# Evaluating Volume Perception Parameters in Volumetric 3D Display Images

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**Abstract:** We conducted a functional simulation of the system for forming a three-dimensional image in volumetric 3D displays using data-flow diagrams. Major parameters of two- and three-dimensional images affecting the quality of 3D images and scenes generated by volumetric displays were recognized. Interrelations of the variables and parameter impacts were described. Evaluation scales of image perception parameters were introduced, and weighting factors for the parameters responsible for image volume perception were identified.

**Keywords:** 3D display, 3D image, monocular cues, optical system, data-flow diagram, weighting factors.

## Introduction

Majority of information is perceived by humans visually, which is due to their physiological capabilities. That is why, currently, we observe a trend towards increased attention to, along with attractiveness and informational content of, the graphic design. Among the factors, affecting these criteria, one of the most important represents the ability to visualize an image in a three-dimensional rather than flat format. Such manner of displaying graphical information includes the possibility to observe an object from multiple vantage points, which makes it more informative for the observer and catches an attention of the latter. Hence, it can be concluded that 3D imaging technologies are currently in high demand.

Among the playback devices, it is necessary to highlight a volumetric display [1-3]. It creates images via three-dimensional pixels, hereinafter called voxels.

In order to select the optimal method of constructing a 3D image, it is necessary to solve the problem of describing the relationship, providing required quality of the output volumetric image, depending on selected input image variables, along with a possible external impact. The resulting solution is the proposed version of device configuration, as well as necessary values of the variables required for the input image, and quantitative parameters of the output volumetric image.

To implement the process of converting input information into output information, various modifications of displays selected from previously developed original model series, were chosen. Versions of devices were determined from the analysis of their statistical demand among the users [4].

## Study Goal and Objectives

The goal of our study was evaluating the aspects and parameters affecting the perception of a 3D image by an individual. To achieve this goal, the following objectives had to be completed:

1. To simulate the process of forming a resulting image based on an analysis of the data stream in order to detect multiple parameters:

a) Two-dimensional image;

b) Three-dimensional image or scene;

2. To classify the parameters by group-associated features;

3. To define relationships between the parameters;

4. To evaluate a magnitude of a generated image effect on its quality.

## Materials and Methods

The display of the first type was installed on the screen of the portable playback device (Figure 1). In order to form a 3D output image, it was necessary to prepare an input image split into n scenes located on the screen. Each frame was refracted on projection faces made of translucent material located at 45 degrees relative to the reference image. The resulting images on each layer were imaginary. They were 'suspended' in the air, which created a 3D effect.

The second type of displays was also designed for the screens of mobile and stationary image playback devices, but represented an array of flat-out lenses (lenticular lens) in increments of 10 to 40 lenses per inch (LPI) (Figure 2). The display had upper and side mounts for fixing the item on PC or TV screen.

To avoid observing the dispersion effect, a rear-projection film was applied to the rear surface. The playback footage involved a set of frames combined by interlacing [5].

The third type of display (Figures 3) included the following:

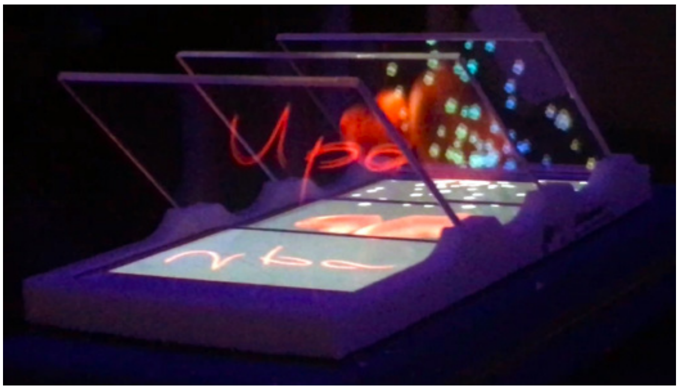

Figure 1. Display of the first type

Figure 2. Display of the second type

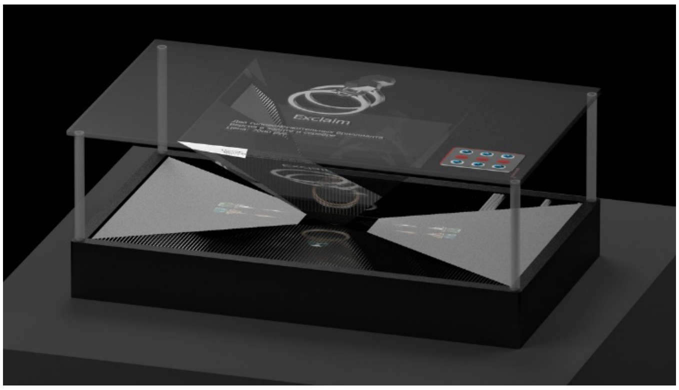

Figure 3. Display of the third type

a) Display screen aimed at forming the input image, which was divided into four sections, corresponding to the viewing angles, i.e. right, left, front and rear views. The original 3D object on the screen was presented in the format of four projections of the main views, each of which, in its turn, was divided into 10 frames with a nine degree step. The resulting

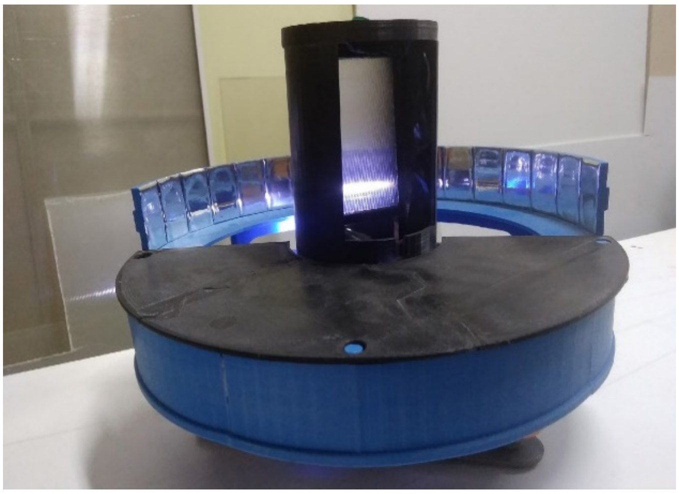

Figure 4. Display of the fourth type

Figure 5. Display of the fifth type

images were aligned into the original (input) image by interlacing;

b) A parallax barrier from a 20-LPI lenticular surface was divided into four equal trapezoids representing four types of the input image. At an azimuth viewing angle, the bands of one particular image were falling into the focus of the lens, increasing its pixels and covering other views;

c) A translucent screen made of a rear-projection film for filtering the portions of visible light between the screen and lenticular lens;

d) Reflected from the mirror surface, the images were transferred to a horizontal plane and overlapped at a single point, represented by a plexiglass pyramid truncated to the top, located at an angle of 45 degrees to the light source.

The fourth type of display (Figure 4) was based on rotation of an opaque through-hole cylinder around the axis of the device at a speed of 1200–1500 RPM. The holes were covered with transparent material. Inside the cylinder, there was a translucent through lenticular plane, on which the image was projected. On the front side of the device, there was a multi-screen panel, which constituted a part of a polyhedral prism. The panel was covered with a rear-projection film to implement the original image output process. Scene views at different angles were generated on all faces of a multi-screen panel via an array of light sources. Using two optical system modules, the formed light beam was passing through the axis of the device, and then was reflected from the mirror surface with a spray-on coating. After that, the light beam was reaching the screen, on which the resulting 3D image was formed.

The fifth type of display [6-7] (Figure 5) was comprised of:

a) A light source – the display screen of the monitor, on which an initial frame was projected;

b) Twelve trapezoid mirrors with a spray-on coating, forming a mirror polyhedron for image transfer into a vertical plane [8];

c) Array of lenses magnifying and focusing the image [9];

d) Output diaphragm cutting off side frames and excessive light from the image source;

e) A Fresnel lens of the output block, which created an enlarged imaginary image and constituted the output projection plane of the system [10].

## Results: Identifying the Parameters of Volumetric Displays

Let us consider the process of forming a 3D image on volumetric displays [11] of the proposed model series shown on a data-flow diagram depicted in Figure 6. In general, the process involves:

a) The user who selects required 3D image for demonstration;

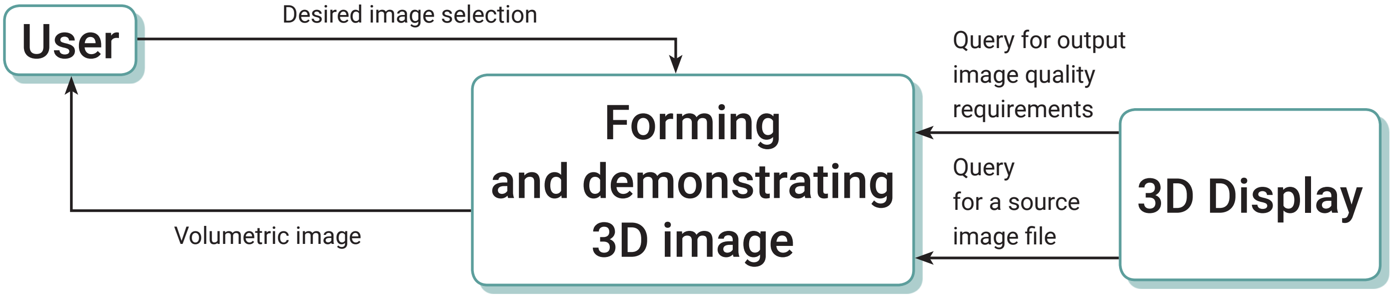


Figure 6. **Data-flow diagram (DFD), level 0**

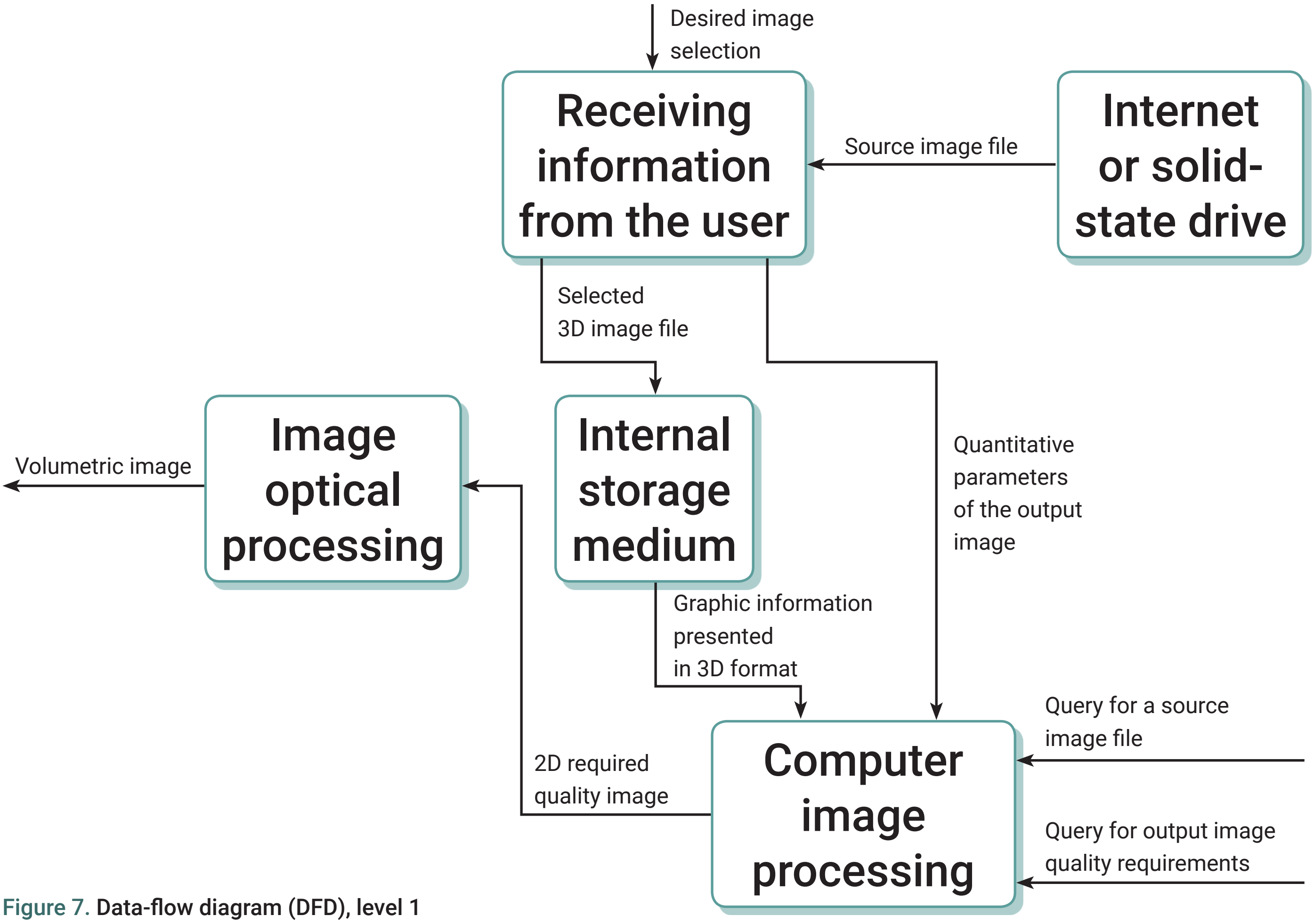


Figure 7. **Data-flow diagram (DFD), level 1**

b) Volumetric display that imposes restrictions on the output image quality on the basis of the user's query.

In order to operate, the device needs to obtain a file to form an output image for further processing by the computer optical system.

Let us review the level 0 data-flow diagram, in particular, let us consider the relationships within the block 'Forming and demonstrating 3D image' (Figures 6 and 7). The most important process for identifying image parameters is the 'Computer image processing' block, which receives three-dimensional graphic information. Changing input image parameter values directly affects the resulting volume perception effect. Limitations introduced into computer processing procedure are related to the technical characteristics of the volumetric display design, and impact the final qualitative and quantitative outputs of the projected image.

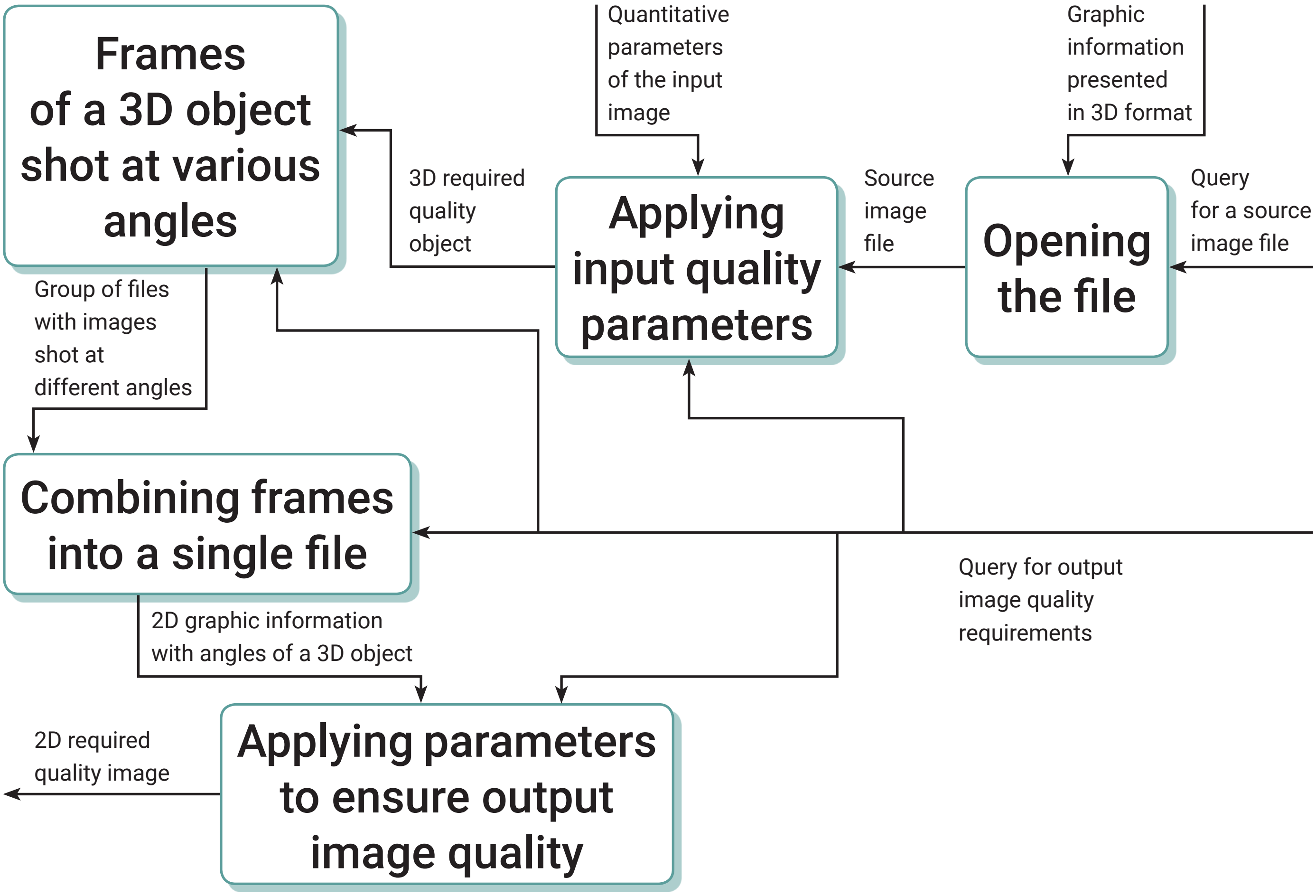


Figure 8. Data-flow diagram (DFD), level 2

Further decomposition of the data-flow diagram to the level 2 (Figure 8) enhances our understanding of the stages related to the primary and secondary processing of graphic information. In the course of these processes, the parameters, affecting the quality of the output image, are being changed. After opening the file containing original graphic information, or prior to initiating the telecommunication process, the user sets the quantitative parameters of the reference image and can also change them during the operation of a volumetric display. The range of changes, however, is limited by the capabilities of the technical solution. After the primary processing, the resulting image of preset quality is converted into a two-dimensional image. Object storyboard is implemented by separation into views or scenes with different depth levels. An array of frames depicting the object is implemented by separation into angles, or scenes, with different levels of depth. The obtained set of images is combined into a single file and undergoes secondary processing, while taking into account limitations and preferences imposed by the volumetric display, its optical system, user, PC and environment [12-13].

After decomposing the block 'Applying input quality parameters' (Figure 9), it is possible to identify the variables characteristic for input volumetric images.

## Criteria for Monocular Cues of 3D Image Perception

Source variables describing 3D scenes or objects can change qualitatively during the output generation process. Such characteristics define a set of criteria for the perception of a three-dimensional image by a person, i.e., the image depth.

They can be divided into monocular (Table 1) and binocular (Table 2).

Monocular cues are not quantitative; their presence is taken into account while creating

**TABLE 1.**
**Monocular cues of volume perception**

| Key parameters | Cues | Short description | Range / possible values |
|---|---|---|---|
| Monocular cues of volume perception | Motion parallax | Object movement relative to a viewer is perceived | N |
| | Aerial perspective | Objects at a distance look indistinct | N |
| | Shadows | Presence of shadows on the object | N |
| | Linear perspective | The perspective is observed | N |
| | Occlusion (interposition) | Blocking the sight of objects by other objects | N |
| | Object rotation | Presence of rotation | N |
| | Relativity of the sizes | Closer object appears larger | Large differences, noticeable differences, small differences S |
| | Texture gradient | Larger texture is seen in closer objects | Pronounced texture, some texture, none S |

Scale: N – nominal, S – serial

initial volumetric scenes or objects and is aimed at strengthening perception of a volume effect. Their main feature is that objects coming into view can be perceived by a single eye. Among such cues, we should mention the following:

- Relative sizes of objects. Objects placed on an image may have sizes different from actual, creating a scene depth effect. This characteristic varies depending on the location of an observer relative to an object. The closer the observer is to the object, the larger the object is perceived in its dimensions [14];

- Texture gradient that consists of elements, forming microstructural pattern [15], and depends on the distance between an object and an observer. Proportional to the observer's distance from the object, size, shape and pattern of the texture elements decreases, i.e. the detail of the image and the clarity of its texture deteriorates with distance [16];

- Relative arrangement (image occlusion effect) is described by the process, when a closer located object partially obscures a more distant one [17];

- Linear perspective: objects decrease in size proportionally to their distance from the foreground, i.e. even parallel lines are depicted converging closer to the horizon. For observation, it is necessary to maintain a fixed vantage point, which would allow observing a single convergence point on the horizon line [18];

- Aerial perspective is defined by loss of image clarity, its outline sharpness. It is formed due to increase in defocusing when forming background objects. Aerial perspective has an effect on saturation, so distant objects appear lighter than a foreground [19];

- Motion parallax includes cues relating to perception of the relative movements. As the observer's visual analyzer shifts when the entire body moves along with the head, or else when the head turns, then movements in the vision organ occur. That is why the projections of the objects, located closer to the observer, on the retina shift faster than the projections of more distant objects [20].

## Variable Image Attributes

While decomposing the block 'Applying output image quality parameters' (Figure 10), it is possible to identify parameters varying during the processing of input mages, and characteristics varying in the course of forming the images for projection of a volumetric image at the output of the device.

The quantitative characteristics of images depend on the electronic components of the system, in particular on the devices for forming source (input) images: displays, projectors and graphics cards. In the diagram, the constraints are referred to as 'Query for output image quality requirements'. Data defining the variation range come from the source image forming elements.

The quality of the generated 3D image depends upon the following:

**TABLE 2.**
**Variable Image Perception Attributes**

| Parameters | Attributes / dependence | Unit of measurement | Description | Range / possible values / scale |
|---|---|---|---|---|
| Volumetric Image Area Size | Width × Height × Depth | $mm^3$ | The size of the formed image | Few cm to several meters |
| Viewing angle | Sagittal and azimuth viewing angles | Degrees | Maximum angle, at which the image quality does not change significantly | 110-360° |
| 3D resolution | Virtual or real object (on which the image is generated) | Voxels | Number of voxels per unit area | Range is limited by actual object size or monitor resolution |
| 2D resolution | Aspect ratio (format) (e.g. 16:9, 5:4) | PPI | Number of points describing the image per unit area | from 320 × 240 to 8192 × 4320 |
| Lineature | Lens viewing angle and direction | LPI | Number of lenses per line or row (depending on lens direction) | 10-200 |
| Luminance | Backlight uniformity (uniform, or decreasing from the center to the edges) | $cd/m^2$ (candela per square meter) | Ratio of the light intensity, emitted by the surface, to the area of its projection on the plane perpendicular to the observation axis | 1...1500 |
| Contrast | Sensitivity of eyes | Dimensionless (coefficient) | The ratio of the luminance values or the lightest to darkest points on the image | 40:1... ...1000:1 |
| Color depth | Colors used to obtain other colors: Binary RGB HighColor TrueColor DeepColor | Bits | Number of bits used to generate and store the colors | 8, 16, 32 |
| Sharpness and blurriness | Visual acuity, observation distance, optical components | Nominal unit | Reproducibility of small details and the minimum distance between them, ensuring that they are perceived as separate in the image | N |
| Array of frames frequency of change | Maximum hertz (Hz) number supported by the device | Frames per second (FPS) | Number of frames per unit time | 16–60 |
| Speed of generation (movement) | Human ability to perceive information at a certain rate (human factor) | Dimensionless (coefficient) | | 0,25–5 |

- Possibilities of their implementation by available technical means of information output;

- Variation ranges of the variables;

- Values assigned by the user during the setting of input image quality variables (Figure 9).

Table 2 presents the list of the variables describing graphical information.

Assessment of these variables allows determining the quality of the input frame and also places limitations on the variable attributes of the images. Thus, they can be adjusted in their ranges so that

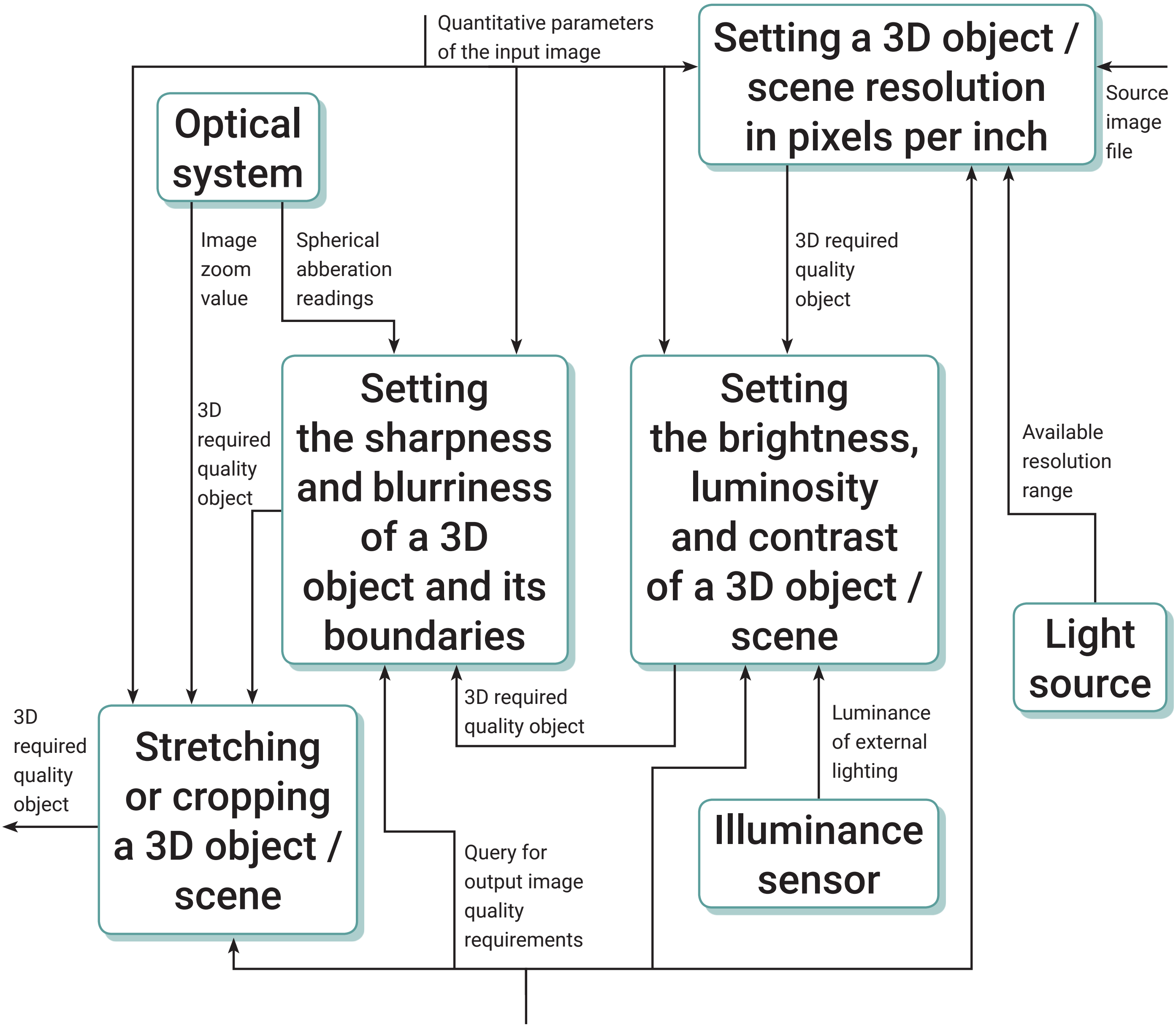


Figure 9. **Data-flow diagram (DFD), level 3 (Volumetric image quality parameters)**

the nominal values of the quality indicators were maintained:

■ Contrast and/or luminance are directly proportional to the shadow effect. Excessive values of these variable indicators will light up the frame, reducing the visibility of shadows, which would reduce the volumetric effect. If their values, on the contrary, are not high enough, areas of the image will darkened, reducing the visibility of the shadows, or making them completely invisible, which would also have a negative impact on the quality of the 3D scene.

■ Motion parallax and object rotation depend directly on the frequency of changing the array of frames. At FPS (frames per second) < 25, there is a sharp change of frame and position at the moment of its rotation or at change of a viewing angle. At such low FPS values, motion parallax would appear somewhat 'spasmodic' for the observer, which would negatively affect the integrity of the scene and quality of 3D information.

■ Sharpness and blurriness influence the change in quality of a texture gradient. Increased sharpness includes a more detailed pattern of the surface

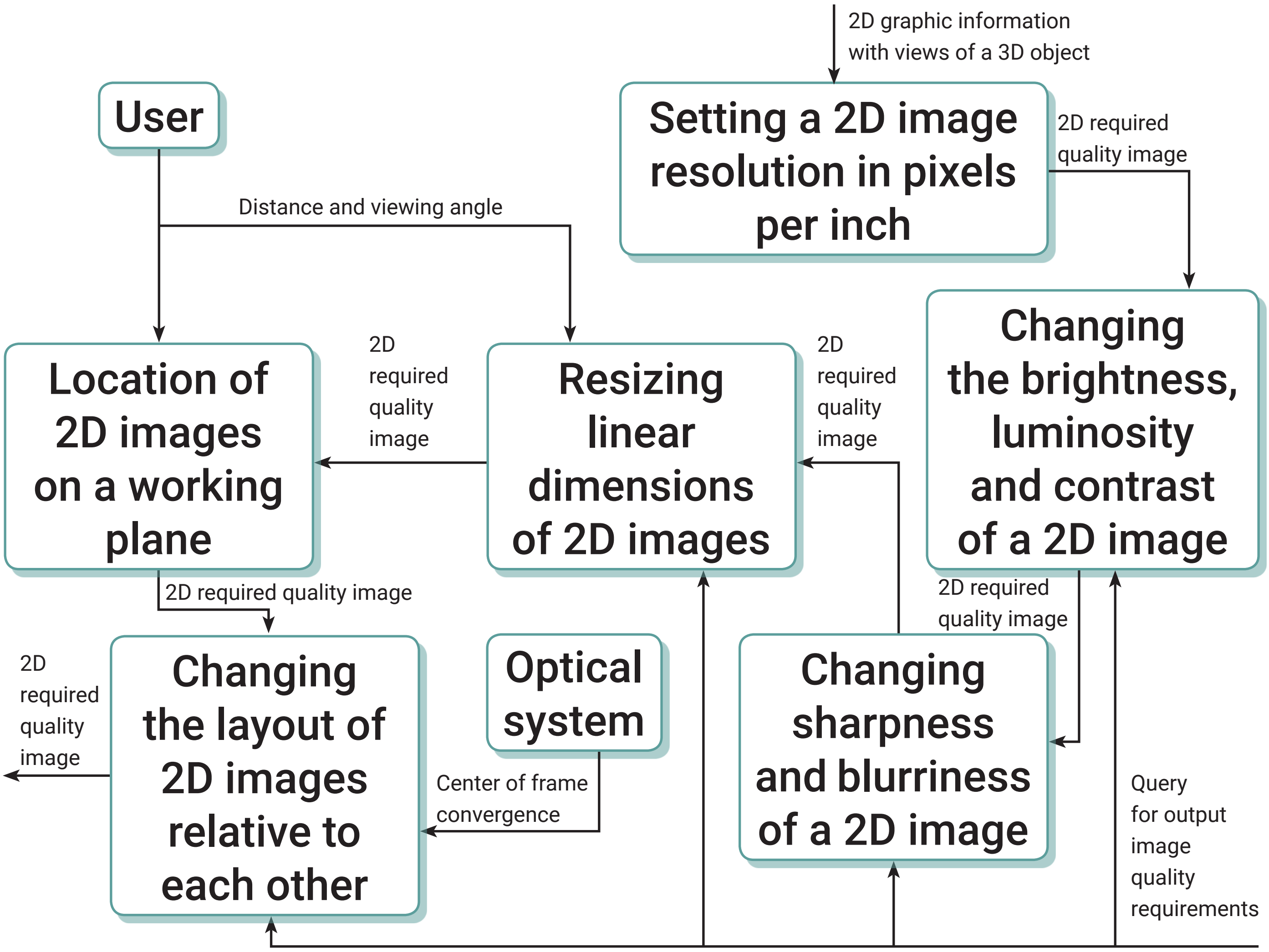


Figure 10. **Data-flow diagram (DFD), level 3 (Applying output image quality parameters)**

texture in a 3D object. This can be achieved by increasing the resolution as well as the difference in color balance and contrast between the pixels in charge of the texture. However, blurriness allows smoothing the texture gradient, especially while creating volumetric scenes, when the viewer sees an item against the background. For the observer, the sharpness of the object's boundaries is blurred, and the color balance and contrast are averaged between the pixels in charge of the object's texture.

■ Screen resolution affects such characteristics as lineature (LPI), number of frames (k) when using lenticular surface. The linear dimensions of the screen are inversely proportional to these variables. PPI (pixels per inch) should be used to estimate the imposed constraints: $PPI = LPI \times k$.

## Optical Characteristics

They include convergence and binocular disparity. These are binocular properties based on the optical principles of human vision. Both characteristics can vary under changing configuration of the optical display system.

1. Binocular convergence characterizes the contractions of an eye muscles responsible for the curvature of the lens, as well as the eyeball shape and convergence angle of the eye visual axes. The value of convergence varies due to the fact that, during perception of approaching objects, moving towards the center, eye muscles experience increased tension, while during the perception of remote objects, eyes relax [21];

2. Normal binocular disparity determines the magnitude of deviation of two point light sources, projected

**TABLE 3.**
**Binocular Properties of Volume Perception**

| Key features | Properties | Description |
|---|---|---|
| Binocular properties of volume perception | Convergence | Eye convergence when looking at close objects. Can be qualitatively evaluated by the ordinal scale: normal, complex, none. |
| | Binocular disparity | The difference between two images projected onto the eyes. Can be qualitatively evaluated by the ordinal scale: normal, complex, none. |

**TABLE 4.**
**Adjacency Matrix of Inter-parameter Relationships Affecting Generated 3D Image Quality**

| | Relativity of the sizes | 2D resolution | Motion parallax | Object rotation | Shadows | Perspective | Occlusion | Shape heterogeneity | Texture gradient | Convergence | Binocular disparity | Volumetric image area size | Viewing angle | 3D resolution | Lineature | Luminance | Contrast | Color depth | Frequency of change |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Relativity of the sizes | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 2D resolution | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Motion parallax | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 |
| Object rotation | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 |
| Shadows | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| Perspective | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| Occlusion | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| Shape heterogeneity | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| Texture gradient | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| Convergence | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Binocular disparity | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Volumetric image area size | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Viewing angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| 3D resolution | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Lineature | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Luminance | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Contrast | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Color depth | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Frequency of change | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

**TABLE 5.**
**Weighting Factors of the Effects Caused by Various Parameters on the Output Image**

| Parameters | Experts | | | | | | | | | | Average factor value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Relativity of the sizes | 0.07 | 0.02 | 0.04 | 0.05 | 0.04 | 0.07 | 0.03 | 0.02 | 0.04 | 0.02 | 0.04 |
| 2D resolution | 0.08 | 0.02 | 0.04 | 0.06 | 0.03 | 0.02 | 0.08 | 0.07 | 0.06 | 0.04 | 0.05 |
| Motion parallax | 0.06 | 0.04 | 0.04 | 0.07 | 0.06 | 0.06 | 0.05 | 0.03 | 0.06 | 0.03 | 0.05 |
| Object rotation | 0.06 | 0.04 | 0.06 | 0.03 | 0.03 | 0.04 | 0.02 | 0.04 | 0.05 | 0.13 | 0.05 |
| Shadows | 0.04 | 0.04 | 0.07 | 0.09 | 0.07 | 0.10 | 0.07 | 0.07 | 0.08 | 0.07 | 0.07 |
| Perspective (forward, reverse, panoramic, spherical, aerial, perceptual) | 0.12 | 0.08 | 0.10 | 0.11 | 0.1 | 0.1 | 0.10 | 0.10 | 0.1 | 0.09 | 0.1 |
| Overlapping Objects (Occlusion) | 0.05 | 0.1 | 0.07 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.03 |
| Shape heterogeneity | 0.02 | 0.08 | 0.08 | 0.06 | 0.05 | 0.05 | 0.07 | 0.06 | 0.09 | 0.04 | 0.06 |
| Texture gradient | 0.02 | 0.05 | 0.08 | 0.12 | 0.07 | 0.08 | 0.07 | 0.08 | 0.06 | 0.07 | 0.07 |
| Convergence | 0.04 | 0.08 | 0.04 | 0.03 | 0.07 | 0.06 | 0.08 | 0.05 | 0.07 | 0.08 | 0.06 |
| Binocular disparity | 0.09 | 0.09 | 0.1 | 0.1 | 0.1 | 0.1 | 0.12 | 0.1 | 0.1 | 0.10 | 0.1 |
| Volumetric image area size | 0.04 | 0.09 | 0.04 | 0.07 | 0.09 | 0.08 | 0.07 | 0.07 | 0.07 | 0.08 | 0.07 |
| Viewing angle | 0.08 | 0.06 | 0.04 | 0.03 | 0.07 | 0.05 | 0.02 | 0.06 | 0.04 | 0.05 | 0.05 |
| 3D resolution | 0.07 | 0.06 | 0.05 | 0.04 | 0.02 | 0.03 | 0.01 | 0.03 | 0.02 | 0.07 | 0.04 |
| Lineature | 0.02 | 0.02 | 0.02 | 0.05 | 0.06 | 0.06 | 0.05 | 0.05 | 0.06 | 0.01 | 0.04 |
| Luminance | 0.02 | 0.04 | 0.02 | 0.02 | 0.04 | 0.02 | 0.06 | 0.05 | 0.02 | 0.01 | 0.03 |
| Contrast | 0.02 | 0.03 | 0.04 | 0.02 | 0.03 | 0.02 | 0.04 | 0.06 | 0.02 | 0.02 | 0.03 |
| Color depth | 0.06 | 0.04 | 0.02 | 0.02 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.06 | 0.04 |
| Array of frames frequency of change | 0.04 | 0.02 | 0.05 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 |
| Total | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

onto one eye retina, from the position of the corresponding points. Deviation values are positive because the distance between light sources is greater than the distance between matching points [22].

The change in disparity depends on the perception of various distances to the objects. For nearby objects, there is a significant disparity between what is seen by each eye, whereas for remote objects, the disparity is of a smaller magnitude.

Optical features of a person's visual apparatus and assessment of perception level do not affect technical characteristics of the system and image. However, changes performed in reverse order have a significant effect on optical characteristics.

To reflect inter-dependencies of described characteristics in more detail, we generated an adjacency matrix (Table 4). Detected dependencies helped identifying the input characteristics, taking into account the degree of awareness about the output characteristics.

However, the perception of a volumetric image is also affected by psychological and physical capabilities of a person. Therefore, an important aspect of developing a three-dimensional imaging method is the necessity to test it on different groups of recipients.

There are many experiments proving this point, including:

1. Gregory's visual assumption theory [23];

2. The phenomenon of binocular rivalry [24];

3. Perception of the scene essence *sensu* Castellano and Henderson [25];

4. Cognitive, image-structured visual perception [26].

In addition to described factors, there are specific psychological factors, which are still not recognized by medical science. A number of ailments affecting the brain and visual apparatus of humans should also be taken into account:

1. Astigmatism;

2. Refraction;

3. Visual agnosia.

## Analysis

In order to determine the degree of influence of image attributes on the final perception of volume, it is necessary to introduce an expert evaluation factor. The significance of the characteristics is described by weighting factors. Specificity of image perception by an individual has an effect on impartial evaluation. That is why it is advisable to compute weighting factors on the basis of expert evaluations. Nineteen most significant variables were selected for expert evaluation. The cumulative evaluation of characteristics shall not exceed 1.

The expert group included ten people. Based on evaluation results, the average values of the coefficients were entered into the chart presented as Table 5.

## Conclusion

Quality assessment of images generated by 3D displays has a subjective nature due to inherent perception uniqueness of each individual observer. That is why the most significant effects include image volume, clarity and color perception.

When testing the output values by the users in terms of image quality assessment, it is advisable to use categorical evaluation scale: excellent, good, fair and unsatisfactory.

For adequate evaluation, a sufficiently large sample should be used, taking into account different physical and psychological states of participating subjects.

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