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An Advanced Methodology for Visualization of Changes in the Properties of a Dye

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***Abstract*: The application of dye to the surface is one of the varieties of technological processes in engineering. This operation is very important for the manufacture of various details and finished products. Therefore, quality control is an important element when painting the product. For such control, a methodology for visualizing changes in the properties of a dye is proposed. The input data are spectroscopic data. Next, we propose to carry out wavelet analysis. For this analysis, we use the wavelet coherence. We have shown that the wavelet coherence can be used as a visualization tool of changes in the properties of a dye. We conducted a study for a dye that was applied to various surfaces. We have shown that wavelet analysis makes it possible to distinguish surfaces for one dye.**

***Keywords*: engineering, dye, wavelet analysis, spectroscopy, wavelet coherence.**

I. INTRODUCTION

Mechanical engineering is a production whose products are an important element for various spheres of human activity. Modern engineering consists of many different types of technological processes. Among such processes there are: creation of a product design; creation of the design of parts for the product; manufacturing of parts; assembling products from various parts; product testing [1], [2].

One of the elements of the process of manufacturing parts is the application of a dye. Such a dye performs various functions. An important function is the protective function. For example, applying paint on a detail of iron can protect such products from corrosion, the effects of various environmental factors [3]. Therefore, an essential element of any technological processes is the stage of quality control of the product. At the same time, it is important to take into account the specifics of a particular stage of the manufacturing process of the product. In this case, we must take into account the peculiarities of the stage of coating parts or products with some dye.

The solution of the task can be achieved by visual analysis for finished products or production stages. However, not all methods of visual analysis allow for in-depth studies. For this study, it is necessary to apply a sequence of different analysis methods [4], [5]. In this case, such a sequence of methods should expand the capabilities of each of the methods separately, which are used. This was the basis for the formation of the main goal for this paper work.

II. MATERIALS AND METHODS

A. Traditional Methods for Controlling the Quality of Coating the Product with Dye

Among the many approaches for visual analysis of the quality of detail (products), it is necessary to distinguish methods of image processing.

In article S. Lee, L. M. Chang, and M. Skibniewski, a method for analyzing defects in an image using an image processing technique is used [6]. These images are presented as digital information. Such information is processed as a color image. M. Erdogan explores methods of image analysis to measure the surface brightness of different types of polished rocks [7]. It uses computer software to quantify the brightness index values.

F. P. Leon and S. Kammel present new strategies to inspect specular and painted surfaces [8]. At the same time, they note that simple approaches are ineffective. These approaches provide information for only one color space. At the same time, for example, V. Briones, J. M. Aguilera abd C. Brown, use the ideology of topography to study the characteristics of chocolate. [9]. Method of assessing uneven paint coatings is described in article M. Aoyagi, T. Hiraguri and T. Ueno [10]. This method makes it possible to consider various irregularities for products that are varnished. In this way, an express analysis of coatings can be carried out. This analysis is based on visual inspection. Hyper-spectral imaging has been applied for the study of various surfaces (of coated and uncoated) in article I. Burud, L. R. Gobakken, A Flo, K. Kvaal and T. K. Thiis. For this analysis, the principal component method was used. This allowed us to determine the area of mold coverage could. Boundaries were also obtained for such areas of mold coverage [11]. Another, equally important approach for analyzing the quality of details (their coating with a dye) is the ideology of spectroscopy [12]–[14]. Such an analysis allows us to identify individual elements of the substance that our product has been painted with. We can compare various spectrograms among themselves.

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We can also detect changes in the structure of the dye for various surfaces. However, this method does not allow for a visual analysis of the differences that can be.

Therefore, we suggest using the ideology of wavelets to visualize differences in the dye that is used for various surfaces or under different external conditions of use of the product.

B. Wavelets as a Tool for Visualizing Differences in Dye Properties

The ideology of wavelets is one of the tools that allow you to get an additional data set. This data set allows us to draw new conclusions. To do this, we will analyze the source data. We are looking for significant changes in the source data. These changes are break points (transition points). These transitions provide new information [15], [16].

Wavelet coherence can be used to analyze time series using wavelet ideology. Then we can do cross-analysis for the data series. Thus, we can estimate the local correlation. To determine the values of wavelet coherence, we consider the values of cross wavelet spectra $W_{xy}(z,k)$ (x is the variable that displays the data number in the series under investigation and y is the variable that displays the depth of cross-links for a time series). These values are presented as absolute values. We also normalize some variables. The general formula has the following form [17], [18]:

$$R^2(z,k) = \frac{\left|V(k^{-1}W_{xy}(z,k))\right|}{V(k^{-1}\left|W_x(z,k)\right|^2)V(k^{-1}\left|W_y(z,k)\right|^2)}, \qquad (1)$$

where V is a smoothing operator.

To implement formula (1), the Morlet wavelet is used. This wavelet has a good time-frequency localization, as a parent one [17]–[20]. The squared wavelet coherency coefficient is in the range $0 \le R^2(u,s) \le 1$. If these values tend to zero, then we have a weak correlation. Otherwise, we have a strong correlation. This allows analysis for various cross-links for time series. Moreover, such relationships are analyzed for different depths of cross-references between data series [17], [18].

We also take into account the fact that spectroscopic data is a series of data that reflects information about the properties of the dye.

C. Data for Analysis

For the study, we use data from the ASTER spectral library [21].

In Fig. 1 shows the spectrum of one slightly translucent coat of alkyd gloss black paint on an aluminum surface. Painted surface was smooth and glossy [21]. We call its spectrum 1.

In Fig. 2 shows the spectrum of two smooth coats of a slightly translucent alkyd gloss black paint on an aluminum surface [21]. We call its spectrum 2.

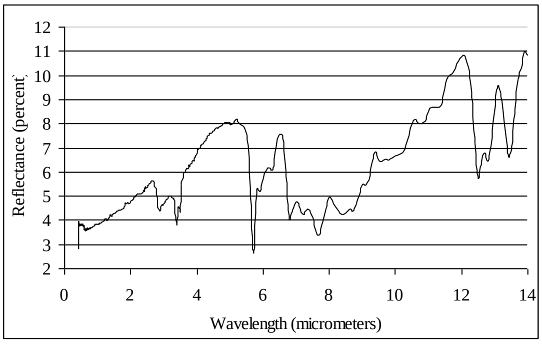


Fig. 1. Spectrum 1.

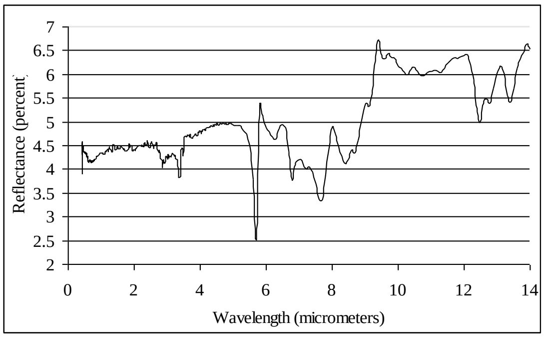


Fig. 2. Spectrum 2.

In Fig. 3 shows the spectrum of a slightly translucent coat of alkyd gloss black paint on construction lumber (pine) [21]. We call its spectrum 3.

In Fig. 4 shows the spectrum of two slightly translucent coats of alkyd gloss black paint on construction lumber (pine wood) [21]. We call its spectrum 4.

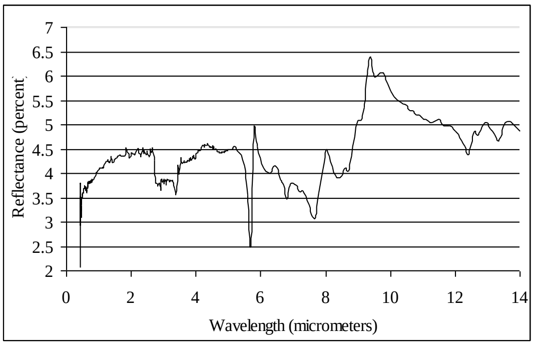


Fig. 3. Spectrum 3.

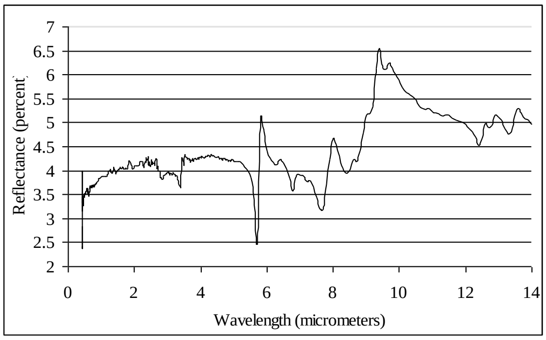


Fig. 4. Spectrum 4.

X Units: Wavelength (micrometers) – this is the range that was used to obtain the reflectance of the dye. Y Units: Reflectance (percent). These data form the basis for the analysis.

III. RESULTS AND DISCUSSION

We can see that the data in Fig. 2 – Fig. 4 in general are similar. Moreover, Fig. 3 and Fig. 4 can be considered identical (visually). Therefore, to identify the differences, we will analyze the wavelet coherence. For this we use the data in Fig. 2 – Fig. 4.

It should also be noted that the data for the X-axis (wavelength (micrometers)) have a different interval. We can distinguish three periods:

0.42-0.8 (change interval - 0.002);

0.8-5 (change interval - 0.02);

5-14 (change interval - 0.1).

Therefore, we will take this into account when carrying out wavelet analysis.

In Fig. 5 – Fig. 7, one can see the wavelet coherence for the data for Fig. 2 – Fig. 4. Each figure shows:

along the X axis, changes in wavelength;

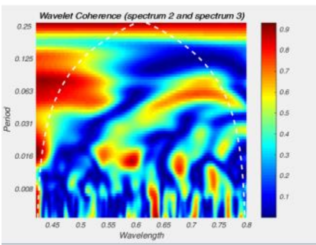
along the Y axis, the consistency period for wavelength;

white dotted line - cone of influence (inside the cone the reliability of influence is greatest).

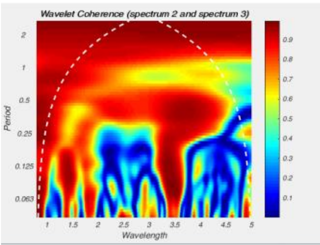
The figure also shows the scale of importance. This scale has numerical values and color characteristics to visualize wavelet coherence values. We can see a change in consistency for different wavelength periods, which are shown in Fig. 2 – Fig. 4.

In Fig. 5 shows the wavelet coherence for data spectrum 2 and spectrum 3.

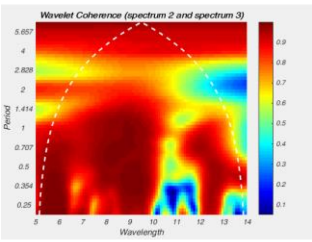
We see that the wavelet coherence for the wavelength 0.42-0.8 mm. is the lowest for the data spectrum 2 and spectrum 3. The largest wavelet coherence is for wavelength 6-10 mm. We also see that the largest wavelet coherence appears for large periods of consistency (see the Y axis).



a) wavelength 0.42-0.8 mm



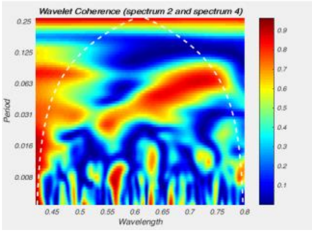
b) wavelength 0.8-5 mm



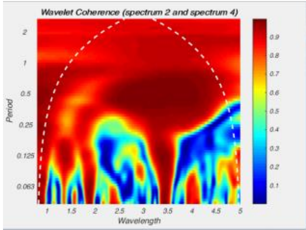
c) wavelength 5-14 mm

Fig. 5. Wavelet coherence (data spectrum 2 and data spectrum 3).

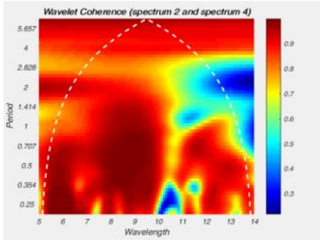
In Fig. 6 shows the wavelet coherence for data spectrum 2 (Fig. 2) and spectrum 4 (Fig. 4).



a) wavelength 0.42-0.8 mm



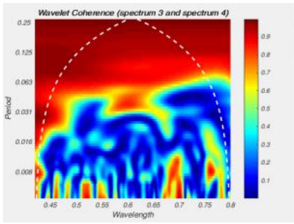
b) wavelength 0.8-5 mm



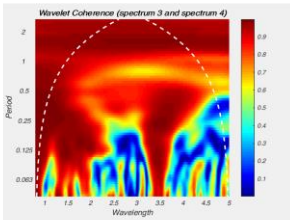
c) wavelength 5-14 mm

Fig. 6. Wavelet coherence (data spectrum 2 and data spectrum 4).

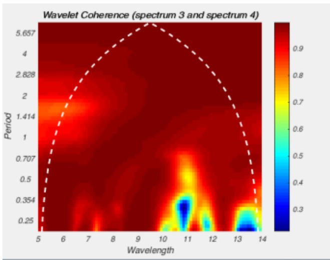
In Fig. 6 we see data similar to Fig. 5. In Fig. 7 shows the wavelet coherence for data spectrum 3 (Fig. 3) and spectrum 4 (Fig. 4).



a) wavelength 0.42-0.8 mm



b) wavelength 0.8-5 mm



c) wavelength 5-14 mm

Fig. 7. Wavelet coherence (data spectrum 3 and data spectrum 4).

The data in Fig. 7 differ from the data in Fig. 5 and Fig. 6. We see that large values of the wavelet coherence are observed for a larger range of wavelengths for which the reflection coefficients were obtained. We also see that the largest wavelet coherence appears for a wider period of consistency (see the Y axis).

This is explained by the fact that spectrum 3 and spectrum 4 are obtained for the dye on the same surfaces (this is spectrum of black paint on construction lumber - pine).

At the same time, spectrum 2 is the spectrum of black paint on an aluminum surface.

Thus, to identify differences in the properties of a dye, we offer:

1. As input data, consider the data of the spectrum of the dye.
2. Use the wavelet coherency to visualize differences.
3. Pay attention to the wave band, which was used to get the reflectance of the dye.

IV. CONCLUSIONS

We have considered the possibility of using wavelet coherence to visualize differences in the properties of the dye. For this we use the spectroscopy data. At the same time, we perform wavelet analysis for different wave bands, which are used to obtain reflection coefficients. It is also important to consider the range of consistency of data.

We have shown that the wavelet coherence is higher for the dye spectra on identical surfaces. At the same time, the wavelet coherence is low for the spectra of the dye on different surfaces. This makes it possible to distinguish surfaces for one dye.

We have shown that the wavelet coherence can be used as a visualization tool of changes in the properties of a dye. This allows us to expand the spectral analysis.

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