Real time 3D Holographic display

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ABSTRACT

In this article is described a Real Time 3D video display of holographic images based on the principle of sequential scanning of holograms with HPO (horizontal parallax only) generated by a high speed computer and sent at high frame rate to DMD, and visualized by an anamorphic optical group. The device displays binary amplitude and phase modulated images opportunely synchronized and scanned by a galvanometric mirror or polygonal mirror driven by the control electronic circuitry. The elementary holograms are generated by a resident hardware which, through interpolation, generates single elementary holograms starting from images and depth map. The device operates with incoherent light (integral images) or with coherent light (holographic display) by changing the optical visualization group.

Keywords: 3D display, DMD, integral display. Holographic display,

1. INTRODUCTION

At present there exist several types of 3D displays; some of them make use of special glasses of different types (stereoscopic systems), others make use of special output lenses (lenticular screens) in order to visualize different points of view of the image to be displayed (auto-stereoscopic systems).It is known that the only real 3D visualization of an image is given by holography, which reproduces exactly the wave fronts reflected by objects. Several attempts have been made to visualize holograms in real time (MIT et alt.), although only very small holograms (about 15 cm) have been visualized up to now. The override these problems, our company decided to design a display engine which can be used to for different display technique, like multiview, lenticular view or holographic view, depending on the optic realized. The engine is based on the use of the Texs DMD microdisplay combined with a scan system done with a galvo scanner or polygonal scanner and using different original systems simultaneously as:

- Resolution of a general hologram in many vertical elementary holograms
- Use of an optoacoustic device and/or analog modulation at the laser source.
- Fast synchronized loading of the elementary hologram into the DMD
- Anamorphic optical system for the horizontal reduction and vertical expansion of the hologram
- Scanning system for the sequential visualization of the elementary holograms
- Horizontal scanning system for the sequential visualization of the elementary holograms
- Synchronization of the modulation system, scanning and deflection
- Optical telecentric visualization group
- Firmware to drive the entire system using FPGA
- Software and GUI to control the system.
- Purpose of this project is the realization of a big sized display (50 inches) by adopting technologies presently existing and developing an original vertical scanning system, together with a control electronic circuitry which allows the visualization of big-sized holograms real time.

2. SYSTEM OVERVIEW

2.1 General

The base system is composed of a coherent light source (laser), a spatial filter, an amplitude modulator of the laser source by an AOM, a beam expander for lighting up the DMD uniformly, a TIR prism (Total Internal Reflection prism) for separating the direct and reflected light and the DMD as shown in fig.1.

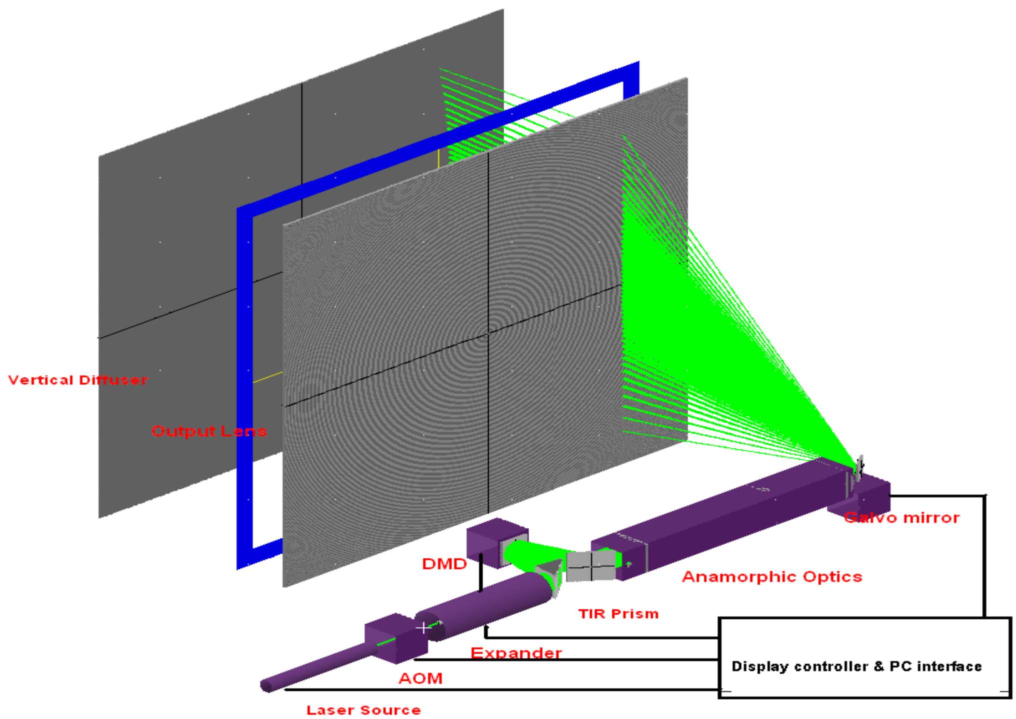

Fig. 1 Set of the display, composed of a laser source, an optoacoustic modulator, a beam expander, a TIR prism a DMD), a group of anamorphic lenses for optically modifying the image reproduced, a galvanometric mirror for horizontal deflection, a telecentric output optical group and a general control electronic circuitry and synchronization.

The light coming from the DMD is directed to an optical system by which the image is horizontally compressed and vertically expanded through a system of cylindrical lenses. In the nodal point (focus common to vertical and horizontal lenses) of the anamorphic system is inserted a galvo mirror or a rotating polygonal mirror and the reflected light is therefore sent to an output optical group composed of a telecentric lens and a vertical diffuser for the display.

The galvanometric system acts as a horizontal scanner, projecting the light coming from the DMD onto the screen to generate vertical lines. An electronic controller synchronizes all the operations of loading binary images on the DMD; give the appropriate light amplitude on the light source, control the scan system to display sequential images created by the control software. The complete design can be divided into 4 main subparts:

- Optic & mechanical design
- Opto-electronic design
- Electronic & firmware
- Software

2.2 Optics

There are two main problems designing the optics, due to the intrinsic nature of the DMD; which is essentially an array of mirror that act as a grating thus giving different order of diffraction using coherent light sources. The first is to filter the unwanted diffraction order and the second is to choose the right scanning point.

We chose a system as in fig.2 which is composed of a group of cylindrical lens to focalize the image on the mirror and a couple of special designed parabolic mirror to make the optical path telecentric..

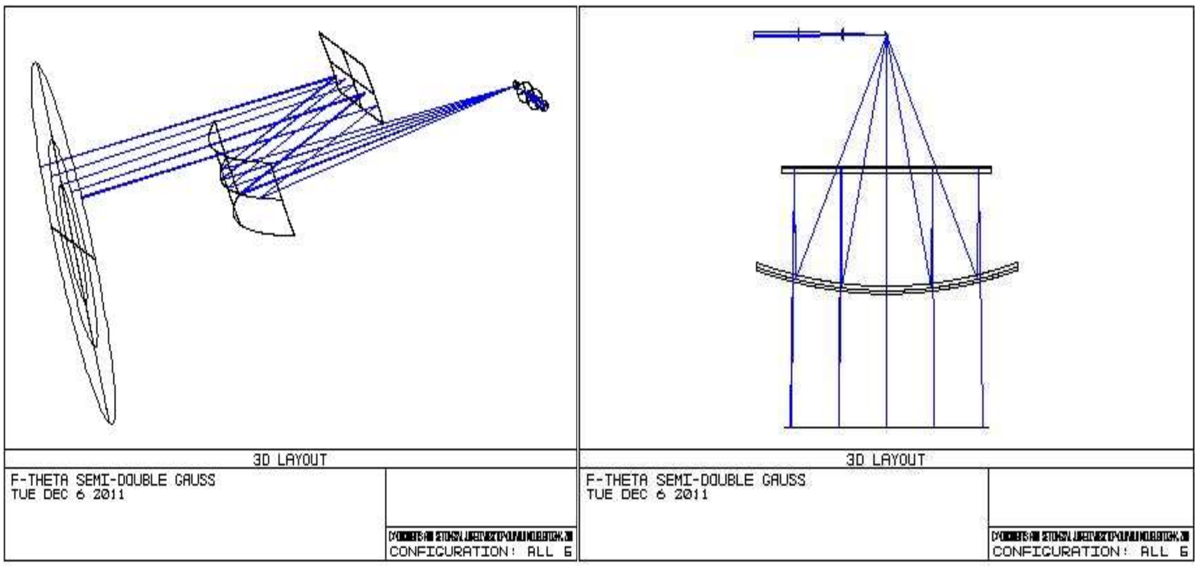

Fig.2 The optical layout with scanning mirror, horizontal parabolic mirror and folding mirror.

An expanded view of the anamorphic optic is shown on fig.3..

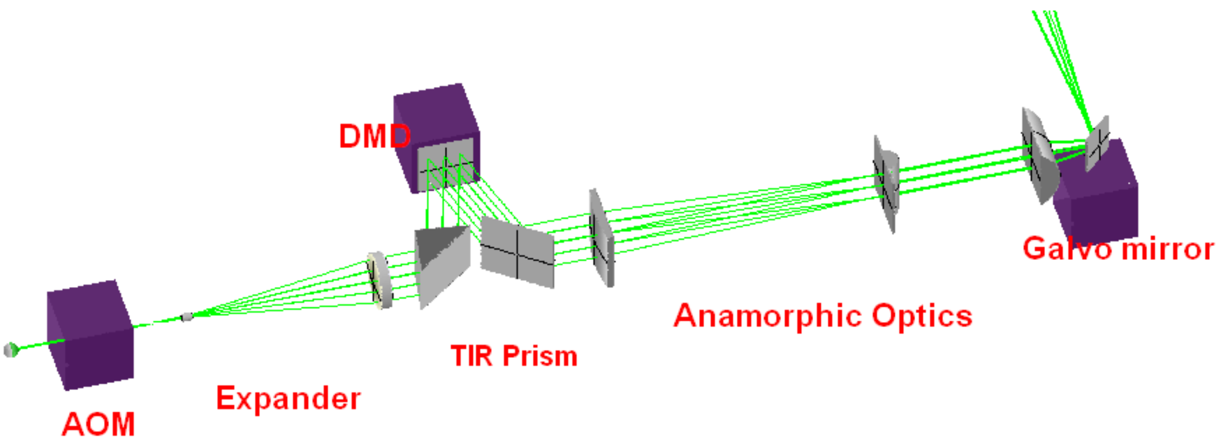

Fig.3 The anamorphic optical system used to visualize a hololine on the screen.

The final image is composed as the sum of all the elementary images as sown in fig.4. The eyes of an observer in front of the screen will receive two different images depending on the distance from the screen and the angle of visualization.

Such images are created by the light diffraction produced by the elementary holograms projected onto the screen.

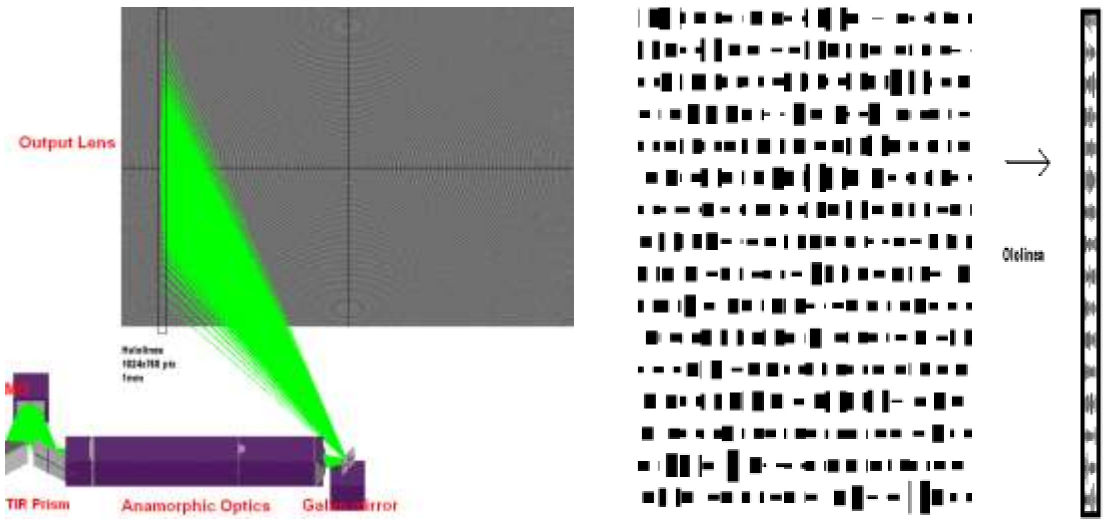

Fig 4 The screen is filled with hololines at a speed of 30 frames per sec. On the right is shown the elementary binary hologram before and after the horizontal compression.

In order to achieve a good resolution and a large angle of view, it is necessary to have a minim of 100 hololines (or points of view) each one composed of at least 1024 pixels, giving a total display of 75M voxel resolution.

The optical output system should be of telecentric type, in order to project the hololines, having the same size, in a parallel way to the observer.

The display screen is a holographic type with a vertical angle of 60° and an horizontal angle of 0.2°. This gives the possibility for an observer to see different pictures on the eyes, either if he stand in front of the screen or if he moves in different positions.

Ir’s possible to have a full color resolution using 3 DMD and 3 optical path for each color.

2.3 Optoelectronics

There are two main parts, laser modulation and scanning system. For laser modulation it's possible to use the internal analog modulation provided on the DpSS laser or use an AOM.

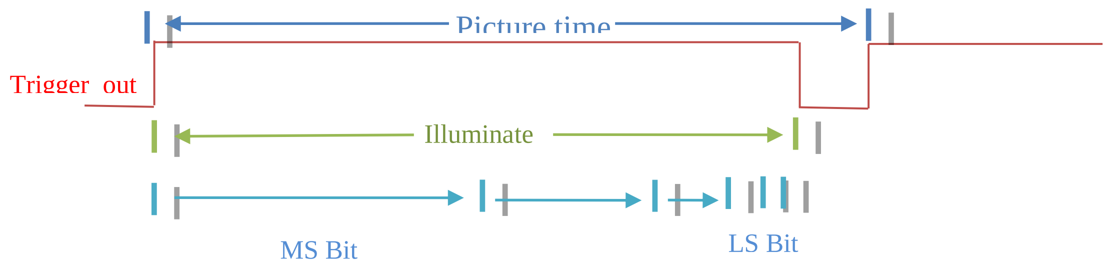

Fig. 5 PWM modulation on DMD

As the DMD is an intrinsic binary display, in order to give a variable intensity on each pixel, the normal way is to make a time modulation, called PWM (pulse width modulation), assuming that the light source is constant, each bit plane of the 8bit image (suppose a monochromatic image) has a display duration relative to it's weight, as shown in fig.5. If the minimum load time of a single picture is T, to achieve a complete 256 gray level there will be needs of 256*T time slot for a single 256 gray level picture. We used a Vialux ALP-4.1 high speed controller which gives a maxim scan rate of 291 Hz. As the maximum scan rate of the binary patterns is 22.000 Hz , another modulation system was used, using only 8 time slot thus giving a scan rate of 2850 8bit images per seconds.
Taking into account that the output ray amplitude is proportional to the voltage applied to the modulator, and such voltage varies from 0 to 5 V, the latter is divided by the number of image levels (255), which gives a value of about 20mV by step, therefore the modulation sequence consists in visualizing bit planes on the display and simultaneously applying a voltage equals the initial step multiplied by the order bit visualized, as shown in fig6. So depending of which bit plane is displayed on the DMD, light intensity should be varied according to a look-up table like the one sown below:

1° bit 20mV Minimum intensity of the modulated beam
2° bit 40 mV
2° bit 80 mV
4° bit 160 mV
5° bit 320 mV
6° bit 640 mV
7° bit 1280 mV
8° bit 2560 mV. Maximum intensity of the modulated beam .

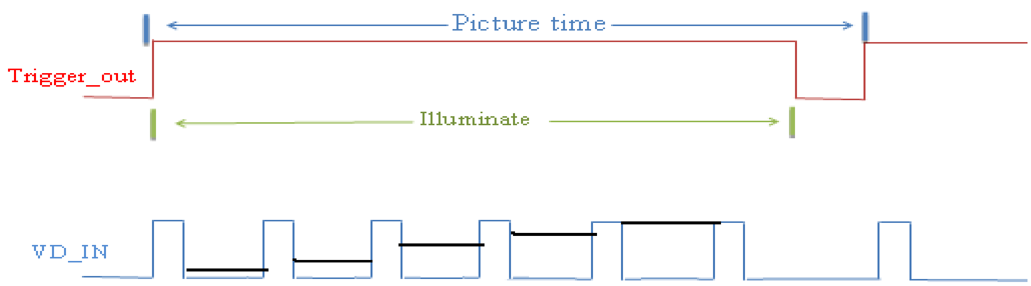

Fig 6 Bit plane modulation

In this way in 8 consecutive frames the visualized video signal is modulated in 255 amplitude levels and the conversion is executed by the persistence of the image on the eye retina.

The scanning system could be made in two ways, with scanner (we use CTI 6220) or with a rotating polygonal mirror (we use an 8 side from Lincoln Laser).

As we said before, each image is composed of 8 single picture for a total display time of 350 microseconds, it will be necessary a scanner which has a small angle response of at least 200 microseconds. The Cambridge Tech CTI6220 is good enough for this purpose. The sequence display will be:

1st image 1st bitplane, 1st image,2nd bitplane…1st image,8th bitplane:

Change position of scanner

2nd image,1st bitplane……2nd image,8th bitplane…

……

…..

100th image,1st bit plane…100th image, 8th bitplane

End of scan

[backward direction]

99th image, 1st bitplane,….99th image,8th bitplane

……

……

1st image,1st bitplane,…1st image, 8th bitplane

Using a polygonal mirror is a little bit different, as each side of the polygon should display e single bit of the displayed image, thus after a complete turn all the 8 bit are displayed. So the sequence that has to be loaded on the DMD is different and will be:

1st facete

1st image 1st bitplane, 2nd image,1st bitplane…100tn image,1st bitplane

next facete

: 1st image,2nd bitplane……2nd image,2th bitplane…100th image,2nd bitplane

……

8th facete

1st image, 8th bit plane… 100th image,8thbitplane...

As the response of AOM or analog modulation on the laser is not linear, it's possible to store a look-up table of the values needed to achieve the desired value of voltage to be applied on the modulator., that can be different from type to type. This calibration is easy to perform using a gray scale ramp.

2.4 Electronics

The system is based on Texas DMD, a commercial device normally used in video projectors. The essential characteristic of this device is its data loading speed allowing it to visualize up to 30,000 images per sec. if opportunely controlled.

In principle, the DMD is composed of an array of 1024 x 760 micromirrors which can vary their tilt angle according to the latch connected to a memory. On loading a logic state the micromirror is forced to deflect its position of about 12°, thus deflecting the light projected on it. The combination of several micromirrors will produce a spatially modulated live image and an image (negative) which will be rejected. In order for an image to be loaded, it is divided in bit planes, each plane is loaded into the DMD memory and so applied to a reset pulse which positions all micromirrors, then the second bit plane is sequence-loaded and the same operation is repeated up to the last bit plane. The signal is thus PWM modulated, which means that the visualization length of each image is proportional to its weight. Such modulation has been rejected because it would take too much time for the image to be visualized and it has been designed the previously described system equipped with an AOM which modulates the light reflected by the DMD. The image loading system becomes synchronized together with the modulation system and the scanning system described below.

The main problem is that of visualizing at least 30 complete images made up of at least 500 elementary holograms per sec; which means to visualize 15,000 frames per sec. with a load time for each image of about 60 microseconds.

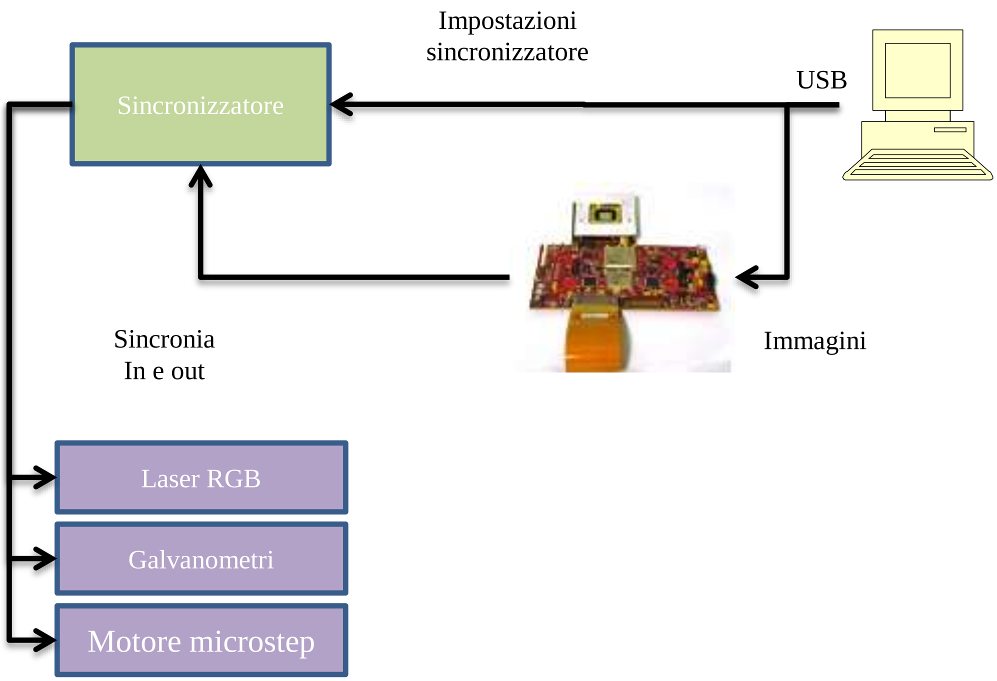

Fig.7 block diagram of electronic control

The system use a Vialux 4001 discovery board and is controlled by an external board which controls the scanning system, the modulation of the Laser and the microstepper motor for the polygonal mirror. We used a Xilinx board to write the necessary VHDL control code to drive all the necessary state machine. Below is a representation of the VHDL core module of our system, which mainly are dedicated to the synchronization of the different module, loading the appropriate sequence into the Vialux board, e give the right switching time and modulation to laser source and scanning system.

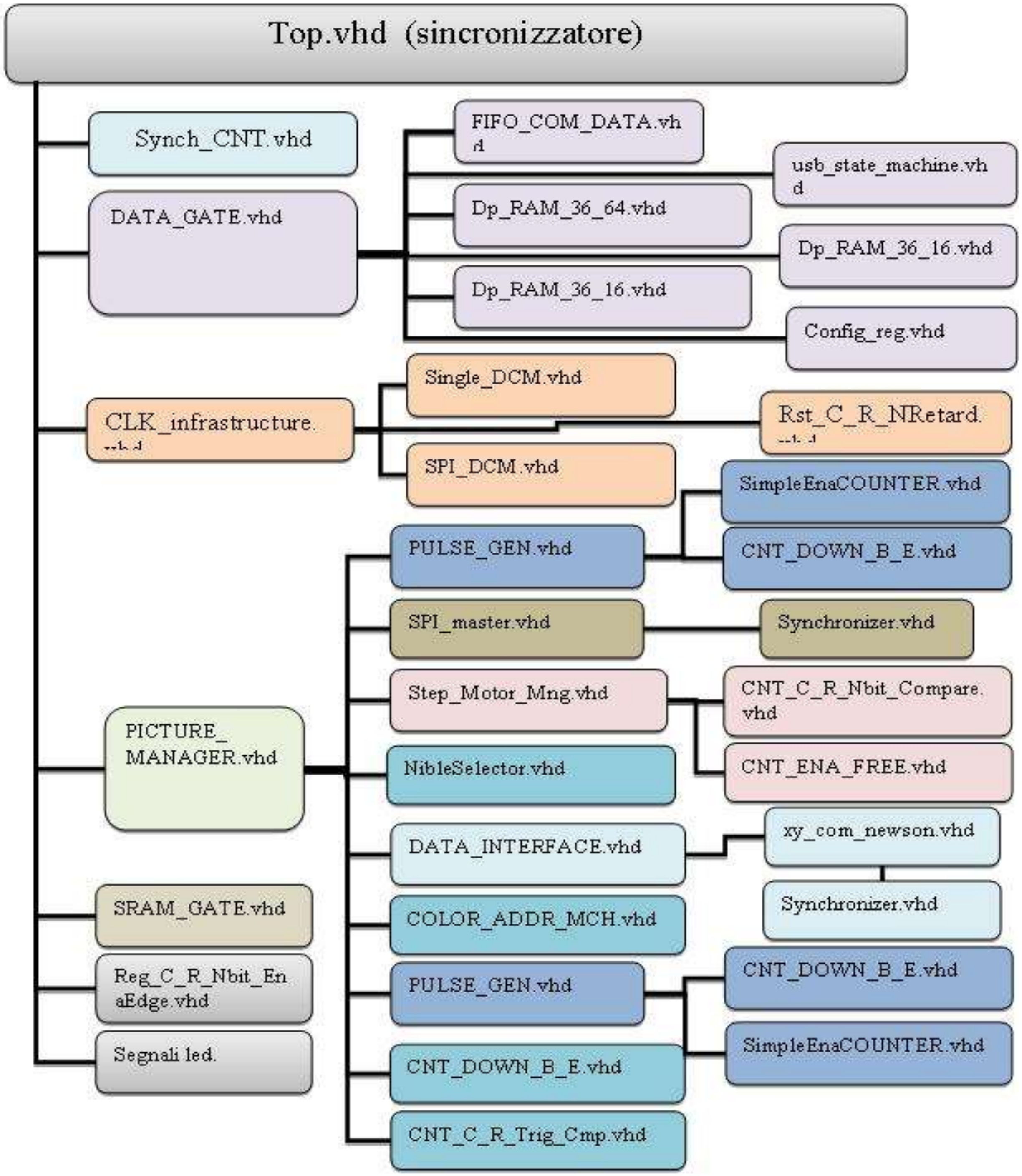

Fig 9 Electronic control flows of the display

2.5 Software

The software developed for the system implement different tasks:

- DMD control
- Galvo control
- Polygonal control
- Laser RGB source control
- Modulation control
- Sequence control
- Camera capture
- OpenGL (Obj) import and sequence generation
- CGH computation
- Images interleave for lenticular display
- Kinect interface

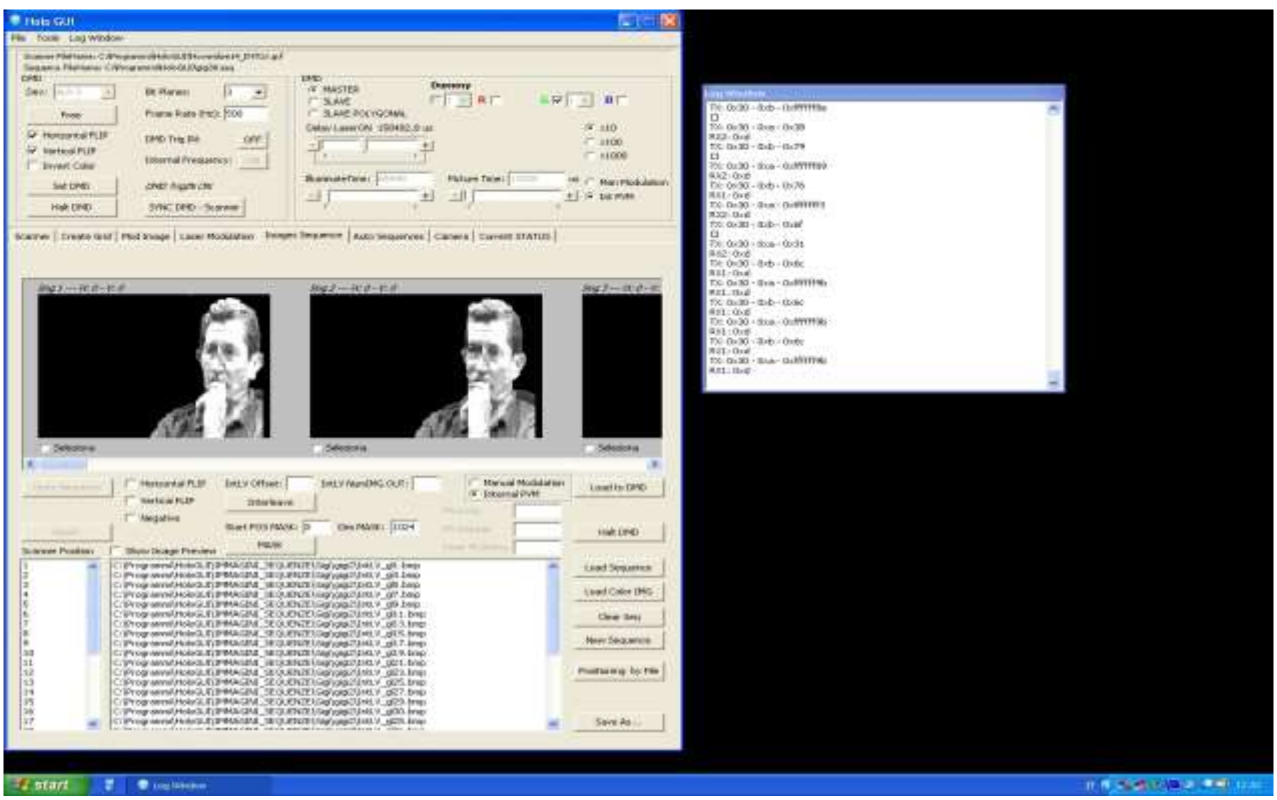

Fig.10 Screenshot of the Hologui software control suite.

3. EXPERIMENTAL RESULTS

It has been developed a complete prototype of the system using a 1w green laser. A discovery 4100 board, a CTI 6220 x-y scanner.(fig.11 and fig.12) The first approach was to display 30 images, in two rows, 15 for each row just to test the system e test performances. All the images were directed trough an holographic vertical diffuser screen with an horizontal angle of 0.2° and vertical angle of 60°. Images comes from an wavefront obj file from which the software extracts 30 different views, all displayed by a certain direction to the holographic screen. An observer could see e real 3D images formed on the plane of the screen as seen in fig. 13 and 14.

Fig 11 View of the prototype with 30 display lens

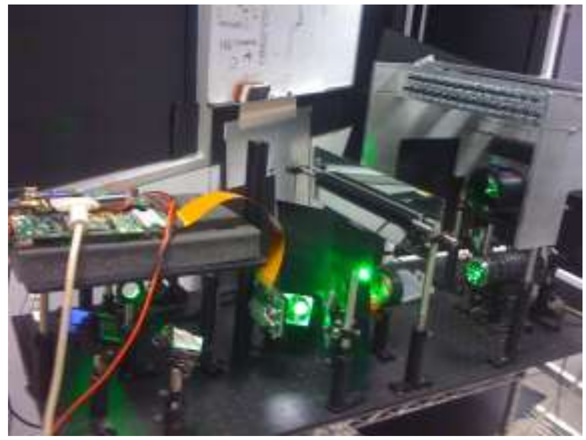

Fig 12 View of the prototype with discovery and lens

Images show a very good horizontal parallax (60°) view with a depth of about 30 cm. Depth and size depends on the way the system draws images and how large is the output lens array.

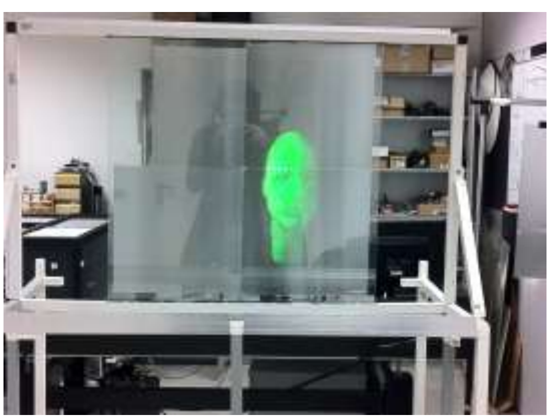

Fig 13-14 Views at left and center, showing a good parallax.

The second experiment use images (fig. 15-16) captured from a camera . (Instead of moving the camera, it was used the same scanning system to capture images, putting the camera at the place of the DMD). The quality was not very good due to the low optical system and improvements are in progress.

Fig 15-16 Display of 30 views capture from a live camera.

4. IMPROOVEMENTS

Next step is to built a 64 views system with full color images . This means that the improvement will regards:

- Design of a low cost parabolic mirror and achromatic optics
- Implementation of a RGB laser sources
- Implement all the electronics in a single board
- OpenGL import of any kinds of 3D data
- Implement the 64 view capture camera

5. CONCLUSION

The realization of a low cost real time 3D holographic display has been tested and demonstrated. The use of high frame rate microsdisplay like DMD permits a fast loading of pictures up to 30.000 frame per second. The engine built will be a good starting point to develop different display type, from holographic to multiview display.

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