Information Pattern in Imaging of a Rough Surface

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Abstract. In this paper, we have proposed a method of parametrization of a rough surface image based on its information pattern. We have determined that the image information pattern makes it possible to keep track of any variations in the number of pixels in the image of the controlled rough surface of at least 0.192 per cent of the total number of image pixels. The offered method permits to compensate a non-linear perception of the controlled surface by a human eye. We have determined a ratio of the number of these pixels to the total number of image pixels. Such ratios, was treated as a certain square area. We packed this squares without intercrossings in the square of 2. This type of squares packing was designated as an information pattern. Using the information pattern, the parameter value was obtained. We have determined that the parameter value can keep track of any variations of the number of pixels in the image of the rough surface from at least 0.192 percent.

1. Introduction
In a framework of the descriptive approach in the technical literature, the influence of roughness character on some performance properties of component parts, operating under different conditions, was consistently reviewed [1, 2]. This approach allows us to draw certain conclusions about the interrelationship between the roughness parameters regulated by normative documents and the surface properties such as, for example, corrosion resistance, durability, fatigue endurance, etc.

Existing specified roughness parameters, being defined, for instance, by standards, can ambiguously characterize the controlled surface [3, 4]. For this reason, the numerical estimate of microroughnesses by a profilogram of the controlled surface is considered to be limiting [5, 6].

We know some works [7-9] where profilogram values of the rough surface are considered as numerical series. Such series are analyzed by means of spectral correlation methods. The disadvantage of these techniques is the difficulty in establishing relationships between the obtained results and the current experience of using standard roughness parameters.

In some papers, the authors determined a correlation value of profilogram fragments [10] or rough surface fragments [11] via their scaling. Disadvantages of fractal methods for engineering application are the following factors: fractal dimensions of a set being analyzed can hardly be compared with standard parameters of the rough surface; fractal dimensions for self-affine fractals cannot clearly be defined [12].

We think it is not practical to use any statistical methods to identify the most unique characteristics of profilogram fragments or controlled surface fragments and also to assess the stability of certain
properties. Rough surface profilogram or images have finite sizes that restrict a sample length. A representative sample for reliable calculating, for example, of Hurst coefficient should contain several thousand measurements [13, 14].

The authors [15, 16] point out that new roughness parameters being developed must correspond to the standard roughness parameters. This means that parameters of three-dimensional surface microroughnesses must have profile prototypes which are regulated by normative documents.

We propose to characterize the rough surface by building its information pattern through imaging microroughnesses on the controlled surface and using the parameter value which is computed by the information pattern.

The purpose of this paper is to create visual and numerical tools to analyze the rough surface by its imaging.

2. Problem description

Human vision perceives the light brightness nonlinearly and has a limited response at very high or at very low intensities of the light flux being observed. Besides, a human eye can badly perceive small details of the image and the total image as a whole at the same time [17]. For these reasons, a person cannot keep track of any small changes in the image of the rough surface.

In order to eliminate the influence of physiological individualities of human perception of two-dimensional images, we propose to use the information pattern. When analyzing a raster image of the rough surface to create the information pattern, we used an image histogram. We considered a black-and-white image of the rough surface (Fig. 1). We referred the number of pixels, which conform to a certain color index in the image, to the total number of image pixels. We treated any obtained dependence as a square area. The number of such squares is always finite, since computer graphics palettes contain a finite number of colors. In accordance with paper [18], a finite sequence of squares (squares of the same area are assumed), the total area of which equals to one, may be arranged without overlapping within the square of 2. We propose this kind of arrangement of the squares, each area of which corresponds to the number of pixels with a certain colors index in the image, be considered as the information pattern of the rough surface image.

We consider that this information pattern does not depend on the number of colors in the image and on the selected indexed computer graphics color palette. We think that this information pattern may be used to study time changes of the rough surface (provided that the images of the same surface fragment obtained at different time intervals will have the same sizes).

In our opinion, among the profile parameters regulated by the National State Standard GOST 2789-73, a relative reference profile length (tp) may be considered as a prototype of the information pattern. In accordance with ISO 1302-2001 Indication of Surface Texture, the profile parameter \( R_{mr}(c) \) may be considered as a prototype of the proposed information pattern.

3. Research procedure

For our research, we used a titanium alloy sample BT9 (Ti – 6.8 Al – 3.2 Mo – 2.0 Zr – 0.3 Si). The sample surface was treated by polishing (Fig.1).
Figure 1. The surface of the titanium alloy sample after having been polished (×100).

The image of the rough surface 515×529 pel in size was obtained by means of an electron microscope Quanta 200.

A human eye can perceive different colors in the result of addition of three basic colors with different color intensities [19]. For this reason, we selected the RGB color palette in which different colors are formed in a similar way. We built up the image histogram shown in Fig. 1 using a Matlab based software environment. For this purpose, we put each index of the gray scale in correspondence with an appropriate RGB palette index (see Fig. 2).

The squares obtained from the histogram were arranged in the square of 2 in accordance with the following algorithm [20 p. 515] as follows:
1. The square S1, corresponding to the first element of the histogram, is set up at the bottom left corner of the square of 2 (hereafter referred to as the square S0). The rest of the square S0 is divided into two rectangles. A rectangle, whose height is greater than its length, is called a “vertical” rectangle. A rectangle, whose height is less than its length, is called a “horizontal” rectangle (Fig. 3).
2. In step k, the square Sk is set into one of the formed vertical and horizontal rectangles. To arrange the square Sk, we select the rectangle in which either the height (for the horizontal rectangle) or the length (for the vertical rectangle) differs slightly from the side of the square Sk.
3. The square Sk is set into the selected rectangle at the bottom left corner. If the selected rectangle is vertical, the top side of the square proceeds to its intercrossing with the left vertical side of the rectangle. If the selected rectangle is horizontal, the right side of the square Sk proceeds to the top horizontal side of the rectangle. In both cases, new horizontal and (or) vertical rectangles are formed.
4. The algorithm’s execution returns to item 2 until the squares Si are settled.

Figure 4 shows the arrangement of the squares, which were calculated in accordance with section 2 of the histogram shown in Fig 2. This type of the arrangement will thereafter be called a packing.

4. Research results
To determine the sensitivity of the proposed method to changes in the image of the rough surface, we have built the information patterns for the image in Fig. 1 without first and last lines and without first and last columns (Fig. 5).

Figure 5 shows that the information pattern is well sensitive to any losses within one line or one column in the image in Fig. 1. The loss within the sizes of one line amounts to 0.192 per cent (the line is 529 pel in length) and of one column – to 0.194 per cent (the column is 515 pel) of the whole image.
of the rough surface. We consider it necessary to denote that Figure 5 shows also the method’s sensitivity to sizes of the image of the controlled rough surface.

The loss of a line or a column results not only in the loss of some number of pixels from a certain gray scale. Figure 6 shows the histograms of lost lines and columns and also a percentage value of lost pixels of the certain gray scale. It is apparent from Figure 6 that the proposed method is sensitive to a set (a variety) of small variations in the number of pixels of the certain gray scale.

**Figure 3.** The arrangement of the first square, corresponding to the first element of the histogram, in the square of 2.

**Figure 4.** Packing of the finite sequence of the squares, corresponding to the histogram shown in Fig. 2, into the square of 2.

Figure 6 shows that for the image given in Fig. 1 the loss of one line or one column may cause the change in the number of pixels, corresponding to the certain gray scale, in the range from 1 to 13 pixels. Figure 5 also shows that lost pixels of the certain gray scale may be estimated at from 0.1 to 15.3 per cent from the total number of similar pixels in the image in Fig. 1.
Figure 5. Information patterns of imaging of the rough surface with different losses: a – no first line and b – no last line; c – no left column and d – no right column.

Figure 6. Histograms of lost lines and columns and the percentage value of deleted pixels with some gray scale steps: a – the first line and b – the last line; c – the right column and d – the left column.

5. **Parameter value of packing of the image histogram**
The applied method of packing the squares, whose area corresponds to the number of pixels of the certain gray scale, forms horizontal and vertical rectangulars in the range of the square of 2 (Fig. 7).
We consider that a ratio of the aggregate squares of vertical and horizontal rectangulars can serve as a numerical characteristic of the information pattern of the roughness image in Fig. 1. Table 1 shows the values of the proposed parameter for the packings in Fig. 3 and Fig. 5a, b, c, d.

Table 1. Parameter values for packings

| Packing | Fig. 3 | Fig. 4a | Fig. 4b | Fig. 4c | Fig. 4d |
|---------|--------|---------|---------|---------|---------|
| Parameter value | 0.324 = 0.685 | 0.7641 = 0.2648 | 0.7271 = 2.8985 | 0.7488 = 2.495 | 0.7463 = 2.5874 | 0.7463 = 2.6663 |

Table 1 shows that the parameter value is varied in the range of 429-513 per cent when the number of pixels in the image is changed within the range of 0.192-0.194 per cent.

6. Conclusions
We consider that the conducted research of the proposed method of building the information pattern of the rough surface has made it possible to determine the following: the information pattern visually displays changes of the roughness image in the range of at least 0.192 per cent of the total number of image pixels; the change of the number of pixels from 0.1 to 15.3 per cent in the groups of image pixels with some code of the gray scale results in the change of the parameter value within the range from 429 to 513 per cent (in this case, the number of lost pixels is not less than 0.192 per cent of the total number of image pixels); the information pattern can keep track of the dynamics of small variations (at least no less than 0.192 per cent) of the number of pixels in the image.

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