Appropriate Pixel Size for Orthophotography

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Abstract

Pixel size is a basic parameter for digital imagery. It is shown, that there exists no general rule for an appropriate pixel size: It is a function of many parameters, like object frequency, image quality, specific application andeconomical restrictions of date processing and storage.

Zusammenfassung

Pixelgröße ist ein Basisparameter für digitale Bilder. Es wird gezeigt, daß keine allgemeinen Regeln für geeignete Pixelgrößen existieren: Sie ist eine Funktion vieler Parameter, wie Objektfrequenz, Bildqualität, jeweilige Anwendung und wirtschaftliche Beschränkungen von Bildverarbeitung und -speicherung.

1 Introduction

Orthophotos, i. e. rectified photogrammetric imagery, are used since many decades as a substitute or a supplement for topographic maps. There exist without doubt many advantages like quick and economic production, actual and complete information, especially for the environmental domain.

Nevertheless, orthophotography was not always generally accepted like one should have expected (e. g. KELLERSMANN 1985). This was due to completely different technology from conventional cartography: a half-tone paper-print photography is not „compatible“ to a conventional line map. Combinations of both products are offered („photo maps“)and show the way to follow in future:

Things are going to change drastically by digital image processing. This is because 3D-information of the Earth's surface is stored in large data bases, no matter what data acquisition system was applied: The data bases provide compatibility. Images will generally be a very important layer in Geo-Information Systems. Moreover, images are the starting point for automatic data extraction. All these factors contribute to the fact, that digital orthophotos suddenly are becoming more and more important for industry and application (COLOMINA et al. 1991, HÖHLE 1992, MAYR 1992).

2 Economical Considerations for Orthophoto Production

Recent presentation of digital orthophoto systems by industry show that production costs apparently have dropped to economy level. This is really prooved by BÄHR/WIESEL 1991, giving approx. US $ 25 computing cost for colour orthophotos of 230 mm x 230 mm standard format plus manpower. The equation

$$C = t_i C_i + t_m C_m \qquad (1)$$

presents the total cost C of an orthophoto as a function of instrument C_i and instrument time t_i plus manpower cost C_m and operator time t_m. Though today the manpower component is still higher than the instrument component, there is a chance that manpower costs will drop considerably when automation is more commonly applied.

Considering pixel size of digital orthophotos, it of course enters t_i in equation (1). Therefore, it will always be an important factor, even if instrument cost will continue to go down.

This is a particular factor for digital systems which does not exist for analog systems, where „geometric resolution“ principally does not play an important role for economy, exept for scale considerations, which finally are the same for digital systems.

For economical consideration we may approximate the pixel number in a standard photogrammetric image by

n [MB] $\sim (0,5 \cdot LP)^2$,

where LP stands for geometric resolution in linepairs/mm (see BÄHR 1989). This relation is visualised in Fig. 1. Standard values are given by 25 LP/mm and corresponding pixel size of 20 μm. This quantity may be exactly stored on a 9-track tape of 6 250 bpi.

Storage will not represent a considerable cost factor any more as shown by BÄHR/WIESEL 1991, even when producing colour orthophotos. Resampling is a more important factor, influencing not only cost but also time, because the operational environment, time for orthophoto production is most important; „economy“ is highly correlated with „time“. Adding the working steps to produce an orthophoto digitally, reduction of pixel size from 50 to 25 μm raises the total processing time by 100 % (BÄHR/WIESEL 1991).

Therefore, adequate pixel size for orthophotography has to be selected carefully according to the respective needs in order to meet cost **and** time requirements.

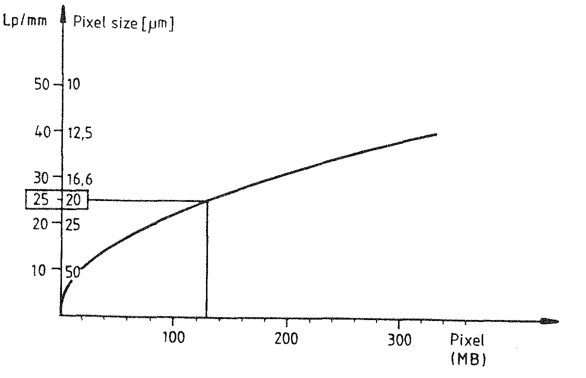


Fig. 1 Data quantity in [MB] as a function of resolution and pixel size for photogrammetric imagery (BÄHR 1989)

3 Parameters for Pixel Size

The term „orthophoto“ relates to a well-known analog rectification technology, which is at its end since digital systems have become operational. Data type is the conventional, analog photogrammetric image of 230 mm x 230 mm format.

The word „orthophotography“ defines geometric properties different from the original central projection of analog photography. An „orthophoto“ is a standard product in Photogrammetry, somewhat „historic“ on photographic paper.

A „digital“ orthophoto on the other hand, may be taken as a standard product, too. This is correct, when it means only the substitution of analog photographic technology by digital components. In this case, the final product is well defined, i. e. identical to the conventional product „on a sheet of paper“.

However, this is for sure not the correct way to handle new technology. Real new technology - and digital image processing in photogrammetry is one - will necessarily lead to new products and provoke new applications, starting may be from the old ones. In the next paragraphs we shall discuss the appropriate pixel size in the light of changing technology and changing products.

3.1 Theoretical considerations

Pixel size is a parameter of image quality, more specifically a parameter of geometric resolution, which is always connected to (technical or biological) systems. The „real world“ has no „resolution“, it can be represented by a fractional model, which is technically infinite.

Once the „real world“ is imaged, the imaging process is band limited. This means, that in the frequency domain the resulting image H (u, v) is restricted to a spectral band $\pm\nu$:

$$-\nu \leq H(u,v) \leq +\nu \qquad (2)$$

due to Modulation Transfer which in practise always produces degradation of the image.

$$H(u,v) = F(u,v) \cdot G(u,v) \qquad (3)$$

where F (u, v) is the spectrum of an original image, and G (u, v) the transformation function.

The Modulation Transfer Function $MTF = |G(u,v)|$ in (3), which designes the geometric resolution of the system output, is composed by the respective MTF's of the subsystems. For conventional orthophotos we may write for instance:

$$\text{MTF} = MTF_a \cdot MTF_{gl}\, MTF_{cf}\, MTF_{cd} \cdot MTF_{ol}\, MTF_{of}\, MTF_{od} \qquad (4)$$

where the indexes stand for „atmosphere“ (a), „lens“ (l) „film“ (f) and „development process“ (d). l, f and d appear for both the photogrammetric camera (c) and the orthophoto projector (o); the respective factors are not the same (i. e. $MTF_{cf} \neq MTF_{of}$).

Asking for the appropriate pixel size for the image H (u, v) in (3), it is theoretically given by the NYQUIST frequency ν, i. e. the highest frequency transferred by the MTF of the whole imaging process (4). This leads to the well-known Sampling Theorem

$$\alpha \leq \frac{1}{2\nu} \quad (5)$$

giving the descrete pixel values α as a function of the limiting frequency (supposing isotropic character).

The determination of ν, being the basic parameter for pixel size, is not trivial. Just one number to characterize the highly complex data set of a two-dimensional image will only present a very rough reference. This becomes evident, when analysing a straight lines in an image. Lines are the most critical components in (digital) images in theory and in practise, and therefore we will take them for discussing some basic issues.

An „ideal straight line" theoretically contains all frequencies, as it is composed of points without space in between. This may be visualised clearly in the frequency domain, where straight lines in the image appear again as straight lines. Consequently, there is no band limitation for such an „ideal straight line", and **any** pixel size would deteriorate it.

A straight line is a „model from analytical geometry", which means a high level of abstraction. By the way, we run into the same problems for „points", which again are nothing than an abstract model and do not exist in reality. In practise, lines do not correspond rigerously to the ideal model, neither in the real world nor in the „recorded version" on imagery. One should add „fortunately", because otherwise there would be no solution for our question.

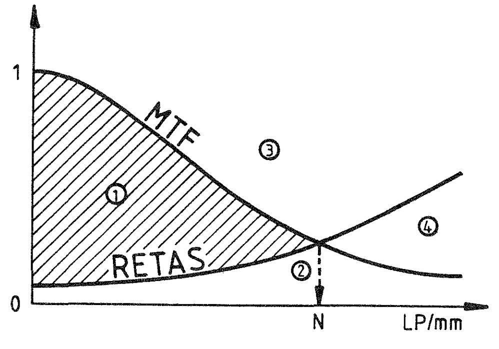


Fig. 2: Pixel size N/2 as a function of MTF and Resolving Threshold of Application System (RETAS). For the numbers see text.

3.2 Practical considerations

In practise, there is always band limitation as images in any case have passed a technical or physiological system in order to be real. Consequently, we may derive a MTF according to (4); different methods to do this are reported in BÄHR, 1988.

Fig. 2 explains how to derive the appropriate pixel size from the MTF. After the Sampling Theorem it corresponds to N/2, where N marks the intersection of the MTF with the Resolving Threshold of the Application system (RETAS).

The two curves separate four areas, which caracteristically show the conditions for pixel size:

Only in area 1 the information transported by the MTF satisfies the requirement of the RETAS; the areas 2 and 4, below the RETAS curve are **principally excluded,** i. e. there exist no pixel size which would correspond to the requirement of the application expressed by the RETAS curve.

Area 3 may be varied as a function of pixel size, which directly designs the MTF.

It is very important to point out, that two factors contribute to the appropriate pixel size, the MTF and the RETAS. As far as the MTF is concerned, it relates to the input data, whereas the RETAS relates to the output data.

Having in mind digital orthophoto production, input data may for instance be

* Conventional photogrammetric imagery

* Photography from amateur camera

* Scanner imagery from aerial or space platforms

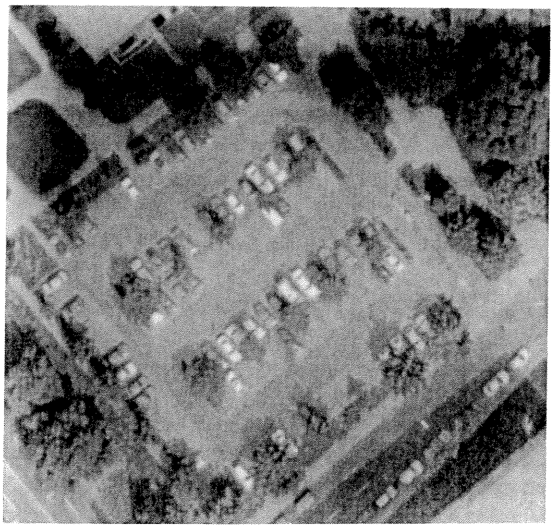
While scanner imagery is already digital, photography has to be converted into pixels. This process has to take into account not only the MTF of the original photography, but also the RETAS as shown. In other words, the pixel size has to consider the intended further application for the output data, which may for instance be

* Production of conventional orthophotos, substituting only analog projection by digital resampling

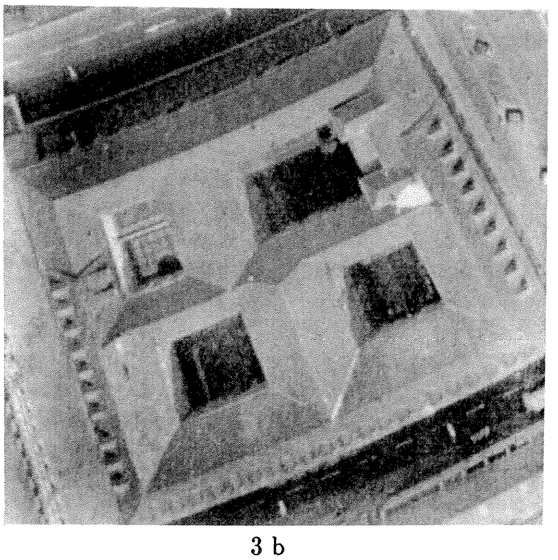
* Orthophoto layer in digital data base

* Digital orthophotos for separate applications, like environmental monitoring or point measurement

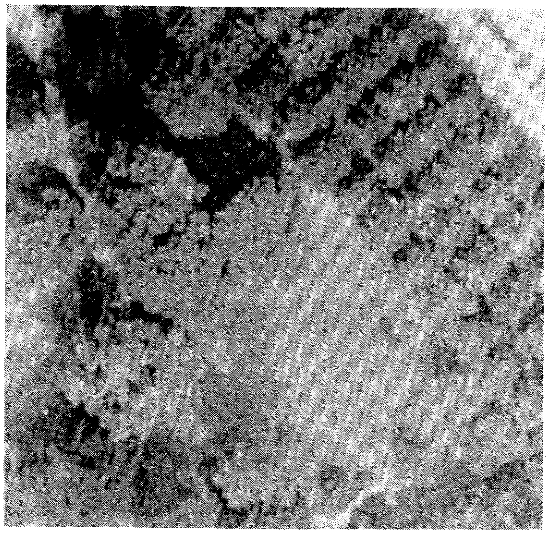
We take the first point for an example: The final result, a paper print orthophoto, has to serve for analysis by a human operator without using visual assistance by lenses etc. The resolution of the human eye affords a pixel size of about 50 μm for 1,4' viewing angle, given by the theoretical physiological treshold. This relates to a quality which had been guaranteed by the conventional rastering and printing process (see WIESEL, 1985).



3 a



3 b



3 c

Fig. 3 Test objects from aerial photography 1 : 6 000 50 μm pixel size, area 256 x 256, **original** (100 %) a: „cars"; b: „building"; c: „forest"

Evidently, the RETAS of this example does not seem to be in accordance with the potential of a photogrammetric image - „its curve in Fig. 2 is too steep".

The human eye is not the adequate sensor for looking at an original photogrammetric image. This of course does change when armed by a lens, i. e. when the hatched area in Fig. 2 grows due to smoother inclination of RETAS.

Conditions for pixel size change considerably when the human eye is eliminated from the system. This happens for computer vision, where the input for the grey values after resampling is a digital system. In this case, the signal is practically transformed without any degradation caused by a MTF, and the RETAS does not exist. Consequently, the digital system may use the input data fully, without regarding a RETAS. An example is digital correlation of targets (point signals) as shown by BÄHR (1988), where correlation accuracy only depends on the number of pixels which do show gradient effects. This is exclusively a function of scale.

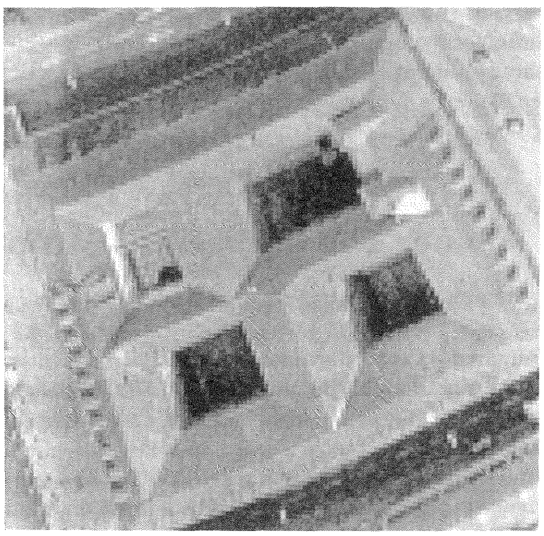
4 Variable Pixel Size in one Scene: The degressive Sampling Approach

It is evident, that image scale, geometric resolution or pixel size should be an issue of the respective application. Different from analog photography, digital orthophotography is not necessarily restricted to a uniform resolution in one scene. Within one scene we may vary pixel size due to well-defined demands by operator's request. A very simple example follows from the above mentioned determination of targets in computers vision systems: Here small pixels must be available only in areas close to the targets. We should remember that the human vision system depicts carefully only a very small portion of the sphere by mecanically moving head and eyeballs and optically focusing the point of interest.

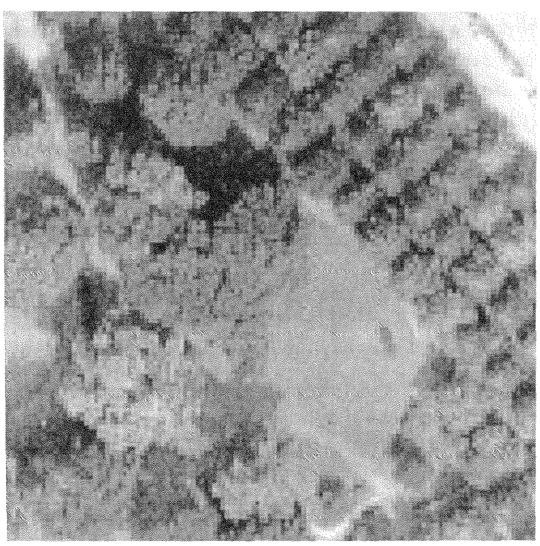
The selection of different pixel size within one scene may follow various algorithms, 2 of them have been studied here. It is one of the advantages of digital image processing, that the processes are controlled by software and not by hardware.

The objective of the following analysis is to visualise the effect from variable pixel size in one scene of a digital orthophoto. The data was scanned from aerial photography of 1 : 6 000 scale at 50 μm, showing the Campus of Karlsruhe University, Germany. Fig. 3 gives the original data for three characteristic objects: „Cars" (3 a, a parking area and its environment), „building" (3 b, appartment houses) and „forest" (3 c, i. e. part of the gardens close to the famous Karlsruhe

4 a

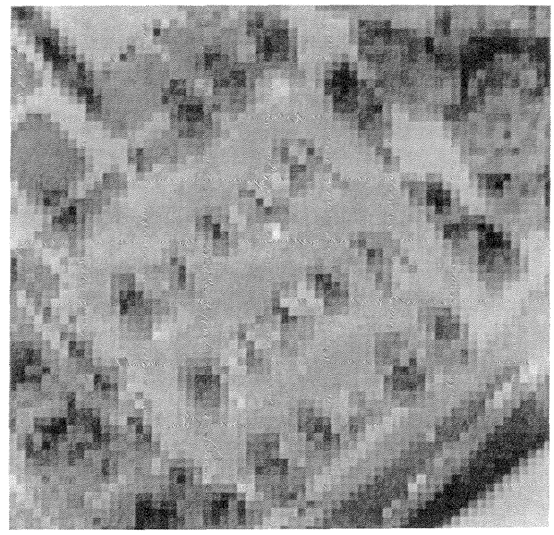


4 b

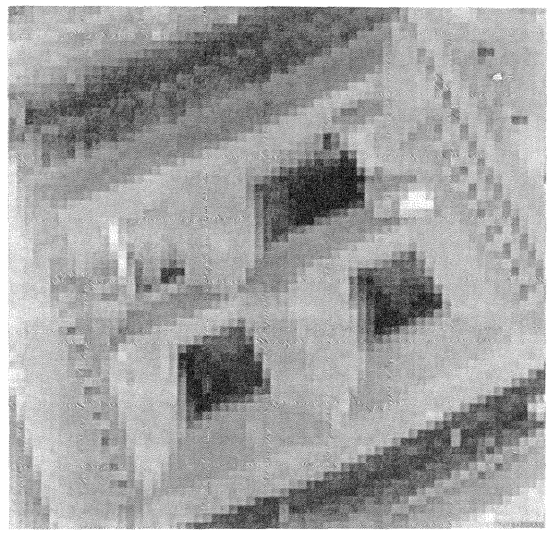


4 c

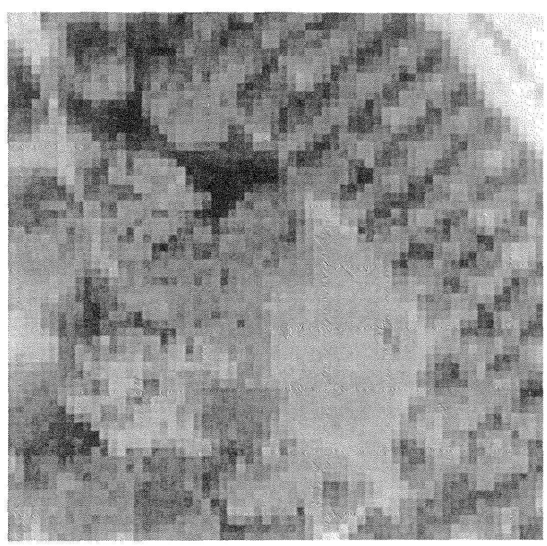
Fig. 4 Effect by uniform data reduction
2 x 2 patches (25 %)



5 a

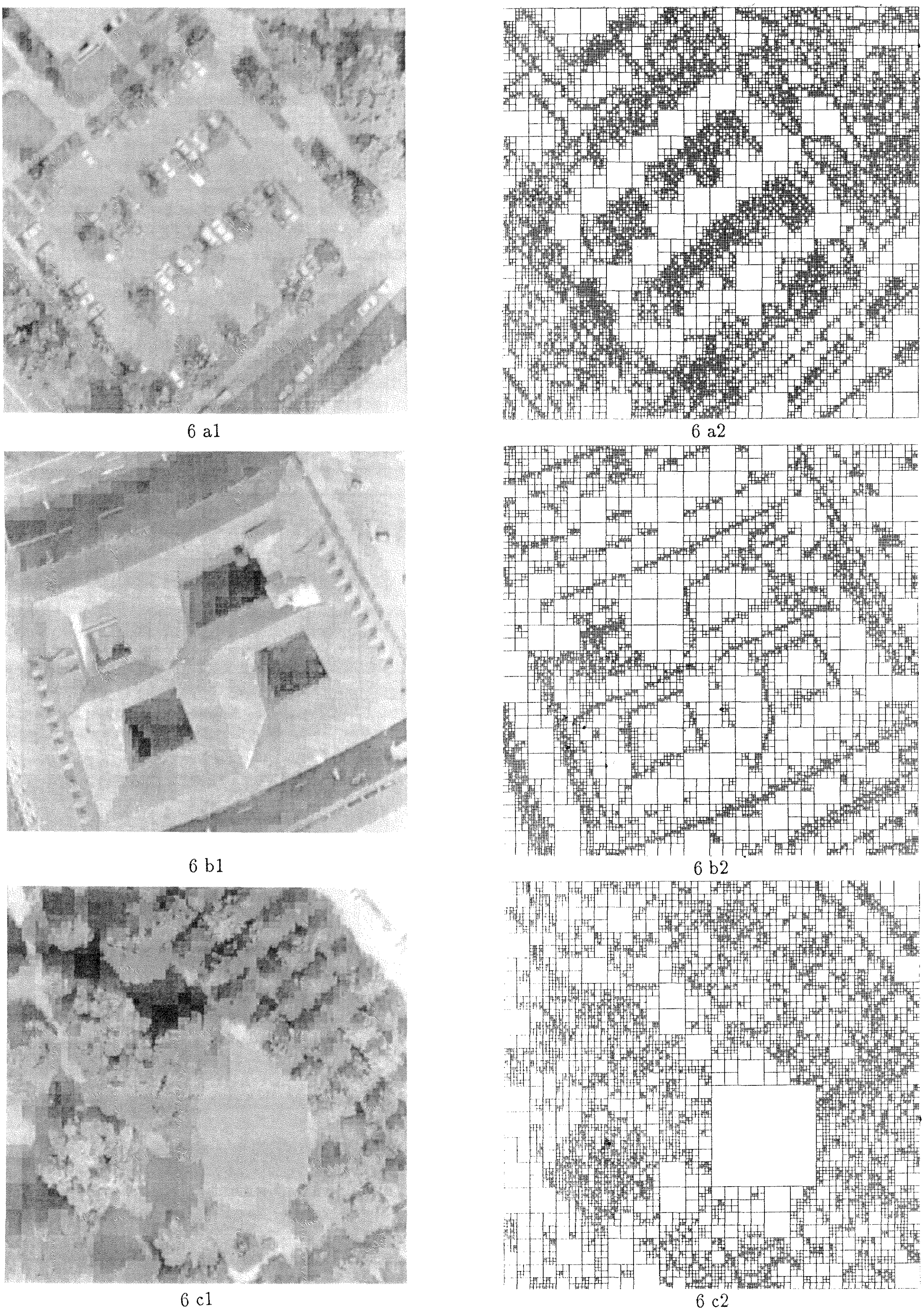


5 b



5 c

Fig. 5 Effect by uniform data reduction
4 x 4 patches (6,25 %)

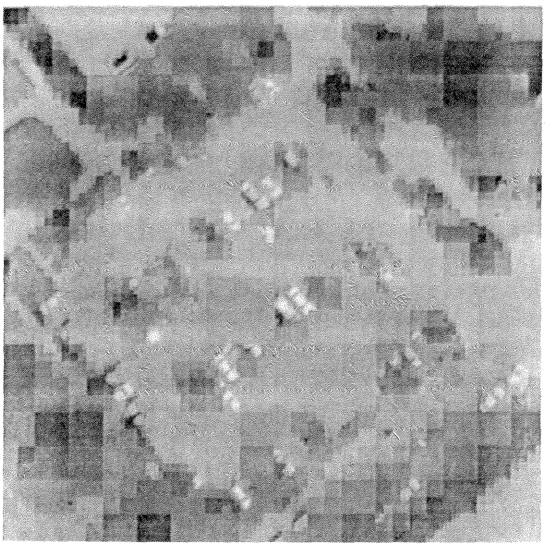


6 a1 6 a2

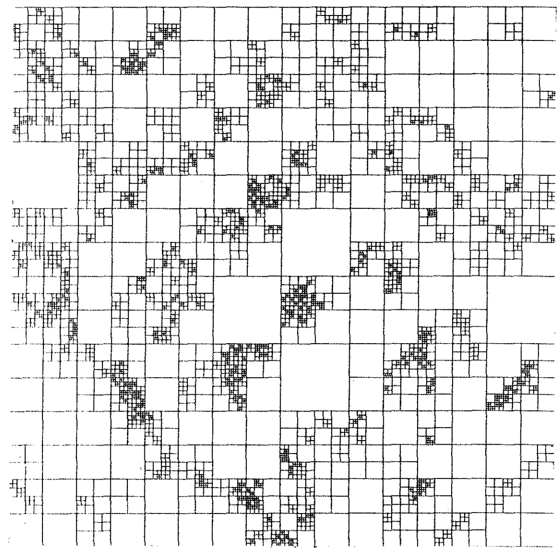
6 b1 6 b2

6 c1 6 c2

Fig. 6 Effect by degressive sampling threshold q10
a = 28,4 %, b = 15,7 %, c = 18,5 %

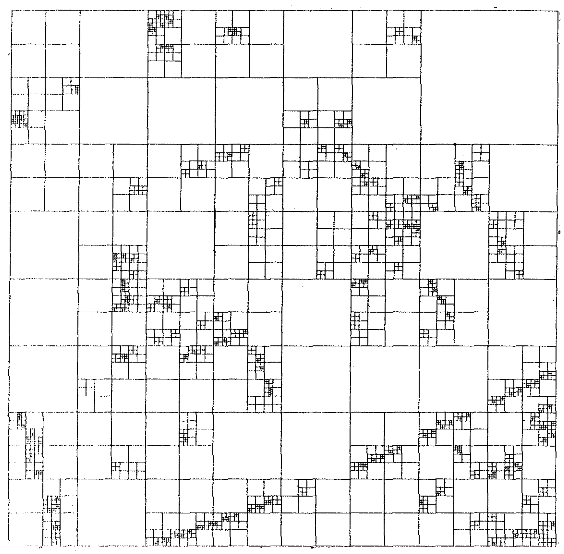


7 a1

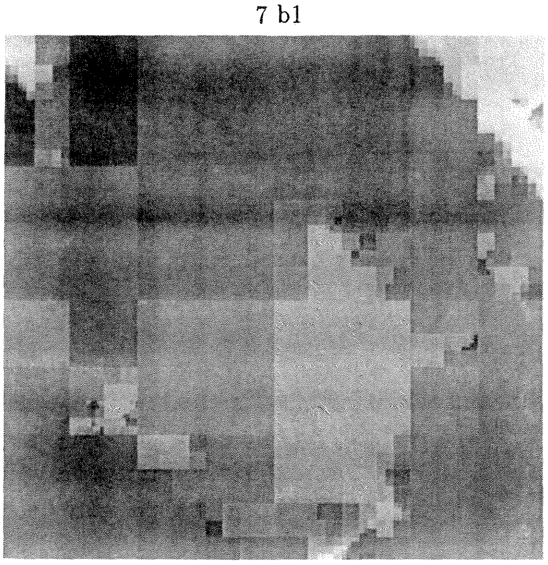


7 a2

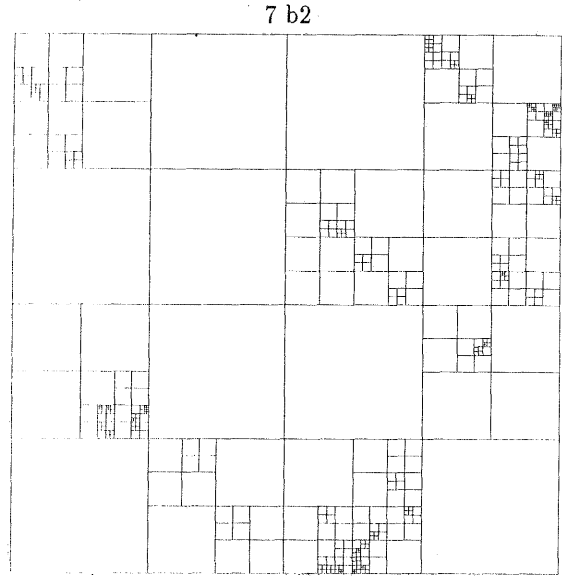
7 b1



7 b2



7 c1



7 c2

Fig. 7 Effect by degressive sampling threshold q20
a = 5,9 %, b = 2,8 %, c = 0,7 %

Castle). The small scenes include 512 x 512 pixels each.

In Fig. 4 and 5 the original data have been compressed to patches of 2 x 2 and 4 x 4, conserving 25 % and 6,25 % of the original data, respectively. This uniform approach does not take into account the image content; consequently it shows a general low-pass filtering effect, which very often will not be accepted for orthophotos.

Different pixel sizes in one scene lead to considerably better results as shown in Fig. 6. The algorithmus used refer to grey value differences. Different grey values of one $patch_i$ are substituted by a single one (e. g. the mean value) if

$$r_i < t_a \qquad (6)$$

where t_a is an arbitrary threshold (in greyvalue units) and r_i the result of an algorithm applied to the patch i.

The procedure may start taking the whole scene of 256 by 256 grey values as the first patch. The subsequent patches then are reduced systematically, following a quadtree approach, going from 4 (of 128 x 128 pixels) to finally 16384 (of 2 x 2 pixels). However we have to substract from this number those patches, which have already been assigned to uniform pixels.

A simple approach for r_i would be

$$r_d = \frac{\sum_{k=1}^{n} \left(\frac{\sum_{j=1}^{n} g_j}{n} - g_k \right)}{n} \qquad (7)$$

where n is the pixel number in one patch; j controls the sum of the individual pixels in that patch and k their difference from the mean value.

Instead of the grey value differences their quadratic sum may be taken, too. This leads to the algorithm r_q, used for the displayed examples in the figures 6 and 7. The reason for taking r_q instead of r_d is because of better contrast for printing. This is a consequence from the quadratic term.

		Quadr. Difference q		Linear Difference p	
	Original	$t_a = 10$	$t_a = 20$	$t_a = 40$	$t_a = 80$
Cars					
Pixel number	65 536	18592	3868	12313	2998
%	100	28,4	5,9	18,8	4,6
Building					
Pixel number	65536	10309	1867	8101	1720
%	100	15,7	2,8	12,4	2,6
Forest					
Pixel number	65536	12145	436	7372	709
%	100	18,5	0,7	11,2	1,1

Table 1: Pixel quantity in a 256 x 256 scene for different scenes algorithms and thresholds

Table 1 displays the values obtained for the three scenes, giving r_q and r_d as well as different values for t_a.

For analysing the results, we have 3 references: the images, the respective pixel pattern (Fig. 6 and 7, right column) and table 1. The visualisation shows that reduction to approx. 20 % of the original pixel size does not lead to considerable degradation. This is not the case when using the uniform reduction (Fig. 4 and 5). Moreover, further reduction to below 10 % is critical as expected. On the other hand, the pixel pattern show that frequencies of high contrast are still preserved, even for only 1 % of the original pixel quantity. The pixel pattern are very useful for the analysis, as the human eye alone is often mislead.

Very interesting is the process for the forest scene; here the meadow in the center is substituted by an isolated single pixel already for 18,5 % of the information. At this stage ($t_q = 10$); high frequencies of the trees are still preserved. This goes drastically down for $t_q = 20$ (only 0,7 % of the original information), where no useful information is any more present.

Fig. 8 demonstrates clearly the different effect for the 3 scenes. High frequencies afford large pixel numbers, and „forest“ behaves differently from „man made features“ like cars and buildings.

We call the procedure „degressive sampling“, for it starts at small pixel sizes and leads to coarser representation for aeras of lower frequency which in general may be less interesting. Anyway the potential of this approach does not end here. Both thresholds t_a and algorithms r_i may be varied in order to design the required result properly.

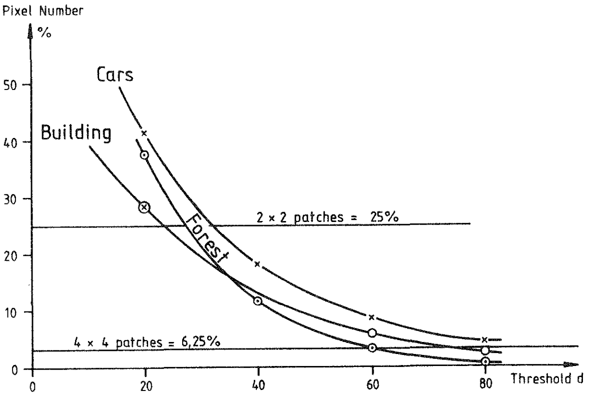


Fig. 8 Reduction of pixel numbers in % as a function of density differences (threshold d) and uniform pixel clustering (2 x 2 and 4 x 4 patches)

5 Conclusion

Pixel size will always play an important role for orthophoto production, even if some parameters, like data storage, are going to become obsolete. In future, pixel size is not necessarily any more a fixed standard value, but within a scene a flexible function of many parameters, which depend on specific applications. The degressive sampling approach seems to be a flexible procedure which consequently makes use of the potential of digital image processing for orthophoto production, not accepting uniform pixel size for a complete scene. The data reduction effect and the conservation of high frequencies may only be the starting point for a new thinking. The next step will apply itfor image segmentation, as a preprocessing approach.

6 Acknowledgement

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