UDK 528.714:681.783.322:528.715:629.735
Pregledni znanstveni članak / Review

Testing of Image Quality Parameters of Digital Cameras for Photogrammetric Surveying with Unmanned Aircrafts

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ABSTRACT. Nowadays, unmanned aircrafts are more frequently used for measurement purposes. Size of aircrafts is often proportional to its price and load. Aircraft load of 2–3 kg, as required to lift DSLR camera, lens and gimbal (camera stabilizer) in the air, are higher-priced (>50,000 kn). Those kinds of aircrafts have their limits within the law, but also practical limitations because of its size. With the development of autonomous small size cameras such as action cameras appeared the ability to use cheaper, smaller and unmanned aircrafts with lower load in photogrammetric purposes. Of course, to use such a camera in measuring purposes first it is necessary to carry out adequate calibration method and define the elements of internal orientation of the camera. It is important to emphasize that the geometric calibration, or the elimination of geometric errors in the mapping is the key precondition to create idealized images i.e. images of actual optical mapping. This paper researches the quality of content mapped on images with the purpose of investigating the possibility of using action cameras in measuring purposes. The study is based on objective indicators such as global statistical image quality parameters, Modulation Transfer Function and visual analysis of test field images. For the purpose of the paper a modified test field based on the ISO 12233 standard was developed and for the first time used.

Keywords: image quality, unmanned aircrafts, MTF, ISO 12233.

1. Introduction

We are witnessing the increasing use of unmanned aircrafts in measuring purposes. There is a wide range of unmanned aircrafts that can be used in the measurement purposes but a basic requirement in order to use the aircraft for photogrammetric measurement is the possibility of installing digital cameras on the aircraft. One of the limiting factors of unmanned aircrafts is its load. There are aircrafts from several hundred to several million Euros that are used in measurement and

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other purposes and on it, as one of the basic measuring devices, is a digital camera. With the development of technology of digital cameras a wide range of digital cameras is produced regarding the quality, price, size and weight of the camera itself. Several years ago the market was flooded with small, so called high resolution action cameras. Such cameras are primarily developed and can be applied for documenting extreme sports, but because of their compactness they are also used in many other cases. The authors Schmidt and Rzhanov (2012) tested the possibility of using action cameras in underwater stereographic survey.

Of course, for the action cameras to be used in photogrammetric purposes it is necessary to conduct the calibration process, as well as for the other amateur cameras. In the paper Balletti et al. (2014) scientific research with the aim of determining the parameters of calibration and internal orientation in action camera was carried out. Along the process of geometric camera calibration, important information is the image quality if the camera is used for photogrammetric purposes. One of the main indicators of image quality in geometrical terms is the spatial resolution. The problem of determining image quality was researched by numerous authors in their works: Eskicioglu and Fisher (1995), Wang and Bovik (2002), Wang et al. (2004), Wang and Bovik (2009) and Gašparović and Malarić (2012). The real spatial resolution of digital camera is not set only by the number of effective pixels on image sensor matrix, but also by the quality of lens mapping, accuracy of focusing the camera lens to the object, atmospheric conditions, shutter speed and dynamics of the camera or the object. The impact of all the above mentioned elements takes into account the Modulation Transfer Function (MTF). MTF of digital images was researched by many authors in their works: Williams (1998), Burns (2000), Estribeau and Magnan (2004), Gül and Efe (2010) and Roland (2015).

In this paper the most important parameters for evaluating the image quality taken with Nikon D800E camera and Xiaomi Yi action camera will be given. On the basis of objective indicators comparison of the two cameras, conclusion and possibilities of action cameras application in the aerial photogrammetry will be given.

2. Image quality parameters

The image quality can be assessed by objective and visual methods. Image quality expressed in the resolution values, or the ability of recognizing number of lines per image height (LN/H) can be obtained by simply reviewing the image of the test fields template developed for the purposes of this research (Fig. 5). Such a parameter may be determined in different parts of the images and of course, in different axis.

Objective parameters for assessing the image quality can be divided in two categories: global statistical image quality parameters and MTF (Modulation Transfer Function).

2.1. Global statistical image quality parameters

For the purpose of this paper global statistical image quality parameters are:
- RMSE (Root Mean Squared Error)
- PSNR (Peak Signal-to-Noise Ratio)
- SNR (Signal-to-Noise Ratio)
- Korr (Correlation coefficient)
- σ (Standard deviation).

Formulas for statistical indicators SNR, RMSE, PSNR and Korr are given in the expressions (Gašparović and Malarić 2012, Gašparović 2015):

$$\mathrm{Korr} = \frac{\sum_{0}^{n_x-1}\sum_{0}^{n_y-1}\left[(r(x,y)-\bar{r})(t(x,y)-\bar{t})\right]}{\sqrt{\sum_{0}^{n_x-1}\sum_{0}^{n_y-1}\left[r(x,y)-\bar{r}\right]^2 \sum_{0}^{n_x-1}\sum_{0}^{n_y-1}\left[t(x,y)-\bar{t}\right]^2}} \tag{1}$$

$$\mathrm{SNR} = 10\log_{10}\left[\frac{\sum_{0}^{n_x-1}\sum_{0}^{n_y-1}\left[r(x,y)\right]^2}{\sum_{0}^{n_x-1}\sum_{0}^{n_y-1}\left[r(x,y)-t(x,y)\right]^2}\right] \tag{2}$$

$$\mathrm{MSE} = \frac{1}{n_x n_y}\sum_{0}^{n_x-1}\sum_{0}^{n_y-1}\left[r(x,y)-t(x,y)\right]^2 \tag{3}$$

$$\mathrm{RMSE} = \sqrt{\mathrm{MSE}} \tag{4}$$

$$\mathrm{PSNR} = 10\log_{10}\frac{L^2}{\mathrm{MSE}}, \tag{5}$$

where L is the dynamical range of allowable image pixel intensities. For 8-bit image L is $2^8 = 256$. Variables $r(x,y)$ and $t(x,y)$ represent two visual images, discrete signals, where n_x and n_y are numbers of matrix columns and rows, $\bar{r}$ and $\bar{t}$ are the mean raster matrix.

From conducted previous research (Gašparović and Malarić 2012, Gašparović 2015) and researching literature (Wang et al. 2004, Wang and Bovik 2009) it is known that greater value of PSNR, SNR and Korr or lower RMSE values and σ indicates a better and more accurate image. That kind of image represents a higher quality input, with higher spatial resolution and more realistic radiometric characteristics which is the foundation for further photogrammetric survey.

2.2. Modulation Transfer Function

Modulation Transfer Function is a value expressing how faithfully a system has mapped the taken scene, or the ratio of the output modulation produced by the system, and input modulation of spatial frequency (Holst 1998). Digital record of the taken scene, due to the imperfections of electro-optical system through which it was created, will not be identical to the real scene. This happens due to the limitations of certain parts of the system where it creates image. Modulation (M) is a variation of a sinusoidal signal around its mean value (Fig. 1), which can be described in the expression (Boreman 2001):

$$\mathrm{M} = \frac{\mathrm{V_{MAX}} - \mathrm{V_{MIN}}}{\mathrm{V_{MAX}} + \mathrm{V_{MIN}}}, \tag{6}$$

where $\mathrm{V_{MAX}}$ and $\mathrm{V_{MIN}}$ are maximum and minimum signal values.

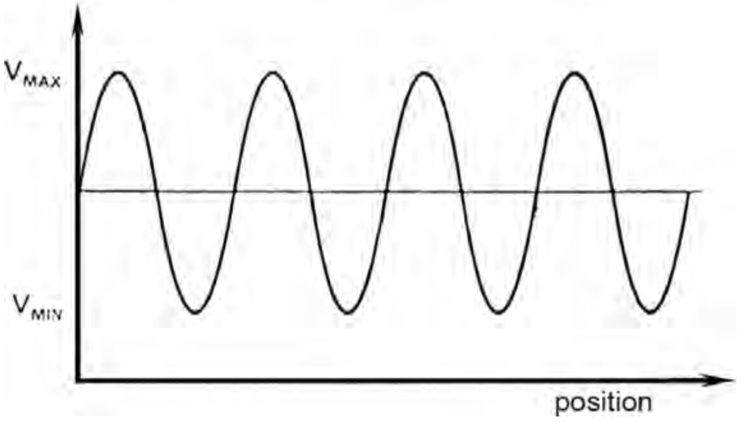


Fig. 1. *The definition of modulation described in expression (6) (Boreman 2001).*

MTF consists of magnitudes of sinusoidal response of different spatial frequencies of the optical system, or it shows the decrease of the modulation with increasing spatial frequency (Fig. 2).

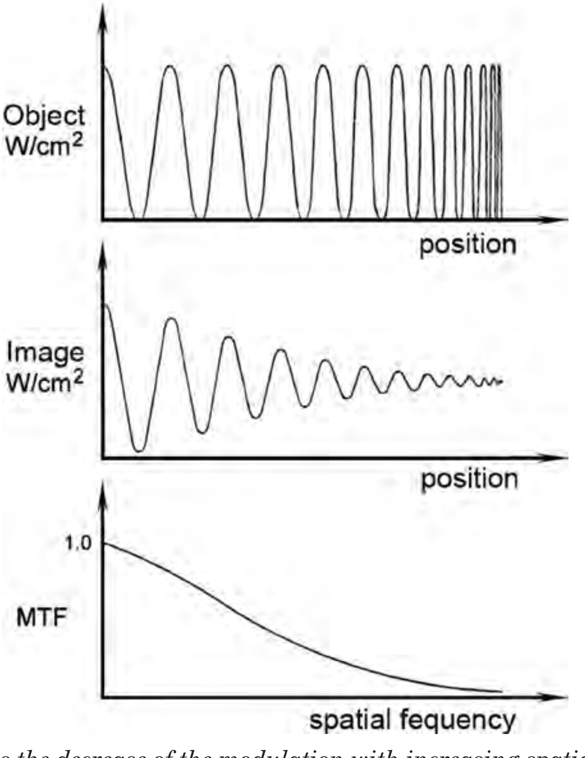


Fig. 2. *MTF shows the decrease of the modulation with increasing spatial frequency (Boreman 2001).*

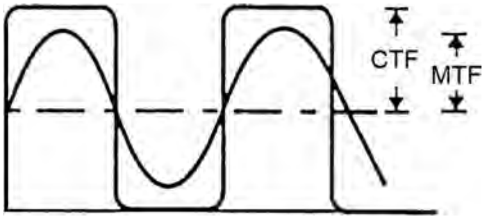


Fig. 3. *Representation of CTF and MTF (Holst 1998).*

There are two general methods for the determination of the MTF: direct method, based on measuring the response of sinusoidal signals with descending line width on the taken template and indirect method, which is based on the calculation of Fourier transformation of linear transfer function. Template with dotted lines with descending width is used to retrieve Contrast Transfer Function (CTF) and is mathematically translates into a sinusoidal response (MTF) using serial approximation. CTF is not a substitute for MTF, but presents a suitable measurement technique (Fig. 3). The response of the system in the form of rectangular waves is called the Contrast Transfer Function, which is usually equal to or higher than the MTF (Holst 1998).

The spatial frequency ξ is the reciprocal value of the spatial period X (distance between two peaks, amplitude, repeated value). The angular spatial frequency ξ_{ang} is the distance ratio of the system R from the object and the spatial period X (Fig. 4),

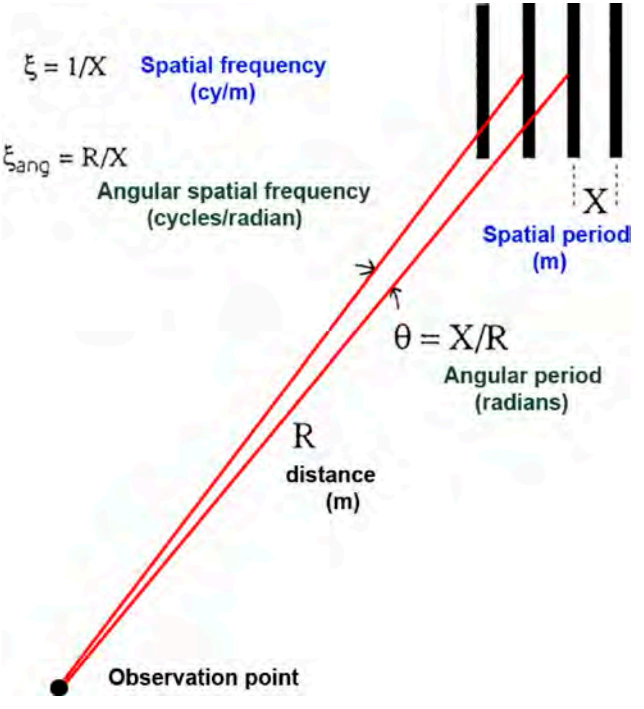


Fig. 4. *The spatial frequency (Boreman 2001).*

while the angular period Θ is the reciprocal value of spatial frequency $\xi_{ang.}$ (Boreman 2001). In the event that the samples are not periodic, or total line width is reduced, the minimum angular frequency determines the spatial resolution of the image.

The static response of the sensor is determined according to the expression (Holst 1998):

$$MTF\left(f_x\right)=\frac{\pi}{4}\left|CTF\left(f_x\right)+\frac{CTF\left(3f_x\right)}{3}-\frac{CTF\left(5f_x\right)}{5}+\frac{CTF\left(7f_x\right)}{7}+\frac{CTF\left(11f_x\right)}{11}\right| , \qquad (7)$$

where is:

$MTF\left(f_x\right)$ – Statistical MTF

$CTF\left(f_x\right)$ – Contrast Transfer Function

f – Spatial frequency.

3. Test field development and measurement

To be able to implement all previous theoretically explained research it was necessary to define an adequate test field. Today, for testing spatial resolution in digital cameras according to ISO standard (URL 1) it is most commonly used ISO 12233 test field (URL 2). To further examine the focus of the optical system on the test field a template of the Siemens star was added (URL 3). For more precise determination of the MTF (indirect method) slanted-edge chart is added on the template. In order to more accurately define the maximum value in determining MTF, sinusoidal field with bars was added to the chart. The final template of the test field underlying this study is shown in Fig. 5. The numbers shown in the test

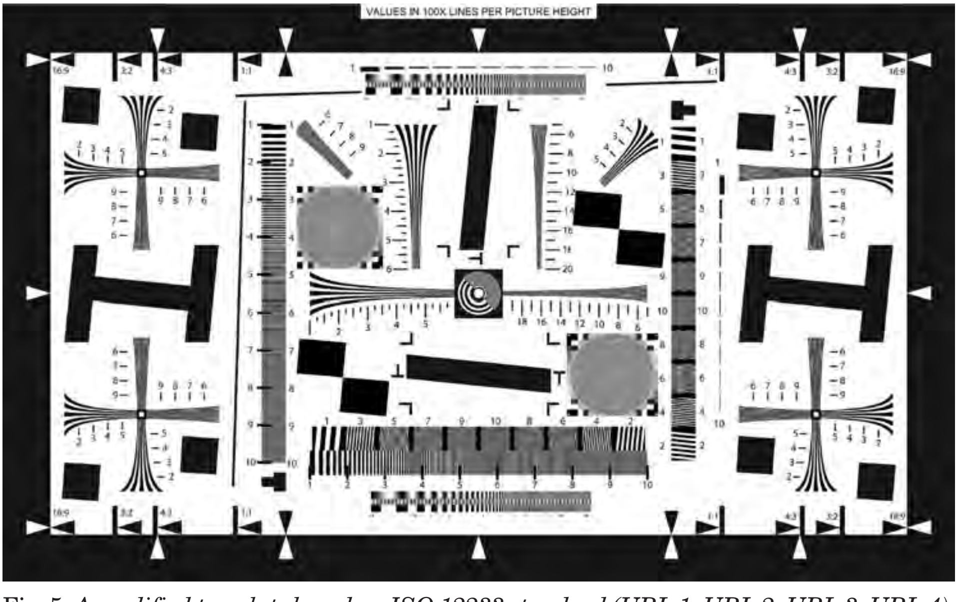


Fig. 5. *A modified template based on ISO 12233 standard (URL 1, URL 2, URL 3, URL 4).*

field indicate the resolution in 100X line per raster matrix height. So, if we can discern the bars through the number 19 in test field, this means that maximum of 1900 lines in image height can be discern in the digital image. If digital image height is 4912px, that means that for defining a pair of lines (black and white) or one cycle takes 2.59px.

In this study two cameras were tested: DSLR (Digital single-lens reflex camera) Nikon D800E camera (No. 6021274) with SIGMA DGRF20/1.8 lens (No. 2004569) and Xiaomi Yi action camera (No. Z221514A4991014). Table 1 shows the characteristics of digital cameras used in this study.

Table 1. *The characteristics of digital cameras used in the research (URL 5, URL 6, URL 7).*

Digital camera	**Nikon D800E**	**Xiaomi Yi**
Sensor type	CMOS	CMOS
Sensor size	35.9 x 24.0 mm	6.2 x 4.7 mm
Pixels size on the sensor	4.9 μm	1.34 μm
Number of pixels	36.8 million	16 million
Max. image size	7360 x 4912 px	4608 x 3456 px
Sensor sensitivity	ISO 100 – 6400	ISO 100 – 25600
Max. aperture	F1.8	F2.8
FOV	94.4°	155°
Focal length	20 mm	3 mm
Size	146 x 123 x 81.5 + 87 mm lens	60.4 x 42 x 21.2 mm
Weight	1000 g + 520 g lens	76.6 g

The research was conducted in the laboratory of the Chair of Photogrammetry and Remote Sensing of the Faculty of Geodesy. Given that both cameras have a fixed focal length they are set at an appropriate distance from the template so that the height of the images coincides with the height of the template. Both cameras captured the RAW and JPG format images which were used in the study.

4. Image quality analysis

In this chapter the results of research based on the test field developed for this study were given (Fig. 5). The main objective is the testing and analysis of spatial resolution of Nikon D800E camera and Xiaomi Yi action camera.

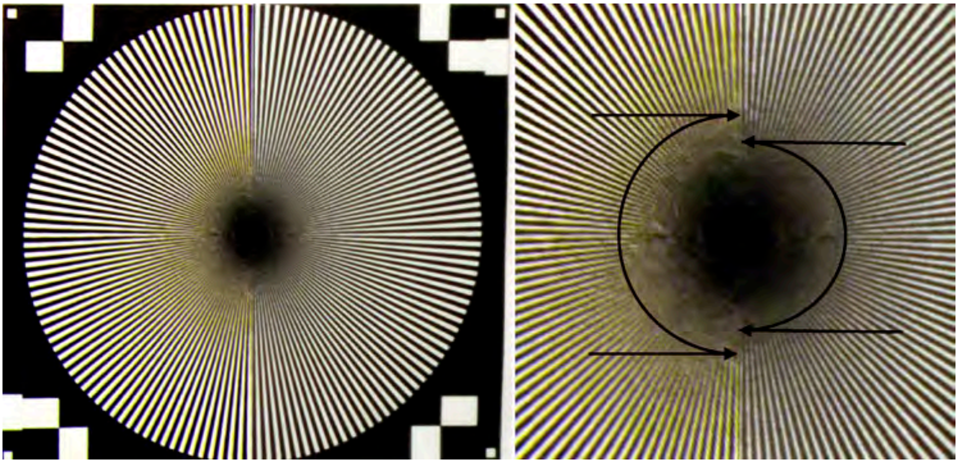


Fig. 6. *a) Siemens star taken with Xiaomi Yi camera (left) and with Nikon D800E (right) and b) magnification.*

From the Fig. 6 and Fig. 7 parameters of images resolution from different cameras are determined by visual analysis (Table 2). For the purposes of determining the objective indicators of image quality, MTF graphs for images obtained by

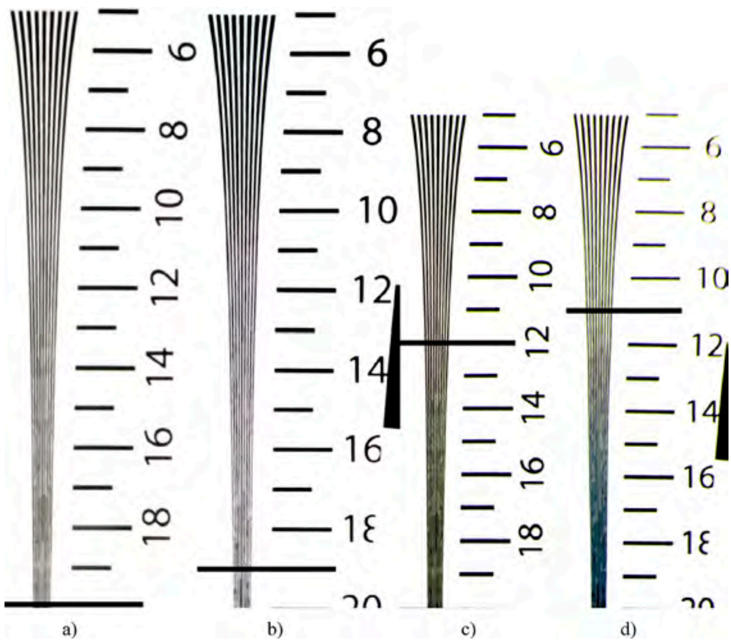


Fig. 7. *Testing the resolution of images taken with Nikon D800E camera (left – a and b) and Xiaomi Yi camera (right – c and d) along the vertical axis (a and c) and along the horizontal axis (b and d).*

different cameras were made (Fig. 8 and Fig. 9, Table 2) as well as global statistical image quality parameters (Table 3). Since it was necessary to examine the resolution on the horizontal and vertical axes, special graphs were made. Authors Holst (1998) and Boreman (2001) note that the limit resolution defines the value of 10% of the MTF or on the Fig. 8 and Fig. 9 it is the MTF = 0.1. The value of frequency, or cycles per pixel for the MTF value it is the minimum value that can be detected on the image.

Table 2. *Image resolution obtained by an objective analysis of the test field.*

Axis	**Unit**	**Nikon D800E**	**Xiaomi Yi**
Vert.	No. lines per image height	2000	1200
Horiz.	No. lines per image height	1900	1100
Vert.	No. lines per px (Freq.)	0.4072	0.3472
Horiz.	No. lines per px (Freq.)	0.3868	0.3183
Vert.	No. px per line	2.46	2.88
Horiz.	No. px per line	2.59	3.14
Vert.	Freq. for MTF=0.1	0.308	0.266
Horiz.	Freq. for MTF=0.1	0.264	0.223

From the values shown in Table 2 it is clearly seen the correlation between the data obtained by the MTF graph and by visual analysis. The values of frequency for MTF = 0,1 and the number of lines per pixel should be identical for the same cameras and axes. Of course, as the values of the number of lines per pixel are obtained by visual assessment of the observer there is a small deviation. It is important to emphasize that trends and relative relations match, so it can be said that the Nikon D800E camera has a better resolution than Xiaomi Yi.

Independent objective assessment of quality was carried out on the basis of the previously described global statistical parameters (section 2.1). To determine the parameters σ, Korr, RMSE, PSNR and SNR images taken with Xiaomi Yi and Nikon D800E cameras were compared with the original template in digital form. Raster matrix of the template was taken as “should”, and images taken by each camera as “is”. The values of the image quality parameters calculated for each band (red, green and blue), and for the grayscale band are shown in Table 3. From these values it is clear that for each band values of PSNR, SNR and Korr are higher in Nikon D800E while the values of RMSE and σ are higher in Xiaomi Yi.

This confirms that the images obtained by Nikon D800E camera are better or more accurate.

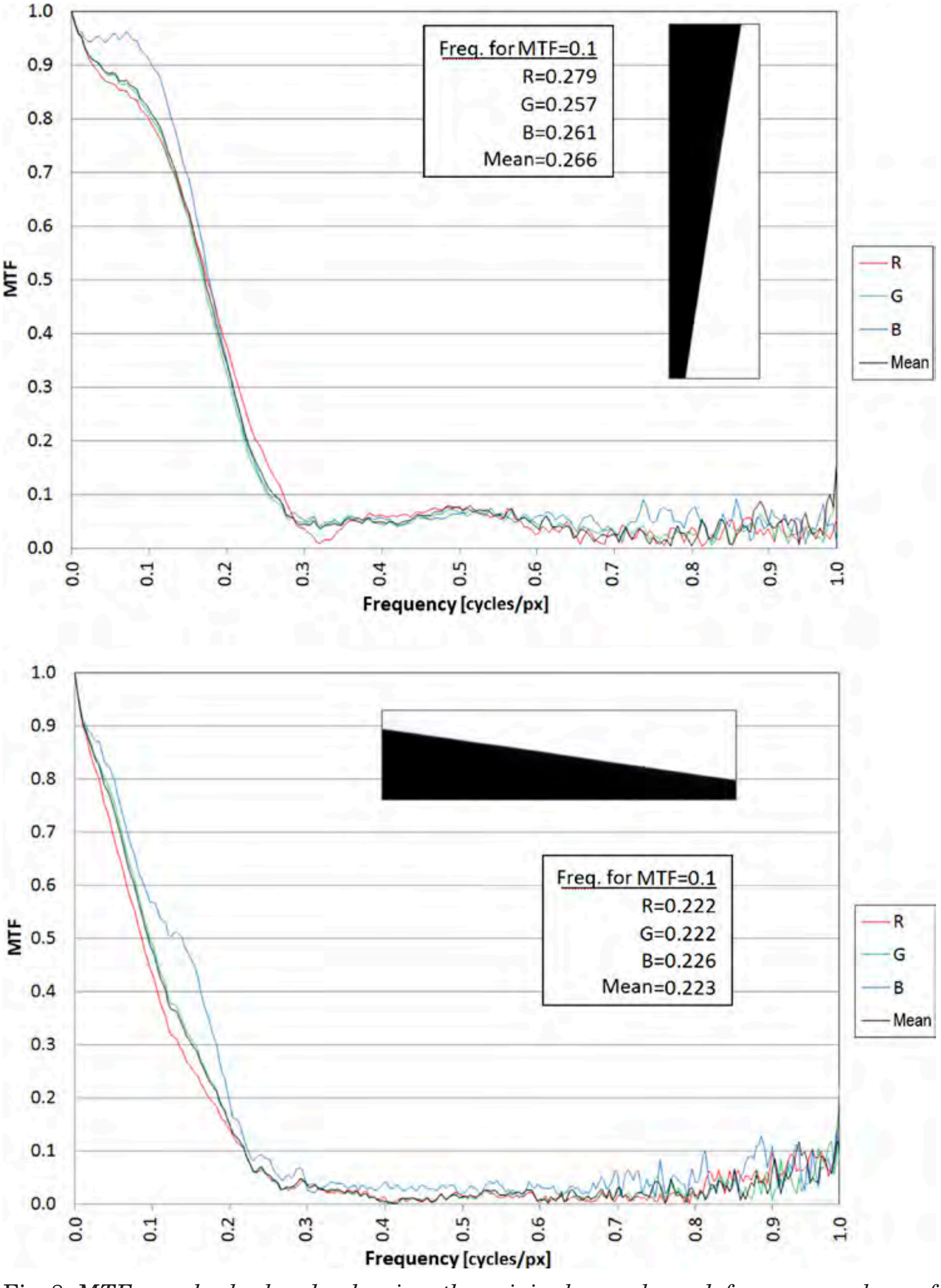
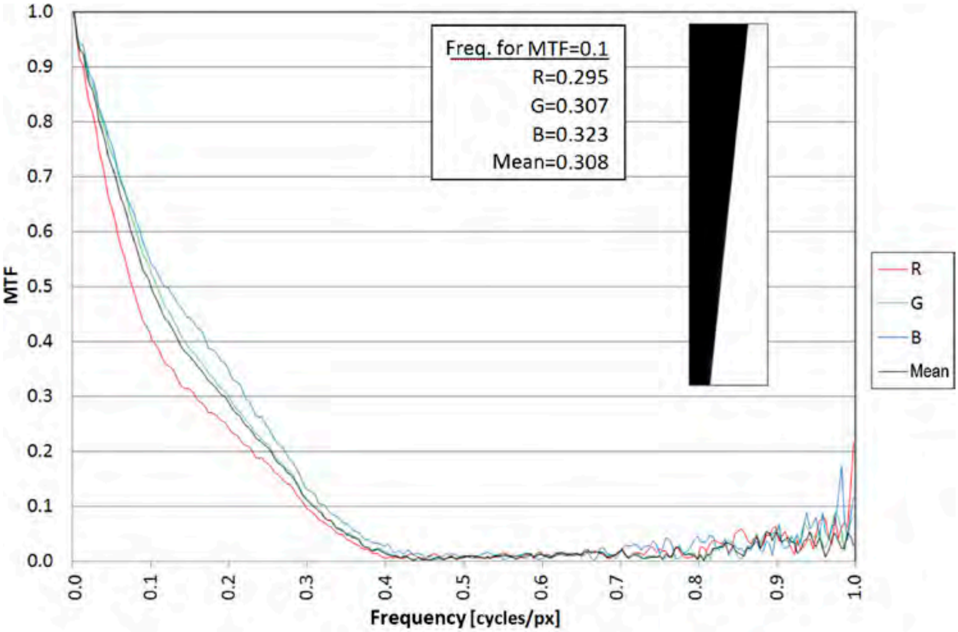


Fig. 8. *MTF graphs by bands showing the original sample and frequency values of MTF = 0.1 for the Xiaomi Yi camera based on the vertical (up) and horizontal (down) slanted-edge.*



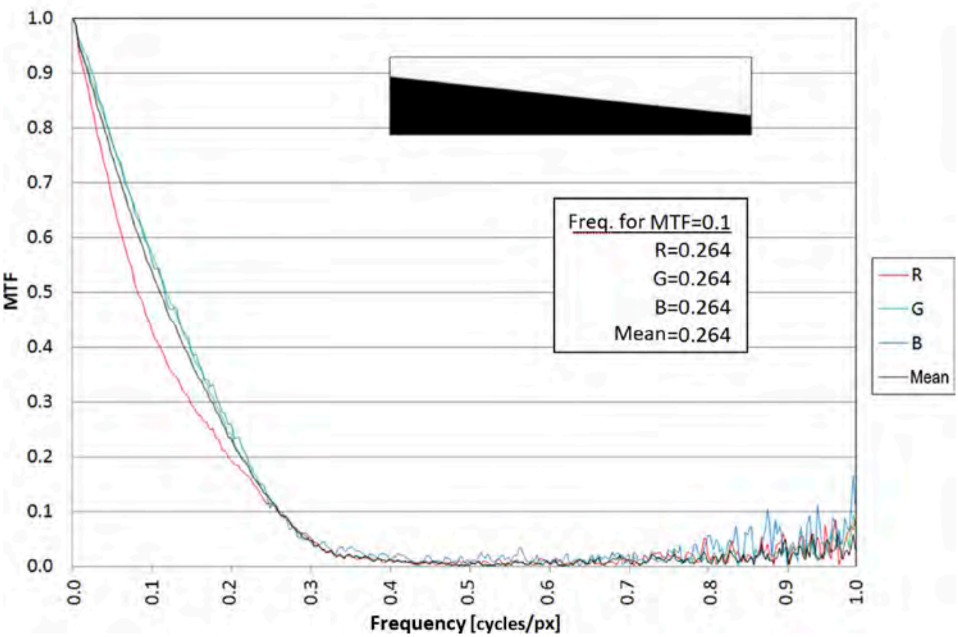


Fig. 9. *MTF graphs by bands showing the original sample and frequency values of MTF = 0.1 for the Nikon D800E camera based on the vertical (up) and horizontal (down) slanted-edge.*

Table 3. *Global statistical image quality parameters*.

Camera	Band	σ	Korr	RMSE	PSNR [dB]	SNR [dB]
Nikon D800E	Red	94.9368	0.56450	94.8559	8.6235	7.079
Nikon D800E	Green	96.5606	0.55429	97.8910	8.3499	6.814
Nikon D800E	Blue	100.2938	0.54868	99.5109	8.2074	6.673
Nikon D800E	Grayscale	95.4030	0.55786	96.9637	8.4326	6.886
Xiaomi Yi	Red	120.2579	0.49555	98.2373	8.3193	6.911
Xiaomi Yi	Green	121.5206	0.49981	99.5298	8.2057	6.767
Xiaomi Yi	Blue	120.1591	0.47431	106.6444	7.6060	6.281
Xiaomi Yi	Grayscale	116.6063	0.49905	99.2006	8.2345	6.776

5. Conclusion

Primarily, it can be concluded that action cameras with their size and weight compared to DSLR digital cameras make photogrammetric survey with unmanned aircrafts cheaper and easier. The Xiaomi Yi camera is 20 times lighter than the Nikon D800E and if we add the weight of the gimbal which is usually as heavy as the camera then it comes to unbelievable 40 times difference in weight between the recording systems on the aircrafts. In this way the costs are optimized and the aircraft itself becomes more practical for the field work. Also, the legal framework restricts the use of aircraft depending on their weight.

Of course, to use such a camera in photogrammetric purposes first it is necessary to carry out camera calibration and examine the image quality. The main aim of this study was to assess and compare the image quality obtained by the action and DSLR cameras. From the results of independent research conducted in this study it is clearly demonstrated that the Nikon D800E camera has higher quality than the Xiaomi Yi camera. We can single out two indicators such as the number of lines per px (Freq.) obtained from the MTF graph for MTF = 0.1 which represents the limit of sharpness. Thus, the Nikon D800E has a frequency for MTF = 0.1 per vertical axis of 0.308, and the horizontal axis of 0.264, while Xiaomi Yi has 0.266 per vertical and 0.223 per horizontal axis. The reciprocal value of this number represents a number of pixels per line and Nikon D800E has 3.25 per vertical and 3.79 per horizontal axis, and the Xiaomi Yi has 3.76 per vertical and 4.48 per horizontal axis. It is shown from these values that the Nikon D800E has about 15% better image quality in both directions. If we compare the values obtained by visual analysis of the test field we come to 16% better image quality on the D800E camera. It should be noted that all global statistical indicators (across all bands) indicate that the images taken with the Nikon D800E camera have higher quality than Xiaomi Yi camera. The differences between the cameras are not so big, which coincides with other studies already mentioned in this paper.

The difference of 15% in the image quality taken with Nikon D800E and Xiaomi Yi is a really surprising result for the action camera. It should be noted that the price of digital camera Nikon D800E and Sigma lenses used in the study is 70 times higher than the price of the Xiaomi Yi action camera. If we add the difference in the weight of one camera over another and the price and the size of the potential aircraft for each of the two tested cameras, we come to the conclusion that the use of action cameras in photogrammetric purposes significantly reduce the cost of the entire system with a small and controlled deterioration of image quality.

References

Balletti, C., Guerra, F., Tsioukas, V., Vernier, P. (2014): Calibration of Action Cameras for Photogrammetric Purposes, Sensors, Vol. 14, No. 9, 17471–17490.

Boreman, G. D. (2001): Modulation transfer function in optical and electro-optical systems, SPIE Press, Bellingham, Washington.

Burns, P. D. (2000): Slanted-edge MTF for digital camera and scanner analysis, Image Processing, Image Quality, Image Capture, Systems Conference, 16–19. 3. 2000, Portland, 135–138.

Eskicioglu, A. M., Fisher, P. S. (1995): Image quality measures and their performance, IEEE Transactions on Communications, Vol. 43, No. 12, 2959–2965.

Estribeau, M., Magnan, P. (2004): Fast MTF measurement of CMOS imagers using ISO 12333 slanted-edge methodology, Proceedings of SPIE, International Society for Optics and Photonics, Vol. 5251, No. 1, 1–10.

Gašparović, M., Malarić, I. (2012): Increase of readability and accuracy of 3D models using fusion of close range photogrammetry and laser scanning, International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XXXIX-B5, XXII ISPRS Congress, 25. 8.–1. 9. 2012, Melbourne, 93–98.

Gašparović, M. (2015): Radiometrijsko izjednačenje tekstura fotorealističnih 3D modela, doktorski rad, Geodetski fakultet Sveučilišta u Zagrebu, Zagreb.

Gül, N., Efe, M. (2010): Improved analytical modulation transfer function for image intensified charge coupled devices, Turkish Journal of Electrical Engineering & Computer Sciences, Vol. 18, No. 1, 71–82.

Holst, G. C. (1998): CCD arrays, cameras and displays, SPIE Optical Engineering Press, Bellingham, Washington.

Roland, J. K. (2015): A study of slanted-edge MTF stability and repeatability, Proceedings of SPIE, International Society for Optics and Photonics, Vol. 9396, No. 1, 1–9.

Schmidt, V. E., Rzhanov, Y. (2012): Measurement of micro-bathymetry with a GOPRO underwater stereo camera pair, Oceans, 14–19. 10. 2012, Hampton Roads, 1–6.

Wang, Z., Bovik, A. C. (2002): A universal image quality index, IEEE Signal Processing Letters, Vol. 9, No. 3, 81–84.

Wang, Z., Bovik, A. C. (2009): Mean Squared Error: Love it or Leave it?, IEEE signal processing magazine, Vol. 26, No. 1, 98–117.

Wang, Z., Bovik, A. C., Sheikh, H. R., Simoncelli, E. P. (2004): Image quality assessment: from error visibility to structural similarity, IEEE Transactions on Image Processing, Vol. 13, No. 4, 600–612.

Williams, D. (1998): Benchmarking of the ISO 12233 slanted-edge spatial frequency response plug-in, Image Processing, Image Quality, Image Capture, Systems Conference, 17–20. 5. 1998, Portland, 133–136.

URLs

URL 1: ISO 12233:2000, http://www.iso.org/iso/catalogue_detail?csnumber=33715, (21. 12. 2015).

URL 2: ISO 12233 Test Chart, http://www.graphics.cornell.edu/~westin/misc/res-chart.html, (21. 12. 2015).

URL 3: High Resolution Test Patterns, http://www.bealecorner.org/red/test-patterns/, (19. 12. 2015).

URL 4: Norman koren, http://www.normankoren.com/, (22. 12. 2015).

URL 5: Nikon Imaging, http://imaging.nikon.com/, (22. 12. 2015).

URL 6: Xiaomi Yi, http://www.xiaoyi.com/, (23. 12. 2015).

URL 7: Sony IMX206CQC/IMX206HQC, http://www.sony.net/Products/SC-HP/new_pro/december_2013/imx206_e.html, (5. 1. 2016).

Ispitivanje parametara kvalitete snimki digitalnih kamera za potrebe fotogrametrijske izmjere primjenom bespilotnih letjelica

SAŽETAK. U današnje je vrijeme sve češća upotreba bespilotnih letjelica u mjerne svrhe. Veličina bespilotne letjelice često je proporcionalna cijeni i nosivosti. Letjelice nosivosti 2–3 kg, koliko je potrebno da se u zrak podigne DSLR kamera i objektiv te stabilizator kamere (engl. gimbal), višeg su cjenovnog razreda (>50000 kn). Takve letjelice imaju svoja ograničenja u zakonskim okvirima, ali i praktična ograničenja zbog svoje veličine. Razvojem autonomnih kamera malih dimenzija, kao što su akcijske kamere, pojavila se mogućnost korištenja jeftinijih, manjih te bespilotnih letjelica manje nosivosti u fotogrametrijske svrhe. Naravno, kako bi se takva kamera mogla koristiti u mjerne svrhe potrebno je prije svega provesti adekvatnu metodu kalibracije te definirati elemente unutarnje orijentacije kamere. Važno je naglasiti kako je geometrijska kalibracija, odnosno eliminacija geometrijskih pogrešaka u preslikavanju, ključan preduvjet u stvaranju idealizirane snimke, tj. snimke stvarnog optičkog preslikavanja. U ovom radu provedeno je ispitivanje kvalitete preslikanog sadržaja na snimke s ciljem ispitivanja mogućnosti korištenja akcijskih kamera u mjerne svrhe. Istraživanje se temelji na objektivnim pokazateljima kao što su globalni statistički parametri kvalitete snimki i modulacijska prijenosna funkcija te vizualna analiza snimki testnog polja. Za potrebe rada razvijeno je i po prvi puta korišteno modificirano testno polje temeljeno na normi ISO 12233.

Ključne riječi: kvaliteta snimki, bespilotne letjelice, MTF, ISO 12233.

Primljeno / Received: 2016-07-04

Prihvaćeno / Accepted: 2016-08-19