Use of Digital Technology for the Attribution of Paintings

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Abstract. Modern attribution of art works depends on the expert experience. This implies some subjectivity of his assessments. Recently for making a more informed decision digital image processing techniques have been used. Therefore, the study of the methods for obtaining additional information about the painting, which cannot be obtained using existing methods, is an important task.

The joint use of several features extraction methods will allow increase the effectiveness of its analysis. The application developed by the authors based on using of several methods (HOG, DCT, frequency analysis of color, color moments, color histograms, LBP, Gabor filter, GLCM, Hough transform) and allows making an assumption about belonging artwork to a particular art school, style or direction. The results obtained are confirmed by historical data about his teacher and where the artist studied, and who of the masters had the greatest influence on him.

Keywords: Attribution of paintings · Digital attribution · HOG · DCT · Frequency analysis of color · Color moments · Color histograms · LBP · Gabor filter · GLCM · Hough transform · Application for attribution

1 Introduction

Attribution of painting – the identification of authorship or belonging painting to an art school based on comprehensive scientific examination. Today it is one of the important research areas of artworks. The attribution is based on the finding out material evidence that allowed accept the expert opinion as indisputable. Such evidence is the author's signature, the presence of the date or monogram of the artist, etc. Unfortunately, on many paintings artist autographs are absent at all. On others these autographs are poorly visible to the naked eye, as they consist of the letters remains that are strongly worn and covered with varnish layers. This is due to the change of paintings over time associated with the influence of the environment, adverse storage conditions and the consequences of illiterate paintings restoration.

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Therefore, experts opinion is the main "method" of attribution, which is based on the its experience, the presence of his penetrating gaze, deep and detailed knowledge about artist and his contemporaries, the conditions in which the picture was created, expert knowledge of the features of brush strokes and the choice of colors by the artist. That is why this method will always include some subjectivity and, therefore, the opinion of different specialists may differ, despite their acceptance by the international community of experts.

2 Modern Attribution Methods

In recent years new physical and chemical methods of evaluating paintings such as ultraviolet fluorescence, infrared reflectography, stereomicroscopy, radiography and etc. have been proposed as additional tools supporting the work of experts in order to make a more justified decision. Dendrochronology and radiocarbon dating are used to study wood panels and paint layers, allowing determining the age of the artworks. For example, radiography can reveal the presence of another image under the painting, which can shed light on its origin or find out about the artist intentions and how his original plan has changed.

Surface analysis of paints is determining the proportion of a certain lead isotope in the paint compared to the expected content allows you to determine the date of writing the picture. Since the painting uses pigments, which are similar in color but differ in composition and crystal structure, the methods of microchemical analysis are used to determine this. However, despite the presence of a wide arsenal and potential of modern research methods, they are not always effective enough for attribution even in combination with art expertise.

3 Application of Computer Image Processing Methods for Attribution

Constantly growing capabilities of digital devices (processors work more and more quickly, computers, scanners and cameras increase resolution, data storages are getting bigger and etc.) generated a desire to use these tools for the study of collections of digitized works of art, whose volume has increased significantly over the last few years. Significant advances in the field of digital image processing, machine learning and artificial intelligence led to the fact that the world of art began to consider the use of computers in the artworks analysis at least as a trial step or the first stage in determining whether the picture is forgery or not.

This became the basis for the active stylometry development– the examination of authorship and the artworks style via statistical and numerical methods. Stylometry is based on the assumption that there are certain differences in the styles of different artists, as well as the characteristic movements of the artist's hand when drawing. Therefore, the characteristics that reflect these habits can be considered as features for determining the authorship of paintings. The methods of stylometry are far from perfect, but over the last few years there have been quite a lot of interesting works deals

with the determination of authorship which based on mathematical description of the unique artist style. This allows distinguishing his work from other authors or detecting a forgery and to determine the artistic reception used by the artist and his original idea. Some method allow us to identify whether the restoration and assess its quality.

The application of existing digital technologies can form a new understanding and new methods of art research, develop tools that will enable the computer to make aesthetic judgments on a semantic level, such as defining a style and genre of a picture based not only on the measure of similarity, but also on understanding art, and also taking into account the historical interpretation of the events depicted in the picture. Of particular note are the works associated with the study of aesthetics using computer vision methods [1]. Do not forget that the constant growth in quantity of digitized art works collections requires the development of multimedia systems for archiving and retrieving all sorts of information from this colossal amount of data.

Accordingly, the problem of researching digital image processing methods that could provide additional information about the artworks, which cannot be obtained using existing methods of studying painting, is currently topical.

For image processing today a large number of methods have been proposed that allow extract of textural, color, spectral, structural, statistical features for image analysis. Some methods have also been used to process the paintings of artists. The most widely used methods are color histograms [2, 3] and color moments [6].

Estimating the pixel frequency of different colors helps to get important information about the painting - to determine the colors that the artist loves and the most likely color scheme that he uses in his paintings.

Calculation of the histogram in different color spaces, such as RGB, HSV, CYK, etc. allows you to get the colors distribution in the painting and estimate the “amount” of a certain color in the painting. Unfortunately, analyzing the histograms of color, we cannot estimate the details of the paintings, describing the orientation, shape of objects, textures. In addition, histograms are largely dependent on lighting and are influenced by various kinds of noise.

Another frequently used method is the Histogram of Oriented Gradients [2, 4, 5]. Typically, these descriptors are used to define the edges or corners of an object. It is in these places that the gradient values change significantly.

Well-known methods such as discrete cosine transform (DCT) [7, 14], Fourier transform [2, 14], wavelet transform [1, 8–13], Gabor filters [7], hidden Markov models [12, 15, 16] have found application in this area.

Local Binary Patterns (LBP) [2] are used to evaluate the texture of an image, which is important for the study of an artist’s brushstroke and helps to determine its style.

However, most of the published works do not explain the criterion for the selection of paintings and their authors for analysis, and there is also no justification for the choice of processing methods.

This allows us to conclude that the methods are determined purely empirically and based on the experience of researchers or the presence of already implemented processing methods. In our opinion, the joint use of several methods of feature extraction from paintings will allow to increase the effectiveness of the analysis, since more data is objectively used: the space of image representations is expanded and a greater number of hypotheses are considered, reducing the risk of a wrong decision.

4 Application for the Attribution of Paintings

The application for automatic attribution has been developed and allows using the following methods: histogram of oriented gradients, discrete cosine transform, frequency analysis of color, color moments, color histograms, local binary patterns, Gabor filter, Gray-Level Co-Occurrence Matrix (GLCM) and Hough transform.

Table 1. Description of the digital art collection.

Artist	Painting school	Painting direction	Genre
Ivan Aivazovsky	Cimmerian Art School	R	M
Konstantin Bogaevsky	Mir Iskusstva (World of Art), Cimmerian Art School, Union of Russian Artists	S	L
Alexey Bogolyubov	Peredvizhniki (Society for Traveling Art Exhibitions)	R, Re	M, C
Karl Bryullov	Imperial Academy of Arts, Saint Petersburg, Russia	N, R	L
Konstantin Makovsky	Peredvizhniki (Society for Traveling Art Exhibitions)	Ac, R, Re	H, P
Edvard Munch	Berlin Secession, Degenerate art	S, E	G
Wassily Kandinsky	Blue Rose, Der Blaue Reiter (The Blue Rider), Bauhaus, Degenerate art, Der Sturm	E, Ab	A
Amedeo Modigliani	École de Paris, La Ruche	E	N
Arthur Segal	Der Blaue Reiter (The Blue Rider), Die Brücke (The Bridge)	E, D	F
Boris Grigoriev		E	
Claude Monet		I	
Edouard Manet		Re, I	
Valentin Serov	Peredvizhniki (Society for Traveling Art Exhibitions)	Re, I	P
Henri Matisse	École de Paris, Les Fauves	I, PI	
Arkhip Kuindzhi	Peredvizhniki (Society for Traveling Art Exhibitions)	Re, I	L
Theodore Rousseau	Barbizon school	Re	L
Alexey Venetsianov		Re	
Boris Kustodiev	Mir Iskusstva (World of Art), AKhRR (Association of Artists of Revolutionary Russia), Union of Russian Artists	Re, AN	
Ilya Repin	Peredvizhniki (Society for Traveling Art Exhibitions)	Re	
Ivan Shishkin	Peredvizhniki (Society for Traveling Art Exhibitions)	Re	L

The Table 1 describes the digital collection of paintings used in the experiments. The following notation is used in the Table 1: for genre M – Marina, L – Landscape, C – Cityscape, H – Historical painting, P – Portrait, G – Genre painting, A – Abstraction, N – Nude painting (nu), F – Figurative painting; for painting direction: R – Romanticism, S – Symbolism, Re – Realism, N – Neoclassicism, E – Expressionism, I – Impressionism, PI – Post-Impressionism, AN – Art Nouveau, Ac – Academic Art, Ab – Abstract Art, D – Dadaism.

The developed application allows you to perform an analysis of paintings on the similarity with the works of other artists and the artist's belonging to a particular style, movement, genre by using extracted features. Informative visualization simplifies the work of an expert in the study of a work of art, when hypotheses are put forward (for example, whether a picture is fake or not, which direction the picture belongs to, etc.) and allows flexible selection of specific features to substantiate his conclusion.

The Fig. 1 shows the result of images classification using the features extraction method selected by an expert for set of images. To do this, the following metrics are calculated: the number of neighbors for the most accurate classification by the k-nearest neighbors method, the prediction accuracy with this number of neighbors, the report on the quality of the classification (prediction accuracy, recall, F-measure), the error matrix, image feature mapping into two-dimensional space which is performed by the t-SNE method.

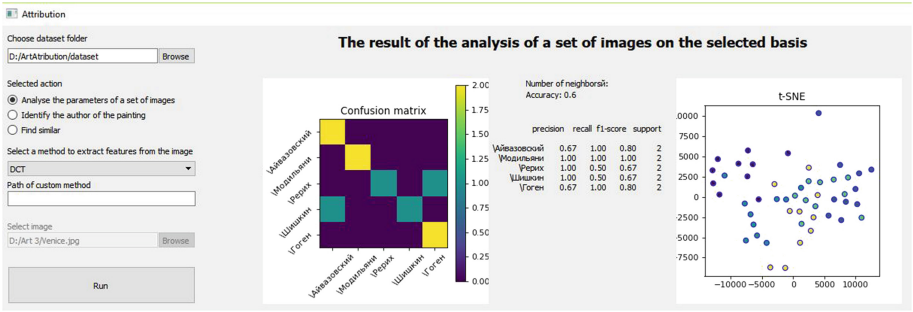

Fig. 1. An example of defining the parameters of a set of images of paintings.

The user is given the opportunity to determine the author of the painting on based on the chosen features of him. The application displays the name of the intended author and three images that are closest to the given, with the visualization of the selected features, as well as the distance between them and the original image in multidimensional space (see Figs. 2, 3).

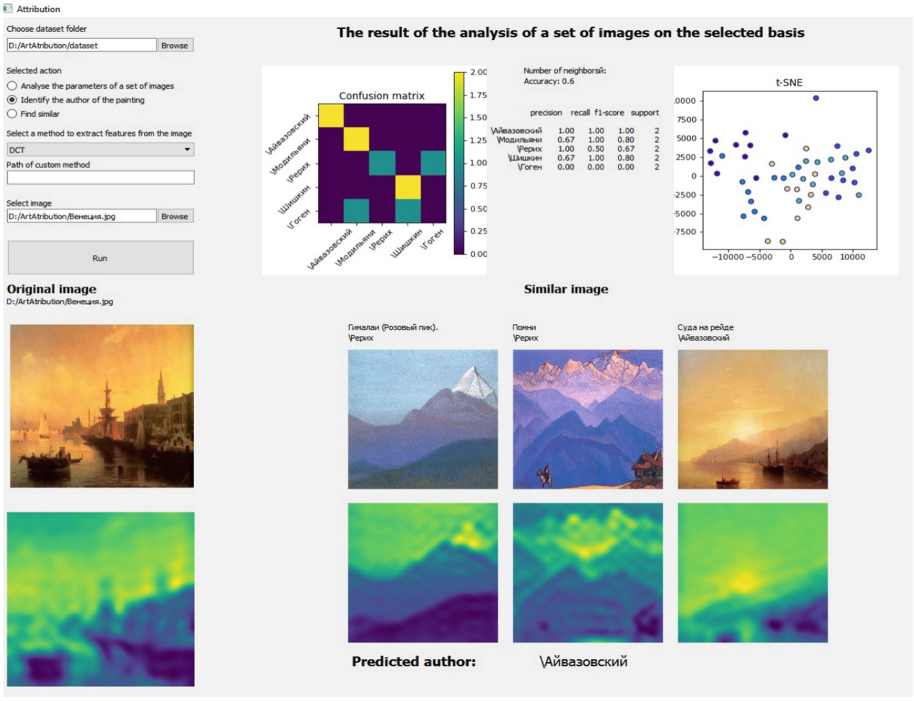

Fig. 2. The definition of the author of the picture based on the methods chosen by the user.

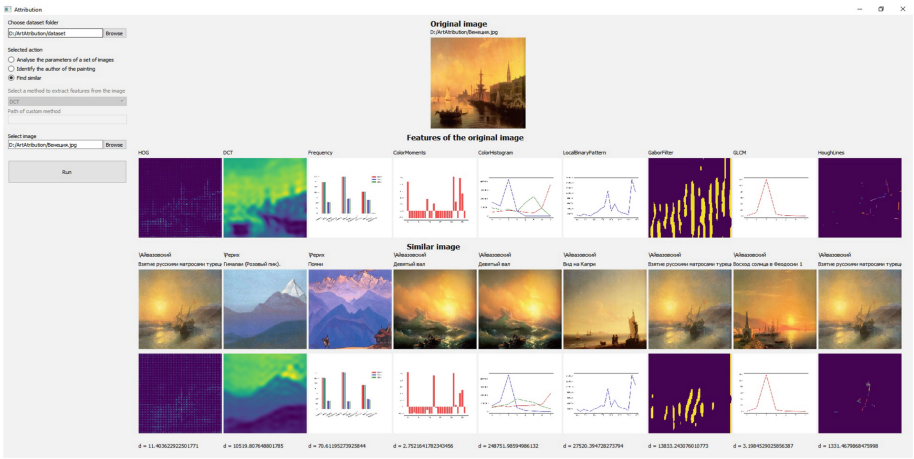

Fig. 3. The definition of the author of the picture on the basis of all the features of the extraction of characteristics implemented in the application.

Tools and libraries used for application development: OpenCV – image processing, Pandas – data analysis, NumPy – multidimensional array processing, Scikit-learn – machine learning, PyQT5 – graphical interface development.

5 Experimental Results

We present the most interesting from our point of view the results of the study. The use of the Gabor filter, a method for extracting textural features with orientation to the boundaries of objects, turned out to be the most effective for determining of Ivan Aivazovsky works. The works of Alexey Bogolyubov are most similar to the Ivan Aivazovsky works, which is understandable, since both which is understandable, since they are also marine painters.

The most significant for determining the authorship of Konstantin Bogaevsky are color histograms. Very interesting is the similarity of Konstantin Bogaevsky and Ivan Aivazovskyart works on the features extracted using the HOG and the Hough method, as well as Konstantin Bogaevsky and Arkhip Kuindzhi according to the features extracted using the Gabor filter and Hough transform. All methods have shown that the work of Konstantin Bogaevsky refers to romanticism.

The results of the experiment showed a variety of interests and techniques used by Karl Bryullov. In his works there was something similar to the work of each artist in the collection. Perhaps this is due to a significant number of Russian authors. Karl Bryullov influenced not only the creativity of each of them as a colleague, mentor or inspirer, but also the entire Academy of Arts as he used his own new teaching methods.

Karl Bryullov's works can be attributed to the romanticism and realism movement. The values of HOG-features and features extracted by the Hough transform are close to Ivan Aivazovsky however to a less so (Ivan Aivazovsky was inspired by the work of Karl Brullov and took some of his techniques). Despite the variety of works, the meanings of textural features extracted using LBP are very close.

Romanticism and realism can be traced in the works of Konstantin Makovsky and relationship with Peredvizhnikiart school (Arkhip Kuindzhi, Valentin Serov, Ilya Repin, Ivan Shishkin). For example, the similarity of Konstantin Makovsky's paintings with Aivazovsky's work in HOG-features can be noticed. Also they are similar in texture features with Arkhip Kuindzhi's and Valentin Serov's works (the Gabor filter and local binary patterns) and with Alexey Venetsianov's paintings in the composition construction (the location of the main lines identified by the Hough transform). This can be explained by the fact that Konstantin Makovsky is the latest representative of romanticism in this collection of images and he studied each of its representatives.

Experiments have shown that the works of Ivan Shishkin are best described by color features: the method of extracting the color moments and discrete cosine transformation. It should be noted that the texture characteristics (HOG, Gabor Filter, Hough transform) of the Ivan Shishkin works are similar to the work of Ivan Aivazovsky, but the texture features poorly describe the Ivan Shishkin's works because of the due to the extremely detailed portrayal of landscapes.

For the works of Boris Kustodiev it was not possible to identify the features that uniquely characterize his work. However, it was found that his paintings clearly belong

to the realism direction. His used colors are close to Valentin Serov, Edouard Manet and Claude Monet.

Ilya Repin's paintings were extremely diverse. It was not possible to distinguish from the features analyzed in the experiment those that most clearly describe his work. However, there is a similarity with artists of romanticism (to a greater extent) and realism movement. The influence of Ivan Aivazovsky and Alexey Venetsianov, that is typically for the artists of realism (HOG and Hough transform), should also be noted.

According to the results of the experiment, Theodore Rousseau's work is at the junction of romanticism and realism. DCT features are characteristic of his artworks. According to the texture features based on the Gabor filter, the paintings are close to Ivan Aivazovsky and Arkhip Kuindzhi.

Realism and romanticism brightly expressed in the paintings of Arkhip Kuindzhi. The paintings of this author are well characterized by features obtained by methods describing the structure and texture of the image (DCT, Local binary patterns, Gabor Filter), as well as methods reflecting the color distribution (moments of color and color histogram). Very interesting is the similarity of Arkhip Kuindzhi and Aivazovsky on the values of the features extracted with the help of HOG and Hough transform. This indicates that both authors painted color transitions and guide lines in a similar way. Note that the Arkhip Kuindzhi began his studies at the Ivan Aivazovsky's studio.

According to the results of the experiment, it was not possible to identify signs features of Valentin Serov. He was the closest to romanticism and realism. Textures used by Serov are similar to Munch's textures (LBP). It is interesting that the portrait of Ilya Repin in style close to Ilya Repin's artworks.

None of the features presented in the experiment fully characterize Claude Monet. In a sense, the work of this artist can be evaluated by color characteristics: color moments and histograms of color.

The diversity and versatility of Edouard Manet's works did not allow revealing the features characterizing the author. Also, according to the results of the experiment, it is impossible to determine which movement the artist belongs to.

Thus, the study results of the digital images collection showed that Aivazovsky stile plays a very important role for the artists of romanticism. The similarity with it can be estimated belonging to the works of painting to this area. For realists clearly traced the dependence on the Venetsianov works, manifested in the use of straight lines identified by the Hough method. The works of expressionists have similar values of the features obtained by color frequency analysis.

6 Conclusion

The article shows that the problem of developing new approaches to the study of art works, which could provide additional information about the paintings, which cannot be obtained using existing traditional methods of studying painting, is currently topical.

One of the possible ways to solve this problem is the use of computer image processing methods for automatic assessment of the paintings features, which will help to give more reasonable conclusions about the authenticity, authorship or stylistic qualities of painting.

Experiments have shown that on the basis of image processing methods it is possible to make an assumption about the belonging of a painting to a certain art school, style, movement. This conclusion is confirmed by historical data on who taught him and where the artist studied, and who of the masters had the greatest influence on him.

The most promising for solving the problem of attribution is the use of color moments method, histograms and local binary patterns. However, do not discard other features, as they complement the description of the picture. It is necessary to emphasize the great importance of the images set contents and its role in the analysis of works.

The application does not give a clear answer to the question of whether a particular author or direction belongs to the picture, but gives reason for reflection and justification for the study of art works by art historians and experts in a certain direction.

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