$$\Phi_7 = \frac{\sum_{x=1}^{N}\sum_{y=1}^{N}\frac{vv(x,y)}{x^4}}{\sum_{x=1}^{N}\sum_{y=1}^{N}\frac{vv_0(x,y)}{x^3}}. \quad (26)$$

4. Functions of basic groups of image normalization with levels of wavelet decomposition of the image under study

As a result of conducted experiments and analysis of the first level of decomposition, using calculation formula of mean difference, maximum difference and mean square error, the conclusion was made that for compensation of geometrical distortions one can use the following levels of decomposition.

The view of separate normalizers and functions is shown below:

1. For groups $G_{c,x}$, $G_{c,y}$, $G_{c,x,y}$:

General view of normalizers:

$$WF_{c,x}(B) = WB(x + \Phi w_1^{(i)}, y), \quad (27)$$

$$WF_{c,y}(B) = WB(x, y + \Phi w_2^{(i)}), \quad (28)$$

$$WF_{c,x,y}(B) = WB(x + \Phi w_1^{(i)}, y + \Phi w_2^{(i)}), \quad (29)$$

General view of functions:

$$\Phi w_1^{(i)} = \frac{\sum_{x=1}^{N(i)}\sum_{y=1}^{N(i)} x\cdot vv_0^{(i)}(x,y)}{\sum_{x=1}^{N(i)}\sum_{y=1}^{N(i)} vv_0^{(i)}(x,y)} - \frac{\sum_{x=1}^{N(i)}\sum_{y=1}^{N(i)} x\cdot vv^{(i)}(x,y)}{\sum_{x=1}^{N(i)}\sum_{y=1}^{N(i)} vv^{(i)}(x,y)}, \quad (30)$$

$$\Phi w_2^{(i)} = \frac{\sum_{x=1}^{N(i)}\sum_{y=1}^{N(i)} y\cdot vv_0^{(i)}(x,y)}{\sum_{x=1}^{N(i)}\sum_{y=1}^{N(i)} vv_0^{(i)}(x,y)} - \frac{\sum_{x=1}^{N(i)}\sum_{y=1}^{N(i)} y\cdot vv^{(i)}(n,m)}{\sum_{x=1}^{N(i)}\sum_{y=1}^{N(i)} vv^{(i)}(x,y)}. \quad (31)$$

2. For groups $G_{h,x}$, $G_{h,y}$ и $G_{h,x,y}$:

General view of normalizers:

$$WF_{h,x}(B) = WB(x + \Phi w_3^{(i)}\cdot y, y), \quad (32)$$

$$WF_{h,y}(B) = WB(x, y + \Phi w_4^{(i)}\cdot x), \quad (33)$$

$$WF_{h,x,y}(B) = WB(x + \Phi w_3^{(i)}\cdot y, y + \Phi w_4^{(i)}\cdot x), \quad (34)$$

General view of functions:

$$\Phi w_3^{i} = \frac{\sum_{x=1}^{N(i)}\sum_{y=1}^{N(i)} x\cdot y\cdot vv_0^{(i)}(x,y)}{\sum_{x=1}^{N(i)}\sum_{y=1}^{N(i)} y^2\cdot vv^{(i)}(x,y)}, \quad (35)$$

$$\Phi w_4^{(i)} = \frac{\sum_{x=1}^{N(i)}\sum_{y=1}^{N(i)} x\cdot y\cdot vv_0^{(i)}(x,y)}{\sum_{x=1}^{N(i)}\sum_{y=1}^{N(i)} x^2\cdot vv^{(i)}(x,y)}, \quad (36)$$

3. For group G_r:

General view of normalizer:

$$WF_r(B) = WB(x\cdot \Phi w_6^{(i)}, y\cdot \Phi w_6^{(i)}), \quad (37)$$

General view of function:

$$\Phi w_6^{(i)} = \frac{\sum_{x=1}^{N(i)}\sum_{y=1}^{N(i)} vv^{(i)}(x,y)}{\sum_{x=1}^{N(i)}\sum_{y=1}^{N(i)} vv_0^{(i)}(x,y)}. \quad (38)$$

4. For group G_s:

General view of normalizer:

$$WF_s(B) = WB\left(\frac{x}{\Phi w_7^{(i)}\cdot y + 1}, \frac{y}{\Phi w_7^{(i)}\cdot y + 1}\right), \quad (39)$$

General view of function:

$$\Phi_7^{(i)} = \frac{\sum_{x=1}^{N(i)}\sum_{y=1}^{N(i)}\frac{vv^{(i)}(x,y)}{x^4}}{\sum_{x=1}^{N(i)}\sum_{y=1}^{N(i)}\frac{vv_0^{(i)}(x,y)}{x^3}}. \quad (40)$$

So, we have defined the type and shape of different functions for normalization based on the use of various levels of wavelet decomposition of the image under study. Now, the open issue is how to define different groups of transformations for image normalization on basis of wavelet decomposition.

5. Definition of Transformation Groups for Image Normalization Based on Wavelet Decomposition

To determine transformation groups for further image normalization with the help of wavelet decomposition based on a number of experiments the following decomposition coefficients have been analyzed. It has been determined, that the obtained coefficients allow locally analyze those parts of the image that make it possible to determine to which type of geometric transformations changes occurring with the image can be referred to.

The general scheme for defining transformation groups look as follows:

1) Observing the behavior of coefficients starting from the last level of wavelet decomposition of the test image to the first one.
2) On the last level, finding the maximum coefficients and track their behavior on the following levels.

3) Calculating the energy of coefficients maximum, taking into account coefficient values of all levels of decomposition.
4) Analyzing the obtained energies in accordance with the following expressions:

If

$$W_G = \frac{\sum_{yy=1}^{N(i)} (\max_{xx}(v4_H^1))_{yy}^2}{\sum_{yy=1}^{N(i)} (\max_{xx}(v4_B^1))_{yy}^2} \approx 1, \quad (41)$$

then image transformation occur in the same plane, so it can be concluded that the image was subject to the group of shift transformations $G_{c,x}$, $G_{c,y}$, $G_{c,x,y}$ or to the group of rotation G_u. Otherwise, image can be subject to the change of scale and belongs to the groups of scale transformation G_r or was subject to projective distortions and belongs to the group of perspective G_s.

For the further determination of transformation groups belonging to the affine group of transformation, let's consider vertical and horizontal matrixes resulting from decomposition.

If

$$W_G = \begin{cases} \dfrac{\sum_{yy=1}^{N(i)} (\max_{xx}(v3_H^1))_{yy}^2}{\sum_{yy=1}^{N(i)} (\max_{xx}(v3_B^1))_{yy}^2} \approx 1 \\ \dfrac{\sum_{yy=1}^{N(i)} (\max_{xx}(v2_H^1))_{yy}^2}{\sum_{yy=1}^{N(i)} (\max_{xx}(v2_B^1))_{yy}^2} \neq 1 \end{cases}, \quad (42)$$

then there is a shift on the axis Y. Then the group of transformations corresponds to the group of parallel shifts along the axis $G_{c,y}$. Otherwise, we can say that there is a shift along axis X, and it corresponds to the group of shifts along $G_{c,x}$ axis.

If

$$W_G = \begin{cases} \dfrac{\sum_{yy=1}^{N(i)} (\max_{xx}(v3_H^1))_{yy}^2}{\sum_{yy=1}^{N(i)} (\max_{xx}(v3_B^1))_{yy}^2} \approx 1 \\ \dfrac{\sum_{yy=1}^{N(i)} (\max_{xx}(v2_H^1))_{yy}^2}{\sum_{yy=1}^{N(i)} (\max_{xx}(v2_B^1))_{yy}^2} \approx 1 \end{cases}, \quad (43)$$

then there occurs shift along X and Y axis. Then the group of transformations corresponds to the group of parallel shifts along axes $G_{c,x,y}$.

At image shift the values

$$W_G = \begin{cases} \dfrac{\sum_{yy=1}^{N(i)} (\max_{xx}(v3_H^1))_{yy}^2}{\sum_{yy=1}^{N(i)} (\max_{xx}(v3_B^1))_{yy}^2} \neq 1 \\ \dfrac{\sum_{yy=1}^{N(i)} (\max_{xx}(v2_H^1))_{yy}^2}{\sum_{yy=1}^{N(i)} (\max_{xx}(v2_B^1))_{yy}^2} \neq 1 \end{cases}, \quad (44)$$

that defines the group of rotations in G_u plane.

If the number of maxima of decompositions coefficients for the reference image H does not correspond to the number of maxima of decomposition coefficients of the test image B, then it can be stated, that the image has undergone sharp distortions and corresponds to the group of perspective G_s. Defining transformation group of scale G_r follows as a consequence, based on the consideration of the previous groups.

As a confirmation of the arguments above, there are some experiments results below – the results of studying the abilities and practicability of realization of image normalization procedure based on the use of the levels of its wavelet decomposition.

6. Some experiments concerning the processing capabilities and the practicability of the realization of image normalization procedure based on the use of the levels of its wavelet decomposition

Fig. 6 shows the results of wavelet decomposition into separate levels of images decomposition using Daubechies Wavelet, which has been subjected to a group of shift transformations $G_{c,x,y}$.

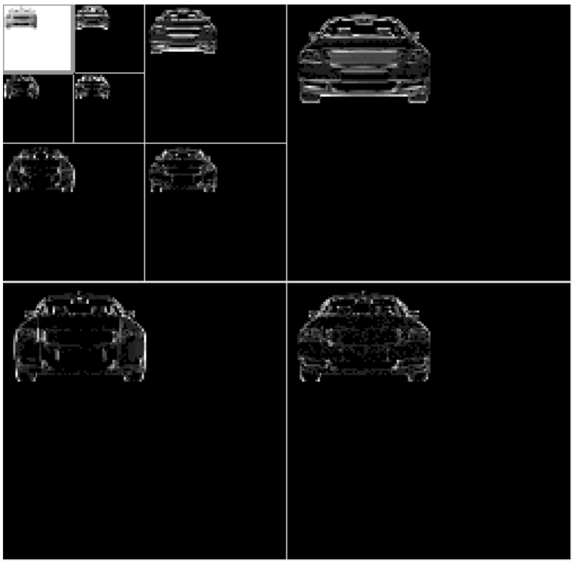

Figure 6: Wavelet decompositions of the image exposed to the group of shift transformations $G_{c,x,y}$

As seen from Fig. 6 the object under study does not change its dimensions and orientation, moves along axes X and Y. The results of the calculations showed that for W_G the conditions are performed in accordance with formula (43) -

$$W_G = \begin{cases} 0{,}92 \\ 0{,}98 \end{cases}.$$

Fig. 7 shows the results of wavelet decomposition into separate levels of image decomposition using Daubechies Wavelet, which was subjected to the group of rotation transformation G_u.

As seen from Fig. 7 the object under study does not change its dimensions and rotates on angle φ. After calculation $W_G = \begin{cases} 0{,}37 \\ 0{,}41 \end{cases}$ in accordance with formula (44), it can be stated that this transformation corresponds to a group of rotations on the plane G_u.

However, it should be noted that if the image has a fractal structure, errors in the determination of the group occur.

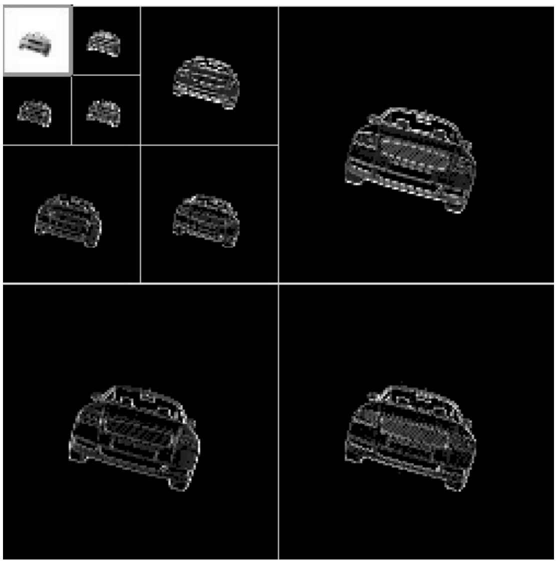

Figure 7: Wavelet decomposition of the image exposed to group of shift transformations G_u

Table 1 and Table 2 show the results of experiments that relate to the determination of transformation parameters for the normalizer describing a group of transformations of perspective G_s.

Table 1 shows the results of the determination of transformation parameters using classical procedure for description of the corresponding functions – formula (26).

Table 2 shows similar results for the search of the corresponding functions through the use of image wavelet decomposition into three levels of decomposition – formula (40). In both cases the same paramenters of the perspective change of test image were used. Measure of inaccuracy reflects the value of change of the real perspective parameters from the obtained calculated in the result of using the considered formulas for calculating functions in the classical form (table 1) and in the form of normalizers construction with the account of wavelet decomposition for test image (table 2).

Table 1: The result of determination of transformation parameters, describing the group of perspective transformations G_s by means of classical procedure of describing the corresponding functions

Transformation parameters (for different perspective distortions)	*Standard deviation* Δ, %
3,27	1,52
4,21	1,59
6,01	1,63
8,33	1,71

Table 2: The result of determination of transformation parameters, describing the group of perspective transformations G_s by means of the corresponding functions based on the use of wavelet decomposition of image into three decomposition levels

Transformation parameters	*Standard deviation* Δ, %
1st level of decomposition	
3,23	1,54
4,19	1,61
6,12	1,67
8,27	1,72
2nd level of decomposition	
3,13	2,74
4,17	2,12
5,78	2,01
8,28	1,83
3rd level of decomposition	
3,18	3,21
3,98	2,73
6,25	3,32
8,21	4,17

As is clear from table 1 and table 2, calculated parameters defining the group of perspective transformations using different computing techniques of the corresponding functions correlate between each other. This proves the correctness of the discussed above and the possibility of using the proposed methodology for realization of image normalization procedure a whole based on the use of the levels of its wavelet decomposition. In this connection, it should be underlined, that this occurs because of applying image decimation procedure on each level of its decomposition, as there occurs partial loss of information. It should also be emphasized that it occurs as a result of application of image decimation procedure on each level of its decomposition, as there occurs loss of partial information. It should also be noted that values of inaccuracy are not critical – they do not exceed 5%. Nevertheless, we should talk about the advisability to limit the level of image decomposition when considering image normalization procedure based on the use of levels of its wavelet decomposition. As such threshold limit can be taken a limitation of not more than three levels of decomposition of the test image by using appropriate normalization procedures.

7. Conclusions

As the result, the paper studies key points relating to the summary of realization methodology of image normalization procedure based on the use of its wavelet decomposition levels. Here the main point of using wavelet decomposition for realization of image normalization procedure is to establish the possibility of using image thumbnails as the result of wavelet decomposition of the analyzed image. The use of such wavelet decomposition of an image allows reducing time for normalization of input image for further recognition of the object under study.

The possibility and practicability of the realization of image normalization procedure based on the use of its wavelet decomposition levels is shown by the example of calculating different geometric distortions of the analyzed image. To confirm the suggestion there was conducted a number of experiments, the results of which are shown in this paper.

The practical implications of the obtained results are that in modern computer vision systems the type of geometric transformations should be determined. It is also shown, that the suggested methodology removes restrictions on conducting normalization in the specified group with the help of defining groups of transformations.

Disadvantages of this methodology of image normalization include insufficient study of the constructive method of controlling "false" upper limits that affect the definition of transformations groups. Though this aspect, as well as definition of the optimal level of image decomposition for its further normalization, can largely depend on the type of wavelet used. This allows defining these tasks as future directions of the research. Another aspect, which may also require addition research, is the use of adaptive wavelets in the realization methodology of image normalization procedure based on the use of its wavelet decomposition levels.

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