Using 3D for Rebalancing the Visual System of Amblyopic Children

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***Abstract*—Amblyopia or "lazy" eye is a disorder of the visual system that causes poor vision in an eye that is otherwise physically normal, and it affects 2-3% of the population, which equates to conservatively around 10 million people under the age of 8 years worldwide. Amblyopia is a neurologically active process: the problem is caused by either no transmission or poor transmission of the visual stimulation through the optic nerve to the brain. With time, if no treatment is performed, the weak eye becomes even weaker and the other eye becomes dominant. Amblyopia is classically treated by clarifying the visual image with glasses, and patching (totally or partially) the dominant eye in order to force the use of the amblyopic eye. Patching suffers from several problems: it is unpopular, prolonged, and it can sometimes disrupts any residual fusion between the visions of the eyes. This results often in noncompliance with the therapy. Several alternatives have been introduced, including partial occlusion and vision rebalancing in which the image to the lazy eye is enhanced and the image to the good eye is penalized. We present how a 3D technology can be used to realize a system for vision rebalancing of video clips which exploits the stereo vision of the 3D system. This technology is relatively inexpensive, easy to use also in a domestic environment, with recreational activities enjoyable by the children, and easy to extend. We have implemented a prototype software system which processes a video and sends a penalized version to the good eye and an enhanced version to the lazy eye. We use a "framesever" for runtime video processing and several image filters and meta-filters to obtain the final video to be viewed by the patient. We argue for the viability of the proposed method in the treatment of amblyopic children.**

***Keywords*-Amblyopia treatment, virtual rehabilitation, 3D, video rebalancing, partial occlusion**

I. Introduction

Amblyopia, otherwise known as 'lazy eye', is reduced visual acuity that results in poor or indistinct vision in an eye that is otherwise physically normal, or out of proportion to associated structural abnormalities. It may exist even in the absence of any detectable organic disease. Typically amblyopia is present in only one eye and 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.

There exist several causes of amblyopia. Anything that interferes with clear vision in either eye during the critical period (birth to 6 years of age) can result in amblyopia. The most common causes of amblyopia are constant strabismus (constant turn of one eye), anisometropia (different vision/prescriptions in each eye), and/or blockage of an eye due to trauma, lid droop, etc. If one eye sees clearly and the other sees a blur, the good eye and brain will inhibit the eye with the blur. The brain, for some reason, does not fully acknowledge the images seen by the amblyopic or lazy eye. Thus, amblyopia is a neurologically active process. The inhibition process (*suppression*) can result in a permanent decrease of the vision in that eye that can not be corrected with glasses, lenses, or surgery. This condition affects 2-3% of the population, which equates to conservatively around 10 million people under the age of 8 years worldwide. Children who are not successfully treated when still young (generally before the age of 7) will become amblyopic adults. As amblyopic adults, they will have a normal life, except that they are prohibited from some occupations and they are exposed to a higher risk of losing the good eye due to injury or eye disease and became seriously visually impaired.

Amblyopia is currently treated by wearing an adhesive patch over the non-amblyopic eye for several hours per day, over a period of several months. This treatment was introduced in the 18th century [4] and is commonly used also nowadays. It can require up to 400 hours in total to be effective [6]. This conventional patching or occlusion treatment for amblyopia often gives disappointing results for several reasons: it is unpopular, prolonged, and it can sometimes make the squint worse because it disrupts whatever fusion there is [11]. These issues frequently results in poor or *non-compliance* and since the success of patching depends on compliance, it performs on average very poorly. The treatment by itself works well, but it is often abandoned because it is too much trouble to take. Very often, children are averse to wearing a patch and parents found occlusion difficult to implement [8]. As noted in [22], a treatment whose unacceptability is greater than the motivation of the patients to apply it, will be often abandoned. And if the treatment of patching is not continued, it will eventually fail [19]. For this reason, the orthoptists and ophthalmologists are continuously looking for a more acceptable solution to the problem, i.e. an effective treatment that is also complied with and so really works [15].

There exist several attempts to introduce variations to occlusion which could perform nearly as well as the occlusion without the problem of compliance and the risks of disruption of any existing binocularity. In particular, *partial occlusion* consists in wearing an adhesive filter to attenuate the vision of the good eye [5]. This method is also known as *penalization* and it can be also performed optically by using defocusing lens or pharmaceutically by using atropine which causes blurring of the sound eye. This kind of treatment has proved to be effective [21], especially in amblyopia of mild and moderate degrees. In [3], the authors experimented the occlusion of the lens over the preferred eye with a translucent tape. This technique permitted uninterrupted and prolonged occlusion, with a successful visual outcome. However, this kind of treatment has still some problems of compliance and applicability (e.g. pharmaceutical penalization must be administered by a physician). There are some attempts to use computer systems to implement a sort of virtual penalization, called *rebalancing*. In [10], the authors introduce a vision system based on a head mounted display (HMD) which performs rebalancing of the vision by using a simultaneous enhancing/attenuation image adjustment. The image presented to the normal eye is attenuated while the image presented to the amblyopic eye is enhanced. The main problem of such system is that binocular HMDs have a limited wearability for young children, they either have a very low resolution and a limited weight or a good resolution but a considerable weight, they are costly, and not easily extensible. For instance, the HMD used in [10], has resolution 320x240 (not ideal for viewing images or clips), it costs around 300$, it requires modification of the hardware to allow separate image control for each eye, and it allows only the modification of contrast and luminosity.

In this paper, we present in Section II a system for vision *penalization* and *enhancement* which is based on a 3D technology. It exploits a standard 3D technology based on active LCD active shutter glasses and it allows the implementation of a **low-cost** flexible software system for video rebalancing. The 3D system is used not to recreate an actual 3D virtual reality with an illusion of real depth of the scene, but to provide the two eyes with two different video streams. The actual implementation, using a video frameserver for real time video rebalancing, is explained in Section III where also some filters and their temporal application (by a meta-filter) are briefly introduced. In Section IV we present some related work. We discuss our approach and we argue for its viability in Section V. Section VI concludes the paper and presents some future work.

II. Video Rebalancing by 3D Vision

The main goal of our research project has been devising a system for vision rebalancing that is accessible. With the term "accessible" we mean:

- **Inexpensive:** the system needs to be relatively *low* in cost, it must be affordable by a family. To be so cheap, the system may be based on standard off the shelf technologies, which could be bought in stores open to the general public. Possibly, it must reuse appliances normally used for other kinds of activities.
- **Friendly to use:** the system needs to be friendly in its use such that the patients can use it without requiring a particular education or skill. Once that the therapist has decided the prescribed activities, the system can be operated autonomously by the children themselves and the intervention of an adult (which does not need to be a medical doctor) may be limited to initially set up the system (installation) and to start the treatment at least. To be so easily usable, the system may use standard user interfaces like a keyboard, a remote control, or a mouse.
- **Suitable for domestic use:** the system can be used at home without frequent time-consuming visits to the hospital. In this way, the timing of the treatment can be decided by the patients (and the system must be able to record the actual use of it). It may use other domestic appliances normally used not for the treatment itself like standard personal computers and televisions.
- **Enjoyable:** it must propose recreational activities which should be appealing for young children. The children should not feel under an actual medical treatment during its use.
- **Easily extensible:** it must be possible to easily develop new applications and programs to be added to the system. For this reason, standards and open software libraries may be used for developing the applications. It must also be possible to add new activities for the patients in order to variate the kind of activities proposed to the patient.

All the characteristics listed above should reduce the compliance problem and make the proposed treatment acceptable. In [14] we have presented a system, called 3D4Amb, which is based on 3D vision technologies and which is extended in this paper for video rebalancing having all the desired features listed above. In the following we explain its basic principle.

A. 3D systems and binocular vision

The devised system is based on the 3D technologies, although its goal is not to provide the patients with the 3D experience but to allow binocular vision. The classical use of a 3D system is to provide the two eyes with two different images of the same scene with a slightly offset viewing angles which correspond to the different viewpoints of our left and right eye. This vision produces an illusion of real depth of the scene and it is the basis of the *3D virtual reality*. We exploit only the capability of the 3D system to send two different images to the eyes while we do not want to recreate a virtual reality.

The working prototype of the proposed system we have already built, is based on the NVIDIA® 3D Vision™ technology, although other 3D technologies may be supported as well in the future. The NVIDIA 3D Vision technology is one of the most accessible 3D technologies available on the market today, it requires a standard personal computer with a NVIDIA graphic card (also entry level NVIDIA graphic boards work), a monitor 3D Vision ready, which is capable of a refresh rate of 120 Mhz, and a NVIDA 3D glasses. Figure 1 shows the 3D glasses with their synchronizing emitter to be connect either to the USB port of the PC or directly to the graphic board.

Figure 1. NVIDIA 3D glasses

The NVIDIA 3D vision is based on LCD active shutter technology. With this technology, the left and right eye images are presented on alternating frames, but since the monitors used are capable of 120Hz, each eye still sees a full 60Hz signal that is equivalent to the refresh rate on LCD monitors today. This offers a number of advantages with respect to other stereoscopic technologies like polarized or anaglyphs glasses or head-mounted displays, including:

- **Full image quality per eye**: In 3D mode, each eye receives the full resolution of the display for the highest possible image quality for text and objects. The colors are not altered and both eyes can receive images of the same quality.
- **Wide viewing angle for 3D**: Because full images are presented on alternating frames, there are no restrictions on the viewing angle in 3D mode. Users are free to move their heads vertically or horizontally within the full viewing angle of the display without losing the 3D effect or suffering increased ghosting which allows for comfortable viewing for continuous gaming or movie watching.
- **Excellent 2D Operation**: If the user decides to switch back to 2D at any time (for the normal use of the PC), the performance of 3D Vision PCs supports a 120 Hz higher refresh rate that reduces ghosting and blur typically found during motion on existing PCs that have 60 Hz displays.
- **Personalized fit**: the NVIDIA glasses have top-of-the-line optics, include adjustable nose pieces, and are modeled after modern sunglasses. They can be worn over prescription glasses. This is important, since most of the amblyopic children use glasses.
- **Acceptable cost**: The cost of the glasses is around 140$, while the 3D ready monitors cost a little more than the traditional monitors but they offer a better quality also in 2D.

The system we have developed for 3D4AMB consists in a normal PC desktop connected to a 3D monitor (3D Vision-Ready Display). The PC must be 3D capable and have all the 3D4AMB software installed on it. The patient wears the NVIDIA active LCD shutter glasses that allow viewing a different image from the left and right eye. The scenario is depicted in Figure 2 and explained below.

B. *3D for video rebalancing*

The basic principle of the system is that the amblyopic or 'lazy' and the normal eye can be shown two different images or videos. This principle can be used in practice for video rebalancing, where the amblyopic eye is shown an enhanced version of a video, while the non-amblyopic or 'good' eye is shown a penalized version of the same video. The video to be shown by the patient is duplicated by 3D4AMB in two versions and each version is then modified: one for the right eye (the amblyopic eye in the Figure) is enhanced and one for the left eye (the good eye in the Figure) is penalized. The 3D4AMB software decides how to process the video depending on the type of the desired treatment. In this way, the lazy eye of the child is more stimulated to work, but the non-amblyopic eye is not patched. The patient brain joins (or fuses) the two video versions in one unique vision experience. To make sure that the patient can join the two videos, the two versions must be not too much different. Note that the final video is a bidimensional video because the goal is not to stimulate the stereo vision of the patient (at least initially). We plan to work on the use of real 3D stereo video streaming to combine vision rebalancing with depth perception.

III. IMPLEMENTATION OF THE SYSTEM

To implement the video rebalancing system described above, we have used a frameserver, which allows real time video rebalancing. A video frameserver provides instant editing and processing without the need for temporary files. There are several advantages of such system:

- Any video content can be processed. The patient can freely choose the preferred video of its choice and feed it into the system to have that video rebalanced.
- No video "pre-processing" or editing is required. The patient does not have to wait until she/he can perform the activity.
- It can be adjusted easily by the therapist which prescribes the treatment: the enhancement/penalization editing can be adapted depending on the patient (e.g. its visual acuity) and on the desired strength of the treatment (e.g. for maintenance exercise, a light treatment may be preferable).

As frameserver we use the AviSynth software [1]. AviSynth is a powerful software tool for video post-production for Microsoft Windows and it is free software under GNU GPL license. It provides several ways of on-line editing and processing videos. AviSynth itself does not offer a graphical user interface (GUI) for editing videos (although some third party GUI editors are available), but instead provides a simple yet powerful scripting language which is used to describe the video streams processing. AviSynth is controlled entirely by a script file which acts as a "fake" video (avi) file and can be loaded by any video player. In this way, in our approach, every activity to be carried on by the patient is a simple script file which contains a reference to the video to be rebalanced and the type of processing to be applied (e.g. the filters to

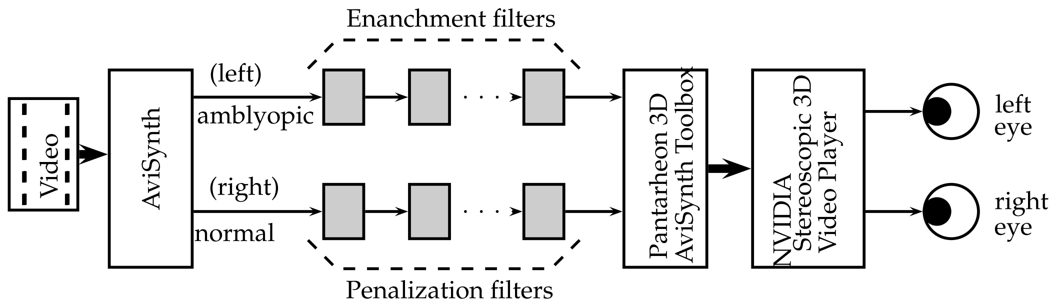

Figure 3. Real time video rebalancing by using AviSynth

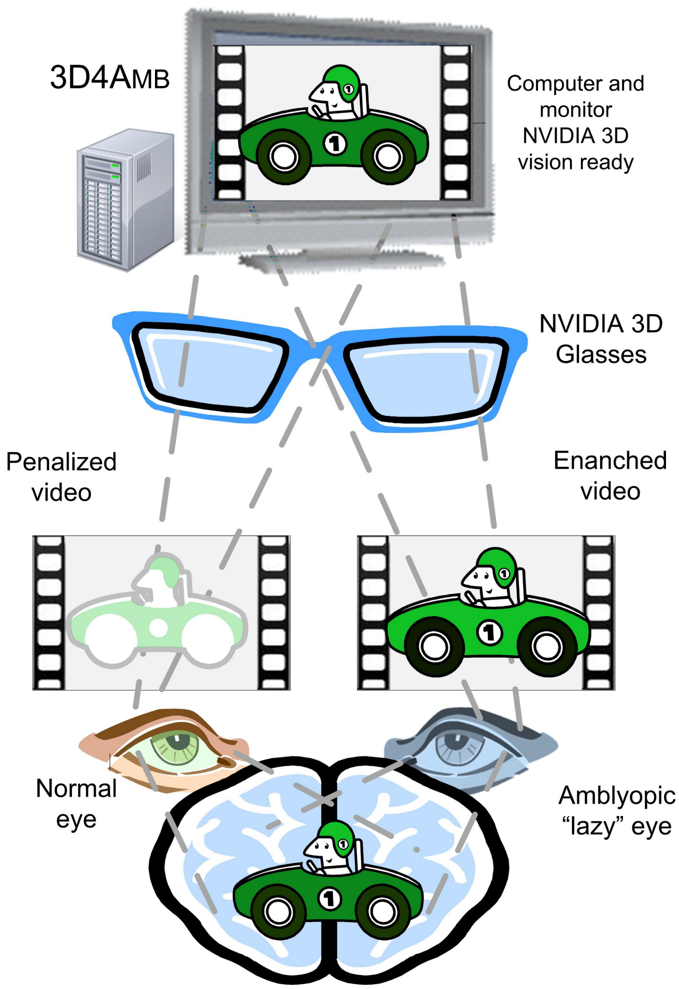

Figure 2. Video rebalancing: basic principle

Basic filter	**increase/decrease**
Brightness	the luminance (reflating or radiating light)
Contrast	the difference in color and light between parts of an image
Chroma correction	colorization of the video: from color to scales of gray
Advanced filter	**effect**
Blur/Sharpen	softens the details of an image. It defocuses the video/sharpens the image
FadeIn/FadeOut	causes the video stream to fade linearly to black at the start or end.
Noise introduction	Introduce some noise
Translate	translates a video by adding some border at left or right

Table I
ENHANCEMENT/PENALIZATION VIDEO FILTERS

be used). The entire treatment consists in a set of script files prepared by the therapist in advance.

A. *Video processing and streaming*

The system we have implemented works as shown in Fig. 3, which describes the video streaming and processing performed by every single activity and exercise prescribed by the therapist. A video (any normal avi clip) is loaded by AviSynth from which two independent video streams are obtained, one for the amblyopic eye (for example the left one) and one for the normal one. The first stream is enhanced by using some enhancement filters described below, while the other video stream is penalized by some penalization filters. The AviSynth framework comes with hundreds types of filters and any filter can be easily added in the pipeline in order to enhance/penalize the video stream. The two video streams are then recomposed by pantarheon AviSynth plugin[1], which is capable of building a 3D video from two separate video streams. The final video is open by using a 3D video player (we use that one provided by NVIDIA) to show the two streams separated to the two eyes. Note that the several filters (in gray in the Figure) can be applied to the same video and they are decided by the therapist depending on the kind of the desired treatment requested by the single activity.

B. *Enhancement/penalization filters*

AviSynth comes with hundreds video filters and new ones can be found on the Internet. We have experimented the filters reported in Table I. Apart the basic filters which can change brightness, contrast and chroma, we have found useful also the filters that soften images details (blur) or increase their

[1]http://www.pantarheon.org/AviSynth3DToolbox/

sharpness (sharpen filter). We have also experimented the use of the noise introduction filter and fade in/fade out. We are also experimenting the translation process, which shifts in position the video stream sent to one eye with respect the video sent to another eye and it may useful for patients with strabismus to encourage fusion. Note that although AviSynth offers a very rich set of standard filters, we could in the future define our own (also non linear) filters using the AviSynth scripting language.

C. Applying filters only in temporal intervals

AviSynth allows the application of filters in temporal intervals by using the meta-filter ApplyRange. In our system, we have experimented the application of the filters in the following predetermined ways, illustrated in Fig. 4:

- **(a)** **continuous** application: a filter is applied from the beginning to the end of the video;
- **(b)** **delayed** application: the filter is applied only after a desired amount of time. In this way, the child initially is unaware of the treatment which begins only after a while, while the child presumably is absorbed in viewing the video and her/his defenses guards are lower than at the beginning. We have experimented a delay of around 10 seconds, but the therapist may decide a longer or shorter delay.
- **(c)** **periodic** application: the filter is applied with a certain delay and only for a period of time. Then it is suspended for a while, and then re-applied again. This kind of treatment should further reduce the problem of compliance. Indeed, a light penalization may be not enough to effectively treat the patient and with a strong penalization there is the risk that after a while of viewing the penalized video, the child quits the treatment. Interrupting the penalization should reduce the annoyance of the viewer. We have experimented this kind of processing with a period of 30 seconds, 10 secs of no application plus 20 seconds of application. Again, the therapist may decide a longer or shorter period.

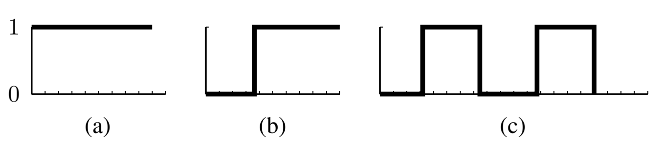

Figure 4. Temporal application of the filters

Example 1. By applying the brightness filter as penalization filter in modality (a), we can simulate the *partial occlusion*, in which no filter is applied to enhance the video for the amblyopic eye, while a brightness filter that reduces the luminosity is applied to the video for the normal eye.

Every kind of treatment provides for a series of penalization/enhancement filters decided by the doctor and applied to a video, each with a given temporal interval. The single treatment activity consists in an AviSynth script file which can be opened by the 3D NVIDIA video player. For instance, Listing 1 shows the script to be used for the partial occlusion with an initial delay. The initial delay is obtained by applying the meta-filter ApplyRange, while the reduction of brightness is obtained by the Tweak filter.

Listing 1. An Avisinth script

```
# example of partial occlusion script with delay
# load a video
video = AviSource("cartoon.avi")
# do not apply any filter to the left
lv = video
# decrease the luminosity from frame n. 240
rv = video.ApplyRange(240, 10000,"Tweak", bright = −20)
# build the 3D video
LeftRight3D(lv, rv)
```

IV. Related work

In the last years, several research groups have experimented treatment of amblyopia by exploiting and adapting information technologies (including Virtual Reality systems). There exist several Personal Computer (PC) based software programs that allow vision training but they still require patching of the good eye. The most original system which does not require patching, is the I-BiT™[2] system described in the following.

The VIRART group at the University of Nottingham has developed a novel virtual-reality based display system which avoids occlusion of the nonamblyopic eye and facilitates the treatment of amblyopia with both eyes stimulated simultaneously [9]. The I-BiT™ system itself consists of a viewer which is linked to a PC. The PC has a standard monitor for the clinician while the viewer allows binocular vision.

Figure 5. A child using I-BiT™ Copyright University of Nottingham, printed with permission.

Several types of viewers were tested, like binocular headsets and several types of viewers called "cyberscopes" similar to

[2]http://hfrg.nottingham.ac.uk/ibit/

that shown in Figure 5. This system incorporates adapted VR technology and specially written software providing interactive 2D and 3D games and videos to the patient via a stereo (binocular) display.

Treatment consists of watching video clips and playing interactive games in the clinic with specifically designed software to allow streamed binocular image presentation. The children sit in front of the viewer and play with the software designed for this kind of treatment, as shown in Figure 5.

An evaluation of I-BiT™: The experiments show that this type of treatment can be efficiently employed and it performs better than the classical treatment. In [24], the results of the use of I-BiT™ in six children are presented. In the case study, treatment consisted of watching video clips and playing simple interactive games with specifically designed software to allow streamed binocular image presentation via I-BiT™. Improvements in vision were demonstrable within a short period of time, in some children after 1h of treatment. In another case study [7], the system was applied in 12 older amblyopes (from 6 to 11 years), who had not complied with or responded to occlusion. Virtual reality images were projected to each eye simultaneously via a headset during eight treatment sessions of 25-min duration. Improvements in the vision were observed in more than half of the children.

However, the proposed system has some limits. The kind of used hardware makes the treatment rather costly and performable only in suitable clinic rooms under the supervision of a doctor (or at least of an adult). The cure can be performed only for a limited time and only with precise time scheduling. For these reasons, we believe that the I-BiT™ system has a limited accessibility and may suffer from the similar problem of compliance as the patching treatment. The goal of this project is to design a more accessible system as described in Section II.

Other Binocular Computer-based Approaches: Other research works present similar approaches. In [10], the authors describe their preliminary efforts to develop a convenient and viable binocular head mounted display (HMD) interface to rebalance the vision between the good and the lazy eye. The image presented to the normal eye will be attenuated while the image presented to the amblyopic eye will be enhanced. As already noted, that system has a limited applicability (due to the low resolution or the high weight of the HMD) and it is scarcely extensible (the HMD allows only the change of contrast and brightness).

In [23] the authors present a multimedia viewer that uses high contrast images of increasing complexity to stimulate the lazy eye. In [17], the authors developed a software system to examine and to treat squint (small and middle range) and amblyopia. It requires an LCD display and anaglyph glasses.

In [18], shutter active glasses are used to study the effect of the binocular vision over the resolution acuity of normally sighted adults. At the best of our knowledge, no group has experimented the use of the stereo 3D vision systems for video rebalancing.

V. Discussion

We believe that our approach can be effective in the treatment of amblyopia for the following reasons.

- **Compliance**: the system should not suffer the same problem of compliance of the occlusion since it proposes an appealing activity (like watching the favorite cartoons), in a domestic environment, in a graduate and personalized manner. It can be performed for a long time period also as maintenance exercise.
- **Binocularity**: the system is based on the use of both eyes. Studies show that binocular interaction plays a fundamental role both in the visual acuity of normally sighted people [18] and in amblyopic patients [16] as well, even in the presence of strabismus [2]. The studies with I-BiT [7], [24] have shown that the binocularity has a positive effect in the treatment of the amblyopia.
- **Video rebalancing**: partial occlusion can achieve a better visual outcome then the complete patching [3]. Some studies show that video penalization and enhancement (even of the simple contrast) can be used to improve vision [12], [13], [20].

We have experimented the system with a normally sighted child of age 6. We found that with light and moderate delayed penalization of the favorite cartoon, she completed the vision of the entire video without notice and without any complaint. She complained only with stronger treatment (like total occlusion).

VI. Conclusions and Future work

In this paper we have presented a 3D system for video rebalancing and motivated its use for the treatment of amblyopic children.

We have started the clinical experimentation with children which are non compliant with the occlusion to check if this technique can actually provide some improvements in the vision. We plan to extend the experimentation with older children (8-12 years), which still suffer from a mild/moderate amblyopia, to see if this exercise can further improve the vision in the lazy eye.

We plan also to write a GUI interface for the therapist to produce the AviSynth scripts with ease in a simplified way. New filters and meta-filters could be defined and/or experimented. For instance, we are working on the definition of an AviSynth Bangerter filter which is based on other AviSynth filters and realizes the partial occlusion of optical Bangerter foils often used in the treatment of the amblyopia. We are also working on the use of the meta-filter Animate which allows the gradual application of filters.

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