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Calculation of a Parallaxpanoramogram in Autostereoscopic Systems with Inconsistent Monitor and Lens Raster Parameters

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Abstract

A significant disadvantage of the multi-point of view autostereoscopic method is a drop in image resolution with an increase in the number of points of view. An effective means of increasing the resolution is the use of an inclined lens raster and vertical encoding the colors of the point of view. Algorithmically simple coding is obtained at optimal tilt angles, the tangent of which is 1 divided by a multiple of 3 (1/3, 1/6, etc.). This requirement imposes significant restrictions on the coordination of the geometric parameters of the equipment – the display panel and the lens raster. The approaches to spatial color coding proposed in this article and the algorithms implementing them make it possible to significantly expand the possibilities of creating autostereoscopic displays. The experimental work carried out convincingly confirms the theoretical conclusions. The main practical result was the developed software that allows fine-tuning of the angle of inclination of the raster and calculating a multi-point of view parallaxpanoramogram for a specific set of equipment.

Keywords: autostereoscopy, parallaxpanoramogram, color coding, lenticular raster, multi-point of view image.

1. Introduction

The demonstration of three-dimensional images, especially without glasses, has always aroused increased interest both among specialists engaged in image visualization [30, 36-40] and among consumers of attractions, various shows, etc.

For the individual consumer, the issue of displaying three-dimensional images has been resolved to one degree or another. Various kinds of pictorial holograms and methods of their demonstration are known [1]. Various stereo postcards or posters are mass-produced [2], and other various methods of forming three-dimensional images are also known [3 - 5]. For example, in [6] it was proposed to create a 3D display, which is a three-dimensional array of special liquid crystal light scattering cells with ultra-high speed, on which images of cross sections of the original 3D scene are projected alternately and consistently.

Technologies and equipment that allow providing a spectacle with a group display of three-dimensional moving images are still in the experimental development stage. These issues are also dealt with in advanced firms in Japan, Korea and the USA [7-9].

At the same time, it should be noted that back in the middle of the last century, research and development was actively carried out in the Soviet Union to create a stereoscopic cinema without glasses [10-13]. Such a cinema (see Figure 1a) was opened in Moscow in 1940 before the Great Patriotic War.

For this purpose, a special raster screen was made, consisting of a set of thin stretched strings (see Fig. 1b). The screen was a conical surface, which ensured that the vision zones were placed in the right places of the auditorium.

Further, by improving the manufacturing technology, it was possible to create a high-power lenticular lens screen. Their overall dimensions are shown in Table 1. It was with such lenticular lens screens that six stereoscopic cinemas without glasses were built and operated in different cities in the Soviet Union.


a)

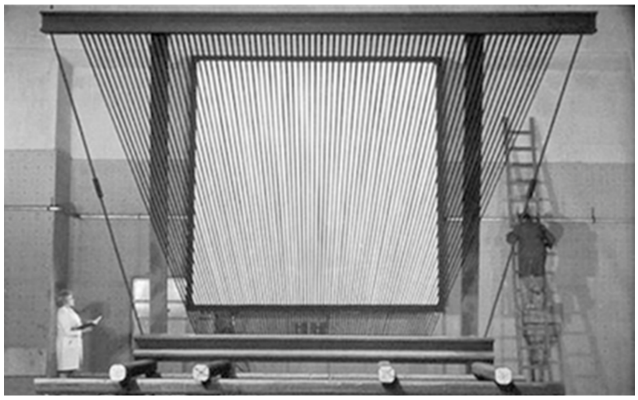

b)

Fig. 1. The world's first point-less stereoscopic cinema (a) and its slit raster screen (b).

Table 1. Overall dimensions of a stereoscopic cinema

Screen size		Number of viewers	Number of rows	Width of the vision area	
At the beginning	Then			For the first row	For the last row
3x3 sq.m	4x3 sq.m	About 100	10	65 mm	130 mm

This development was certainly a pioneer and represented a great technical and technological breakthrough in the methods and means of forming three-dimensional images for group display. Apparently, until now it has not been functionally repeated, because there is not a single operating cinema known to have a stereo display without glasses.

Nevertheless, the development did not find further development and in the 60s of the last century it was closed and replaced by conventional eyeglass technology. Without delving into the subtleties, we will only note that the problem was caused by the presence of only two points of view, as a result of which the vision zones were very limited areas of no more than 130 mm. And it was impossible to increase the number of zones in the film technology that existed at that time.

Significant progress in the development and creation of autostereoscopic systems for displaying three-dimensional images, and for group demonstration, occurred at the end of the last century, in the 90s, due to the rapid progress of computer technology, including powerful software and various optoelectronic equipment. Small-sized digital video cameras and miniature video projection devices made it possible to approach the construction of such systems at a new level of development of the technology of digital recording and reproduction of stereoscopic images. It became possible (fig. 2) to carry out multi-point of view video shooting of the scene and multi-objective demonstration on a lenticular lens screen. What was impossible in film technology was solved by switching to digital methods and modern technologies – obtaining a sufficiently wide and comfortable vision zone in which the viewer can be.

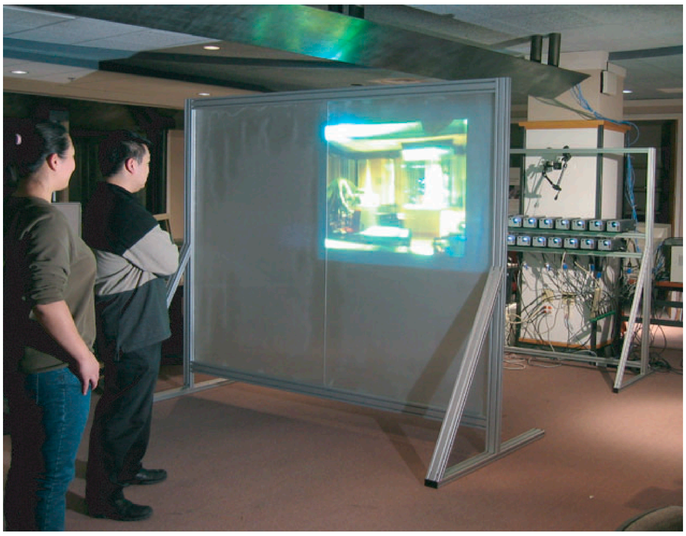
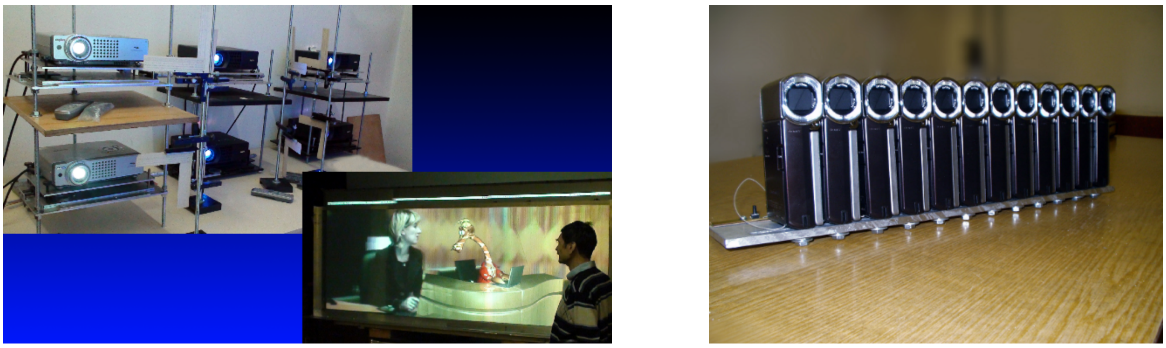


Fig. 2. Multi-point of view stereoscopic projection system with a lenticular lens screen.

Fig. 2 uses a projection system consisting of a block of mini projectors, each of which forms one perspective of a three-dimensional image on a special lens screen [14].

Another modular autostereoscopic system and a sample of a multi-point of view camera are shown in Fig. 3 a, b [15, 16]. Here, each projector projects the corresponding sections of the parallaxpanoramogram from a 12-points of view three-dimensional image onto the lenticular lens screen.

With the advent of flat-screen LCD TV panels, it seemed natural to create autostereoscopic devices for displaying three-dimensional images without glasses. Indeed, it is enough to install a lens raster on the panel, calculate a parallaxpanoramogram for a set of different points of view images of a certain scene, display it on the screen, and an autostereoscopic three-dimensional image will appear.



a) b)

Fig. 3. Modular multi points of view stereoscopic projection system (a) and multi points of view shooting video camera (b).

Works [30, 36-37] describe the use of an autostereoscopic lens-raster display from Dimenco M654MAS [41] for demonstrating images reflecting the course of complex physical processes in time and space, constructing presentation complexes, which, among other things, allow demonstrating the results of scientific research in stereoscopic mode. As a source of information, this display can use either a depth map of the so-called 2D+Z format, or a sequence of multi-view images of an object obtained by flying around the object with a real or virtual camera. The images reproduced on such monitors can be virtual scenes and objects synthesized on a computer for various kinds of simulators, video surveillance systems and training systems using virtual reality technologies. Visual representation of such information in stereo mode gives the researcher the opportunity for a deeper understanding and thorough analysis.

Volume reproduction is important when quickly estimating distances on various types of simulators and video surveillance systems [31-34].

The use of autostereoscopic stereo monitors that do not require additional devices on the observer may be in demand in medicine. When performing a surgical operation, it is important to see the volume of the operated field and know where the surgeon's instrument is located. To make a diagnosis from images obtained using a computed tomograph, it is also important to have a volumetric image [35, 38, 39].

2. Problems of creating autostereoscopic monitors

Unfortunately, the direct way of using the vertical arrangement of the raster lenses turned out to be uninteresting for practice. This was caused by the limited resolution of television devices. Indeed, the drop in the horizontal resolution of a three-dimensional image on such a screen is proportional to the number of points of view used in the system. To obtain a sufficiently comfortable and convenient observation in the vision area, it is necessary to have at least 8-10 points of view. Indeed, taking into account the minimum size of the total vision area of 300 – 350 mm and the size of the zone of one point of view of 30-35 mm, we obtain the above parameters. Thus, with the number of resolution elements in a row of the order of 2000, the resolution of a three-dimensional image in a row will be only 250-200 elements, which is clearly insufficient.

A certain breakthrough in the development of television autostereoscopic systems was caused by the appearance of a patent by a number of employees at Philips, according to which the image resolution could be increased three times [17-19]. This is achieved by using an inclined lens raster and the method of encoding the color components of the parallaxpanoramogram.

The scheme of formation of vision zones of a conventional lens raster autostereoscopic monitor is shown in Fig. 4.

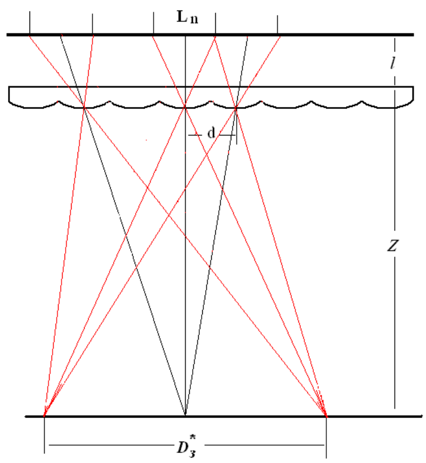


Fig. 4. Diagram of the formation of observation zones in the autostereoscopic lenticular lens raster system. (top view of the plane perpendicular to the screen and forming the lens raster).

Each successive group of n pixels, having a size Ln in the direction perpendicular to the lens raster generators (equal to the period of the location of these groups), forms observation zones at a distance Z from the raster, consisting of a sequence of enlarged pixel images. Each pixel carries information about the color and intensity of the corresponding point of the picture of a certain point of view. With a perfect setup, the images from all pixel groups and the corresponding pixels in the groups are exactly superimposed on each other. This allows the observer to see from the observation area with each eye its own perspective of the three-dimensional picture.

A color image consists of pixels, each of which includes three sub–pixels - red, green, blue. Figure 5 shows a fragment of the monitor scan of three lines, including 3x5 pixels of three RGB sub-pixels each.

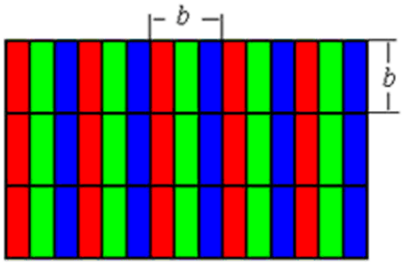


Fig. 5. A fragment of the monitor scan of three lines, including 3x5 pixels of three RGB sub-pixels each; b is the pixel size.

There are N pixels behind each raster lens and, accordingly, the resolution in the horizontal direction decreases by N times and does not change vertically. It is easy to see that if you do not take into account the difference in colors, then taking into account the sub-pixels, the resolution is 3 times greater. This was the basis of this patent – to change the angles without taking into account the color in a row by sub-pixels, and to form the color by tilting the raster set at an angle with a ratio of 1:3 legs (see Fig. 6).

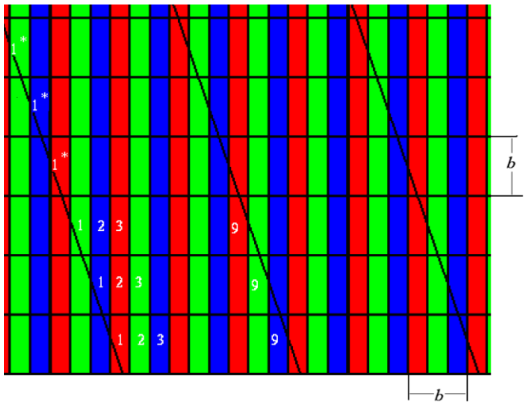


Fig. 6. A fragment of the monitor scan with inclined lens lines. b is the pixel size. The same numbers indicate colored sub-pixels corresponding to the same point of view.

The angle of inclination of the lens raster is selected so that the points of view in the observation area are formed by groups of pixels from adjacent rows and columns. For LCD TVs, this almost uniquely determines the choice of the slope of the forming raster to the vertical. However, unlike the television standard, the capabilities of computer inputs allow you to independently and separately control the brightness of the colors of each pixel of the matrix. This significantly expands the possibilities of adapting the matrices of existing LCD TVs when switching to the sub-pixel encoding level.

Each pixel is formed from different colors of sub-pixels located along the forming lenses of the raster on three adjacent lines. Figure 6 shows a diagram of the formation of 9 points of view in the observation area, using the example of one zone. The first foreshortening is formed by sub-pixels of red, blue and green, indicated by the number 1, matrix pixels located on three adjacent rows. The second point of view includes sub-pixels of green, red and blue, indicated by the number 2, etc. up to the 9th point of view. This process is periodically repeated on all three adjacent lines.

3. Problem statement

For the technical implementation of such an autostereoscopic display with a three-dimensional image, it is necessary to perform a combination of the parameters of the monitor used for this device and the lens raster. This includes the relative position of pixels and subpixels on the screen, the pitch of the raster and the focal distance of its lenses, that is, a combination of geometric and optical parameters of all elements of the device.

In [20, 21], a method for creating such an autostereoscopic device from independent elements is proposed and implemented. On the one hand, an ordinary commercially available TV or monitor, on the other – a lens raster, also available and selected from the catalog with the closest possible correspondence to each other geometric parameters.

The analysis of literary sources [7, 9, 22-24] and the experience of our own developments [25, 26] allowed us to identify two main areas of improvement of autostereoscopic displays.

1. The construction of multi point of view monitors is complicated by a limited choice of lens rasters with parameters that exactly match the parameters of the original 2D monitor. It is necessary to learn how to share rasters with different numbers of lenses per unit length and monitors with different screen sizes, resolutions and sequences of RGB or BGR subpixels.

2. An unpleasant effect in raster multi point of view monitors is moire, which occurs due to the addition of the spatial frequencies of the lens raster and the pixel raster of the imaging monitor. The easiest way to detect the presence of moire is to fill the screen of the imaging monitor with a uniform white color. When the lens raster is rotated relative to the monitor, the moire pattern will change, as shown in Figure 7. This figure shows two options for the tilting of the lens raster relative to the screen.

The angle is chosen in such a way that the moire has a sufficiently high frequency, is visually unobtrusive and at the same time is close to arctg(1/3) ≈ 18.4° (see Figure 8).

To improve the quality of the three-dimensional image and the process of its demonstration, the task is to create a mathematical description and a software product that allows you to adjust and adjust these elements and functions of the autostereoscopic system.

As monitors, the 43-Inch TV of SONY with a resolution of 3840x2160 with a retard of 20LPI focal length of the Linza 12mm, the 41-inch of the SUPRA with a resolution of 1920x1080 with a 20lpi focal length of the 12mm lens and a laptop monitor 15.6 Inches with the INCOLUTION 25 60x1440 with a friley 40LPI and focal lens distance 6mm. Image quality was assessed based on subjective feelings.

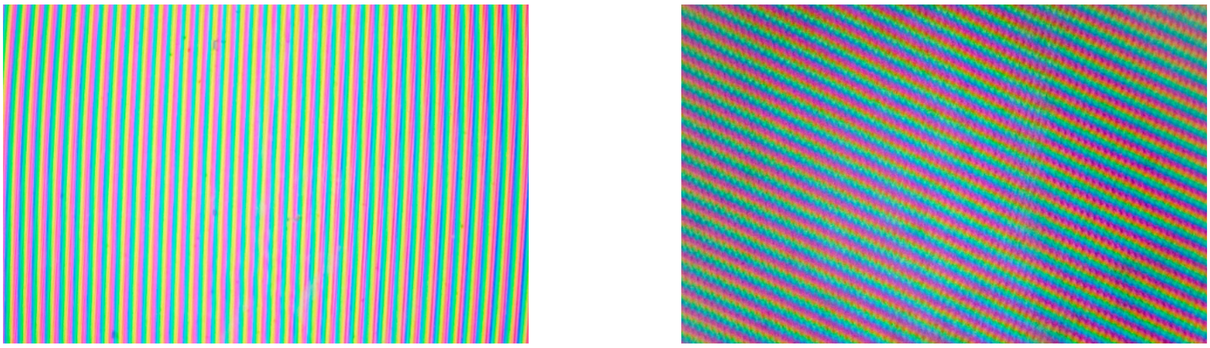


Fig. 7. Various moire patterns when the lens raster is tilted relative to the pixel.

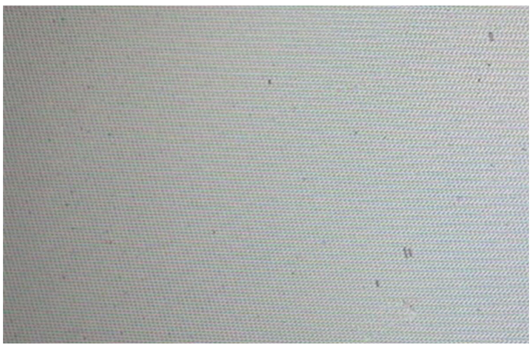


Fig. 8. At a certain inclination of the raster relative to the monitor screen, the moire has a sufficiently high spatial frequency and is not visible from an observation distance.

4. Calculation algorithm and software implementation

To store the parameters of the 2D monitor and the raster installed on this monitor, the "monitor" class has created in the program. This class includes parameters for a 2D monitor, this is the diagonal of the monitor, its resolution, a sequence of sub-pixels per pixel (RGB or BGR). For a lens raster, this is the number of lenses per inch, the focal length of the raster lenses, the angle of the raster relative to the monitor. The same class also stores observation parameters, such as the distance from the screen to the observer.

The interface of the monitor settings panel is shown in Figure 9. In the Monitor section, the parameters of the 2D monitor are set, Raster – the parameters of the raster, and the tilt of its lenses is set in the Ang of rast panel. The distance to the observer is set by the Distance to the raster slider. The Calc button calculates the test parallaxpanoramogram based on the parameters selected on the monitor control panel.

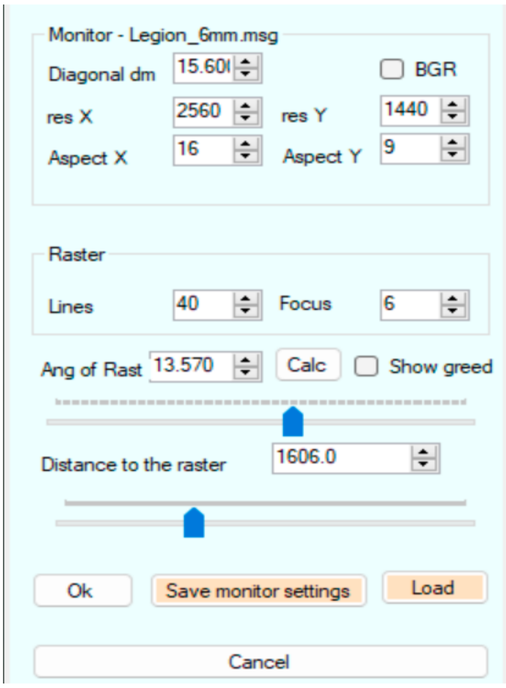


Fig.9. Monitor setup panel.

In the test paralaxpanoramogram, the pixel corresponding to the first view is white, the rest remain black. Creating such an image is necessary to configure the resulting 3D monitor. After configuring the monitor-lens raster system, the combination of parameters is stored in a file named. This file can be called for further use of the configured settings with this monitor. When changing the monitor and/or raster, the parameter system is configured for the new monitor and stored with a different name, which allows you to use the same program on different monitors.

The calculation of the parallaxpanoramogram is as follows:

1. Find the size of the projection of the lens of the inclined raster on the screen of the original monitor, taking into account the distance to the observer;
2. Find the pixel size of the original monitor;
3. For the current point of the monitor, we find which part of the lens is above this point;
4. Fill in the matrix of views, coinciding with the parallaxpanoramogram in size;
5. Fill the parallaxpanoramogram with colors corresponding to the colors of the current view;
6. We produce color coding.

Projection of the lens of the Ln raster in millimeters onto the screen of a 2D monitor from an observation point at a distance L from the raster (Figures 10 and 11).

$$L_n = \frac{d}{\cos(\alpha)} * (L + f) / L, \quad (1)$$

where Ln is the projection of the width of the lens tilted by an angle α onto the screen of a 2D-monitor,

d is the lens size or the period of the lens raster = 25.4 divided by the number of lenses per inch,

f is the distance from the raster to the monitor screen,

α is the angle of inclination of the raster.

The pixel size of the Dpms monitor, which has a square shape, is calculated using the following formula:

$$L_{pm}X = W / X_{res}, \quad (2)$$

where Xres is the resolution of a 2D monitor,

W is the horizontal size of the 2D monitor.

The horizontal size of the 2D monitor W can either be measured or obtained from the diagonal size of the monitor.

$$W = \sqrt{D^2 / (aW^2 + aH^2)} * aW, \quad (3)$$

where D = Diag * 25.4;

Diag – the diagonal of the 2D monitor in inches;

aW and aH are the horizontal and vertical aspect ratios of the monitor, respectively. For example, 16:9.

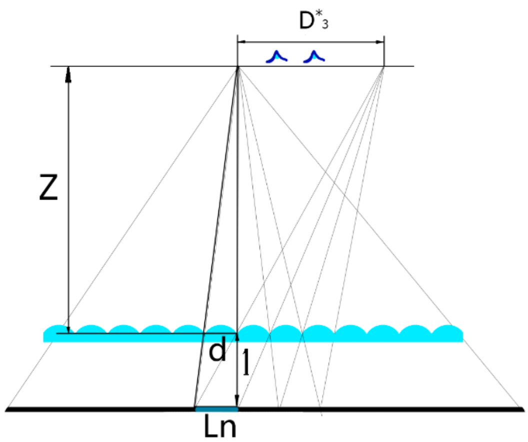


Fig. 10. For calculating the projection of the raster lens, where d is the size of one raster lens, Ln is the projection of the lens onto the monitor screen from an observation point located at a distance Z from the raster surface, D*3 is the size of the observation area, l is the distance from the raster to the surface of the 2D monitor screen.

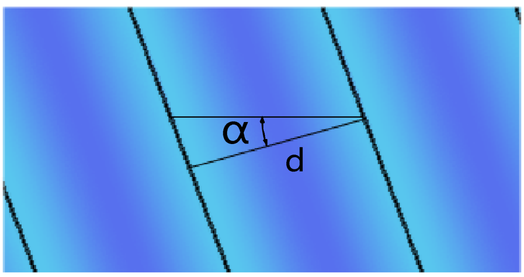


Fig. 11. Horizontal size of the raster lens, where d is the size of the raster lens, α is the angle of rotation of the raster lenses relative to the horizontal.

The number of pixels behind the lens of raster

$$N_p = L_n / L_{pm}X. \quad (4)$$

If Np is an integer, then we get a parallaxpanoramogram, where each pixel corresponds to its own point of view. But practically in the general case we get Np non-integer.

Let's take an arbitrary pixel on the screen of a 2D monitor P(x, y). And suppose that at point P(0, 0) the lens begins. This means that at this point the phase of the lens is zero, and this point corresponds to the zero point of view.

Horizontal distance from the left edge of the monitor to the pixel P(x, y):

$$X = x * LpmX \tag{5}$$

Accordingly, given the square shape of the pixel, the distance from the top edge of the monitor to the pixel is P(x, y):

$$Y = y * LpmX \tag{6}$$

Next, you need to determine which point of view should be at point P (x, y).

First, we find how much the zero phase of the lens has shifted at the left border of the screen along the line belonging to point P(x, y). Then, knowing the period of the raster in the horizontal direction Ln, we determine the phase of the lens at point P(x, y).

The initial phase of the lens at the left border of the PH screen on the y line.

$$PH = y * L_{pm}X * tg(\alpha). \tag{7}$$

And the distance from the zero phase in the line y,

$$T = X - PH, \tag{8}$$

The number of lenses on this segment

$$PH_{xy} = T / L_n \tag{9}$$

The fractional part of Phx, denoted as phy, is the phase of the lens at the point P(x, y). Its values lie in the range from 0 to 1.

This interval is divided into R – the number of points of view that we want to display in a three-dimensional image. The point of view number NR is calculated by the formula:

$$NR = phy * (R - 1), \tag{10}$$

The rounded value of NR is the point of view number at point P(x, y).

The point of view number is one less, since the first point of view has a zero value. The found point of view number is entered into a matrix of points of view with coordinates x, y. Based on this matrix, a parallaxpanoramogram of a specific picture is constructed. The color of the panorama pixel with the x, y coordinates is filled from the pixel of the image with the x, y coordinates of the corresponding point of view.

Fig. 12 shows how the parallaxpanoramogram point of view from 20 points of view are located under a lens with a width of Nr =L/cos(α), where L is the width of the lens projection on the monitor screen, taking into account the distance to the observer and the distance of the raster to the screen, which is very close to the focal length of the raster lens, a is the angle of rotation of the raster relative to the vertical.

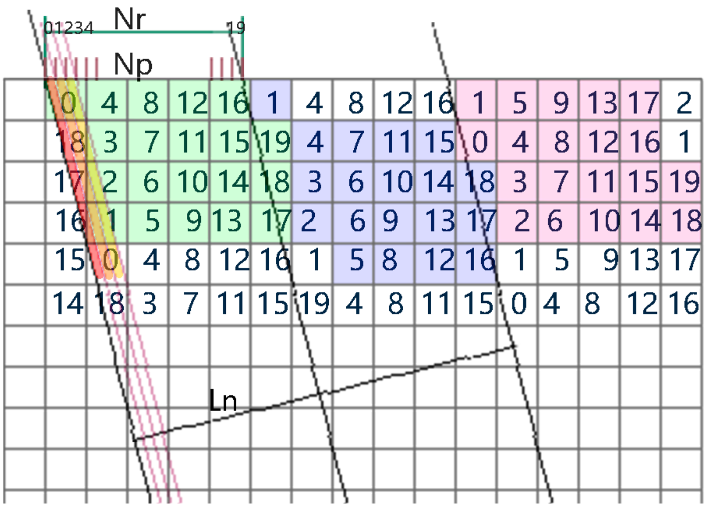


Fig. 12. For the calculation of a paralaxpanoramogram from 20 points of view. Ln is the size of the projection of the raster lens onto the 2D monitor plane, Np is the point of view number assigned to a specific pixel, Nr is the point of view number corresponding to a specific part of the raster lens.

The number of pixels under the lens is not necessarily an integer. In Figure 12, there are slightly less than 5 of them. The calculation of the panoramogram was performed for a laptop monitor with a size of 345x194 mm, which corresponds to a diagonal of 15.6 inches with a resolution of 2560x1440, for a 40LPI raster with a focal length of 6mm. The distance to the viewer is 1600mm. In the figure you can see that the voxel does not have a rectangular shape. Each voxel does not necessarily have all the points of view, if their number is greater than the "optimal" one. If their number is less than "optimal", they can be repeated. In Figure 12, the number of points of view – 20 is taken arbitrarily. If the number of points of view is more or less when shooting, you need to select the number that is available. At the same time, of course, the number of views and the distance between the lenses must be chosen correctly [25].

A single-lens camera, such as a mobile phone, was used to create stationary parallaxpanoramograms. The shooting was carried out using the integral stereo method, while the camera moves parallel to the object being shot, and for the synthesis of the parallaxpanoramogram of the image, a sequence of n frames is selected from the stream, where n is the number of views that are placed behind one raster lens or which is necessary to achieve the artist's idea. At the time of writing, you can choose from 2 to 40 views that the program will select from the stream. In general, not an integer number of views is placed behind the lens, then the task of the program is to choose which view should be assigned to a pixel on a 2D monitor behind a specific section of the lens of the lens raster. At the same time, the number views can be either more or less than optimal. The optimal number of camera views is calculated when setting up the monitor depending on the resolution of the 2D monitor, the frequency of the lens raster, its tilt, the focal length of the raster lens and the distance from the monitor to the observation point.

The setup process is as follows. At the very beginning, when there are a lot of unknown parameters, we start moving the Ang Of Rast engine. A series of lines appears on the screen, which need to be oriented approximately as the raster lenses are located. Fig. 13.

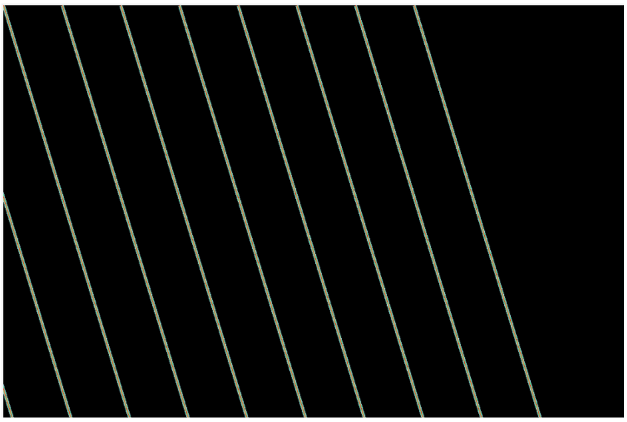


Fig. 13. Lines on the monitor for quick 3D monitor presetting.

After the preliminary setup, it is necessary to make an exact adjustment. To do this, fill in the values of the parameters of the imaging monitor in inches and its resolution, raster parameters, such as the number of lenses per inch and the focal length of the lens in mm. We set the distance from the monitor to the viewer in meters using the 'Distance to the raster' engine on the monitor settings panel (Fig. 9). Press the Calc button. A parallaxpanoramogram is calculated, the image of which must be viewed from the central zone where the viewer will be located. In case of fine tuning, the screen should be completely white, but since the monitor screen is not flat, and the lens raster plate is not absolutely flat, there will be dark areas on the real screen. For shallow scenes, this is not terrible, but with a large depth of the scene or with a narrow observation area, this leads to observation discomfort.

The interface for creating and viewing an image on a composite 3D monitor is shown in Fig. 14.

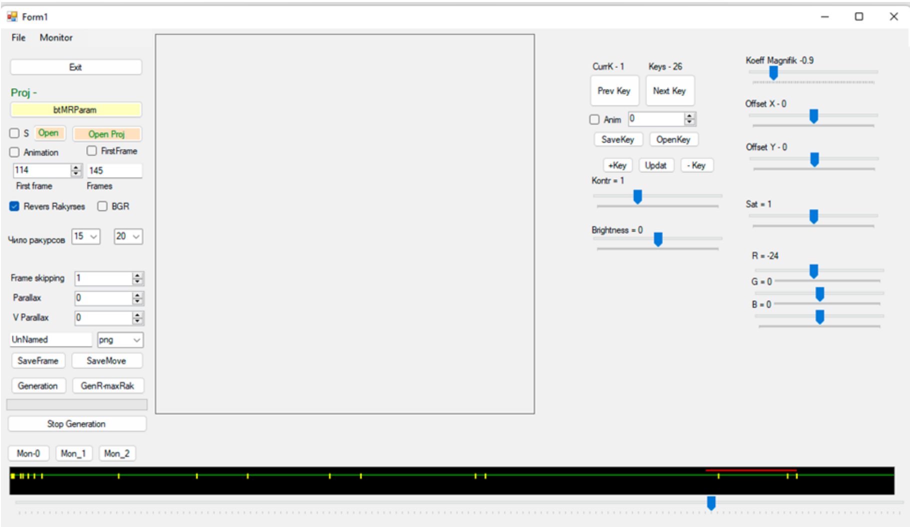


Fig. 14. Interface for managing the synthesis of parallaxpanoramograms and displaying them on a point-less raster 3D monitor.

In the program, you can select a folder with a sequence of images that can be obtained from a video shot with a single-lens camera, obtained from a 3D editor, or any other way where you can get a series of different point of view shots. This series should be placed in a separate folder. In the program, you can select the first point of view in the sequence, choose how many points of view will be used in creating a parallax panorama, set the depth of the scene. The depth of the scene depends on the speed of the camera when shooting and the frame rate. The higher the speed of movement, the deeper the scene will be, and the higher the frame rate when shooting, the less, provided that every next frame is selected. By choosing the number of frame skips in the sequence, you can adjust the depth of the scene. Based on this, the speed of movement should be low, or the frame rate when shooting the maximum possible.

Examples of images on a point-less monitor based on a 43-inch SONY TV are shown in Fig. 15

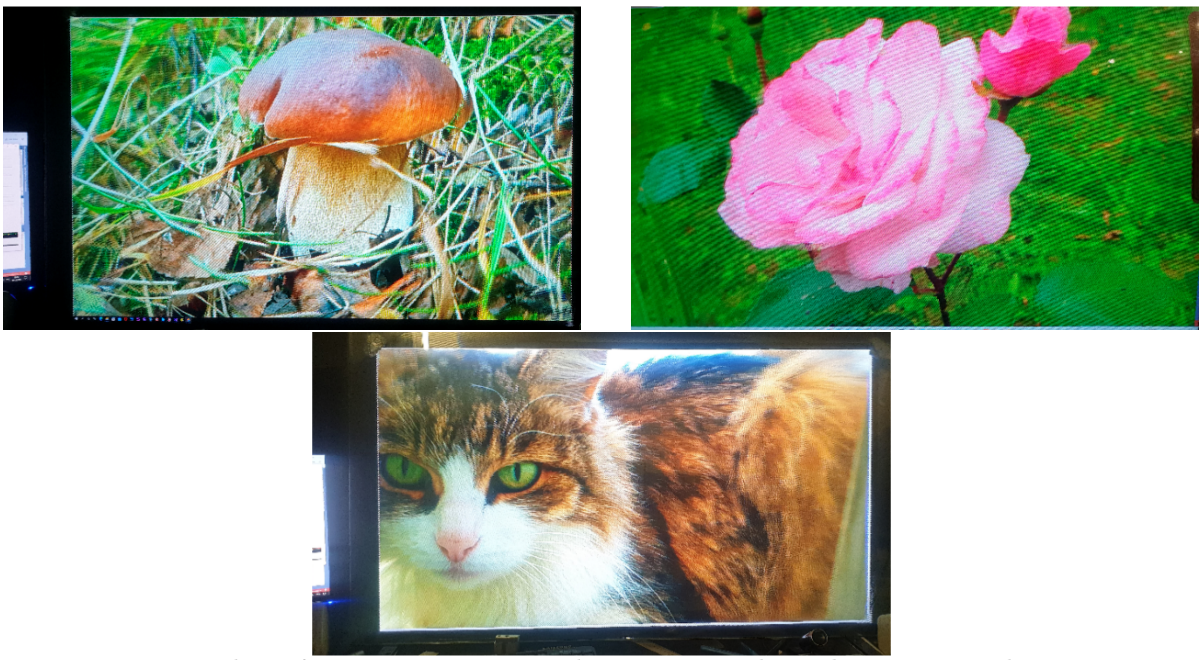


Fig. 15. Examples of images on a point-less monitor based on a 43-inch SONY TV.

The program was used to translate the film "The Southern Coast of Crimea" to a point-less monitor based on a 43-inch SONY TV, which was filmed using integrated technology in the 60s in the Soviet Union.

5. Conclusion

One relatively simple way to create a 3D image is to use a lenticular array and a regular high-resolution 2D monitor. In this case, we need to pay attention to two circumstances.

The first is a reduction in the resolution of the resulting 3D monitor in comparison with the original 2D monitor. When the raster grid lines are arranged vertically, the resolution drops by a factor equal to the number of points of view. It is believed that for comfortable observation of a three-dimensional image, 8 - 10 points of view are necessary. In this scheme, to obtain an acceptable 3D image resolution, it is necessary to use a 2D monitor with a horizontal resolution of more than 5000 pixels or several ordinary monitors combined into a single screen. The color coding does not change at the same time.

The solution proposed in a number of patents [18, 27 - 29] to use an inclined lens raster and to encode color using pixels of several adjacent lines (vertical color encoding) makes it possible to reduce the loss of resolution compared to the considered case by a number of times equal to the cotangent of the angle of inclination of the lens raster. In general, the angle can be chosen at any angle, but usually the tangent is equal to one third due to the fact that the color is encoded by 3 subpixels: red, green and blue. This makes it possible to encode color by considering three pixels located along the raster tilt line and belonging to different television resolutions lines as an elementary raster cell.

For an arbitrary raster tilt angle, you must use your own specific color-coding scheme.

This paper proposes a color-coding algorithm that adapts to the geometry of the television resolution, lens raster and tilt angle. It is based on a calculated arrangement of subpixels in a raster unit cell.

The second difficulty in the conventional approach is due to the variety of television resolution and lens rasters. An exact match of their parameters or tools for adjusting both the angle of inclination of the lenticular grating and the color-coding scheme are required.

Experience has shown that the flexible software solution proposed in this work for each specific television resolution is acceptable and stable with a slight change in the geometric dimensions and/or angle of inclination of the lens raster array.

The photographs shown demonstrate the absence of a noticeable moiré grid, characteristic of such autostereoscopic images. The high quality of the species plots also confirms the effectiveness of the chosen heuristic approach.

The created software currently has non-commercial experimental status. The program is written in the C# programming language on the Dot NET Framework4.8 platform. The program uses only standard instructions and does not use external libraries. The development data was not made publicly available, in particular on the GitHub web service.

Further development of the software is associated with the expansion of its functions. It is planned to create a module that will make it possible to make three-dimensional films from materials shot by flying around an object or using a multi-lens camera. The module should allow you to select the first frame, the direction of flight, adjust the position of the ramp, select the distance between adjacent angles and, thus, change the depth of the scene and save the selected parameters to a file.

The module is under development. Currently it works in the mode of a static image viewer, which forms a stereo image from a sequence of multi-angle pictures taken with a single-lens camera, allows you to call up the next or previous image, and also show them in automatic display mode. The module has controls for brightness, contrast, color saturation, brightness of each color and image size. A separate option allows you to make a series of parallax panoramic images from a video film shot using integral technology (continuous flyby of objects).

The results obtained attract attention and interest and can be used not only in the field of screen arts (cinema, television etc.), but also in medicine, for example, to accompany surgical interventions, as well as for volumetric visualization of scientific experiments, for example, biological objects.

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