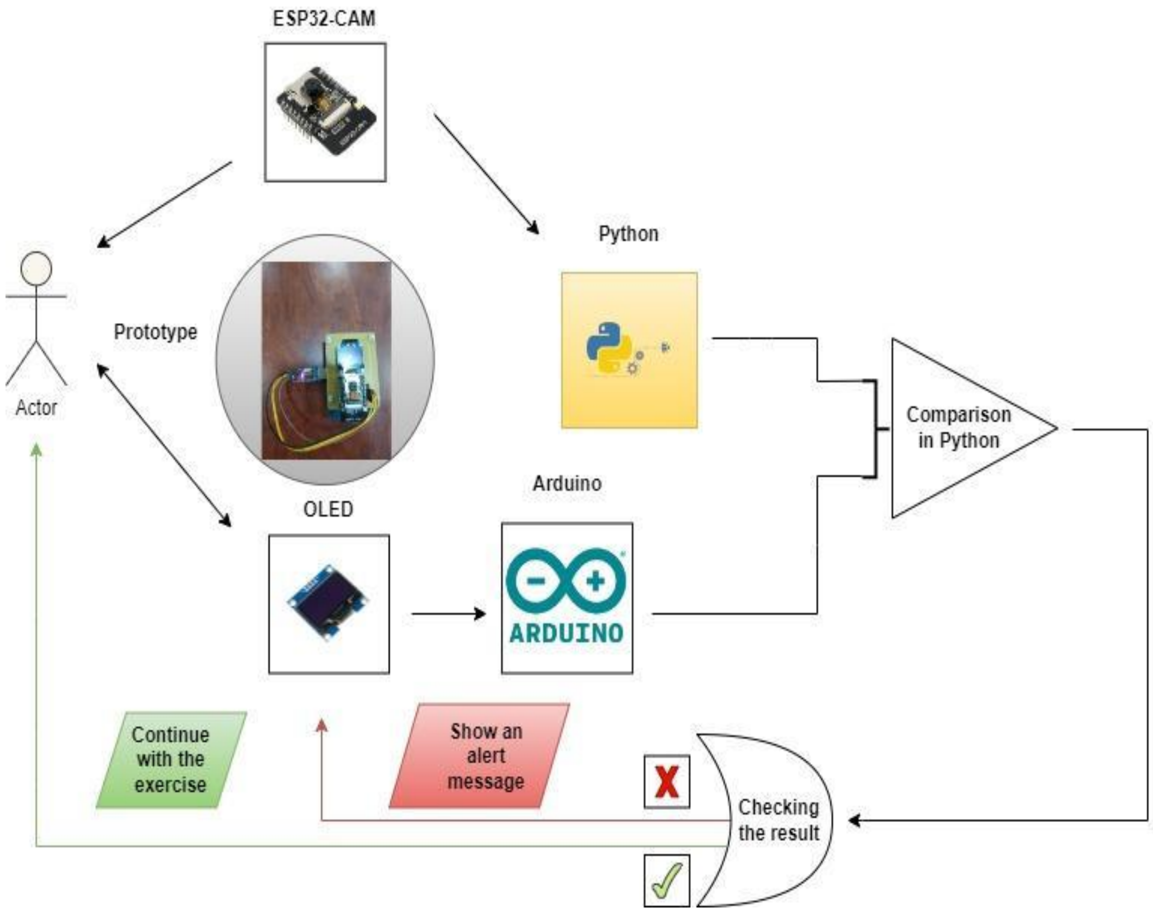


Figure 3: technological architecture of the prototype. Own authorship

(a) (b) (c) (d)

Figure 4: Testing and the System Design. (a) Looking Center. (b) Looking Right. (c) Looking Left. (d) ESP32 CAM & OLED

3.2. Software: Eye Tracking for Rehabilitation

This system is a combination of OpenCV and Python. It uses video to identify pupil position and evaluate amblyopia cases based on pupil position. According to the eye exercise, the vision system built for eye tracking relies on a microcontroller, a camera and an OLED display. The OLED screen produces a circular figure that moves and bounces off the corners of the screen as a tracking element, which the user will try to follow this object with his eyes while in parallel the camera takes facial images user, which are processed by software to obtain the exact position of its pupils. If the exercise is carried out correctly, the prototype continues normally, on the contrary, if the user fails or the deviation in the eyes is detected, an alert will be displayed on the OLED screen, which will tell the user to look towards the center again to restart the training section. The interface created is responsible for displaying the coordinates of the eyes of the user on the screen when they are detected, and when this occurs, a message appears on the screen indicating which direction the eyes are pointing. Figures 4a, 4b, 4c and 4d show the eye-tracking interface for rehabilitation with various face positions and eye direction and for white and dark- skinned people.

(a) (b)

(c) (d)

Figure 5: Eyes Recognition. (a) Front face and look, white skin. (b) Front face, side look, white skin. (c) Front face and look, white skin. (d) Front face and look, dark skin. Own authorship

For each process, a green marker at the positions of each pupil is located on the face and the corresponding text with the position of the pupils is depicted on the top-left on the screen. The position of the face and eyes helped to check the tracking system. The skin tone helped to verify the inclusivity of the system and improve the prototype. The person in figure 4.a, 4.b and 4.d are looking center, it means, they are looking the camera. The person in 4.b is looking left. The person in 4.d is a dark skin woman. For each one is identify the position of the left and right pupils.

The position on the eyes are important to identify the distance between the person and the camera. Usually, the exercises should be performance in a specific distance of the camera, then the distance of separation of the eyes on the image, help to identify the distance of the person to the device. According to Table 1, the identification of the both eye pupils position (X and Y) in several test of the prototype for distances between 10 and 80 cm with 10 cm of separation each one, the last column has the difference between the pupils. The X coordinate is related to de vertical position of both eyes and the X difference between pupils decrease proportionally to the distance, it means, the closest distance between the person and the device have the biggest difference, which is normal, because the closest object to the camera occupies more pixels than the nearest. Finally, the Y coordinate is related to the horizontal position of both eyes, and the values of the Y difference between 1 and 12 shown a weak inclination of the head, which is not important for the results.

Table 1
Testing the Eye Recognition in different distance from the camera

Distance (cm)	Left Eye (X, Y)	Right Eye (X, Y)	Difference (X, Y)
10	299, 176	566, 176	267, 0
20	303, 193	526, 205	223, 12
30	470, 175	322, 169	148, 6
40	329, 252	442, 251	113,1
50	358, 162	454, 158	96, 4
60	390, 76	467, 78	77,2
70	410, 148	484, 148	74,0
80	404, 124	468, 126	64,2

Additionally, figure 4a, 4b and 4c depicts three tests of the prototype for face motion for tracking with head up, left and right rotation. Those testing help to identifying the angle of tracking of eyes, when there are head motion, which is closed to 45°. It is important guarantee the functionality of the tracker with motion people because these exercises are mainly for children and they move constantly. In all cases, the eye tracking works correctly, the eyes are correctly identified by the tracker system, however the results of the process depends on the captured information.

(a) (b) (c)

Figure 6: Motion Test. (a) Up face. (b) Side face and look. (c) Occluded eye. Own authorship

The test of the system involve differences in people, background, distance, eye color, eye tone, head rotation, children and skin color. All test performed shown a correct tracker result and pupils position, the test with more than one person in the scene is not valid for the system, for it is impossible to identify two or more faces and show all results, however the purpose of this approach is not focus on multiple users detection and tracking. The test with one eye obstruction was performed, it does not identify the visible eye, however, the system was created to tracking both eyes, the operation are focused on both eyes tracking, but the result is not significant because it not affect the results.

4. Conclusions

Visual impairment is not a fatal disease, however, it reduce the quality of life of the people, reduce the social interaction and become an obstacle for mobility, transportation, secure walking, social interaction, independence, among others. Even though there are arguments to include therapeutics solution based on technology, there are contrary arguments to avoiding children interaction with electronic devices. The proposed device help to training the eye using a specific configuration defined by the specialist and take advantage of the tracker object to save precise information based on, the distance of the device to the patient and the time and frequency of each training section.

This training process related to track the eyes is not invasive method and it is suggested as a passive gymnastic training for office workers in order to exercise the ocular muscles continuously. It is suggest to performance gymnastic eye routines between 5 to 10 minutes each 2 hours. This system can track be used to save information about the training execution and results.

As a future work, the system have to configure the treatment, it means, according to the exercises routines, it will be configured follow a therapy program based on several exercises and specific patterns for a limited time, which are defined for orthoptic specialist as a treatment for a patient. The orthoptic specialist receives the information to identifying the sections performed by the patient, the quantity and quality of the routines and the expected and real improvements in the patient caused by the exercises. It helps his or her to take action as increase, maintain or reduce the number exercises, increase, maintain or reduce the frequency of the exercise or change the exercise, among others. In other words, it helps his or her to identify the moment when the exercise is not working any more or the necessary changes the routine or the intensity to improve the results of the treatment.

Gamification is a future option to stimulate early children to use the prototype in the next phase of development. The final propose of this research is focused on create a devise with a small screen, that can be used for people living in rural zones to train children. Additionally, the prototype should include Artificial Intelligence and Machine Learning to support diagnosis, treatment, training and rehabilitation with high precision, even though it will not constructed to replace the orthoptic specalist.

5. Acknowledgements

The authors would like to thank to Universidad de San Buenaventura for the financial support of this article. Equipment has been provided by Robotic Laboratory, Universidad Santiago de Cali, Cali, Colombia. LIDIS and GIEIAM Research Laboratory from Universidad de San Buenaventura and Universidad Santiago de Cali, respectively, which supported this work.

6. References

[1] R. M. Benetti Zagui, MD, PHD. Amblyopia: Types, Diagnosis, Treatment, and New Perspectives. In American Academy of Ophthalmology. https://www.aao.org/disease-review/amblyopia-types-diagnosis-treatment-new- perspectiv. June 2019.

[2] R. Kaiti, R. Shyangbo, S. Singh and C. Pandey. Visual Impairment and its Rehabilitation: A

Review. Tr Ophtha Open Acc J 3(1)- 2020. TOOAJ.MS.ID.000152. DOI: 10.32474/TOOAJ.2020.03.000152.

[3] Naciones Unidas, CEPAL. La Agenda 2030 y los Objetivos de Desarrollo Sostenible, Una oportunidad para América Latina y el Caribe. 2018. https://repositorio.cepal.org/bitstream/handle/11362/40155/24/S1801141_es.pdf

[4] World Health Organization. World Report on Vision. 8 October 2019. https://www.who.int/publications/i/item/9789241516570

[5] K. Blair, G. Cibis and A. C. Gulani. Amblyopia. [Updated 2022 May 8]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2022 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK430890/

[6] K. Seignette and C. N. Levelt. Amblyopia: The Thalamus Is a No-Go Area for Visual Acuity. Curr Biol. 2018 Jun 18; 28(12):R709-R712. DOI: 10.1016/j.cub.2018.04.081. PMID: 29920266.

[7] D. Hunter and S. Cotter. Early diagnosis of amblyopia. Vis Neurosci. 2018 Jan; 35:E013. DOI: 10.1017/S0952523817000207. PMID: 29905128.

[8] J. M. Holmes and D. M. Levi. Treatment of amblyopia as a function of age. Vis Neurosci. 2018 Jan; 35:E015. DOI: 10.1017/S0952523817000220. PMID: 29905125.

[9] H. Hashemi, R. Pakzad MSc, A. Yekta, P. Bostamzad, M. Aghamirsalim, S. Sardari MSc, M. Valadkhan MSc, M. Pakbin MSc, S. Heydarian and M. Khabazkhoob. Global and regional estimates of prevalence of amblyopia: A systematic review and meta-analysis. Strabismus. 2018 Dec; 26(4):168-183. DOI: 10.1080/09273972.2018.1500618. Epub 2018 Jul 30. PMID: 30059649.

[10] M. Cartaxo Barbosa, M. Pereira de Ávila, D. L. Cruvinel Isaac, M. Cartaxo Rebouças, L. M. Oliveira Salviano, J. J. Nassaralla Neto, C. Campos Teixeira, R. Rocha Luzini and C. de O. Trentin Strabismic Amblyopia: Compliance With Occlusion Treatment in a Tertiary Hospital in Midwestern Brazil. Revista Brasileira de Oftalmologia January 2020. DOI: 10.5935/0034-7280.20200065

[11] W. Cheng, M. H. Lynn, S. Pundlik, C. Almeida, G.Luo and K. Houston. A smartphone ocular alignment measurement app in school screening for strabismus. BMC Ophthalmol 21, 150 (2021). https://doi.org/10.1186/s12886-021-01902-w

[12] C. -C. Lin and C. -H. Chou, "A New Method of Visual Training for Amblyopia Using Binocular Training and Virtual Reality," 2021 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR), 2021, pp. 302- 305, DOI: 10.1109/AIVR52153.2021.00064.

[13] P. Vichitvejpaisal and T. Chotined, "Virtual Reality Photo Hunt Game Application for Amblyopia Patient," 2017 21st International Computer Science and Engineering Conference (ICSEC), 2017, pp. 1-5, DOI: 10.1109/ICSEC.2017.8443805.

[14] Á. S. do Prado and J. C. de Oliveira, "A serious game using virtual reality for treatment of Amblyopia," 2020 22nd Symposium on Virtual and Augmented Reality (SVR), 2020, pp. 277-284, DOI: 10.1109/SVR51698.2020.00050.

[15] J. T. Panachakel, A. G. Ramakrishnan and K. P. Manjunath, "VR Glasses based Measurement of Responses to Dichoptic Stimuli: A Potential Tool for Quantifying Amblyopia?," 2020 42nd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC), 2020, pp. 5106- 5110, DOI: 10.1109/EMBC44109.2020.9176510.

[16] A. Vitali, G. Facoetti and A. Gargantini, "An environment for contrast-based treatment of amblyopia using 3D technology," 2013 International Conference on Virtual Rehabilitation (ICVR), 2013, pp. 76-79, DOI: 10.1109/ICVR.2013.6662073.

[17] J. Ríos, L. Bettin, S. Naranjo, J. Suárez, and C. de Vivero. (2017). Pautas para el examen oftalmológico. Enfoque para el estudiante de medicina y el médico general. Pontificia Universidad Javeriana. Universitas Médica, vol. 58, núm. 2. (Pág. 15). de https://doi.org/10.11144/Javeriana.umed58-2.ofta