Amblyopia Rehabilitation by Games for low-cost Virtual Reality Visors

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Abstract. Amblyopia is the partial or complete loss of vision in one eye (called *lazy eye*). It can be prevented by adequate treatment during the first years of young age. However, the classical therapy of eye patching suffers from a low compliance that can harm the treatment. To increase compliance, we have devised a system based on the combined use of low cost virtual reality visors, like the Google Cardboard, and ad hoc developed games for smartphones. Our system exploits the visor in order to send to the lazy eye an enhanced version of the gaming image while it sends to the normal eye a weakened version of the same image. In this way, the lazy eye must work more than the normal eye. We present here the principles, some issues we encountered, the integration of the games with a service that collects the data, and two games, namely a car racing and a tetris game.

Keywords: Amblyopia, Cardboard, Virtual Reality Visor, Rehabilitation, Android, Mobile games

1 Introduction

Amblyopia, otherwise known as 'lazy eye', is reduced visual acuity that results in poor or indistinct vision in one eye that is otherwise physically normal. It may exist even in the absence of any detectable organic disease. Amblyopia is generally associated with a squint or unequal lenses in the prescription spectacles. This low vision is not correctable (or only partially) by glasses or contact lenses. Amblyopia is caused by media opacity, strabismus, anisometropia, and significant refractive errors, such as high astigmatism, hyperopia, or myopia. This condition affects 2-3% of the population, which equates to conservatively around 10 million people under the age of 8 years worldwide [13]. If amblyopia is not diagnosed and treated in the first years of life, the lazy eye becomes weaker and the normal eye becomes dominant. The traditional way to treat amblyopia is carried out wearing a patch over the normal eye for several hours a day, through a treatment period of several months. This treatment has some drawbacks: it is unpopular, not well accepted by the young patients, and sometimes can disrupt the residual fusion between the eyes.

Our group has been involved in the use of computer technologies for the treatment of amblyopia for several years. The project 3D4AMB[1] exploits the stereoscopic 3D technology, that through glasses with LCD active shutters permits to show different images to the amblyopic eye and the normal eye. We developed some software both for amblyopia diagnosis [5] and treatment that uses this kind of 3D technology [11]. A form of treatment we have proposed, consists in watching video clips with 3D glasses that realize a virtual visual rebalancing [4]. Note that the classic use of a 3D system (like 3D glasses or Virtual Reality visors like the Oculus Rift) is to provide different images to the two eyes of the same scene with viewing angles slightly out of phase, that correspond to the different points of view of left and right eye. This vision produces an illusion of depth of the scene and is the heart of virtual reality. The primary principle of the system is that the images shown to the two eyes are different but related.

In this project, we exploit 3D systems in order to send two different images to the two eye not in order to provide an illusion of depth but to stimulate the lazy eye to exercise more than the normal eye. In this work we plan to advance w.r.t. the existing treatments by using a much cheaper virtual reality device (already used for screening amblyopia [2]) and by increasing the level of activity required from the patients. Indeed, while patching and vision rebalancing are classified as passive method, other treatments which require some activity on the part of the patients are classified as *active*. Active methods are intended to enhance treatment of amblyopia in a number of ways, including increased compliance and attention during the treatment periods (due to activities that are interesting for the patient) and the use of stimuli designed to activate and to encourage connectivity between certain cortical cell types. A good survey and assessment about active treatments and their efficiency can be found in [9].

The active treatment proposed in this paper consists in playing with interactive games or exercises, which will stream binocular images. In this settings, the child plays with a special video game which will exploit the binocular vision to send to the lazy eye all the details while the normal eye will see only a part of the game scene. To successfully complete the game or the exercise the patient must use the information shown to the lazy eye (and possibly fuse it with the information shown to the normal eye). In this way, the amblyopic eye is more stimulated and the fusion encouraged. The game application must continuously monitor the success rate of the game in order to adjust the difficulty based on the real capability of the player. It is well known that video games can be very useful for visual rehabilitation [1]. Classical examples of games found in literature, include PAC-MAN and simple car racing games [12]. This work extends the work presented in [6] by introducing a tetris game (similarly to [10]) besides a simple car racing game.

In this paper, first in Sect. 2, we introduce low cost virtual visors like the Google Cardboards and explain how they work. Then, in Sect. 3, we explain how gaming with this devices can be exploited for our goals. Sections 4 and 5

[1] http://3d4amb.unibg.it/

Fig. 1: The original Google Cardboard VR visor and a plastic variant

introduce our two mobile applications that realize the video game for amblyopia treatment.

2 Low-cost Virtual-Reality Visors

The Google Cardboard platform pioneered the use of low-cost devices for virtual reality (VR). These devises are made by inexpensive material and require the combined use of a smartphone in order to work. The Google Cardboard has been developed by Google and it was created by David Coz and Damien Henry, Google engineers at the Google Cultural Institute in Paris, in their 20% "Innovation Time Off"[8], and introduced at the Google I/O 2014 developers conference for Android devices. It is intended as a low-cost system to encourage interest and development in VR and VR applications [3].

It consists of a fold-out cardboard with two lenses where the user must insert the smartphone (see Fig. 1). While the original device is made by actual cardboard, nowadays plastic devices can be easily found for a price in the order of 30 dollars.

The working principle is simple: the user looks inside in order to see the images displayed by the phone. It permits a stereo vision by sending two different images to the two eyes. It works with different smartphones and can be easily adapted to be used by children. The system proposed in this paper also works with other types of VR viewers (e.g., Samsung Gear VR).

It is not an experience as the strap-on Oculus Rift headset, which requires a computer (and is still in development), or Samsung Gear VR, which costs $200 and only works with the Galaxy Note 4. But it is an easy way to get a feel for what is possible with modern virtual reality, and beyond the low cost of the headset, most of the available apps are free.

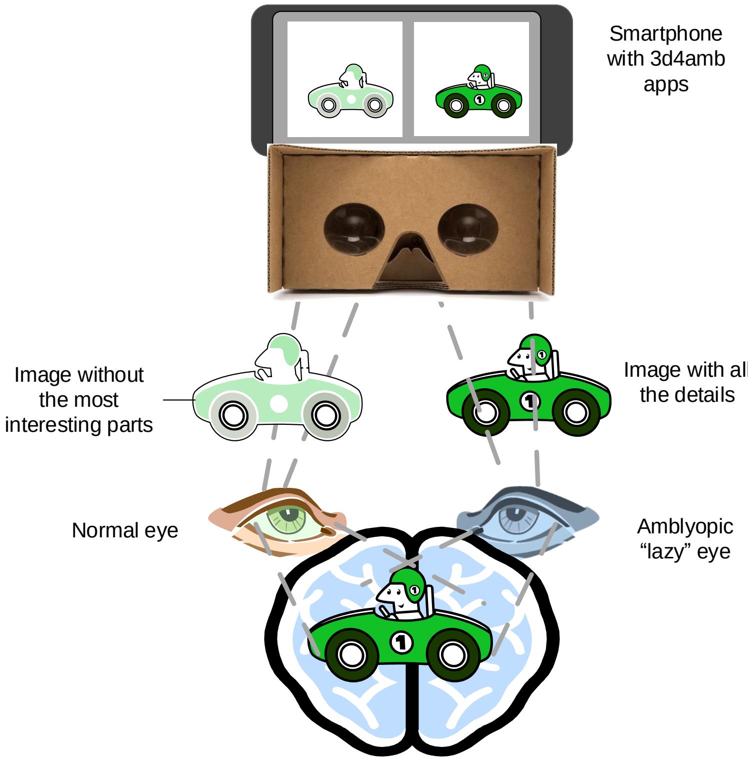


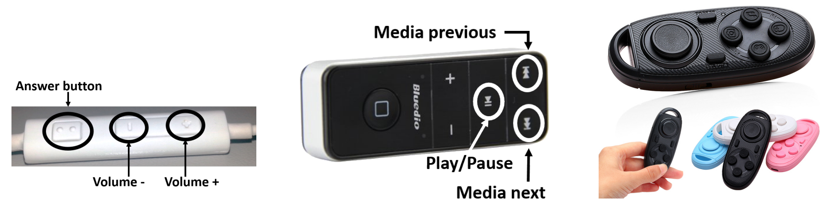
Fig. 2: 3D4AMB system with Google Cardboard

3 Low-cost VR Games for Amblyopia Rehabilitation

In this section we explain how we can exploit low cost VR devices presented in the previous section for our goals. We will discuss the principles, the challenges, and how this system has been integrated in a service able to track the patient exercises and progress.

3.1 Using Low-cost VR for Amblyopia Rehabilitation

Low-cost VR devices can show 3D images by displaying on the phone two different images in the two parts of the screen. This principle can be used in practice also for the treatment of amblyopia by sending two different images to the two eyes: the game app will show the most interesting part of the frame of the clip or game to the amblyopic eye, while we will show the least interesting part to the not amblyopic eye (or good). The principle, in case of use of the Google Cardboard is depicted in Fig. 2. Since the patients are young children, we decided to implement the diagnosis and treatment modules in a form of simple videogames,



(a) Wired headset (b) Bluetooth headset (c) Bluetooth controller

Fig. 3: User interaction with games

in order to make the treatment fun and not boring. The final aim of the project is to give the patients a complete system for the treatment that can be used at home. In fact, a smartphone and an inexpensive Google Cardboard are enough to run the software presented in this paper.

Our project follows the recent trend of using inexpensive technologies for amblyopia rehabilitation. Other approaches are based on the use of anaglyph glasses [7,14]. The main advantages of our approach is that the colour of the images is not change, providing in this way a better experience.

3.2 Interaction with games using Google Cardboard

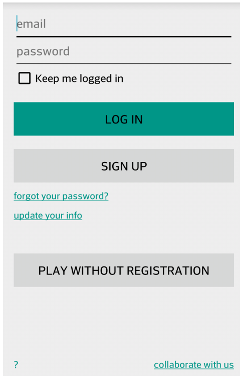
User interaction is not easy because the smartphone is inside the Google Cardboard and the user cannot tap on the screen. We have run up against this problem during the Stereoacuity Test development [2]. To avoid this limitation we suggest and now support several solutions:

– Stereo headset buttons (Fig.3a and Fig.3b)
– Bluetooth remote controller (Fig.3c)
– Speech-controller

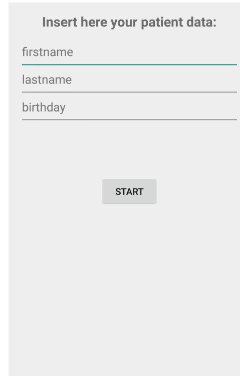
The simplest solution is to use standard *stereo headset*. Stereo headset usable for our applications must contains three buttons, i.e. plus button (+), minus button (-) and answer button. These buttons can be used to perform different actions in the games. The disadvantage with stereo headset is that the buttons are too small and too close, this can cause wrong push during the games. Wired earphones (Fig.3a) has also the problem that the wires can obstacle the use of the VR device. To avoid this problem, bluetooth wireless earphones can be used instead since they provide a controller (Fig.3b) for the earphones that can be used to control our applications.

A more specialized version is a *bluetooth remote controller* that is a special purpose device as presented in Fig.3c. It has more than three buttons and it allows to perform more actions. The market offers different type of bluetooth remote controller, complex and easier, and this allows the developer to choose the one more suitable for the application.

Another possibility is to use the voice to control the games. This software *speech-controller* allows the user to interact with the application using the voice.



(a) Log in activity



(b) Doctor interface

Fig. 4: Interaction with games

There are some available libraries that given sounds translate them into words and the developer can take these words to perform some actions. We have tested two libraries: Android speech recognizer and CMUSphinx. The former works well, but has a bug: after few seconds of silent the speech recognizer crashes and it is not able to continue to take commands. The latter is developed for research projects and has more modules to allows the development of different functionalities. We have tried the second approach with our applications, but we met the following problems: 1. the system does not recognise words if background noise is present 2. the system is slow in processing sounds.

3.3 Traceability of user improvements

During the therapy execution the user is interested in keeping track of his improvement. We have developed a web service that collects games results. Our games interact with this service in order to send data. Before starting the results saving process, the user has to make the registration using the "SIGN UP" button (Fig. 4a). Some information are required to complete the registration, i.e., email, password, name, surname and age. The email and the password, chosen during the registration, are used to LOGIN before the start of the game. At the end of the game the data are sent to the server and the user can ask to receive an email with a summary of the performance to understand if he is getting better. It is available the possibility to play without registration, but this does not allow to trace improvements.

Sometimes could happen that the doctors want to follow the patient improvement during some test sessions in their office. The game applications provide a doctor interface (Fig. 4b) to manage the patients results. The doctor registers using email and password. After the LOGIN, he can choose the patient for treatment session, add patients and check their improvements.

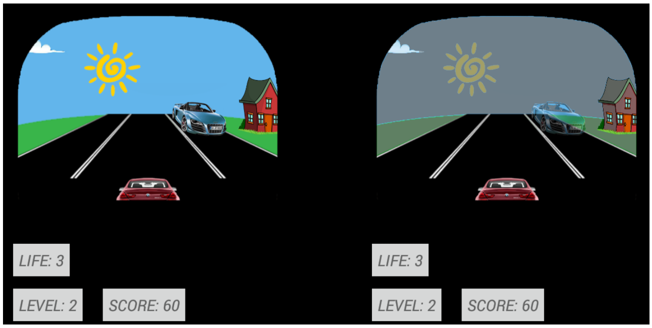


Fig. 5: A simple game scene of CRC

4 Car Racing Mobile Application for Amblyopia Treatment

The principle of using 3D for penalization of the normal eye in amblyopic children, as explained before, has been applied in the game development for the treatment of amblyopia. The game is called *Car Racing Cardboard (CRC)* which works for the Google Cardboard and it is freely available on the Google play store[2]. The goal of this game is to avoid cars coming from the opposite side. The difficult of the game will increase when the user passes to next levels.

Required hardware The CRC application has been developed for Android system. The basic hardware needed to use the game is: Android Smartphone (with the CRC application installed), Google Cardboard, or any other 3D VR glasses and earphone with controller (+, - and confirm) to play with the game.

Game principle As shown in Fig. 5, the game scene shown to the patient is divided in two parts by the application, one for the healthy eye (right eye in the figure) and one for the amblyopic eye (left eye in the figure). The CRC decides which images send to the eyes depending on the type of treatment suggested by the doctor. In any case the lazy eye of the child is stimulated to work and the healthy eye still working. This is a positive aspect since the child does not interrupt the fusion of images between the eyes (the occlusion treatment does not help the improvement of fusion between images coming from the eyes, because the healthy is covered with the patch).

The brain of the patient has to combine the two images coming from the eyes to view the complete frame successfully and to perform simple operations like identifying the incoming cars and move the main car. There is a significant number of common elements between left and right images in order to make sure that the patient can merge them. The final frame is not a 3D-dimensional

[2] https://play.google.com/store/apps/details?id=it.unibg.p3d4amb.carracingcarboard

representation since the objective is not to stimulate the stereo vision of the patient (at least initially), but to make the eyes working together in the same way.

Game description Before the beginning of game, the application allows the user to choose the lazy eye (left or right), in order to decide between two different views (penalize the right or left eye). The goal of the game consists in getting the highest score possible. The gamer moves the main car (in the bottom of the view) in order to avoid obstacles (i.e. incoming cars in the opposite direction), and if it does not hit any obstacle, the score increases. When the child avoids a predetermine number of cars, the level increases. When the level rises, the speed and the number of obstacles increase so as to make the game more difficult. However, the most important aspect is given by the dynamic penalization of the scene shown to the healthy eye. In fact, when the level rises, the application increases the transparency of the panorama and the obstacles displayed for the not amblyopic eye, in order to train the lazy eye. The game ends after 3 collisions (after 3 lives lost). The gamer uses earphone to play. "+" and "-" buttons are used to choose the lazy eye at the beginning of the game and to move the main car in order to avoid obstacles. Instead, confirm button is used to start the game or restart it after the end. If the user is logged into the application, at the end of each game session the data are saved to track the improvement.

5 Tetris for Amblyopia Treatment

As the CRC game, Tetris has been developed for the treatment of amblyopia. The goal of the game is like the original. The screen is split into two parts, one for the left eye and one for the right eye. The blocks get down and the user has to move them in the correct position in order to delete the lower rows. The blocks are not shown with the same definition to both eye, for the healthy eye they are degraded. In this way the amblyopic eye has to work harder to allow the correct recognition of blocks position. The brain combines the images coming from the eyes to rebuild the complete image. At the beginning the game is easier because the image sent to the healthy eye is slightly degraded. When the user deletes lower rows, the difficulty increases and the image sent to the healthy eye is more degraded. At the end of the game, if the user has logged in, the score is saved and is sent to the server. The gamer uses earphone to play. "+" button moves the blocks on the left, "-" button moves the blocks on the right and confirmed button rotates the blocks. As for the CRC, the user is able to follow his improvement during the treatment.

6 Conclusion and future work

The aim of the two applications shown in previous sections is the treatment of amblyopia (or lazy eye). They require the use of inexpensive devices: a visor and stereo headset. By using the applications, people with lazy eye can improve their

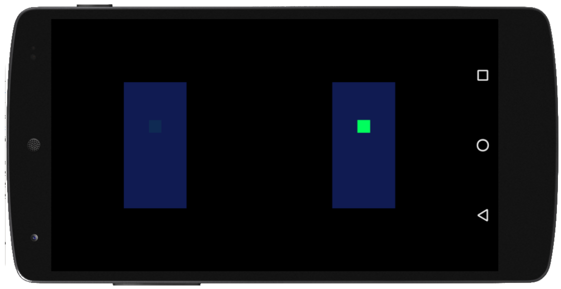


Fig. 6: A tetris cardboard game

vision in the lazy eye. The policy for the treatment of amblyopia proposed by 3D4Amb, also tries to avoid the classical risks of the patch therapy (poor conformance and fusion disruption) and allows a interactive and supervised healing. However, at least initially, this therapy can be performed alongside with the classical occlusion. Although there are not clinical results available at the moment to support the effectiveness of the application, a series of experiments with children are currently carried on at the local hospital in order to check the validity and viability of the proposed approach. At the moment, the system for registration provides the possibility to save the results and check them by email. Feature development will be done in order to offer this service on a web server. We are planning to develop a platform where user can register. Once he is registered can use the same credentials for all games. A web application will be available to consult the results reached in different games during the treatment. A collaboration with some medical centers is going to start with the target to collect data from patients. It is also interesting to analyze how long the child needs to play before achieve some clinical improvement and how this method could replace or help current therapies.

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