OPTIMAL DIGITIZATION STEPS FOR USUAL FILM MATERIALS

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Commission I

ABSTRACT:

The main cause of grey value noise in digitized photographs is the granularity of the film material, especially in the case of high geometric resolution (e.g. 15 μm pixel size). All other factors have nearly no influence on radiometric noise, if the digitizing equipment is well calibrated.

In this paper, a method is presented to obtain the optimal distribution of digitizing steps with respect to radiometric noise in the film. If these steps are used in a digitizing equipment, the radiometric noise is constant for all grey values and no longer dependent on the signal strength.

Key words: Radiometric noise, Digitization steps

1. INTRODUCTION

In imaging applications, the practical difference between a photographic film and a CCD-chip lies in the achievable spatial and grey value resolution. The film has a very high geometric resolution, due to the small size of film grains, which are in the range of some tenths of a micrometer. But a single grain can become only black or white (transparent), no intermediate values are possible.

A CCD-sensor element is much larger, about 10μm, thus the geometric resolution is poorer. But the radiometric resolution of each sensor element is very high, even counting photons is possible /Janesick et al., 1989/. The radiometric noise of well calibrated CCD's is almost negligible /Janesick et al. 1987; Diehl, 1990/, only shot noise of the signal must be considered /e.g. Brügelmann et al. 1992/.

When a photograph is digitized, the radiometric noise in the data is mainly induced by the grain structure of the film. For small pixel sizes, it can amount to more than 20 per cent of the signal, and it depends on the signal height.

In the following, we offer a brief description of the technical background. In addition we present a method to adjust the digitization steps optimally to the radiometric noise.

2. GRANULARITY OF THE FILM MATERIAL

The optical density D of a film is the negative logarithm of the ratio of transmitted over incident light. E.g. for a spot with density D = 1.0 there are 10% of the incident light passing through /e.g. Vieth 1974/.

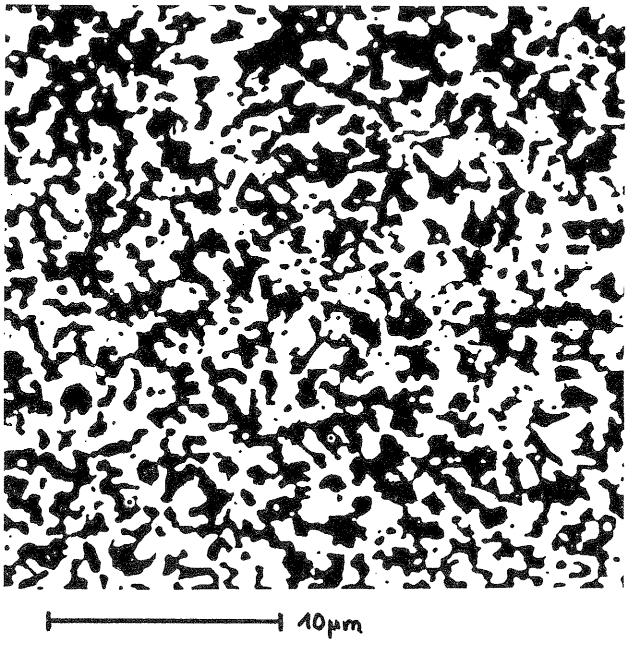


Fig. 2.1 Grain structure of a uniformly exposed film.

Manufact.	Type of film	RMS-Value
Agfa	PAN 50 PE	21
Agfa	PAN 150 PE	25
Agfa	PAN 200 PE	28
Kodak	Tri-x 2403	33
Kodak	Panat.-X 3410	13
Kodak	Plus-X 3411	19
Kodak	High Def. 3414	8
Kodak	Infrared 2424	30

Fig. 2.2 RMS values for usual aerial films

The granularity of a film is expressed as the RMS (root mean square) value of the density D /Kodak 1986/. Following ISO-standards, it is the standard deviation σ_D, measured at an uniform area with D = 1.0. The data are taken with a round aperture of 50μm and are multiplied by 1000 to obtain integer numbers with sufficient precision. Typical RMS values for aerial reconnaissance films lie between 8 and 35 /Kodak, 1986; AGFA/.

Most manufacturers of films specify the RMS-value only for the Density D = 1.0. But from simulation of the exposure process (Fig. 2.3) and from data for AGFA-films (Fig. 2.4) one can see, that RMS increases with density. A rule of thumb for the interdependence of RMS and D is given by

$$\text{(1)} \quad RMS(D) = RMS(D=1.0) * \frac{D + 1.5}{2.5}$$

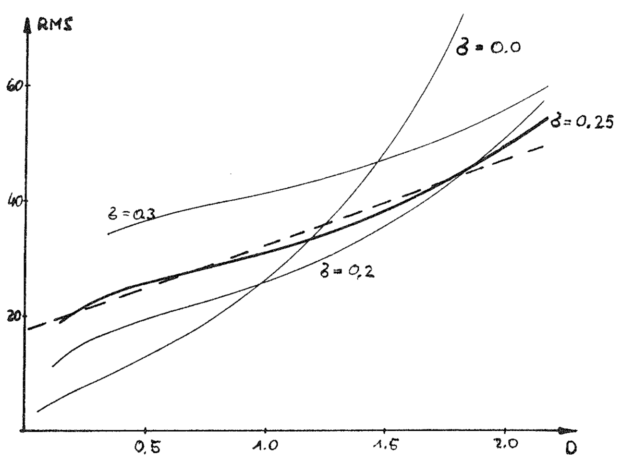
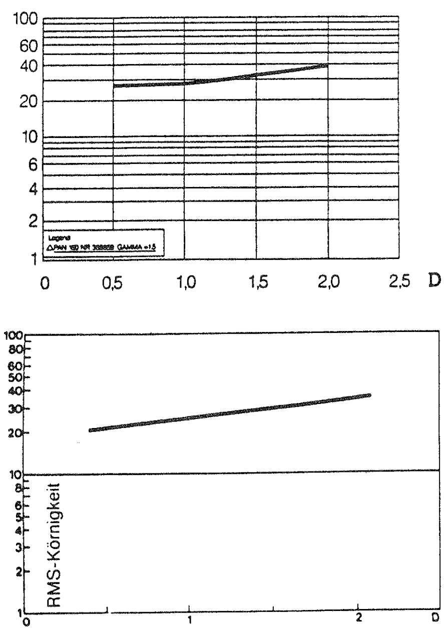


Fig. 2.3 Simulations of the dependence of RMS from D.

For that simulation, the mean grain diameter is assumed to be 1.0 μm. σ is the standard deviation of the diameter in the logarithmic scale. σ = 0.25 is usual for most film materials. σ = 0.3 or σ = 0.2 yield similar values. For comparison, a constant diameter (σ = 0.0) was also simulated. The sensitivity of a grain is assumed to be proportional to its volume (see / Frieser 1975/). The dotted line in fig. 2.3 shows equation (1).



PAN 150 PE

PAN 200 PE

Fig. 2.4 Dependence of the RMS value on D for the AGFA films PAN 200 PE and PAN 150 PE /AGFA/.

3. THE OPTIMAL DIGITIZATION STEPS

Digitization steps for an image can be optimal in the sense of

- -looking at the image
- -being well adapted to some algorithm
- -storing the data
- -examining special effects in the image
- -obtaining the most information

Our optimality criterion refers to the last item, stated more precisely:

(1) Each digitization step should be proportional to the radiometric noise in the data

Or, formulated the other way round:

(2) Radiometric noise must always be a constant amount of digitization steps, independent of signal height.

Of course, the noise is not independent of the signal height, if the signal is formulated in terms of optical density D like in chapter 2. This is even more true, if it is formulated in terms of the transparency $T = 10^{-D}$.

The original signal in a digitizing equipment is always the transparency T. So the first topic here is to formulate a transformation F from Transparency to digitization steps $F : T \rightarrow DS$ in such a way, that the radiometric noise is independent of the signal in terms of digitization steps. The second topic is to show how it could be implemented and finally we will give an overview over the effects, which can be expected from this method.

4. CODE FUNCTION FOR OPTIMAL DIGITIZATION

4.1 Derivation of the code function

At first we look at the range of density values, which occur in an image. The largest possible range for most film materials is D = 0.2 - 2.2 /Frieser 1975/ but in aerial photographs it is often 0.7 - 1.3 or less /Krauss 1982/. Of course the higher value should correspond to the highest digitization value dig = 255 (with 8 bit) the lower to dig = 0 (negative film). Let us assume the largest range, then we have

(1) $\mathrm{dig}\,(D=0.2) = 0$

(2) $\mathrm{dig}\,(D=2.2) = 225$

Our optimality criterion can be expressed as

$$(3)\ \Delta\, dig = \frac{\Delta D}{C_1 * RMS(D)}$$

One digitization step corresponds to a larger step in density, if there is more noise. If we express it infinitesimally, we get

$$(4)\ \ d\ \mathrm{dig} = \frac{dD}{C_1 * RMS(D)}$$

and we can integrate both sides to

$$(5)\ \ \mathrm{dig} = \int d\ \mathrm{dig} = \int \frac{dD}{C_1 * RMS(D)}$$

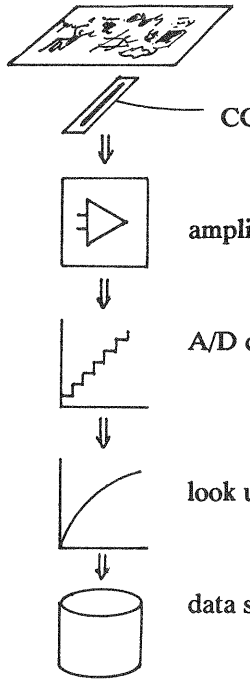


Fig. 4.1 Principal function of a digitizer

We could integrate (5) numerically, if the function RMS(D) is known for the film material. With the assumption from chapter 2, that

$$RMS\,(D) = RMS\,(D=1.0) * \frac{D + 1.5}{2.5}$$

we can approximate it well enough and obtain

$$(6)\ \mathrm{dig} = \int \frac{dD * 2.5}{C_1 RMS(1.0) * (D + 1.5)}$$
$$= C_2 \int \frac{dD}{(D + 1.5)}$$
$$= C_2 * ln(D + 1.5) + C_3$$

With the integration constant C_3. C_2 is the combination of C_1, RMS(1.0) and 2.5.

Thus, with the transparency $T = 10^{-D}$ or $D = -\log(T)$ we have

$$(7)\ \ \mathrm{dig} = C_2 * \ln(-\log(T) + 1.5) + C_3$$
(nearest integer to it)

The constants C_2 and C_3 depend on the density range (1) and (2). It is

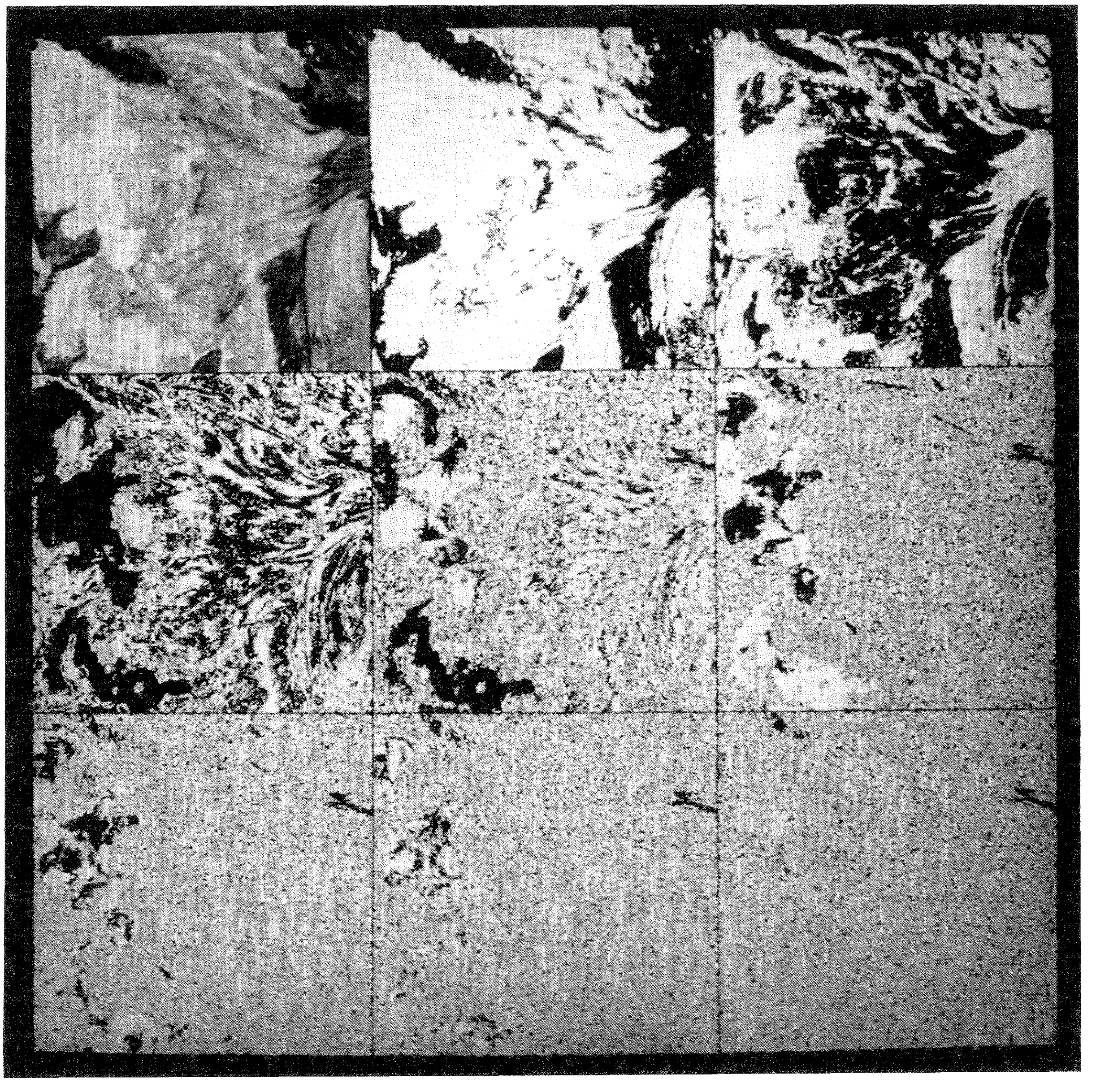


Fig 5.1 Bit planes, usual digitization steps

(8) $dig\,(D=0.2) = 0 = C_2 \ln(0.2 + 1.5) + C_3$

(9) $dig\,(D=2.2) = 255 = C_2 \ln(2.2 + 1.5) + C_3$

C_2 and C_3 in this example can be calculated as

$C_2 = 327.9$

$C_3 = -174.0$

For another density range, C_2 and C_3 must be adapted accordingly.

4.2 Implementation of the code function

The easiest way to implement the optimal code function is to take it in the look-up table of the digitizing equipment (see Fig. 4.1). Good digitizers work with an 12 bit A/D converter, which transforms the amplified transparency signal to a digital signal and use the look up table to calibrate the CCD-pixels. The new transformation function can be combined with that function. But it can also be realized (partly) in the amplifier or even in the A/D converter.

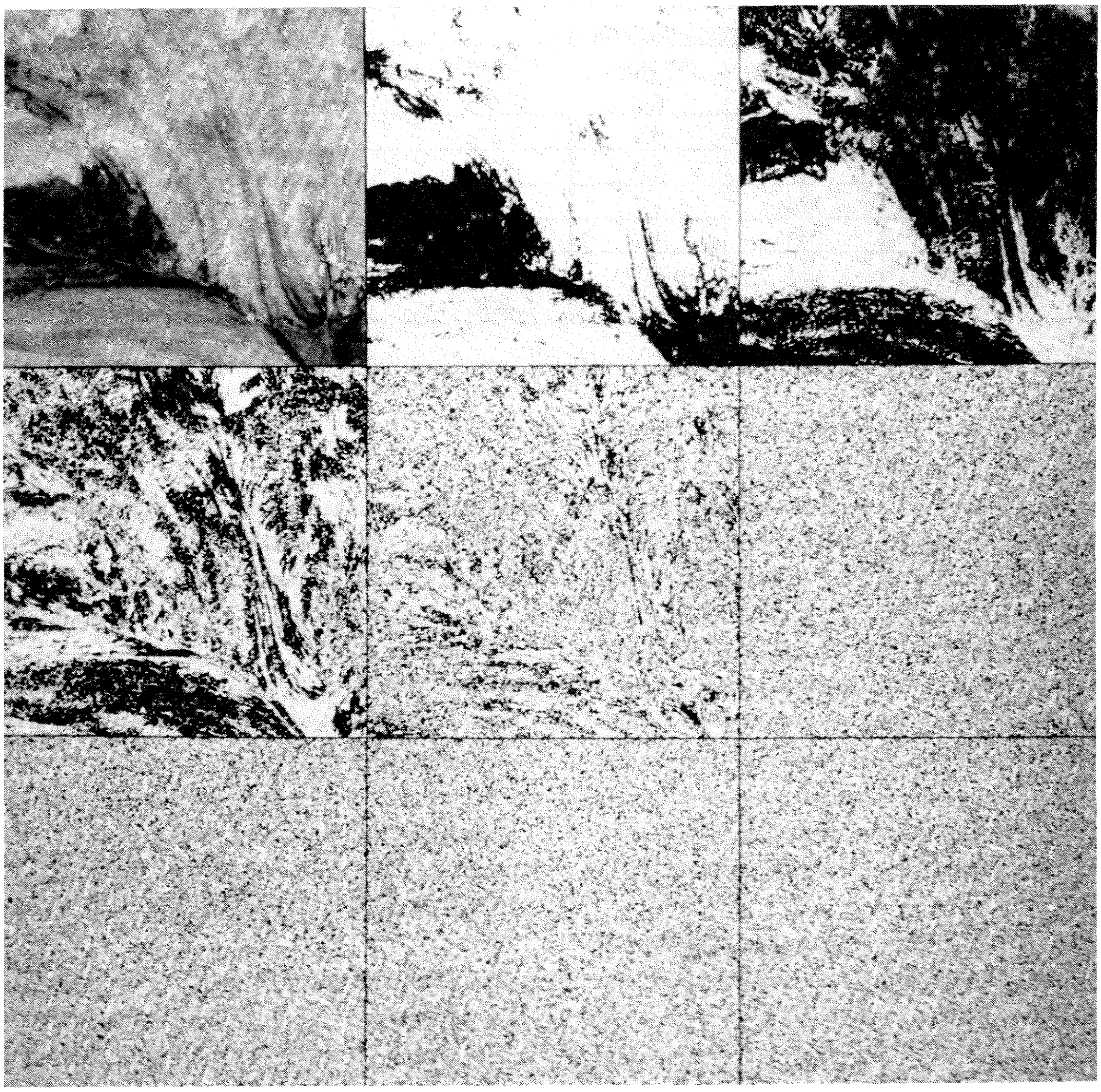


Fig 5.2 Bit planes, optimal digitization steps

In any case, there is no additional hardware necessary, and it does not need more time for operation.

5. EXAMPLES AND CONCLUSIONS

Fig. 5.1 and Fig 5.2 show a part of a digitized image and the value of each bit for each pixel. In the upper left corner is the original image. From left to right and top to bottom the bitplanes from the most significant bit to the least significant bit are shown. A white point means, the bit is 1, a black point means, it is 0.

As can be seen in Fig. 5.1, that most information is concentrated in the upper bit planes, but some information can be found also in the least significant bits. No bit plane can be dropped without loosing information. Fig 5.2 shows an image with better distributed digitization steps. Nearly all information is concentrated in the upper bit planes, the lower planes can be dropped with nearly no loss of information.

Fig. 5.3 shows the radiometric noise in an usual digitized film compared with the optimal digitization. The pixel size is assumed to be 60 μm, the film material corresponds to AGFA PAN 150 PE with an RMS of 28. The

		usual digitization			optimal digitization		
D	T	grey value	rad noise	noise gain	grey value	rad. noise	noise gain
0.3	50.1%	0	9.0	0.05%	0	3.1	0.5%
0.6	25.1%	129	5.3	0.2%	57	3.1	0.5%
0.9	12.6%	194	3.0	0.5%	106	3.1	0.5%
1.2	6.3%	226	1.7	1.5%	149	3.1	0.5%
1.5	3.2%	243	1.0	4.8%	188	3.1	0.5%
1.8	1.6%	251	0.60	15%	223	3.1	0.5%
2.1	0.8%	255	0.41	48%	255	3.1	0.5%

Fig 5.3 Example for usual vs. optimal digitization

density range is assumed from D = 0.3 to D = 2.1, but generally the range is smaller. The density D and the transparency T are shown. The column "rad. noise" contains the radiometric noise by granularity plus the digitization noise, which is always 0.3 digitization steps. It is expressed in digitization steps. The radiometric noise is calculated by the RMS value, the pixel size and the formula (1) in chapter 2. The RMS is measured for a round aperture of 50 μm. That corresponds to an quadratic aperture of 44.3 μm. At a pixel size of 60 μm the noise decreases by a factor 44.3/60 and amounts to 0.02 in terms of density. The column "noise gain" shows, how much the radiometric noise increases by digitization.

As can be seen, 8 bit digitization are not enough for such a density range, if usual digitization steps are used. An increase of the radiometric noise of more then 10% should not occur. On the other hand, with the optimal digitization steps and pixel size, noise increases only by 0.5%, so we can even use less bits if data storage or transmission is a problem. When 7 bits are used, noise will increase by 1.8%, when 6 bits are used the increase amounts to 7.2%.

Finally some remarks to the pixel size and the amount of data. If the pixel size decreases linear by a factor of 2, the radiometric noise increases by the same factor. If we choose 6 bits per pixel at 60 μm, we need 5 bits for 30 μm, 4 bits for 15 μm and so on. So we get 4 times the pixel number, but not 4 times the amount of data. But we should not conclude, that 1 μm pixels with 0 bit each is the best!

6. REFERENCES

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