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The validation model of information measuring channel in technical vision systems

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Abstract
Due to the development of technical vision systems (TVS) and information technology digital images are increasingly used as information models of real and simulated objects allowing to predict, detect and correct the spatial, brightness and color characteristics for different stages of the life cycle. Technical (machine) vision implements the complex process of conversion of video information, which contains six major phases: 1) receiving (perception) of information; 2) preprocessing; 3) segmentation; 4) description; 5) pattern recognition; 6) interpretation. The technical vision system is a sensor device generating images of working scenes and objects, their transformation, the computer processing and interpretation and transfer of results of the control device of the robot. TVS can be classified by principle of operation, functional purpose, autonomy, range, method information, number of cameras, method of placement, method of signal processing, etc. In accordance with the principle of action of TVS it is possible to allocate on the basis of a bistable (logical) systems, coordinators, survey-comparative systems and Biosystems. However, the general basis of these systems is an obtaining of the object digital image as a source of information about it. The process of digital images creating is a technology of the flow of series-parallel operations including data conversion, information and its losses. Therefore, it is necessary to identify and minimize the major sources of losses to obtain reliable and accurate information about the state of the object. This goal can be achieved by properly selecting the elements of information-measuring channel and the organization of the experiment depending on the research objectives. The validation model of a measuring channel based on the presentation of the technical vision system elements as parts of an information measuring channel is described in this article. This model is based on a modular principle and allows to perform measurements in vision systems, depending on the set measuring task.

Keywords: colorimetrical measurement, scale, sample, color space, metrological traceability

1. Materials and Methods

1.1 Digital image as an object of standardization and innovations

Considering the digital image as an object of standardization we can identify the main terms and definitions. According to ISO/IEC 19794-5 [2] an image is a two-dimensional representation of the brightness and texture of the object in certain lighting conditions. The TV and computer image in the digital domain is the set of values of intensities of light flux distributed over a finite area having a generally rectangular shape. We can find other definitions in the technical literature, for example: "a digital image is a data array, obtained by sampling (analog-to-digital conversion) of the original. This array becomes the data file being encoded using a particular algorithm and is written to the media" [3]. In the modern process of printing production all illustrations and design elements are presented by digital images of various types. By the method of discretization of the original digital images are divided into raster, vector and mixed type [3]. Raster is a base raster model and represents the order of points (raster elements) and the matrix of information display elements (pixels) to reproduce certain intensity. There are rectangular, triangular, round and hexagonal rasters in different types of display systems [4].

According to GOST 27459 [5] a pixel is the smallest element surface visualization which can have an independent color, intensity and other characteristics of the image. If the density of lines reaches a certain critical value, they are visually perceived in the form of continuous fields [5]. In computer graphics the term "pixel" refers to several concepts: a single point at the computer screen – "video pixel"; a single point on printer – "point"; private bitmap element or element of digital camera CCD [6]. In accordance with GOST 27883 [7] information display item of the displaying information mean is a minimum part of information on the screen of the information display mean. In this case, the term "pixel" is used to mean "the smallest logical element of two-dimensional digital image".

A digital image is a multi-parameter model of a real or virtual object that is implemented in a two-dimensional non-point extended primary radiator at the macro level, perceived with ever-changing photometric and colorimetric characteristics. At the micro level, the digital image is a periodic structure consisting of discrete elements – pixels or subpixels – counts of intensities in red, green and blue color channels having a geometric reference to a real or simulated object. A certain locus of points in the object corresponds to each pixel (sub-pixel) of a digital image. Thus, the digital image is an ordered set of luma samples and each of them has a geometric reference to a region of a surface of an object. For a real object the digital image is a two-dimensional model of counts its brightness and texture obtained in the process of optoelectronic conversions in the measuring system under certain conditions. According to the theory of measurement information in a discrete system the detected object may have very extensive but nevertheless finite set of implementations in the form of digital images. Joining the opinion of the authors [8-10] we can summarize provisions of the physical illumination model:

1) a specific area of N*M elements of the digital image corresponds to each unit area of the projected three-dimensional space depending on the scale;
2) every single region of the projected space is a primary or secondary source;
3) Each element belonging to the polygon N*M digital image has the photometric and colorimetric characteristics similar to other elements of the array; and within the allocated region the brightness and color represent a re-usable value.

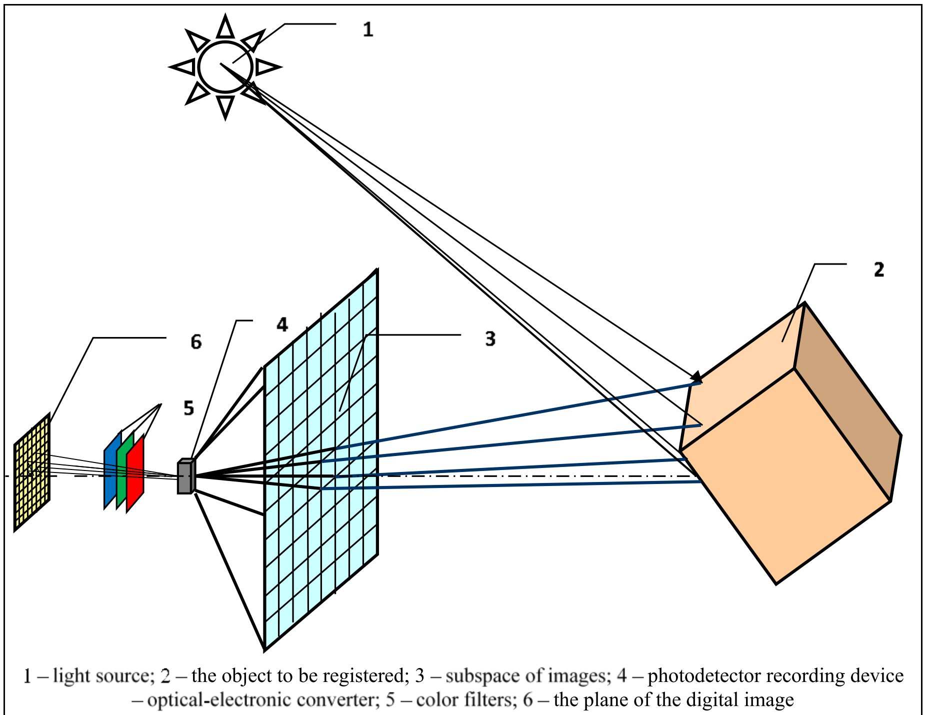
1.2 The Technology of High Resolution Colorimetry

The essence of colorimetrical technologies in software and hardware environments is that the recorded scene is represented as a set of elementary regions [69, 70], which independently radiate and reflect light energy fluxes falling from other areas. Then the radiation energy of the scene element can be written as a function of the intrinsic radiation of the section, the reflection coefficient, and the radiation energy of the other element of the scene. If we select the "zone of interest" on the observed scene, we can split it into N * M fragments A_i,i=1, 2, 3, n-1, then we can get the so-called n-dimensional subspace of the i-th fragment radiosity. The signal i = b (x, y), taken from each pixel of the digital image, is interpreted as a brightness function in the (x; y) coordinates along three color channels and is displayed as a point or vector, which gives it a geometrical meaning [9, p.74]. Thus, the scene is considered as a finite number of brightness samples corresponding to certain points of space. Therefore, with a selected scale W, a certain group of pixels of the image will correspond to each selected area of the zone. The resulting set of brightness samples and the corresponding spatial coordinates of the points form a space of images describing the properties of the object.

This model is the basis for solving two mutually complementary tasks: measuring lighting parameters based on processing of the digital image of the object and its modeling. In this context, the authors propose the so-called validation model of the information channel, which is based on the following provisions.

Consideration of the key directions in the development of standardization and standardization in the field of high-resolution colorimetry will be carried out in the context of the elements of the measuring circuit shown in Fig. 1, including the light source, the surface of the registered object, the recording photodetector device, digital image. Between the object and the recording device, an idealized element 3, called the "subspace of images", is placed in the figure 1 in order to emphasize the features of machine vision: the digital camera "perceives" a three-dimensional object as a collection of brightness readings over three color channels that have a geometric binding of spatial coordinates to pixel ones. Because of the special feature of machine vision it is also needed to use color filters 5 and special software.

Since digital images are increasingly used as information models of real and simulated objects, in order to obtain reliable information about the qualitative and quantitative properties of objects, it is necessary to provide an appropriate evidentiary basis by metrological traceability and validation of the elements of the information-measuring channel.



1 – light source; 2 – the object to be registered; 3 – subspace of images; 4 – photodetector recording device – optical-electronic converter; 5 – color filters; 6 – the plane of the digital image

Fig 1: The principle of forming a digital image of a three-dimensional object

A digital camera "perceives" a three-dimensional object as a collection of brightness readings over three color channels that have a geometric binding of spatial coordinates to pixel ones. The problem of correct color reproduction can be solved on the basis of a detailed analysis of the sequence of transformations of the measured value in the measuring circuit and the establishment of reference points to fulfill the condition of ensuring the uniformity of measurements. Such reference points should be traceable to system or non-system units and implemented through materialized or virtual measures reproduced in standardized models and color spaces.

1.3 Proposed Validational Model

The digital image by its physical realization is a non-point primary radiator at the macrolevel and an ordered set of elements (pixels) at the micro level. The digital image is the final link of the information channel, including a recording device (digital camera, scanner), a data conversion channel and a display device (display, video terminal). Any extended surfaces, as well as each of the information channel elements (scanner, camera, display software) can be objects of research based on the analysis of digital images.

At the macro level, the information-measuring channel is a "black box" modeled by input data – for example, external conditions (illumination, temperature, transparency of the environment), optical, registration and display subsystems, software, and output parameters – spatial, photometric and colorimetric characteristics of a digital image. To solve problems not related to measurement-scaling, color correction, creation of effects, etc., in order to improve visual perception, the "black box" model is acceptable. However, in order to obtain reliable information on the qualitative and quantitative properties of objects, it is necessary to provide an appropriate evidence base through metrological traceability and validation of the elements of the information and measurement channel. Any registered object can have an almost infinite number of implementations in the form of digital images, which is due to a large number of possible combinations of elements of technical and software and technical and information compatibility of channel elements. Therefore, a rational solution is its conditional splitting into blocks "illuminator", "registered object", "matrix photodetector (digital camera)", "software", "display device" and their subsequent element-wise modeling depending on the tasks being solved. Thus, considering the process of obtaining a digital image at the micro level, we proceed to unpacking the "black box" and examining in detail each link of the information-measuring circuit. As a result of such an analysis, we obtain a list of sources of distortion, as well as the degree of their influence on the accuracy of information passing through the information-measuring channel. In this context, we propose a validation model of the information-measuring channel, graphically presented in Figure 2. This model is the basis for solving two mutually complementary tasks: measuring lighting parameters based on processing of the digital image of the object and its modeling. The model is based on the following provisions.

1. The digital image is the result of convolution of the functional property spaces of the channel elements. Therefore, the information channel in this context is considered as a "black box", which can be "unpacked" to restore information.
2. Any element of the channel can be represented by a black box model, which can be unpacked, if necessary, by adjusting the result, and can be the object of investigation itself, in accordance with the stated measurement task, depending on which the other elements are to be validated (confirmed).
3. Each of the channel elements is considered as a source of information about the object and simultaneously as a source of its losses, and the resulting digital image at the output is a trade-off between accuracy, reliability and resource costs.

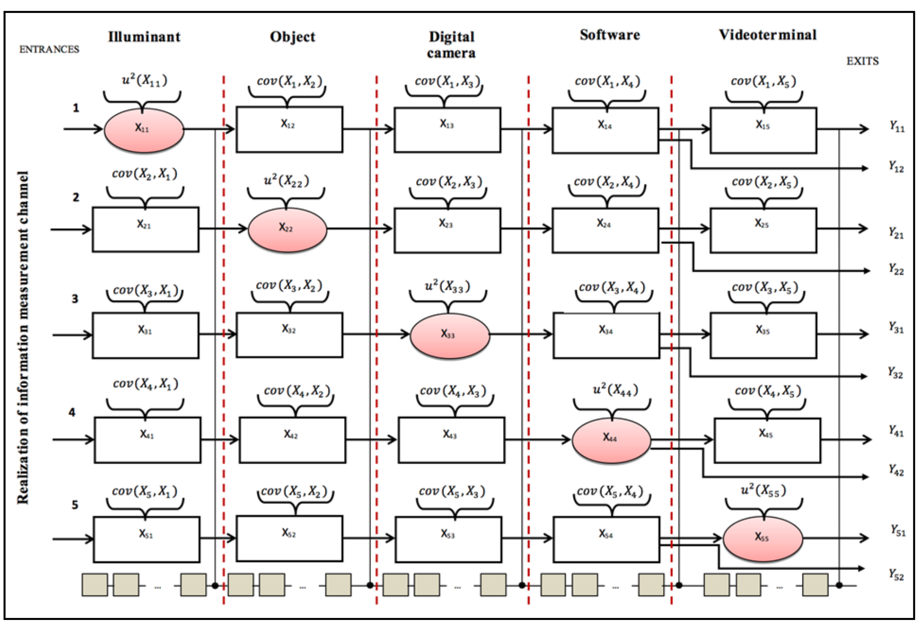


Fig 2

The validation model presented in Figure 2 includes all the links of the information and measurement channel identified above in five implementations corresponding to five measurement tasks. Each element is represented by its variable. In Figure 3.1, the inputs are linked to the channel outputs. It is seen that each implementation has two outputs Y_{lk} (from the software – variable X_{i4}, and from the display device – the variable X_{i5}. This is due to the fact that when solving problems of objective perception, the monitor's parameters are not taken into account, since they do not affect the output value. For the problems of subjective perceptions, the characteristics of the monitor must undoubtedly be taken into account. At the same time, each element of the information-measuring channel can also have a certain number of realizations, which is schematically shown in the lower part of Fig. 3.1 with gray squares.

Implementation 1. The item under investigation is the "illuminator" (variable X_{11}). A possible measurement task is the measurement of color rendition. Technique: the digital image of a standard X_{12} object (surfaces of matte or glossy patterns) illuminated by a standard illuminator is compared with a digital image of the same object illuminated by the illuminated light with subsequent calculation of the color rendering index. Their tasks are possible, for example, investigating the brightness of the illuminator by recording the light flux reflected from the surface of a standard object.

Implementation 2. The investigated element is an "object" (self-luminous or non-self-luminous) – variable X_{22}. Technique: the digital image of the surface of a self-luminous object or the surface of a non-self-illuminating object illuminated by a standard X_{21} illuminator is examined by the photometric and colorimetric properties attributed to the object.

Implementation 3. The item under investigation is a "digital camera" (variable X_{33}). A possible measurement task is the calibration by the camera number. Technique: the digital image of the surface of the standard non-self-illuminating object X_{32} (bar-line world, palette, etc.) illuminated by the standard X_{31} illuminator is a source of information on the possibilities of spatial resolution and color transmission of a digital camera.

Implementation 4. The item under investigation is "software" (variable X_{44}). A possible measurement task is the testing of software used in image processing. Technique: the digital image of the surface of a standard self-luminous or non-self-illuminating object X_{42} (illuminated by a standard illuminator X_{41}), obtained with a standard digital camera X_{43} and digitally processed using the X_{44} software, is compared with a digital image obtained with standard software.

Implementation 5. The item to be examined is a "display device" (variable X_{55}). The possible measurement task is the calibration of the monitor. Technique: A digital image of the surface of a standard self-luminous or non-self-illuminating X_{52} object (illuminated by a standard X_{51} illuminator) obtained with a standard X_{53} digital camera and digitally processed using the standard X_{54} software is examined on the X_{55} monitor to determine its characteristics.

3. Results and discussion

Above are only some typical implementations of the information and measurement channel, it is obvious that there may be others. Like any value, each k-th link can be described with the help of scattering $U(X_{ik})$.

In addition, the basis of the model is the following principle: to uniquely identify the characteristics of the selected link, it is necessary that the characteristics of all other links be known with an established accuracy. Therefore, consistently taking each link unknown, with known others, it is possible to carry out the validation of the information-measuring channel.

As a result, we obtain a multi-parameter validation model, the main characteristic of which is the covariance matrix [12]. According to [12], the covariance matrix is a positively semidefinite N × N matrix, where N is the number of input quantities on the main diagonal of which are squares of standard uncertainties corresponding to the estimated values, and the remaining terms of the matrix are covariances between pairs of corresponding estimates of the magnitude elements. So, for each *k-th* implementation the dimension of the matrix is 5 × 5. On an implementation example 1:

$$u(Y_{1k}) = \begin{vmatrix} u^2(x_{11}) & u(x_{11},x_{12}) & u(x_{11},x_{13}) & u(x_{11},x_{14}) & u(x_{11},x_{15}) \\ u(x_{12},x_{11}) & u^2(x_{12}) & u(x_{12},x_{13}) & u(x_{12},x_{14}) & u(x_{12},x_{15}) \\ u(x_{13},x_{11}) & u(x_{13},x_{12}) & u^2(x_{13}) & u(x_3,x_{14}) & u(x_{13},x_{15}) \\ u(x_{14},x_{11}) & u(x_{14},x_{12}) & u(x_{14},x_{13}) & u^2(x_{14}) & u(x_{14},x_{15}) \\ u(x_{15},x_{11}) & u(x_{15},x_{12}) & u(x_{15},x_{13}) & u(x_{15},x_{14}) & u^2(x_{15}) \end{vmatrix} \quad (1)$$

Where $u^2(x_{ij})$ – the variance of the estimate x_{ij};
$u(x_{ij},x_{mh})$ – covariance between x_{ij} and x_{mh}.

The standard uncertainty $u(Y_{11})$ of the realization k is determined using the expression:

$$u(Y_{11}) = C_{1k} \cdot u(X_{1k}) \cdot C_{1k}^{T}, \quad (2)$$

Where C_{1k} - matrix of sensitivity coefficients of dimension $N \times N$.

The numerical coefficients are determined from the specificity formula. To do this, you need to conduct a test experiment on the basis of comparison with standard methods. If we assume that the degree of covariance between and the influencing quantities is negligible (they can be neglected), then expression (2) is greatly simplified and takes the following form:

$$U(Y_{11}) = \sqrt{\sum_{j=1}^{m} c_{kj}^2\, u^2(x_{kj})}, \quad (3)$$

Where $u(Y_{11})$ – a standard uncertainty of the information-measuring channel, obtained for the implementation of 1;
C_{kj} – Sensitivity factors of each link of the channel;
$u(x_{kj})$ – A standard link uncertainties.

The standard uncertainty $U(Y_{11})$ of realization 1 is defined using the expression:

$$U(Y_{11}) = C_{1k} \cdot u(X_{1k}) \cdot C_{1k}^{T}, \quad (4)$$

Where C_{1k} – matrix of sensitivity coefficients of dimension N×N.

Since the linkage function is implicit, the values of the coefficients of influence of the elements of the information and measurement system C_{1k} can be determined on the basis of specificity, according to the procedure given in [13]. If we assume that the degree of covariance between and the influencing quantities is negligible (they can be neglected), then expression (3) becomes much simple rand takes the following form:

$$U(Y_{11}) = \sqrt{(C_{11}u(x_{11}))^2 + (C_{12}u(x_{12}))^2 + (C_{13}u(x_{13}))^2 + (C_{14}u(x_{14}))^2 + (C_{15}u(x_{15}))^2} \quad (5)$$

Where $U(Y_{11})$ – standard uncertainty of the information-measuring channel, obtained for the implementation of 1;

$C_{11} \dots C_{15}$ – The sensitivity factors of each link of the channel;

$u(x_{11}) \dots u(x_{15})$ – Standard link uncertainties.

Or

$$U(I) = \sqrt{(C_{11}u(x_{11}))^2 + (C_{12}u(x_{12}))^2 + (C_{13}u(x_{13}))^2 + (C_{14} \cdot e^{2\sqrt{3}\sigma}/2)^2 + (C_{15}u(x_{15}))^2} \quad (6)$$

This calculation algorithm is applicable for multidimensional measurement models with an implicit kind of functional dependence and is discussed in more detail in [95].

The formula for determining the root-mean-square deviation of the transformation error σ, subject to the Kotel'nikov theorem [14]:

$$\sigma = \frac{(f_{max} - f_{\min})}{2^L \cdot \sqrt{12}} \quad (7)$$

Where f_{max} – is the largest value of the signal?

$f_{\min}$ – is the smallest signal value,

2^L – The number of quantization levels;

L – is the code length.

The formula (6) is applicable for non-self-illuminating objects. To investigate self-luminous objects, the light source is not required, and therefore the expression will lack the first component of U (X_{11}), and in the case of objective control, the component.

Moreover, this model can be used to validate the information-measuring system as a whole. At the same time, the task becomes much more complicated, because the total number of unknowns will be 25 variables (X_{11}, X_{12}, X_{13}... X_{53}, X_{54}, X_{55}), and therefore, the dimension of the covariance matrix is 25 × 25. The covariance cube of the information-measuring system is shown in Figure 3, where the elements of the matrix are located on the faces of the cube, and the elements of the cube are covariance pairs.

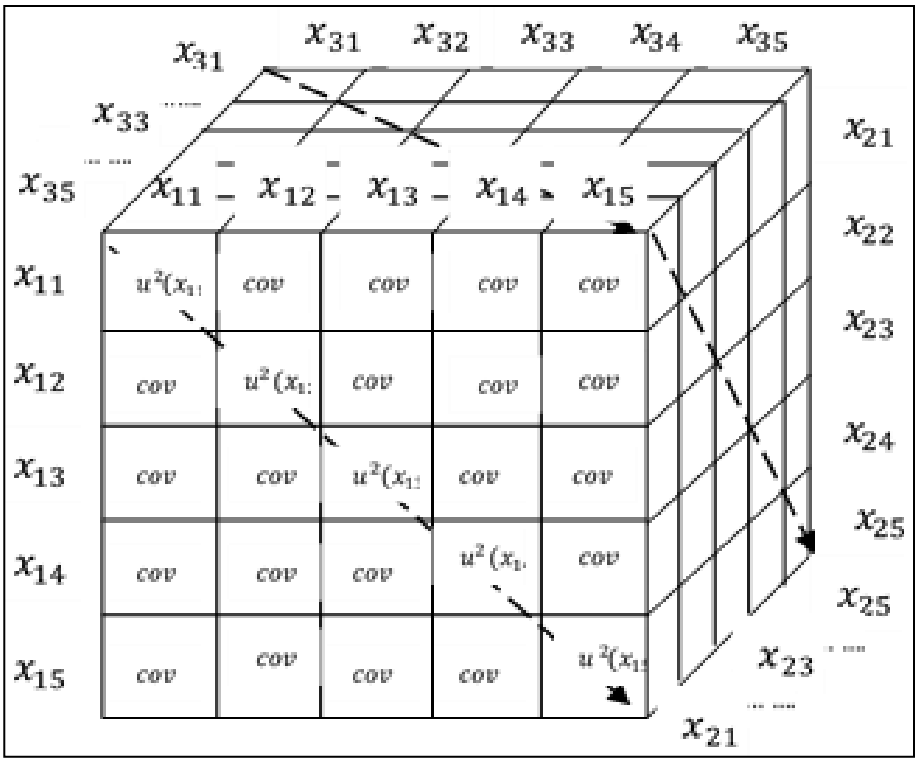


Fig 3: Covariance cube of information-measuring system

The resulting validation model is the basis for solving two mutually complementary tasks: measuring lighting parameters based on the processing of the digital image of an object and its modeling.

4. Conclusion

Taking into account the usage of digital images in innovative technologies in a control and tests of subjects the author makes the following conclusions.

1. Elements of the information channel, such as lighting conditions, reference samples, spectrophotometer, digital camera, information display device, data processing algorithms, are the sources of information and at the same time sources of information losses. Therefore, the result

can be considered as a compromise between accuracy and saving of resources. In general, digital image processing can be reduced to operations of pre-filtering, sampling, quantization, coding, decoding and post-filtering.

2. Every single operation is performed according to the current standards, which are numerous, and involves inevitable loss of data. Thus, the digital image can be viewed as the result of transformation, reception and – at the same time – losses of information, that can be considered as the response of the measuring system about the state of the object at a given time in certain conditions.

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