Methodology for Visual Quality Estimation of Aerial and Satellite Images

Irina Anikeeva[1], Alexandr Chibunichev[2]

[1] JSC "NIIAS", Moscow, Russia – i.anikeeva@vniias.ru
[2] Moscow State University of Geodesy and Cartography, Moscow, Russia – agchib@mail.ru

KEY WORDS: Aerial and Satellite Images, Mapping and Topographic Surveying, Visual Image Quality, Quality Estimation, Visual Quality Indicators, Visual Quality Status

ABSTRACT:

The most widely used remote sensing data are photographic survey systems mounted on aircraft and spacecraft.The problem of remote sensing data quality control arises when evaluating the survey sensor's functionality as a part of validation tests and during topographic surveys as a part of technical check activities. The problem of shortcomings and, sometimes, complete normative regulation absence of main concepts and unified approaches to the methodology of aerial and satellite images quality estimation is raised in the paper. To develop a methodology for visual quality estimation, a number of basic tasks have been formulated and proposed. The main stages description of a proposed methodology are given. The operation principle flowchart of visual quality estimation is presented. The developed methodology makes it possible to estimate the aerial and satellite images visual quality based on quantitative indicators in automatic mode.

1. INTRODUCTION

The remote sensing area represented by a wide range of data, different in their properties and type of contained information. The most widely used data are photographic survey systems mounted on aircraft and spacecraft.

The problem of remote sensing data quality control arises when evaluating the survey sensor's functionality as a part of validation tests. Also, the task of images quality estimation arises during topographic surveys as a part of technical check activities. As a result a decision is made on their suitability for further processing and obtaining high-quality products, based on them.

The relevance of research determines the shortcomings and, sometimes, complete normative regulation absence of main concepts and unified approaches to the methodology of aerial and satellite images quality estimation.

The aim of research is to develop an automatic methodology for visual (photographic) quality estimation of aerial and satellite images. The methodology will allow us to make a clear conclusion about their suitability for creating cartographic products and topographic surveying.

2. METHODOLOGY

To develop a methodology for visual quality estimation of aerial and satellite images, it is necessary to solve the following tasks:
– to determine the requirements for visual quality estimation methodology;
– to determine the main concepts for visual quality estimation;
– to develop the main stages of visual quality estimation methodology;
– implementation on practice the developed methodology.

2.1 Requirements for visual quality estimation methodology

Requirements for visual quality estimation methodology for aerial and space images are as follows:
– the methodology should be a set of operations that include determining the values of quality indicators in accordance with the established list and comparing them with the basic values – the specified quality requirements;
– the methodology should be based on a system of quality indicators – a set of quantitative characteristics, that describe visual properties on which the quality of cartographic products, obtained by images, depends;
– visual quality estimation should be carried out under a unified list of quality indicators, using unified organizational and methodological approaches to ensure the unity of quality estimation.

2.2 Main concepts for visual quality estimation of aerial and satellite images

The estimation of visual quality indicators values should be carried out on a single methodological basis in order to determine whether the quality of aerial and space images meets the requirements that make it possible to use them in topographic surveying. The visual quality estimation of aerial and space images should be carried out in terms of structural and gradation properties (Kuchko, 1974). The structural indicators of visual quality include:
– spatial resolution;
– sharpness.
Gradation indicators include:
– color imbalance;
– the degree of random noise (determined by the RMS of random noise level);
– haze intensity;
– loss of information in shadows and illumination;
– radiometric resolution.

Results of visual quality estimation should be entirely documented for further use, analysis and making the reporting documentation.

Publisher's note: Copernicus Publications has not received any payments from Russian or Belarusian institutions for this paper.

2.3 The main stages of the visual quality estimation methodology

According to determined requirements and main concepts, a visual quality estimation methodology was developed. It consists of three main stages:
- *stage 1* – calculation of visual quality indicators by image;
- *stage 2* – comparison calculated in stage 1 values indicators with the corresponding recommended and acceptable values;
- *stage 3* – assigning the quality status to the image: good, acceptable, unacceptable.

As follows from stage 3, the result of visual quality estimation supposes three categories quality statuses: *good* means that the image’s quality formally meets the requirements of regulatory documentation and actually has high quality; *acceptable* means that the image’s quality does not conflict the requirements of regulatory documentation, sometimes due to the absence or unclear regulation of certain properties, but actually does not have good quality; *unacceptable* means that the image’s quality does not meet the requirements of regulatory documentation and actually has poor quality.

Figure 1 shows examples of aerial images, which quality is recognized as good, acceptable and unacceptable according to technical check results.

Figure 1. Examples of aerial images three quality categories: *a* – good, *b* – acceptable (the image was taken under a solid cloud cover, but does not formally contradict the regulatory documentation requirements), *c* – unacceptable.

2.3.1 Calculation of visual quality indicators by image

The input data for estimating visual quality in stage 1 is an aerial or space image. The output data are calculated values of the following indicators:
- spatial resolution *R* (Anikeeva, Kadnichanskiy, 2017);
- sharpness *s* (Anikeeva, 2020);
- local contrast K_{loc};
- color imbalance *Δ* (Ancuti et al, 2018; Hussain, Akbari, 2018; Ancuti et al, 2020);
- random noise RMS N_{RMS} (Lapshenkov, 2012; Lapshenkov, 2013; Miao, 2019; Chen, Zhang et al., 2019);
- haze intensity *hz* (Su et al, 2020; Yang and Evans, 2021);
- radiometric resolution (R_{img}, R_{eff}) (Chandra, Gosh, 2008);
- loss of information in shadows *shd* and illumination *ill*.

Figure 2 shows the flowchart of stage 1.

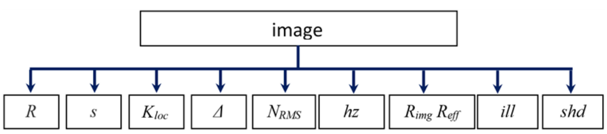

Figure 2. Flowchart of stage 1 – calculation of visual quality indicators.

2.3.2 Comparison calculated values of indicators with the corresponding recommended and acceptable values

The visual quality indicators values, calculated from the image, are compared with recommended and acceptable values for each indicator separately. According to the comparison results, each indicator is assigned status «good», «acceptable», «unacceptable». The «good» status is assigned to an indicator if its value does not exceed the recommended value. The «acceptable» status is assigned to an indicator if its value exceeds the recommended value, but does not exceed the acceptable value. The «unacceptable» status is assigned to the indicator if its value exceeds the acceptable value.

Figure 3 shows the flowchart of stage 2. K_{rec} is the conditional value of local contrast, starting from which it can be assumed that contrasting objects are located on the ground. Let's take K_{rec} = 0.5.

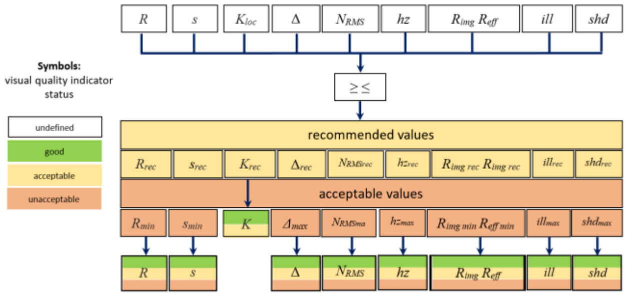

Figure 3. Flowchart of stage 2 – comparison of the image’s quality indicators values with corresponding recommended and acceptable values.

2.3.3 Assigning the quality status to the image

2.3.3.1 The spatial resolution indicator *R*

The image’s spatial resolution *R* is compared with recommended R_{rec} value:
- if $R \leq R_{rec}$, *R* parameter is assigned status «good»;
- if $R > R_{rec}$, *R* parameter is compared with acceptable maximum R_{max} value:
  - if $R \leq R_{max}$, *R* parameter is assigned status «acceptable»;
  - if $R > R_{max}$ the image’s local contrast K_{loc} is analyzed, it compares with recommended contras K_{rec}:
    - if $K_{loc} \leq K_{rec}$, *R* parameter is assigned status «acceptable», the decrease in spatial resolution is due to underlying surface characteristics – low contrast, as indicated by the appropriate note;
    - if $K_{loc} > K_{rec}$, *R* parameter is assigned status «unacceptable», the decrease in the image’s spatial resolution of the contrasting underlying surface is an image defect.

Figure 4 shows a flowchart for determining the spatial resolution quality indicator.

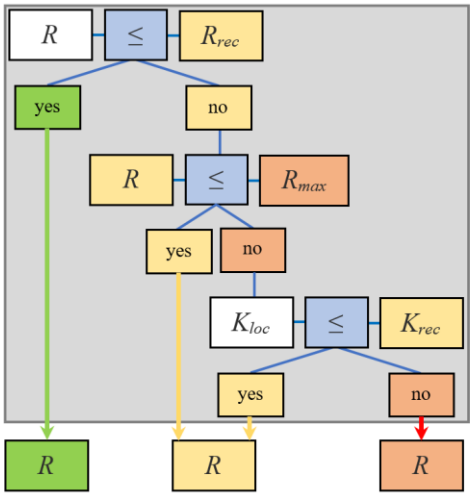

Figure 4. Flowchart for determining the quality indicator status of spatial resolution.

2.3.3.2 The sharpness indicator *s*

The image’s sharpness s is compared with recommended s_{rec} value:

- if $s \geq s_{rec}$, s parameter is assigned status «good»;
- if $s < s_{rec}$, s parameter is compared with acceptable minimum s_{min} value:
  - if $s \geq s_{min}$, s parameter is assigned status «acceptable»;
  - if $s < s_{min}$ the image’s local contrast K_{loc} is analyzed, it compares with recommended contrast K_{rec}:
    - if $K_{loc} \leq K_{rec}$, s parameter is assigned status «acceptable», the decrease in sharpness is due to underlying surface characteristics – low contrast, as indicated by the appropriate note;
    - if $K_{loc} > K_{rec}$, s parameter is assigned status «unacceptable», the decrease in image’s sharpness of the contrasting underlying surface is an image’s defect.

Figure 5 shows a flowchart for determining the sharpness quality indicator status.

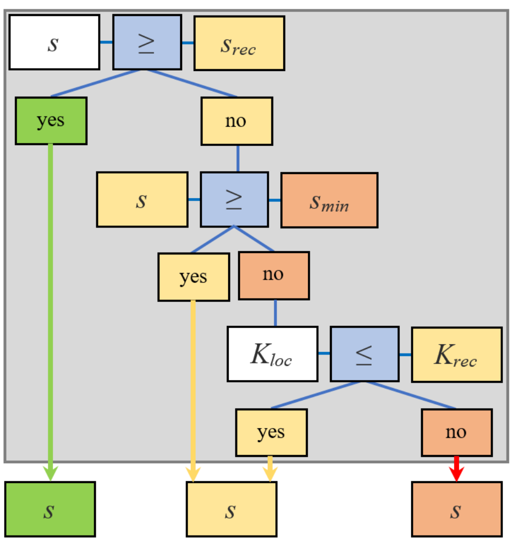

Figure 5. Flowchart for determining the sharpness quality indicator status.

2.3.3.3 The random noise RMS indicator N_{RMS}

The image’s random noise RMS N_{RMS} is compared with recommended N_{RMSrec} value:

- if $N_{RMS} \leq N_{RMSrec}$, N_{RMS} parameter is assigned status «good»;
- if $N_{RMS} > N_{RMSrec}$, N_{RMS} is compared with acceptable maximum $N_{RMS\max}$:
  - if $N_{RMS} \leq N_{RMS\max}$, N_{RMS} is assigned status «acceptable»;
  - if $N_{RMS} > N_{RMS\max}$, N_{RMS} is assigned status «unacceptable», a high level of random noise is an image defect.

Figure 6 shows a flowchart for determining the random noise RMS quality indicator status.

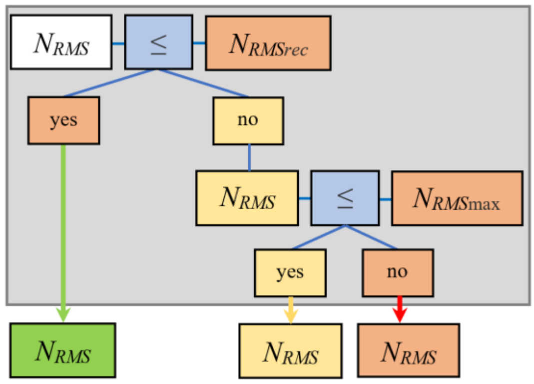

Figure 6. Flowchart for determining the random noise RMS quality indicator status.

2.3.3.4 The color imbalance indicator *Δ*

The image’s color imbalance Δ is compared with recommended Δ_{rec} value:

- if $\Delta \leq \Delta_{rec}$, Δ parameter is assigned status «good»;
- if $\Delta > \Delta_{rec}$, Δ is compared with acceptable maximum Δ_{max}:
  - if $\Delta \leq \Delta_{max}$, Δ parameter is assigned status «acceptable»;
    - if $\Delta > \Delta_{max}$ image’s color balance correction is performed using suitable method of restoring color balance.

The color balance violation is a removable image’s defect without changing its geometric properties. Figure 7 shows a flowchart for determining the color imbalance quality indicator status.

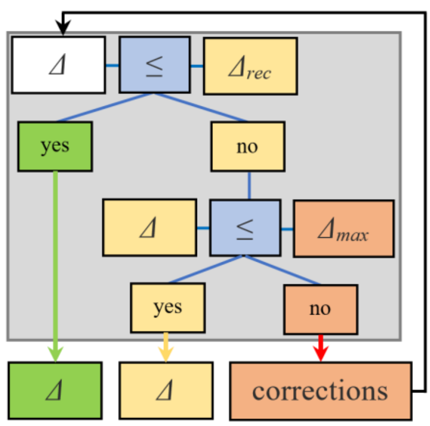

Figure 7. Flowchart for determining the color imbalance quality indicator status.

2.3.3.5 The haze intensity indicator *hz*

The image’s haze intensity *hz* is compared with recommended hz_{rec} value:

– if $hz \leq hz_{rec}$, *hz* parameter is assigned status «good»;
– if $hz > hz_{rec}$, *hz* parameter is compared with acceptable maximum hz_{max}:
  – if $hz \leq hz_{max}$, *hz* parameter is assigned status «acceptable»;
  – if $hz > hz_{max}$, *hz* parameter is assigned status «unacceptable».

Figure 8 shows a flowchart for determining the haze intensity quality indicator status.

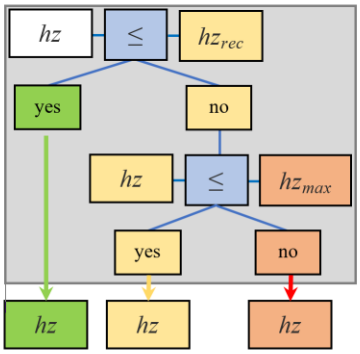

Figure 8. Flowchart for determining the haze intensity quality indicator status.

2.3.3.6 The radiometric resolution indicator R_{img}, R_{eff}

The first step in estimating the radiometric resolution parameter R_{img} and R_{eff} is the analysis of haze brightness indicator *hz* and random noise RMS N_{RMS}:

– if at the same time *hz* and N_{RMS} are assigned as «unacceptable», the R_{img} and R_{eff} value is automatically assigned as «unacceptable»;
– if this condition is not met, the image’s indicators R_{img} and R_{eff} are compared with recommended $R_{img\ rec}$ and $R_{eff\ rec}$ values:
  – if $R_{img} \geq R_{img\ rec}$ and $R_{eff} \geq R_{eff\ rec}$, R_{img} and R_{eff} is assigned as «good»;
  – if $R_{img} < R_{img\ rec}$ and $R_{eff} < R_{eff\ rec}$, R_{img} and R_{eff} are compared with acceptable maximum $R_{img\ min}$ and $R_{eff\ min}$:
    – if $R_{img} \geq R_{img\ min}$ and $R_{eff} \geq R_{eff\ min}$, R_{img} and R_{eff} are assigned as «acceptable»;
    – if $R_{img} < R_{img\ min}$ and $R_{eff} < R_{eff\ min}$, the R_{img} and R_{eff} are assigned as «unacceptable».

Figure 9 shows a flowchart for determining the radiometric resolution quality indicator status.

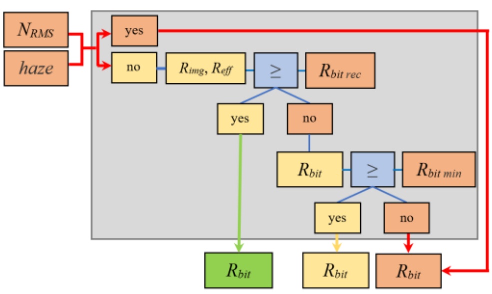

Figure 9. Flowchart for determining the radiometric resolution quality indicator status.

2.3.3.7 The loss of information in shadows indicator *shd*

The image’s loss of information in shadows *shd* is compared with recommended shd_{rec}:

– if $shd \leq shd_{rec}$, *shd* is assigned as «good»;
– if $shd > shd_{rec}$, *shd* is compared with acceptable maximum shd_{max}:
  – if $shd \leq shd_{max}$, *shd* is assigned as «acceptable»;
  – if $shd > shd_{max}$, *shd* is assigned as «unacceptable».

Figure 10 shows a flowchart for determining the loss of information in shadows indicator status.

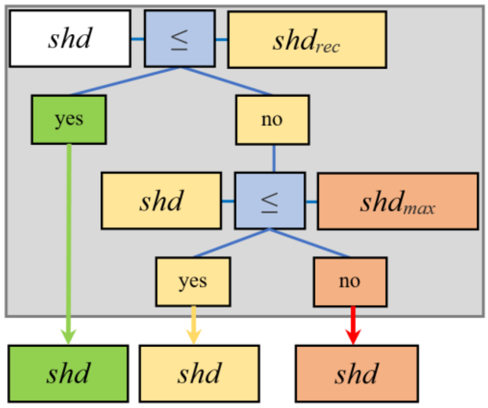

Figure 10. Flowchart for determining the loss of information in shadows indicator status

2.3.3.8 The loss of information in illumination indicator *ill*

The image’s loss of information in illumination *ill* is compared with recommended ill_{rec}:

– if $ill \leq ill_{rec}$, *ill* is assigned as «good»;
– if $ill > ill_{rec}$, *ill* is compared with acceptable maximum ill_{max}:
  – if $ill \leq ill_{max}$, *ill* is assigned as «acceptable»;
  – if $ill > ill_{max}$, *ill* is assigned as «unacceptable».

Figure 11 shows a flowchart for determining the loss of information in illumination indicator status.

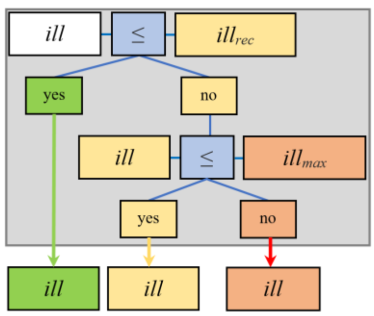

Figure 11. Flowchart for determining the loss of information in illumination indicator status

2.3.3.9 Assigning the «good», «acceptable» and «unacceptable» quality status to the image

Based on comparing results of visual quality indicators with their recommended and acceptable values, the quality status of entire image is assigned the value «good», «acceptable», «unacceptable». The image quality can be considered good if more than 50% of indicators have the status «good». The image quality considered acceptable if more than 50% of indicators have status «acceptable». The image quality considered unacceptable if at least one of indicators has status «unacceptable», regardless the other indicators status.

Figure 12 shows the flowchart of step 3 – assigning a quality status to the image.

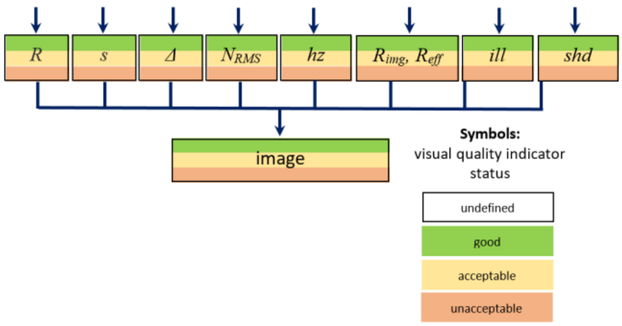

Figure 12. The flowchart of step 3 – assigning a quality status to the image.

The visual quality structural and gradation indicators calculation of color images (except for color imbalance) is carried out by converting in «grayscale» mode.

If a detailed analysis of color images visual quality is required, the calculation of corresponding indicators is performed separately for each color component (red, green, blue)

2.4 Implementation on practice the developed visual quality estimation methodology

The operating principle of developed method for visual quality estimation can be presented as a flowchart (Figure 13).

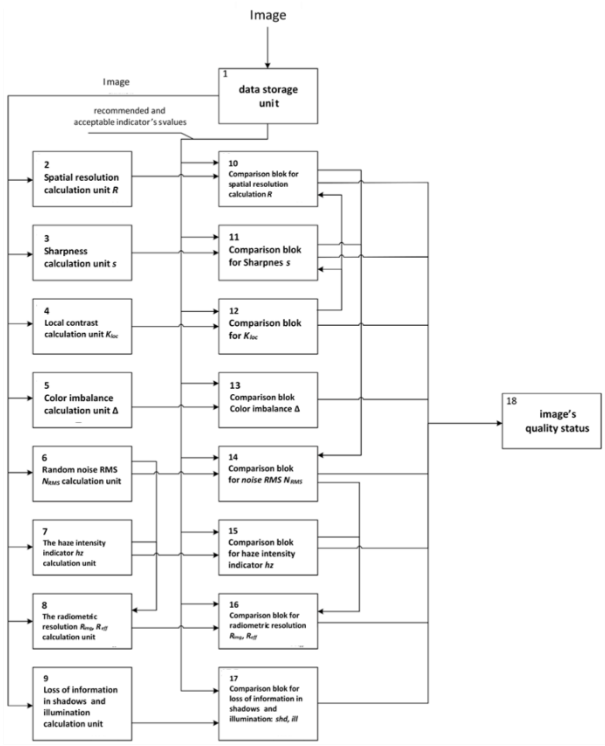

Figure 13. The operating principle flowchart of visual quality estimation.

The visual quality estimation principle is as follows: an image is loaded into storage block 1, next it enters block 2 – calculating the spatial resolution *R*, block 3 calculating the photographic sharpness *s*, block 4 calculating the local contrast K_{loc}, block 5 calculating the color imbalance *Δ*, block 6 calculating the RMS of random noise N_{RMS}, block 7 calculating the haze intensity *hz*, block 8 calculating the radiometric resolution R_{img}, R_{eff},, and block 9 calculating the loss of information in shadows *shd* and illumination *ill*.

Next, each indicator, calculated from image, is compared with recommended and acceptable values separately: in block 10 the spatial resolution *R*, in block 11 the photographic sharpness *s*, in block 12 the local contrast K_{loc}, in block 13 color imbalance *Δ*, in block 14 RMS of random noise N_{RMS}, in block 15 haze intensity *hz*, in block 16 radiometric resolution R_{img}, R_{eff} and in block 17 loss of information in shadows *shd* and illumination *ill* respectively.

According to the comparison results, each indicator is assigned status «good», «acceptable», «unacceptable» according with described above methods.

Additionally, to assign the spatial resolution *R* and photographic sharpness *s* status, the image’s comparing results of local contrast K_{loc} with recommended value are received in block 10 and 11 from block 12.

Also, to assign the radiometric resolution R_{img} and R_{eff} status, the assigned statuses of random noise N_{RMS} and haze brightness *hz* from block 14 and 15, respectively, are sent to radiometric resolution comparison in block 16.

Next, in block 18, based on the assigned image’s quality indicators statuses the image is assigned status «good», «acceptable», «unacceptable».

Figure 14 shows an example of a good visual quality aerial image.

Figure 14. Aerial image assigned with visual quality status «good».

Tables 1 and 2 show the procedure for quality status estimation for images shown in Figures 14 and 15, respectively. The images radiometric resolution is 8 bits/pixel.

The status of each visual quality indicator of image in Figure 14 is shown below:
– spatial resolution – «good»;
– sharpness – «good»;
– local contrast – information parameter;
– color imbalance – «good»;
– random noise RMS – «good»;
– haze intensity – «good»;
– radiometric resolution – «good»;
loss of information in shadows and illumination – «good».

№	Images quality indicators	Calculated		Recommended		Acceptable		Status
1	*R*, pix.	X	1,10	1,2	not exceed	1,3	-	good
		Y	1,10	1,2	not exceed	1,3	-	good
2	K_{loc}	Total	0,36	reference parameter				contrast surface
		Local	0,80	0,5	not exceed	-	-	
3	*s*	X	0,76	0,5	exceed	0,35	-	good
		Y	0,76	0,5	exceed	0,35	-	good
4	N_{RMS}	tone	2,16	2,5	not exceed	7	-	good
5	*hz*	tone	0	20	not exceed	40	-	good
		%	0,00	7	not exceed	16	-	
6	*ill*	%	0,07	0,1	not exceed	0,5	-	good
7	*shd*	%	0,00	0,1	not exceed	0,5	-	good
8	Δ	R	-1,37	reference parameter				
		G	1,69	reference parameter				
		B	-0,46	reference parameter				
		total	**2,22**	**4**	**not exceed**	**10**	**-**	**good**

Table 1. The procedure for quality status estimation for image shown in Figure 14

Figure 15 shows an example of a poor visual quality aerial image.

Figure 15. Aerial image assigned with visual quality status «unacceptable».

№	Images quality indicators	Calculated		Recommended		Acceptable		Status
1	*R*, pix.	X	1,49	1,2	exceed	1,3	-	unacceptable
		Y	1,56	1,2	exceed	1,3	-	unacceptable
2	K_{loc}	Total	0,29	reference parameter				contrast surface
		Local	0,51	0,5	not exceed	-	-	
3	*s*	X	0,48	0,5	exceed	0,35	-	good
		Y	0,29	0,5	not exceed	0,35	-	unacceptable
4	N_{RMS}	tone	0,78	2,5	not exceed	7	-	good
5	*hz*	tone	43	20	exceed	40	-	unacceptable
		%	20,28	7	exceed	16	-	
6	*ill*	%	0,00	0,1	not exceed	0,5	-	good
7	*shd*	%	0,00	0,1	not exceed	0,5	-	good
8	Δ	R	0,00	reference parameter				
		G	-0,03	reference parameter				
		B	0,02	reference parameter				
		total	**0,04**	**4**	**not exceed**	**10**	**-**	**good**

Table 2. The procedure for quality status estimation for image shown in Figure 15

The status of each visual quality indicator of image in Figure 15 is shown below:
– spatial resolution – «unacceptable»;
– sharpness – «unacceptable»;
– local contrast – information parameter;
– color imbalance – «good»;
– random noise RMS – «unacceptable»;
– haze intensity – «unacceptable»;
– radiometric resolution – «good»;
– loss of information in shadows and illumination – «good».

3. CONCLUSION

As a research result the main requirements and concepts for visual quality estimation methodology for aerial and space images are developed. The developed methodology makes it possible to estimate the aerial and satellite images visual quality based on quantitative indicators in automatic mode. This allows to render the decision-making process on images suitability for mapping and topographic surveying as objective and automated as possible.

REFERENCES

Anikeeva, I.A., Kadnichanskiy, S.A., 2017: Evaluation of the actual resolution of digital aerial and satellite imagery using an edge profile curve. *Geodesy and Cartography*. 78(6), 25–36. doi.org/10.22389/0016-7126-2017-924-6-25-36.

Anikeeva, I.A., 2020: Sharpness indicator of aerial- and space images obtained for mapping purposes. *Geodesy and Cartography*. 81(6), 25–36. doi.org/10.22389/0016-7126-2020-960-6-35-44.

Ancuti, C.O., Ancuti, C., De Vleeschouwer C., Bekaert, P., 2018: Color Balance and Fusion for Underwater Image Enhancement. *IEEE Transactions on Image Processing*. 27(1), 379-393. doi.org/10.1109/TIP.2017.2759252.

Ancuti, C.O., Ancuti, C., De Vleeschouwer C., Sbert, M., 2020: Color Channel Compensation (3C): A Fundamental Pre-Processing Step for Image Enhancement. *IEEE Transactions on Image Processing*. 29, 2653-2665. doi.org/10.1109/TIP.2019.2951304.

Chen, M., Zhang, H., Han, Q., Huang, C.C., 2019: A convex nonlocal total variation regularization algorithm for multiplicative noise removal. *EURASIP Journal on Image and Video Processing*. doi.org/10.1186/s13640-019-0410-2.

Hussain, M.A., Akbari, A.S., 2018: Color Constancy Adjustment Using Sub-Blocks of the Image. *IEEE Access*. 6, 46617-46629. doi.org/10.1109/ACCESS.2018.2866792.

Kuchko, A.S., 1974: *Aerial photography. Fundamentals and Metrology.* Nedra, Moscow.

Lapshenkov E.M., 2012: Non-reference assessment of digital image noise based on harmonic analysis. *Computer optics*. 36(3), 439-447.

Lapshenkov, E.M., 2013: Implementation of methods for estimating the image noise in MATLAB. *Bulletin of the Moscow State University of Instrumentation and Informatics. Instrumentation and information technology*. 44, 96-106.

Miao, C., 2019: Research on denoising processing of computer video electromagnetic leakage reduction image based on fuzzy degree. *EURASIP Journal on Image and Video Processing*. doi.org/10.1186/s13640-018-0405-4.

Su J.M., Liu L.L., Wan Q.T., Yang Y.Z., Li F.F., 2020: Dehazing research on brightness equalization model of drone image. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.* XLII-3/W10, 1289–1294. doi.org/10.5194/isprs-archives-XLII-3-W10-1289-2020.

Yang G., Evans A., 2021: Improved single image dehazing methods for resource-constrained platforms. *Journal of Real-Time Image Processing*. 18, 2511–2525. doi.org/10.1007/s11554-021-01143-6.