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Statistical Modeling for Perception of Images in Stereoscopic Displays

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Abstract

Most of the training processes in the stereoscopic displays are performed within the virtual reality environment. Perception analysis of virtual space and operator interaction with the objects being in this space plays a special role when designing and realizing virtual reality systems. The analysis of human factors with further synthesis of the required characteristics will allow providing an optimal way in efficient application of technical capabilities of the complex of virtual reality operational systems and individual operator's peculiarities. In this paper, four main factors were studied to investigate their influence on the degree of efficiency of transfer and perception of information. The four main factors are: resolution, image form, operator's interaction, and control method. A fractional factorial design was utilized to build the experiment. The data was analyzed, and a statistical model explaining the effect(s) of different parameters as well as their interaction, was obtained. It was clear that the 3-D image with high resolution would increase the efficiency of information perception.

Keywords: Virtual reality system; Perception; Fractional factorial design

1. Introduction

There are two main characteristics that differentiate VR system from ordinary systems of computer graphics. First, beside simple transfer of visual information, the system simultaneously acts on several sense organs, namely, hearing, sense of touch, and even sense of smell. Second, VR systems provide direct contact of operator with the medium. The purpose of VR system is to place the participant in the medium which is not only natural, but also easy to study and to get to know. Virtual reality allows enlarging intellectual and communicative operator's abilities due to virtual medium that is generated by knowledge data bases from concrete objects into abstract ones.

The study of virtual reality systems allowed establishing different interaction levels, from limited in certain parameters to entire immersion into VR system. One of VR systems characteristics is preserving interactivity even with large set of data. This characteristic of VR systems provides possibility to interact directly with the real world of data i.e. to use the data sets themselves as objects echo in the cause of interaction [1-3].

The main features of VR systems at present are considered to be the following; immersion, interactivity, and variability. The availability of these features is necessary and sufficient condition of technological system belonging to VR systems class.

Immersion means that the operator is immersed into virtual reality world, and he percepts himself and objects that he sees as a part of this world. There are three forms of immersion: direct, indirect, and mirror. When the participant feels himself as a part of the virtual world, he sees in the virtual world himself or a part of his body, or he sees the virtual world and himself in the mirror respectively [1].

Interactivity is operator's interaction with the objects of virtual reality world for the realization of functions stipulated by VR system program. Interactivity reveals in the form of: own movement in VR-world, interaction with VR world objects, and reaction (impact) of VR-objects on operator. Significant peculiarity of interactivity in VR-system is real time of its action [4-7].

Variability is necessary for improvement of VR systems efficiency in the sense of changing some values of the parameters that affect the output. Variability condition provides possibility to change features of VR worlds, scenarios, surroundings, game rules and etc., in accordance with the purpose of application of VR-system [8].

Future developments in immersive environments for mission planning include several tools which build up a system for performing and rehearsing missions. This system includes tools for planning long range sorties for highly autonomous rovers, tools for building three-dimensional (3D) models of the terrain being explored, and advanced tools for visualizing telemetry from remote spacecraft and Landers. In addition, Web-based tools for scientific collaboration in planning missions and

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performing public outreach and education are under development. These tools comprise a system for immersing the operator in the environment of another planet, body, or space to make the mission planning able to function more intuitively and effectively. The study provides the reader with the best settings of the factors effecting perception in the virtual reality operational systems (VORS). This will enables manufactures to use such settings that increase efficiency of various virtual reality (VR) tools.

2. Virtual Reality System

Depending on the problem, which the developers and users are facing, there are two types of virtual reality systems, namely operational and non-operational. Operational VR systems provide computer interface for specific perceptual and muscular systems for a definite purpose like training operator on the first medical responders [9]. The interface of the similar type allows operator to perform operations that would be impossible in common cases. Operational VR systems provide execution of concrete tasks facing the operator. The sense from the execution process is on the second place.

Non-operational VR systems are referred to VR-systems for entertainment, which is oriented towards out of use purposes as participation purposes. The experience in computer games development can lead to the creation of original non-operational VR-systems.

The interaction scheme of operator with VR system by means of effectors and sensors is considered. Virtual Reality system uses effectors such as; sound, odor, and temperature to stimulate receptors (sensors) of human perceptual system [4].

A display built in a helmet, a device of power feed back, like odor radiator can be used as VR effectors. VR system evaluates operator's activity expressed by the muscular system with the help of sensors. This scheme reacts on emotional response as well as stress states that can be reflected in operator's reactions. Taking into consideration the fact that man-machine interface allowing operator to interact with the modeled media in direct contact is the kernel of VROS system, let us consider its main modules; (i) Module for interaction with operator provides representation of medium state and registration of operator's actions performed with the help of effectors. (ii) Management module carries out analysis of actions made by the participant, determination of medium state changes in time and space and reaction formation on operator's actions. (iii) Module for interaction with the media forms changes of media state in real time. (iv)Module for media modeling provides realistic presentation of media; modeling of media, its objects and their behavior are also included here [10, 11].

Information knowledge base of VR system includes description of media, determination of time and space, relationship in it, as well as models of sensor-effectors systems of operator and system [8, 12]. At present, three types of realization of user's information interaction with VROS objects are considered.

The first type is in the fact of immersion into the virtual world. Operator wearing a space-suit provides with the information field "enters" digital Universe. Manipulating information glove, he has the possibility to interact with the computer touching and replacing objects of the virtual world represented on the display screen, "moves" or "flies" inside it with synchronous audio accompaniment.

The second type is presentation of three-dimensional space of the virtual world on the computer screen. The third type is interaction realization with virtual world objects by "the third person" represented by moving image on the computer screen and identifying with the user, where the user managers actions of "the third person" finding his own image on the display screen. Different forms of VR presentation suppose experimental research and development of recommendations on compensation of psycho-physiological limitations in virtual systems (of VROS type), efficiency improvement of virtual reality technology application. VROS analysis with regard to new technical solutions will allow increasing many times operator's abilities working in VROS [13].

3. Efficiency Criteria

Usually, efficiency of complex and large systems cannot be fully characterized by one single criterion; and is evaluated according to a number of criteria that are naturally much more difficult than system evaluation according to one criterion.

A number of conditions should be taken into consideration when selecting efficiency criterion:

1. Efficiency criterion should characterize not some part of the system nor its separate functions, but the system as a whole.
2. Efficiency criterion and its dependence on established factors should provide possibility of obtaining qualitative evaluation with the required accuracy and reliability.

At present two approaches, which define complex systems efficiency, are known:

- One index is selected from the set of system parameters, supposedly to be the most important. In this case the rest of indices have limitations. In terms of mathematics, the task is reduced to detecting of conditional extremism;
- Some generalized criterion is constructed on the basis of initial parameters set that characterized the system entirely. In this case, as a rule, all the parameters are considered in the system regardless of their values. The selection of the important parameters will be determined according to their influence on the constructed criterion [3].

The process of perception of visual information can be presented in a form of a function depending on a certain number N of factors:

$$Y_B = \sum_{j=1}^{N} \alpha_j E_j (x_1, x_2, \ldots, x_n), \qquad (1)$$

Where E_j - influence of a concrete factor depending in general case on a number of variables, α_j - weight coefficient of the j -th factor.

Function Y_B describes the influence result of some set of factors with fixed levels of information perception; and is presented as a polynomial. The perception efficiency can be achieved by minimizing the difference between the quantity of presented information and the quantity of representing the same information. Then the criterion of information perception efficiency is

$$K_I = \min \{H_n - Y_B\}_T , \qquad (2)$$

where

Y_B - quantity of represented information (in conditional units).

H_n - quantity of presented information (in conditional units), in which operator should interact within the scope of virtual environment.

All features of this environment including the form of objects, orientations, colors, and the scored points in case the operator was playing a 3D game are considered as presented information. And it is fully accessible for operator use without any limitation [3]. According to this fact, the quantity of presented information is considered to be 100%, and criterion of information perception is written in the following way:

$$K_I = \min \left\{ 1 - \sum_{i=1}^{m} \sum_{j=1}^{N} \beta_{ij} E_{ij} (x_1, x_2, \ldots x_n) \right\}, \qquad (3)$$

where m – number of realizations between the four factors per each experiment. E_{ij} and β_{ij} should be determined experimentally.

Our target is to find out how the suitability of the VROS for practical and comfortable operator usage. This target can be achieved through the minimization of the difference between the quantity of certain information presented and represented to an operator.

To study the factors that affect the efficiency of perception for an operator through the VROS, some experiments should be conducted. Those experiments should be designed statistically in order to study all the factors effects and their interactions.

4. Experiment Design

VROS characteristics represented in Table 1 as factors influencing to the greatest degree on the efficiency of transfer, and perception of information are shown to have two level; high, and low.

The experiment was designed to find out how far the operator during his penetration within the virtual environment can be influenced by the selected factors in Table 1. The tool, which was used for testing operator's work, was the head mounted display (HMD) which was connected to the computer (PC). The PC has also a simulator of 3D and 2D game, which was fully designed to work with the VRS or HMD. The operator should spend 30 minutes using the VRS to achieve some progress during the 3D of virtual environment and the same time in the 2D of the same environment. Each VR environment had also different levels of complexity, like first level, which was the easier one, and the second level, which required more concentration. The used displays were represented by two different resolutions: Stereoscopic display that has 220x400 pixels and another display has 640x800 pixels resolution. The method control also was differing for the same period. The number of scores counted the overall output or the operator's progress, where each experiment was repeated 8 times. The four factors selected to be studied were chosen, because they were controllable and measurable, while other factors were inaccessible to be controlled or measured. Some of these factors are: the head-mounted angle, radiation of cathode ray tube and the weight of the HMD.

Table 1: Factors affecting perception rate and their levels.

FACTORS	**CODED LEVELS OF FACTORS x_i**	
	+1 (high)	-1 (low)
(A): x_1 - Image form on VROS	3D	2D
(B): x_2 - Resolution	640 × 800	220 × 400
(C): x_3 - OI Complexity level in VR-media	2	1
(D): x_4 -VROS control methods	VR Mouse + Special keyboard	Special keyboard

Where VR mouse -virtual mouse (manipulator), 3D- three dimensional stereoscopic image, 2D- two-dimensional flat image, resolution in pixels and complexity level of operator's interaction (OI) represents itself a number of objects preventing operator from fulfillment of set in VR tasks. The special keyboard used in this research experiment was a normal one with some buttons removed from its content. Thus, the research consisted in realization of multifactor experiment of "2^4" type (4 factors each of which varies on two levels). The experiment model will be written down in the form of the regression equation .(equation number 4)

Determination of the unknown coefficients of the equation can be made in the result of carrying out 16 experiments. In order to decrease the number of experiments, it is possible to neglect factors interactions of the high order, and to conduct a Fractional Factorial Design called fractional-factor experiment (FFD) wherein the number of experiments is reduced to 8 (half-fractional factorial design). The plan matrix of fractional-factor experiment is represented in Table 2. In Table 2, the negative sign is used for the lower level indication, and the positive sign is for the high level.

$$Y_B = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{23}x_2x_3 + \\ + b_{24}x_2x_4 + b_{34}x_3x_4 + b_{123}x_1x_2x_3 + b_{124}x_1x_2x_4 + b_{134}x_1x_3x_4 + \\ + b_{234}x_2x_3x_4 + b_{1234}x_1x_2x_3x_4 \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

Table 2: Parameter combinations used for the different experiments and their respective average perception.

Exper.Number	X_1	X_2	X_3	X_4	$\bar{y}_i$ (Perception)
1	-	-	-	-	34,58
2	+	-	-	+	70,00
3	-	+	-	+	50,00
4	+	+	-	-	96,50
5	-	-	+	+	34,48
6	+	-	+	-	81,10
7	-	+	+	-	60,00
8	+	+	+	+	93.08

5. Results and Discussion

The results, qualitatively, indicate the following general trends (i) efficiency increases when using 3D image; (ii) when using special keyboard, the efficiency will be better than using VR mouse -virtual mouse (manipulator); (iii) higher resolution will have a positive effect on the efficiency, but this effect is lower than in using the 3D image; and (iv) OI Complexity level in VR-media has the lowest impact on the response.

These experiments were performed and their outputs were analyzed. A statistical model presenting the relationship between the dependent variable (Efficiency) and the independent variables (the four factors) was obtained. Figure 1 shows the half-normal probability plot of the effects' estimates for the different combinations of the four factors used in the experiment. The half-normal probability plot is used here to determine the effect of each factor on the efficiency. The important effects that emerge from this analysis (indicated by their large distance from the straight line) are the image form (A), and the resolution (B). The IO complexity and the VORS method, however, do not have the same level of effect on the efficiency. The image form VROS in the model, also, appears to be the dominant factor in the efficiency model, followed by the resolution and the VROS method, and then by the IO complexity. Figure 1 and the statistical model do not show any interaction-effect to be dominant.

This statistical model (Figure 1) was tested against normality of its residuals, as shown in Figure 2; there was no indication for the presence of outliers. The analysis of variance for the model was also performed and the model was significant. The coefficient of determination was 99.8%, which indicates that about 99.8% of the variability could be explained by the model.

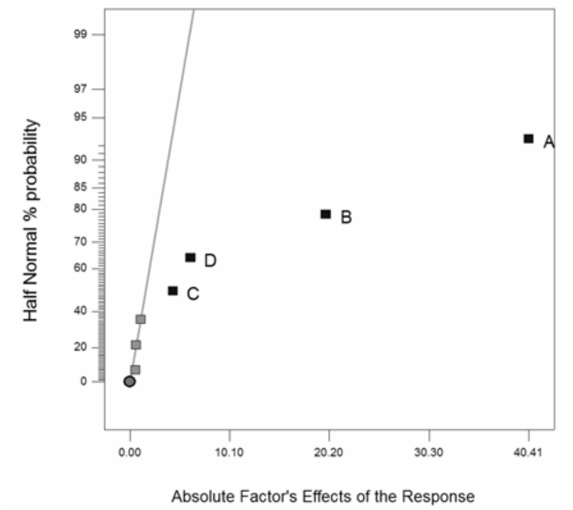

Figure 1: Effects of different factor on the efficiency.

Effeciency = +64.97 + 20.2*A + 9.936*B + 2.2*C - 3.3*D

This statistical model was tested against normality of its residuals, as shown in Figure 2; there was no indication for the presence of outliers. The analysis of variance for the model was also performed and the model was significant. The coefficient of determination was 99.8%, which indicates that about 99.8% of the variability could be explained by the model.

Confirmation tests were performed, and the error (difference between actual and predicted) was negligible. The analysis of variance (ANOVA) for the selected factorial model, Table 3, was significant with p-value < 0.0001, against F-value of 819.49. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Also it is evident from the ANOVA that all the model terms were significant. The model was also checked against any required transformation, and it was clear that no transformation is required. This is clear as shown in Figure 3. Lambda represents the power of transformation if it is needed for the model. The value of lambda for the power transformation is limited to the range of plus or minus 0.01 to 3.0. The Box Cox Diagnostic plot can help in determining the best lambda value to use.

6. Conclusions

he advantages of operators work in VR systems were proved theoretically and experimentally in comparison with the systems of information presentation in the flat image form.

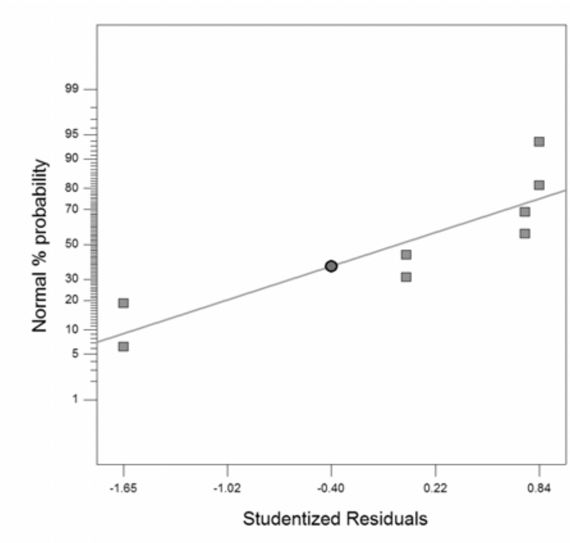

Figure 2: Normal Plot of Residuals.

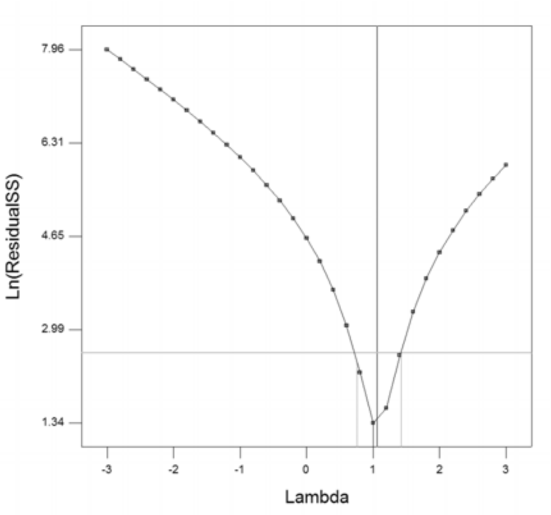

Figure 3: Box-Cox plot for Power transformation.

Table 3: Analysis of variance for the statistical model.

ANOVA for Selected Factorial Model					
	Sum of		Mean	F	
Source	Squares	DF	Squares	Value	Prob > F
Model	4167.97	4	1041.99	819.49	< 0.0001
A	3265.13	1	3265.13	2567.90	< 0.0001
B	788.44	1	788.44	620.08	0.0001
C	38.63	1	38.63	30.38	0.0118
D	75.77	1	75.77	59.59	0.0045
Residual	3.81	3	1.27		
Total	4171.78	7			

From the results obtained from the designed experiments, it is shown that it is better for the trainer to have a 3D flat image and to have a high resolution in order to get more perception and represented information. Also it is recommended to use the special keyboard instead of the virtual mouse for the VROS management method. Therefore, by performing the designed experiments for such system, it will help to understand the behavior and the performance of the factors that have influence on the response. This was achieved by obtaining the statistical model of the process.

7. Future Research

In this paper, the concentration was on the criterion of perception of information efficiency. There are many other criteria that can be visited and perform an optimization among the different criteria.

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