DYI digital holography

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ABSTRACT

We have created a programming tool which uses image data provided by webcam connected to personal computer and gives user an ability to see the future digital hologram preview on his computer screen, before sending video data to holographic printing companies. In order to print digital hologram, one needs to have a sequence of images of the same scene taken from different angles and nowadays web cameras - stand-alone or incorporated into mobile computer, can be an acceptable source of such image sequences. In this article we are describing this DIY holographic imaging process in details.

Keywords: Digital holography; diy, amateur; 3D

1. INTRODUCTION INTO DIGITAL HOLOGRAPHY

Digital holographic printers for image hologram printing are known from 1999, when Geola uab (Lithuania) and Zebra Imaging Inc. (USA) had put their patent applications for, correspondingly, pulsed and CW lasers based printers. Digital holographic printers combines pixels from several hundreds parallax-related 2D images of 3D scene into ensemble of holographic pixels, known as holopixels (Geola) or voxels (Zebra Imaging). By exposing said holopixels on photosensitive media in such a way that all photo-media surface would be covered with holopixels, a digital hologram is recorded.

Each holopixel, in the matter of fact, is a holographic optical element which, when illuminated and viewed from different angles, is seen as certain colour dot. The colour (and brightness) of this dot for particular angle is defined during holopixel's exposure. Those dots forms images, that are different when viewed from different angles and are actually the same parallax-related images that were used for holopixels formation. When viewed with two eyes, each eye sees different parallax-related image and human brain perceives viewed images complex as three-dimensional scene.
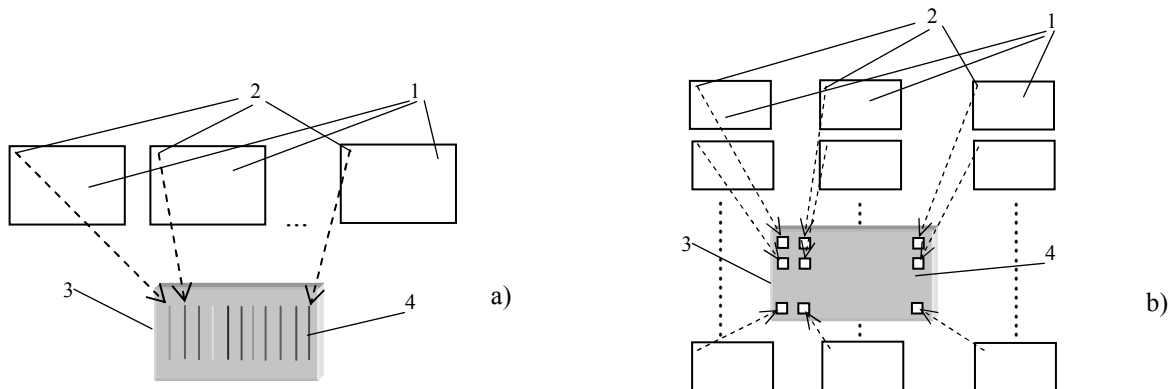

Figure 1. Holopixel's image formation on SLM: a) – for digital hologram with one (horizontal parallax); b) – for full-parallax digital hologram. 1- 2D parallax-related images of 3D scene; 2 - pixels with same coordinates; 3 – SLM; 4 - image displayed on SLM

For holopixel's recording onto photosensitive media are used two laser beams - one is spatially modulated by LCD or LCOS displays and focused into square in size from 0.4x0.4mm to 1.6x1.6mm; another laser beam acts as reference beam. The modulation is performed in such a way that resulting object beam at the place of its interference with

reference beam contains same information that would come to this point from a real object if this object would be used for holographic recording. In digital holography instead of the real object, series of its digital photographs taken from different angles are used. That allows obtaining enough information for single and full parallax digital holograms [1, 2].

Pixels with same coordinates are taken from series of parallax-related images and altogether are displayed on SLM, as is shown on Fig.1.

Quantity of SLM pixels used for laser beam modulation defines quantity of different images viewed under different angles. Laser beam, modulated by SLM is then focused by a special high numeric aperture objective. The key property of this objective is its waist position, which is outside of objective's body - Figure 2.
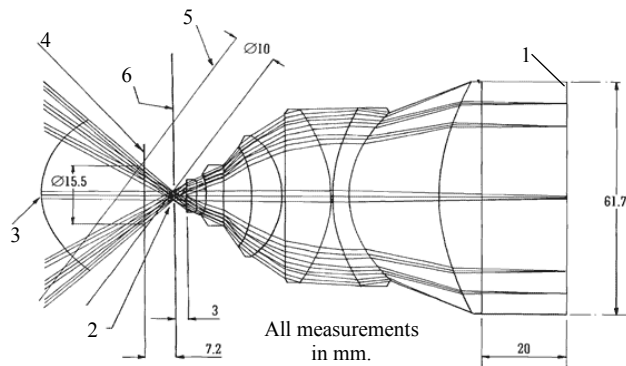

Figure 2. Classical digital holographic printer's objective: 1- SLM; 2 – objective's waist, 3 - objective's FOV; 4 – photomaterial; 5 - reference beam; 6 - Fourier plain.
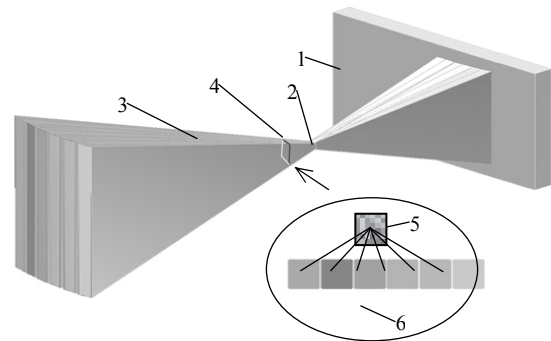
Figure 3. Optical holopixel's formation: 1- SLM; 2 – objective's waist; 3 – viewing angles of particular SLM pixels; 4 – holopixel's recording place; 5 – holopixel; 6 – view from holopixel's window under different viewing angles.

Photosensitive material is placed after the objective's waist. Reference laser beam interferes with modulated object beam and hologram of the image that was projected on SLM is recorded. Since images of different SLM pixels are projected onto photosensitive media from different angles (See Picture 3), the resulting hologram of this SLM image projection also replays different intensity beams under different viewing angles. Elementary hologram (or holopixel) recorded in such a way, contains information about each particular SLM's pixel light intensity as well as angular information about this particular pixel. Whole digital hologram surface is then covered by such holopixels so the resulting ensemble contains angular and intensity information about each parallax-related image used for digital hologram formation pixel - Figure 4.

When lighted, each holopixel is viewed as shiny colour square, which colour and intensity are different under different viewing angles. Altogether, holopixels ensemble under different angles is viewed as one of the parallax-related images used for digital hologram recording. In such a way, two observer's eyes continuously observe two parallax-related images and human brain perceives observed as three-dimensional scene.

Digital hologram working principle is quite similar to lenticular prints. The difference is in quantity of the parallax-related images used for those 3D prints. In lenticular printing only few tents images can be used for 3D perception creation - in digital holography are used few hundreds or even few thousands parallax-related images. This quantity of parallax-related images is enough for human brain to perceive observed as smoothly changing three-dimensional scene in quite a big observation angle (usually not less than 45 degrees).

The key point of digital holography is possibility to completely separate imaging and printing processes. That separated geographically locations of printing facilities and imaging studios and raised needs for new imaging tools.

2. IMAGING FOR DIGITAL HOLOGRAPHY

2.1 Professional imaging

As it was discussed before, digital hologram contains sequence of parallax-related images, which are imprinted on photosensitive media by holographic printer. This sequence can be easily obtained by rendering 3D scene in 3D CAD programs, i.e. is shot by virtual camera. For single parallax digital holograms is possible to use real scenes shots made by

with video- or photo- camera which is precisely moved in front of 3D scene. Virtual and real cameras movement is defined by particular digital holographic printer's design and can not be voluntarily chosen.
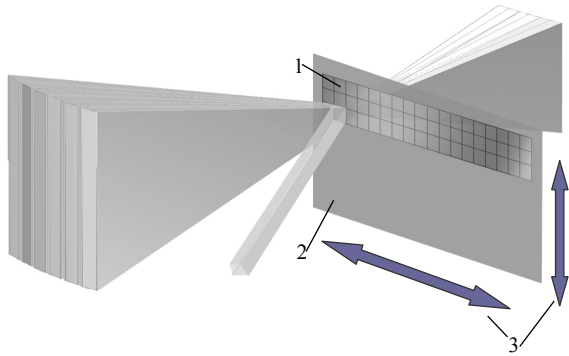

Figure 4. Holopixels exposure onto photomaterial (one parallax hologram): 1- Rows of exposed holopixels; 2 - photomaterial; 3 photomaterial' movement; 4 - reference beam.
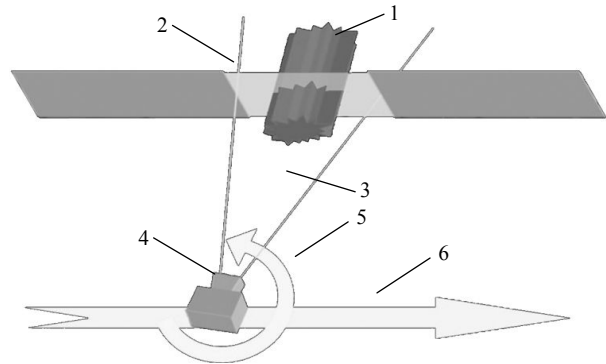
Figure 5. 3D scene's shooting with HoloCam device (for one parallax hologram): 1- 3D scene; 2 - feature hologram's image plane; 3 camera's FOV; 4 - camera; 5 - camera's rotation; 6 - camera's linear movement.

The best way to obtain a sequence of parallax-related images would be to employ a camera with lens having FOV of ~90degrees and with several thousand pixels horizontal resolution. It is quite easy to employ such a camera in 3D CAD software; however in real life such cameras are quire rare and expensive.

To get around this problem, in 2005 we have invented the HoloCam device, which employs a camera moving in front of the 3D scene which also rotates, always pointing to the centre of shot scene [3] - Figure 5. The device shots sequence of parallax-related images, which is then transformed into the sequence of parallax-related images that would be shot with the camera having FOV of ~90 degrees, which would be moving in front of the 3D scene without any rotation - as if the scene would be shot in 3D CAD design program.

HoloCam devices are now successfully used in several studios around the world for 3D scenes imaging. Portable HoloCams allows holographers to get out of their studios and shot 3D scenes at virtually any location.

2.2 Amateur imaging

After the success of HoloCam, we wanted to bring holographic imaging abilities to general public. As it was shown in [4] (Stas SPIE 2010 article)- one can also use for holographic printing the shots of object, which is slowly rotating in front of a steady camera. The central parts of images shot in such a manner, with neglectable distortions correspond to images of same scene's shot by HoloCam device. This means that for digital holograms in size of ~13x18cm one can use a mobile phone's camera, or any other camera capable to shoot videos with resolution of at least 320x240 pixels and framerate of 30Hz.

Figure 6. Mobile phone holographic imaging process.

That allowed us to launch holographic portrait service - the human is filmed with any video camera just slowly rotates his head from one shoulder to another; video obtained in such a manner is sent to us via Internet; we are creating the

preview of future hologram and sending it to the recipient; after his approval digital hologram is printed and sent to him by post - Figure 6.

The process of amateur holographic portrait shooting is quite simple, but it does not allow operator to see the expected hologram views before sending his video file to our server. Therefore, we have developed a program i-LumoLab, utilizing video stream from webcam and allowing operator to see the future hologram preview right after the shooting.

The program runs on any PC with Windows operating system. The program requirements are quite low: Operating system - Windows XP SP3, Windows Vista, Windows 7; DirectX 9.0c or above; any processor above 1GHz; DirectX 9.0 or above compatible videocard; 1GB or above of system memory.

so it can be used with the most home PC and notebooks.

Block-scheme of the program is shown on Figure 7. Web cam video stream is always demonstrated on PC monitor. When user presses the corresponding GUI button, for a limited time of 6 seconds the video stream is starting to be saved into temporal storage. During that time holographed object rotates in front of the web cam for -45÷+45degrees. At the same time frames are extracted from video - and a sequence of parallax related object's images is obtained. Further all those images are transformed with the same algorithm which are used in HoloCam software and are described in [5].
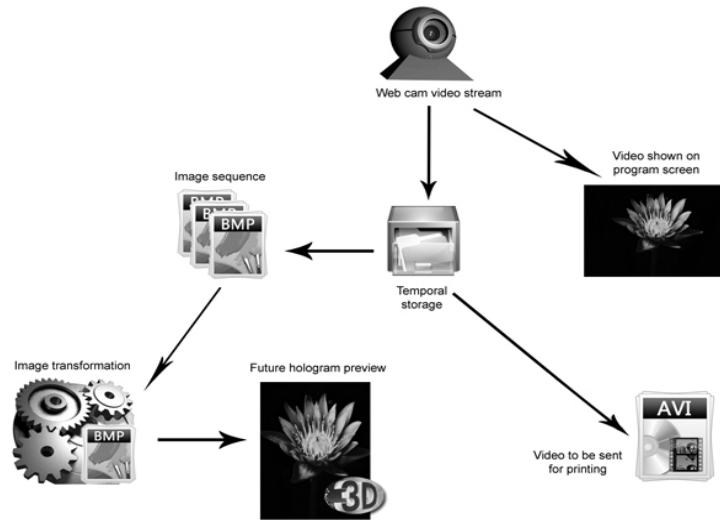
Picture 7. i-LumoLab program image processing workflow

Additionally to standard HoloCam image transformations, we are also applying image size corrections. The images of an object rotating in front of the steady camera always represent same size object; on images obtained by camera which moves in front of the object, the size of object changes according to formula 1:

$$h_1 = \frac{h}{\sqrt{(tg\alpha)^2 + 1}} \qquad\qquad 1)$$

where h is the object image size on central captured image, h_1 is the object image captured when camera is pointed to the object at an angle α. Therefore, all images obtained from steady camera filming a rotating object, shall be resized before applying standard HoloCam transformations.

After the transformations, our software creates future hologram preview which is viewable in program's GUI windows. If operator is satisfied how hologram made from his video will look like, he is sending the initial video file to Geola's printing facility. We are printing his hologram and sending it back by usual post.

Figure 7 shows i-LumoLab program GUI. In web cam window user always sees web cam' video stream and can adjust lighting, colour balance and general holographed object's appearance. By pressing training button, the training window activates and shows the approximate speed, with which holographed object shall be rotated. From this window user also

can get an idea about necessary rotation angles. When the scene is adjusted and user is ready - he presses "Start" button and slowly rotates the object in front of web cam. (If something will go wrong, process can be interrupted by pressing "Stop" button). After that captured video is processed and hologram preview is shown in i-Lumogram preview window.

The process is simple and do not requires a special knowledge about hologram manufacturing. Therefore it is available to all common people having basic computer literacy. There are just few basic rules which shall be governing DIY holographic imaging:

- Object shall be rotated avoiding any shaking in vertical and horizontal directions

- -45÷+45degrees rotation of the object shall happen in not less than 6 seconds

- Object shall be well illuminated

- Object shall be in focus and colour balance of the camera shall be properly adjusted before shooting
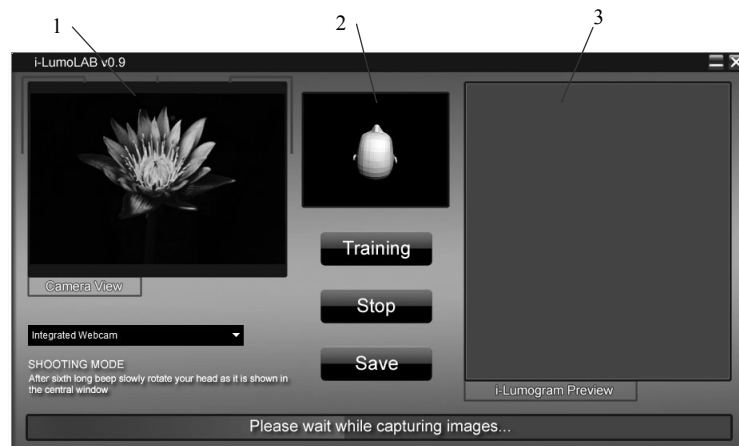
Picture 7. i-LumoLab program GUI in holographic shooting mode:

1 - web cam window; 2 - training simulation window; 3 - hologram preview window.

3. CONCLUSION

- Digital holography entered mature stage allowing people with basic photography knowledge and computer literacy to make live holographic imaging for single parallax holograms on their own and at any location.

- Geographical separation between holographic imaging and holographic printing expands holographic creativity beyond holographic laboratory boundaries.

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