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A structural quality evaluation model for three-dimensional simulations

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Abstract:

Purpose – In recent years, computer simulations have become an innovative approach which enables research in the field of highly complicated physical phenomena and the study of the laws which govern the universe. The proper interpretation of the results of a visual simulation requires the highest quality of the generated image, as every distortion or mistake may have a significant influence on the readability, accuracy and even credibility of the presentation of the results. The aim of this presentation is to determine a model that enables precise quality evaluation of the three-dimensional visual simulations in the field of structural correctness.

Design/methodology/approach – The developed model is a solution that makes it possible to estimate the quality of stereoscopic image in the context of major three-dimensional structural dysfunctions, namely, vertical parallax, rotation mismatch and scale mismatch. Implementing the wrought theoretical model with the use of cost-effective mechanisms of image feature detection creates a robust method which enables the scalar grade of structural correctness of the studied three-dimensional simulation to be computed.

Findings – On the basis of the conducted research, in particular, taking into account three-dimensional simulations, it was stated that the formulated model with the developed method provides an efficient, structural quality estimation tool applicable for a wide variety of three-dimensional images. The obtained results indicate that the wrought method has huge potential in the application of high-resolution simulations by enabling a screening test of the structural quality of the stereoscopic view in quasi-real time.

Practical implications – The developed method may be used both in order to verify the quality of ready-to-use three-dimensional image and also at the stage of the calibration of input parameters of the simulation.

Originality/value – The paper takes into account the selection of the most significant distortions which occur in visual, three-dimensional simulations providing a cost-

effective and versatile tool which allows for the detection and elimination of serious mistakes and dysfunctions as early as at the calibration stage.

Keywords: 3D simulations, stereoscopic image distortions, structural quality evaluation model, three-dimensional simulation improvement

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1 Introduction

The intensive development of software observed over recent years has provided many innovative solutions used commonly in scientific laboratories. Modern computer software provides a convenient research environment allowing for the saving of financial-resources, whilst ensuring a wide variety of simulation functionalities [1–3]. Realizing studies with the use of computer calculation environments is particularly common in the field of exploring physical properties and phenomena [4–6]. The mentioned issues of science commonly use modern technologies to create visual simulations of researched phenomena as it would be extremely expensive or difficult to recreate them in the lab [7, 8]. Preliminary parametrization and calibration of the programming software environment is a key aspect in the simulation realization process [9]. The issues mentioned above are especially significant regarding three-dimensional visual simulations in which the correctness of the generated image has a direct influence on the ability to properly and precisely interpret the obtained results. In the case of three-dimensional simulations, which are based on stereoscopic mechanisms, there is a major risk of structural distortions appearing on an image. Consequently, there is a crucial need to provide tools that

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would enable the precise evaluation of the simulation image quality.

2 Three-dimensional simulation structural distortions

Structural distortions of the image occurring in three-dimensional simulations are mainly conditioned by the inappropriate parametrization of the acquisition tools which are employed. Incorrect settings of the simulation environment may contribute to increasing structural problems, such as vertical parallax, rotation mismatch and scale mismatch [10, 11].

2.1 Vertical parallax

Vertical parallax is a distortion of a three-dimensional image that means a mutual displacement of stereoscopic views occurs in the simulation in the vertical plane (Fig. 1, 2). The described problem is conditioned by the incorrect settings of the convergence or by the inappropriate alignment of the throwing areas of the stereoscopic views of the image in the vertical plane.

Figure 1: Scheme model of the throwing area of three-dimensional views of the simulation affected by vertical parallax distortion.

2.2 Rotation mismatch

Rotation mismatch is a distortion of a stereoscopic image that consists in a mutual rotation of the stereopair views occurring with respect to the axis of the depth of the three-dimensional simulation (Fig. 3, 4). The rotation deformation stems from the incorrect settings of the stereoscopic view throwing area coherence with regard to the axis of the image depth.

Figure 2: Model of the anaglyph image of a three-dimensional simulation affected by vertical parallax distortion.

Figure 3: Scheme model of the throwing area of three-dimensional views of the simulation affected by rotation mismatch distortion.

Figure 4: Model of the anaglyph image of a three-dimensional simulation affected by rotation mismatch distortion.

2.3 Scale mismatch

Scale mismatch of a three-dimensional simulation image is a distortion meaning the size inconsistency of rendered objects occurring in the left and right stereoscopic view (Fig. 5, 6). The scaling problem is conditioned by the inconsistent setting of the stereoscopic views' throwing area placement with respect to the depth coordinate. This, in turn, has an impact on making the stereopair perspective inconsistent which means incorrect object sizes presented on the stereoviews.

Figure 5: Scheme model of the throwing area of three-dimensional views of a simulation affected by scale mismatch distortion.

Figure 6: Model of the anaglyph image of a three-dimensional simulation affected by scale mismatch distortion.

3 Structural distortion measurements

Estimating the values of structural distortions in three-dimensional simulations requires the calculation of geometric dependents between the stereopair views (l - left and r - right) of the considered image. Most solutions applied for this purpose use direct correlation methods of views, which turns out to be too time-consuming in calculations for 4K high-resolution images, such as three-dimensional simulations. Within the framework of the realized research, it was decided to use the modified method based on the detection of image features which enables efficient point matching of high-resolution stereoscopic views whilst ensuring the high quality of the generated results thanks to the use of the sliding window mechanism [12]. The reference method has been modified by an additional mechanism of filtering, which consists in the selection of matchings with respect to the smallest limit vector distance. It provides an efficient solution which allows a low-density map of stereopair views correlations N points $\{P_{(x_l, y_l)_N}\}, \{P_{(x_r, y_r)_N}\}$ with consistent distribution and high-quality matchings to be obtained.

With information about the point correlation of the stereoscopic views, it is possible to calculate the numer-

ical values of the structural distortions of images on the basis of the presented measurements (eq.1-3).

3.1 Vertical parallax

The value of an average vertical parallax Δ of the simulation image can be calculated as the arithmetic average of the subtraction of vertical coordinates of N correlated key points $\{P_{(x_l, y_l)_N}\}, \{P_{(x_r, y_r)_N}\}$ of the stereopair (eq.1).

$$\Delta(\{P_{(x_l, y_l)_N}\}, \{P_{(x_r, y_r)_N}\}) = \frac{\sum_{i=1}^N y_{li} - y_{ri}}{N} \quad (1)$$

3.2 Rotation mismatch

The value of an average rotation mismatch α of the simulation image is calculated as an arithmetic mean of consecutive values of rotation mismatch defined in individual N key points. The value of rotation mismatch at the point can be calculated as the arctg of the angles between chosen pair of corresponding straight lines.

$$\alpha(\{P_{(x_l, y_l)_N}\}, \{P_{(x_r, y_r)_N}\}) = \frac{\sum_{i=1}^N \arctg\left(\frac{\frac{y'_{li} - y_{li}}{x'_{li} - x_{li}} - \frac{y'_{ri} - y_{ri}}{x'_{ri} - x_{ri}}}{\frac{y_{li} - y_{ri}}{x_{li} - x_{ri}} - \frac{y'_{li} - y'_{ri}}{x'_{li} - x'_{ri}}}\right)}{N} \quad (2)$$

The straight lines are defined between the considered point and the one of a remaining point, both in the left and in the right stereoscopic view, creating corresponding pairs of straight lines. The process is repeated for all N points. Calculated in that way, the N values are averaged to obtain the final value of rotation mismatch of the whole image (eq.2).

3.3 Scale mismatch

The average scale mismatch value s of the simulation image is calculated analogously to the value of the average rotation mismatch.

$$s(\{P_{(x_l, y_l)_N}\}, \{P_{(x_r, y_r)_N}\}) = \frac{\sum_{i=1}^N \frac{\sqrt{(x'_{li} - x_{li})^2 + (y'_{li} - y_{li})^2}}{\sqrt{(x'_{ri} - x_{ri})^2 + (y'_{ri} - y_{ri})^2}}}{N} \quad (3)$$

The difference is that the arithmetic mean is computed on the basis of the quotient of the corresponding line segments lengths and defined between points in the left and

right stereoscopic view. The final value of the scale mismatch is the arithmetic mean of the N point values (eq.3).

4 The structural quality evaluation model

The aggregation of values of partial measurements of structural distortions allows for the development of a versatile model that evaluates the quality of three-dimensional simulations.

The research literature provides many methods used for that purpose, but the normalized Minkowski norm (where n is the number of aggregated partial parameters) is favored as the leading solution (eq.4) [13].

$$M = \sqrt[n]{\frac{\sum_{i=1}^n |P_i|^n}{n}} \quad (4)$$

Formulating model Q_s , which enables an evaluation of the structural quality in three dimensional simulations, requires the normalization of three considered values ($n = 3$): vertical parallax Δ in terms of the height of the applied sliding window w , rotation mismatch α with regard to the properties of function $\arctg m = 90$, and scale mismatch s in the range of $< 0, 1 >$.

$$Q_s = 1 - \sqrt[n]{\frac{|\frac{\Delta}{w}|^n + |\frac{\alpha}{m}|^n + |1 - s|^n}{n}} \quad (5)$$

The proposed model (eq.5) allows for an evaluation of the structural correctness of three-dimensional simulations in the scope of vertical parallax, rotation mismatch and scale mismatch, returning a scalar quality value in the range of $< 0, 1 >$. A value of 0 means a high level of distortion while a value of 1 indicates that the three-dimensional simulation is devoid of considered mistakes.

5 Tests

The process of testing the structural quality evaluation model was realized by testing a set of three-dimensional simulations and reference values developed with the 3ds Max Studio 2016 application. The measurement of computational time was carried out with an Intel i5-7200U

2.5 GHz processor, ensuring a single separated processor thread.

The tests have been carried out for a couple of cases differing between each other in sliding window parameters. The below presented tables show the most significant results.

Table 1: Values of the structural distortions calculated in the testing process. A) name L_* - low resolution simulation 1920x1080 [px], H_* - high resolution simulation 3840x2160 [px]; B) reference value of average vertical parallax[px]; C) developed value of average vertical parallax[px]; D) reference value of average rotation mismatch [deg]; E) developed value of average rotation mismatch [deg]; F) reference value of average scale mismatch; G) developed value of average scale mismatch;

A	B	C	D	E	F	G
L_1	0.000	0.003	-0.001	0.000	1.000	1.000
H_1	0.001	0.005	0.001	0.002	1.000	1.000
L_2	5.621	5.687	0.541	0.469	1.101	1.098
H_2	11.245	11.321	0.538	0.464	1.102	1.100
L_3	20.124	20.021	1.112	1.097	1.257	1.262
H_3	40.481	40.381	1.113	1.100	1.254	1.256
L_4	39.096	39.102	9.231	9.234	1.451	1.452
H_4	78.012	78.304	9.233	9.234	1.449	1.450

Table 2: Values of the structural quality calculated in the testing process. A) name L_* - low resolution simulation 1920x1080 [px], H_* - high resolution simulation 3840x2160 [px]; H) reference value of structural quality; I) developed value of structural quality; J) calculation time[ms]

A	H	I	J
L_1	1.000	1.000	1981
H_1	1.000	1.000	11681
L_2	0.891	0.891	1892
H_2	0.891	0.891	10471
L_3	0.636	0.637	1898
H_3	0.635	0.635	9945
L_4	0.301	0.300	1886
H_4	0.302	0.300	10241

6 Conclusions

Simulations make it possible to study phenomena under restriction-free conditions without the risk that the results will be affected by factors that were unknown or impossible to eliminate in the research. However, only a simulation which is developed correctly and calibrated precisely can be a useful tool. This is especially important in three-dimensional simulations where various distortions can significantly affect the quality of the results.

Our proposed structural quality evaluation model aims to provide a simple method to evaluate the structural quality of three-dimensional simulations. Testing the proposed model shows that the results are extremely close to the reference values independent of the input image resolution (Tab. 1). The obtained results and calculation times indicate that the proposed model is an efficient and versatile method which makes it possible to precisely assess the structural quality of any stereoscopic material (Tab. 2). The developed tool has a wide variety of applications in different fields of science, as being able to evaluate the structural quality and, if necessary, refining every single aspect of the simulation to obtain a structural quality value close to 1 allows studies to achieve satisfying and reliable results.

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