THE USE OF WAVELETS FOR NOISE DETECTION IN THE IMAGES TAKEN BY THE ANALOG AND DIGITAL PHOTOGRAMMETRIC CAMERAS

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ABSTRACT:

In the paper the use of wavelet transformation for valorization of random noise content in photogrammetric images is proposed. There were two wavelets indicators studied. The first indicators based on the analysis of the wavelet detail coefficients distribution shape. As the results prove, noise conclusions based on the shape are not always objective. As the second noise indicator the analysis of changing of relative variance during decomposition was researched. Based on the studies, it has been proven that the analysis of the equation of preservation of image relative variance is a good indication of the noise level. The low noise level is proven by a stable increase of the details variance along with the level of decomposition. In case of fine-grained image texture, such increase is undisturbed. For the research a set of aerial images taken by two photogrammetric cameras, analogue LMK and digital DMC was compared. In all examined cases the better parameters of the noise evaluation were obtained for the digital camera. The researches confirmed the possibility to define the noise content indicators based on the analysis of the wavelet detail coefficients.

1. INTRODUCTION

The radiometric quality is often neglected when looking for the reasons of the unsatisfactory quality of the automatic images analysis. Meanwhile, the image noise can substantially reduce the efficiency of image processing, especially in the case of images with low contrast and containing many fragments with fine-grained texture, with which we deal often in photogrammetry and remote sensing.

We have witnessed the process of replacing the analogue photogrammetric cameras with digital ones. Direct digital image acquisition reduces the number of stages in which noise can occur, but does not liquidate the problem of its occurrence. Noise should be regarded as an immanent feature of the photogrammetric images, similarly to, for example, lens distortion.

For some years the discrete wavelet transformation has been used in the image processing. The wavelet transformation is regarded as the most effective method of lossy compression of multitonal images and is more and more often used in the photogrammetric working stations. In this paper the using of wavelets for evaluation of the image random noise is proposed.

2. THE NEED FOR IMAGE NOISE INDICATORS

Noise is any random or deterministic disturbance of luminance of a hypothetical image that would come into existence in the ideal conditions (Morain, 2004). Image noise together with radiometric resolution, contrast, tonal matching are elements shaping radiometric quality. Noise arises in the different stages of the image acquisition: during the image forming, sampling, encoding, compression, transmission and during image processing.

Random noise is present practically in any image, but is not always noticed. In the analogue images, the source of random noise is the granular structure of photographic emulsion. Noise in the digital images is caused by instability of detectors, including - to some extent – detector's own noise.

Random noise, because of its unpredictable character, cannot be removed completely from the image. One can only smooth over the effects of its occurrence. We face a dilemma: Is it better to reduce the noise level at the expense of the edges sharpness or the other way round? The photogrammetric and remote sensing multitonal landscape images, which are taken from large distances predominate, have frequently low local contrast and small signal-to-noise ratio. This is why there is a need to look for the indicators of noise content.

3. THE USEFULLNESS OF WAVELET FOR NOISE DETECTION – THEORETICAL STUDY

3.1 Basic features of wavelet transformation

Wavelet transformation demonstrates some features shared with Fourier transformation. The Fourier transformation converts the signal from spatial domain into frequency domain. The wavelet transform is a frequency-spatial representation, i.e. it is possible

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to localize each coefficient spatially, what is impossible in the case of Fourier transform.

3.2 Mallat's Multiresolution Analysis

The procedure for determining the image wavelet expansions (two-dimensional signals) with the help of multi-level decomposition utilizing one-dimensional filters, separately applied to the rows and columns of the image, was given by (Mallat, 1998). There are four components in the wavelet expansion of the image: so-called coarse component (LL) and three details, named as vertical- (LH), horizontal- (HL) and diagonal (HH) detail. The characteristic feature of wavelet transformation is the possibility to continue applying it to the chosen component. This is the coarse detail that is expanded most often.

3.3 The dependence of noise and wavelet coefficients distribution

Simonceli noticed that wavelet detail coefficients distribution has a sharp maximum in zero and has a good symmetry, whereas the flattening of histogram is correlated with the presence of noise in the image (Simonceli, 1996, 1999). The kurtosis, which is the fourth moment divided by the square of the variance, was employed as a parameter describing the histogram shape.

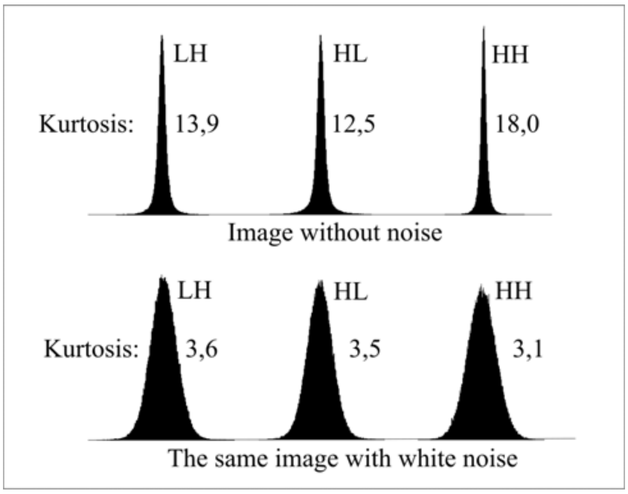

Figure 1. The histograms of wavelets detail components

It was claimed (Pyka, 2005) that the estimation of the shape of coefficients distribution should be made for all three detail components, but it is enough to limit research to wavelet decomposition on one level of resolution. Further decomposition of coarse component (LL) does not give more information on noise, because each subsequent coarse component is the effect of the smoothing of the preceding one, what decreases the noise content. In Figure 1 the typical histograms of three wavelets components for a image without noise and for the same image with white noise are shown.

3.4 The rule of image preservation of energy through its wavelet transform

The wavelet decomposition preserves the image energy (Mallat, 1998). In case of decomposition on first level of resolution we can write:

$$E(I) = E(LL_1) + E(LH_1) + E(HL_1) + E(HH_1) \qquad (1)$$

where $E(I)$ = energy of image I
$E(LL_1)$ = energy of coarse component LL on first level of decomposition
$E(LH_1)$, $E(HL_1)$, $E(HH_1)$ = energy of details components LH,HL,HH (on first level of decomposition)

Further decomposition of coarse component allows writing:

$$E(LL_1) = E(LL_2) + E(LH_2) + E(HL_2) + E(HH_2) \qquad (2)$$

where $E(LL_2)$ $E(LH_2)$, $E(HL_2)$, $E(HH_2)$ = energy of components on second level of decomposition

The general form of equation (1) and (2) is shown below:

$$E(I) = E(LL_R) + \sum_1^R \left[E(LH_R) + E(HL_R) + E(HH_R)\right] \qquad (3)$$

where R = the number of level of decomposition

3.5 The equation of relative variance preservation by wavelet decomposition

The equation (3) is also true when we use variance instead of energy (Pyka, 2005):

$$V(I) = V(LL_R) + \sum_1^R \left[V(LH_r) + V(HL_r) + V(HH_r)\right] \qquad (4)$$

where $V(I_1)$ = variance of image
$V(LL_R$ = variance of coarse components on level R of decomposition,
$V(LH_r)$, $V(HL_r)$, $V(HH_r)$ = variance of detail components on level r of decomposition

The image variance is dependent of pixels value scaling. If we linearly transform the image pixels value (called also brightness or DN) then the wavelet components undergo the same transformation. It is disadvantage of rule given by equation (4). When we divide either side of equation (4) by $V(I)$ we receive the following equation:

$$1 = \frac{V(LL_R)}{V(I)} + \frac{1}{V(I)} \sum_1^R \left[V(LH_r) + V(HL_r) + V(HH_r)\right] \qquad (5)$$

The equation (5) shows that the sum of relative variance of wavelet transform components equals 1 and that is true for any levels of decomposition. It is worth to note that the rule is independent of pixels value scaling. For images without noise the following rule should be true:

$$V(LH_r) + V(HL_r) + V(HH_r) < \\ V(LH_{r+1}) + V(HL_{r+1}) + V(HH_{r+1}) \quad (6)$$

where $V(LH_r)$, $V(HL_r)$, $V(HH_r)$, $V(LH_{r+1})$, $V(HL_{r+1})$, $V(HH_{r+1})$ = variance of detail components on level r and level r+1 of decomposition

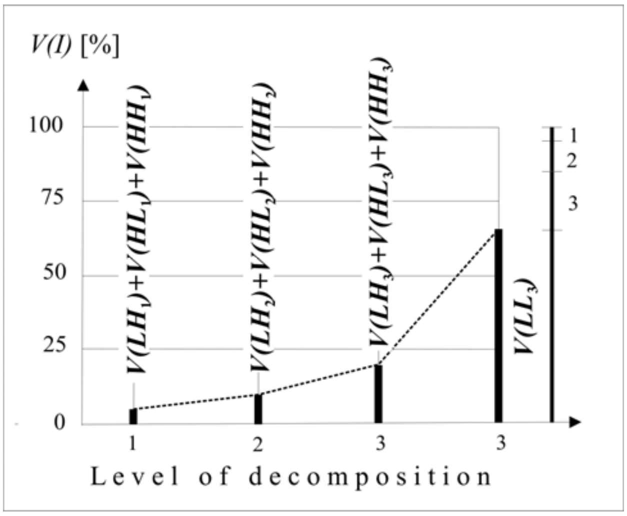

Figure 2. The illustration of equation of relative variance preservation by wavelet decomposition

The speed of the relative variance growing is connected with the density and power of edges. In other words the growing of speed depends of scale and image contents.

For image with noise the following rule was established:

$$V(LH_1) + V(HL_1) + V(HH_1) > \\ V(LH_2) + V(HL_2) + V(HH_{21}) \quad (7)$$

Therefore the equation (5) is useful for comparing multi-level wavelets transform of different aerial images taken from analogue and digital cameras.

4. THE USEFULLNESS OF WAVELET FOR NOISE DETECTION – PRACTICAL STUDY

4.1 The research data

For the research a set of aerial images taken by two cameras, analog and digital photogrammetric, was used. The main characteristic of the research data are described below:

Images from analogue camera:

- camera type LMK1000 (Zeiss Jena),
- lens type LAMEGON,
- focal length 153mm,
- film: AGFA Aviphot Color X100,
- developing process: C-41,
- photo scale: 1:10 000 (medium) and 1:26000 (small),
- scanner: DELTA SCAN
- scanning resolution: 12 µm and 14 µm (respectively for medium and small scale)
- GSD: 12 cm (medium) and 36 cm (small scale),
- photo capturing: October 2003 (medium) and June 2006 (small scale).

Images from digital camera:

- camera type: DMC (Z/I Imaging),
- focal length 120 mm,
- pixel size: 12 µm,
- photo scale: 1:12 000 (medium) and 1:38000 (small),
- GDS=14 cm (medium) and 46 cm (small scale),
- photo capturing: October 2007 (medium) and September 2007 (small scale).

The images were taken and delivered in TIFF format without compression by MGGP AERO company from Tarnow, Poland (http://www.mggpaero.com).

The images were selected in pair which were composed of analogue and digital image. An example of pair in medium and small scale is showed in Figures 3 and 4 respectively.

Figure 3. The pair of analogue and digital images in medium scale

Figure 4. The pair of analogue and digital images in small scale

4.2 The research method and tools

For each pair of photographs, corresponding fragments of the same contents were selected. That task was more challenging for photos in a smaller scale, as the analogue photographs were taken in 2003, and the digital ones in 2007. As far as possible, fragments of uniform land use were selected, e.g. buildings, parking lots, fields, forests. That made it possible to observe how the land use affected the wavelet transform. 25 fragments of images altogether were selected for the tests in the medium scale and 9 fragments of images in small scale. Prior to the analysis of noise content, coloured images were replaced with a resultant luminance image, using equation:

$$I = 0{,}299R + 0{,}587G + 0{,}114B \tag{8}$$

where I = luminance image
R,G,B = channels of colour image

Matrix algorithm with the third order Coiflet filters was used for the wavelet transform. The transform was carried out with the aid of procedures written in the R environment. Selected fragments were sized 1024 * 1024 pixels. Additionally, frames in individual pairs were so masked to have the same contents. That was indispensable due to various scales of the analogue and digital photographs.

The wavelet decomposition was continued until the third resolution level, in which the components had the size of 256 * 256 pixels. Kurtosis and variance for individual components was established. Afterwards, the equation of preservation of image relative variance was formulated.

4.3 The research results

It was found that the kurtosis for analogue photographs is always lower than that of the digital photographs. The kurtosis for analogue photographs varies between 3 and 3.5, irrespective of the method of use and scale of the photos. The variability of the kurtosis between detailed components is not visible. For the analogue photographs examined, the distribution of detailed components may be modelled with the aid of a normal distribution, the kurtosis of which equals 3.

According to the studies, the kurtosis for digital photographs is generally larger and, at the same time, exhibits greater diversity. Both for the medium and small-scale photographs, the detail kurtosis is above 10, with one exception however. The exception refers to forested areas and parks of dense forest stand. The kurtosis in such areas is smaller: for the medium scale, the kurtosis is around 6, and 4 for the small scale accordingly. Such phenomenon may be explained by the fact that the distribution of the wavelet components is sensitive to the natural image structure. The image of trees in the photographs is of grainy structure, the finer the lower the scale of the photos is.

As the results prove, noise conclusions based on the kurtosis are not always objective. There are cases observed in which a flat distribution, resembling the Gaussian one, does not result from the random noise, but is the effect of natural fine structure of the image.

Based on the analysis of the equation of preservation of image relative variance, the following rules were established:

- the relative variance of details in images from digital camera increases along with the decomposition – as indicated by the grey zone in figures 5 and 6, which encompass the results for all examined fragments of photographs,
- the relative variance in images from analogue camera decreases between 1 and 2 decomposition level and, then increases slowly or is stable – as shown by the zone with signature marks in figures 5 and 6, which encompass the results for all examined fragments of photographs

In order to better mark the changes of variance for further levels of decomposition, in figures 5 and 6, the average changing tendency was marked with an open polygon. From the theoretical point of view, figure 2 is more appropriate, which shows the values of relative variance of discrete, not continuous, character. Moreover, figures 5 and 6 do not include the variance of the coarse component. The value of that variance can be easily established based on the formula (5).

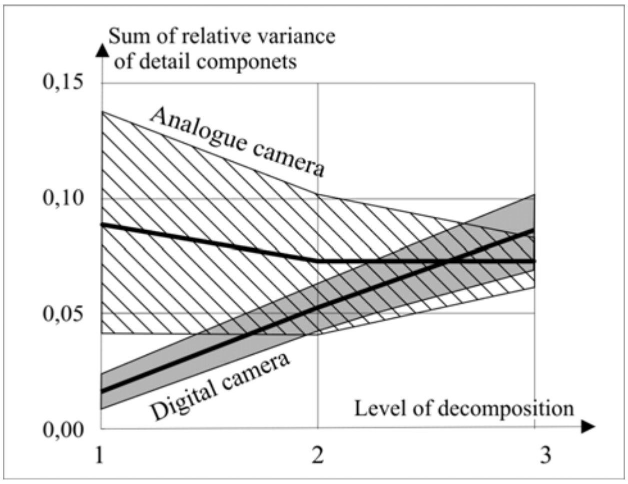

Figure 5. The changes of relative variance for images in medium scale

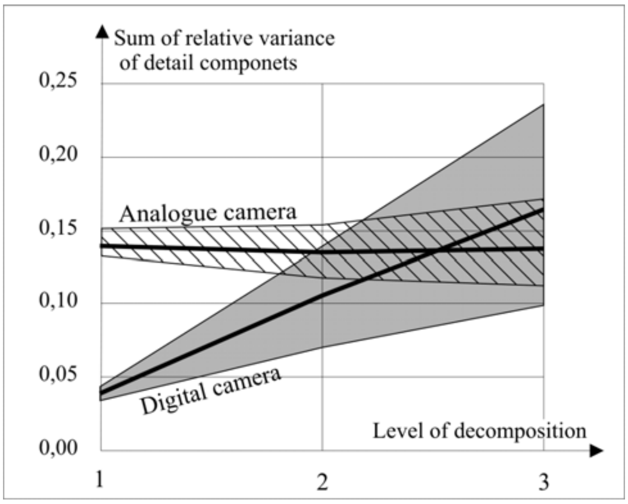

Figure 6. The changes of relative variance for images in small scale

5. CONCLUSIONS

It has been confirmed in the paper that, based on the distribution of wavelet components, the share of random noises in an image can be established. It has been shown that the flattening of the histogram of wavelet coefficients is also affected, apart from the noise, by the natural image texture. Hence, the shape of the histogram of wavelet details is not always correlated with the noise level.

Based on the studies, it has been proven that the analysis of the equation of preservation of image relative variance is a good indication of the noise level. The low noise level is proven by a stable increase of the details variance along with the level of decomposition. In case of fine-grained image texture, such increase is undisturbed.

Great difference in the contents of random noise has been confirmed by the comparison of images from the digital and analogue cameras. The DMC images contain several times less random noise than those from an analogue camera.

The studies described are not exhaustive as regards the use of wavelets for valorisation of radiometric quality of photogrammetric images. Since higher quality of 8-bit DMC images generated from the panchromatic and 3 multi-spectral components has been proven, the quality of individual components would have to be verified. It appears that the wavelet transform can also be used for the optimisation of tonal mapping which takes place while transforming the signal of a broad dynamic range of a digital camera into the 8-bit range.

In the current stage of research it is not possible to use the results of the wavelet-components analysis as an absolute measure of the noise content. Defining such a measure requires carrying out a series of experiments, in which the images taken in the different conditions and seasons, will be studied. Such researches should be carried out in the future, because unsatisfactory quality of the radiometric images makes automation of the photogrammetric technology difficult and reduces the interpretation value of the images, including orthophoto-maps, so popular nowadays.

REFERENCES

Mallat S., 1998: *A Wavelet Tour* of Signal *Processing*. Academic Press, ISBN 0-12-466605-1.

Morain S.A.,. Zanoni V.M:, 2004: Joint ISPRS /CEOS -WGCV Task Force on Radiometric and Geometric Calibration. ISPRS Istanbul 2004, com. I, p.354-360.

Mulcahy C., 1997. Image Compression Using The Haar Wavelet Transform . *Spelman College Science & Mathematics Journal*, Vol 1, No 1, April 1997, p.22-31.

Pyka K., 2005. The Wavelets Indicators of radiometric Changes Taking Place in Orthophoto-map Generation Process (in polish). UWND AGH Kraków, 2005, p. 1-95.

Simoncelli E.P., Adelson E.H., 1996: Noise removal via Bayesian Wavelet Coring. Proceedings of 3rd IEEE International Conference on Image Processing, vol. I, pp. 379-382. Lausanne, Switzerland. 16-19 September 1996. IEEE Signal Processing Society, 1996.

Simoncelli E.P., 1999: Modeling the Joint Statistic of Images in Wavelet Domain. Proc. SPIE 44th Annual Meeting, vol. 3813 Denver, Colorado. July 1999.

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