PROCEDURES FOR RADIOMETRIC QUALITY CONTROL OF SCANNED CIR IMAGES

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ABSTRACT:

In state-of-the-art orthophoto production aerial films are routinely scanned to a digital format using roll-film scanners. Scanning parameters for a large number of images are typically set subjectively based on only a few images and quality check is done visually after scanning. For further use, orthophotos are often radiometrically enhanced, but the criteria for these enhancements are mostly subjective. The objectives of this study were to develop tools for the radiometric quality control (QC) of the scanning process and to investigate the tone tuning process of colour infrared (CIR) images. The central method of the radiometric QC is a 100% histogram control. The histograms of all scanned images are calculated during the scanning process and compared to existing tolerance values. These calculations also aid in the scanning parameter selection. In this study, the tolerance values were determined based on histograms of a total of 2818 images taken using four types of film. The conclusion was that the main statistics of image histograms were efficiency, 99%-efficiency and saturation. Experience has shown, however, that also a visual check of images is essential in addition to the automatic histogram control. Based on extensive investigations of radiometrically enhanced orthophotos, a tone-model-image for the tone tuning process was created.

1. INTRODUCTION

The Ministry of Agriculture and Forestry (MAF) of Finland maintains Finnish Land Parcel Identification System (FLPIS), due to the European Union's (EU) demand on controlling the agricultural subsidies. The FLPIS is a Geographic Information System containing location information of all parcels and farmsteads of farmers that have applied for area-based subsidies. A central component of the FLPIS is a countrywide orthophoto database.

The first FLPIS orthophoto mission was executed in Finland in 1996-1997. Three contractors with different systems produced the orthophotos from existing 1:60 000-scale panchromatic images. Finnish Geodetic Institute (FGI) functioned as the quality control (QC) consultant. The quality and production of those orthophotos has been thoroughly discussed by Honkavaara *et al*. (1999). The five-year update process of the first orthophoto series began in 2002. Several contractors are involved in the production. The orthophotos are produced from 1:31 000-scale colour infrared images (CIR) with 0.5 m pixel size. CIR images were selected to enable the use of the same material in forestry applications. MAF decided to apply a comprehensive QC-strategy in the process; FGI created the quality system (Honkavaara 2003) on the basis of the European Commission's (2004) recommendations. The FLPIS orthophoto production consists of two stages: digital image production and orthophoto production. The QC is divided to an internal control of the contractor and to an external control organized by the customer. An external quality consultant company performs the external QC.

Radiometric quality affects significantly the interpretability of images. Careless treatment may lead to a severe loss of information content. In the FLPIS orthophoto production, after the imagery flight and the film development, the radiometry is treated in the scanning process and in the mosaicking and tone tuning processes

An efficient tool for the radiometric QC of digital images is a 100%-histogram control. The idea of the histogram based QC is to calculate the histograms and histogram statistics of all scanned images and to compare the statistics to the determined tolerance values. The best efficiency of the method is obtained, if it is executed immediately after the scanning process. This method has not been used yet in the FLPIS QC-system, because the tolerance values have been missing. European Commission (2004) gives recommendations for saturation and contrast of luminance-histogram, but these were considered insufficient for the CIR-image based FLPIS process.

Histogram control cannot completely replace the visual check of images. First of all, abnormal histogram properties may be caused by some acceptable phenomena (e.g. large waters). Because of this, the histogram control software should also collect thumbnail images. The second reason for the need of the visual inspection is that consecutive image enhancements may result in artefacts that can be noticed only visually. In the FLPIS process, the external QC checks a sample of images, selected according to ISO 2859-standard, in the acceptance control by interactively viewing the image with a feasible magnification. The QC-strategy of the FLPIS image production process is presented in Figure 1. The orthophoto QC has a similar structure (Honkavaara 2003).

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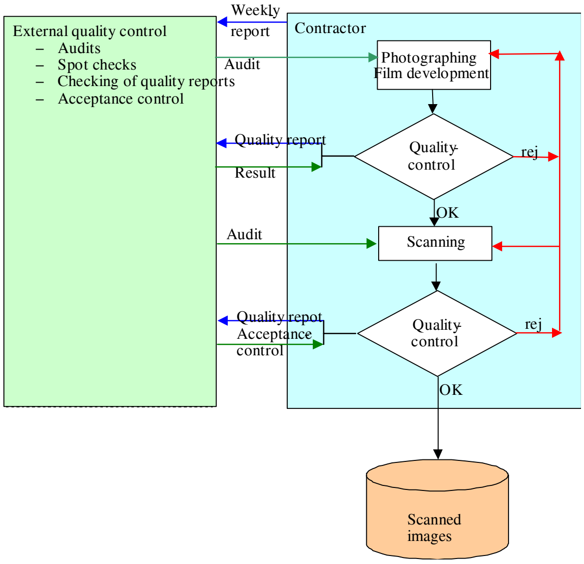

Figure 1. QC-strategy of image production.

The CIR orthophotos are also extensively used in the forestry applications. Orthophotos used in forest planning are radiometrically enhanced to assist forest interpretation. Most of Forestry Centres receive images from companies as tuned all the way, while some do most of the enhancement process themselves. The radiometry of these images have been estimated only visually, criteria have been subjective and varied depending on the person. Because of this, the QC of radiometrically-enhanced orthophotos has been a difficult task for both to the image producer and customer.

The main objectives of this study were to develop automatic procedures for 100%-histogram control of scanned images and to develop an objective way for judging radiometry of enhanced orthophotos. The existing FLPIS orthophoto QC-system will be improved based on the results.

2. RADIOMETRY OF IMAGE

2.1 Digital image composition and colour spaces

A normal digital colour image consists of three channels: red (R), green (G) and blue (B) and one pixel is composition of these three (R, G, B). At the moment 24-bit colour images are used, they contain one 8-bit value (0-255) for each channel. Hence, there are up to 256^3 = 16777216 different combinations of red, green and blue Digital numbers (DN) that one colour pixel may have. In the future with new digital cameras and image processing software also 10-to14-bit data per channel may be used, film-scanners can already produce up to 12-bit per channel images.

In addition to R, G and B-channels, several composition channels based on these three can be calculated from image. Luminosity describes the panchromatic information of the image and in Adobe Photoshop it is calculated with a formula (1) (Kosaka, 2000).

$$L = 0.30*R + 0.59*G + 0.11*B \qquad (1)$$

Intensity (I), hue (H) and saturation (S) colour space is advantageous to RGB in that it presents colours more nearly perceived by the human eye. Intensity is comparable to luminosity and describes the overall brightness of the scene. Saturation represents the purity of colour and varies from 0 (grey) to 1 (pure colour). Hue is representative of the colour or dominant wavelength of the pixel. It is a circular dimension and varies from 0 at the blue midpoint through red and green back to the blue midpoint at 360. Several formulas for RGB to IHS –transformation can be found from the literature (Carper *et al.*, 1990; Gonzalez and Woods, 1992), but in this study the formula given by Conrac (1985) was used.

2.2 Histogram

The image histogram describes the statistical distribution of image pixels in terms of the number of pixels at each DN. Particularly, it contains no information about the spatial distribution of those pixels; two visually different images may have identical histograms. Sometimes, however, spatial information can be inferred from the histogram. For example, a strongly bimodal histogram usually indicates two dominant materials in the scene, such as land and water (Schowengerdt, 1997).

The most widely used histograms are R, G, and B. The RGB-model is applied for producing three-channel colour composites on colour monitors, scanners and other devices, therefore their histograms are the most efficient to calculate. Histograms of other composition channels may give information that would be hard or even impossible to interpret straight from the RGB-histograms. Luminosity-histogram can be used to monitor the number of totally black or white pixels on the image. Hue-histogram can be used to monitor the effect of image enhancement operations, and it is a better indicator of the overall tone of the image than RGB-histograms (Koutsias *et al.*, 2000). A histogram can be calculated either for whole image or for a smaller part of it.

Several statistical quantities can be calculated from histograms:

- Average. Describes the mean value of the DNs.
- Standard deviation. Describes, how widely the DNs are spread around the average.
- Coefficient of Variation. Describes the percentual deviation of the DNs (=standard deviation / average).
- EC Coefficient of Variation (European Comission, 2004). (=standard deviation / 256).
- Median. Describes the center of the histogram; there are an equal amount of DNs on both sides of median.
- Mode. Describes the DN that is the most common.
- Efficiency. Describes how many of DNs is used out of 256. Opposite to unused DNs.
- 99%-efficiency. Describes the width of 99%-part of the histogram (= tail 0.995 - tail 0.005).
- Minimum. The smallest DN used.
- Maximum. The largest DN used.
- Unused Center. The number of unused DNs between minimum and maximum.
- Tails 0.001, 0.005, 0.01, 0.05, 0.999, 0.995, 0.99, 0.95. Describes the place were corresponding amount of histogram is on the left side.
- 0 & 255. Describes the amount of 0 and 255 DNs.
- 0% & 255% (saturation). Describes the percentual amount of 0 and 255 DNs compared to whole image.

3. MATERIALS AND METHODS

3.1 Materials

The investigation was made in close co-operation with three Finnish image producers, Ministry of Agriculture and Forestry (MAF), two Forestry Centres and the Forestry Development Centre Tapio. In the following, the image producers are named Company A, Company B and Company C.

The study of histograms was based on 41 scanned CIR images from Company A and 2818 histograms collected with HISTOQC-program from image servers of Company A and Company B. The scanning process was done using either 10 or 12 bits per channel and images were transformed to 8 bits per channel afterwards. Summary of the histogram material used is presented in table 1. Scanners used are presented in table 2.

Source	Amount	Country	Film	Scanner	Resolution
Company A	5	SWE	Agfa X-100 (colour-neg.)	S2	14 µm
Company A	48	FIN	Avi Chr 200 (colour-pos.)	S1	14 µm
Company A	18	FIN	Avi Chr 200 (colour-pos.)	S2	14 µm
Company A	277	FIN	Kodak 1443 (CIR-neg.)	S1	14 µm
Company A	557	FIN	Kodak 1443 (CIR-neg.)	S2	14 µm
Company A	6	LTU	Kodak 1443 (CIR-neg.)	S1	14 µm
Company A	131	LTU	Kodak 1443 (CIR-neg.)	S2	14 µm
Company A	2	SWE	Kodak 2444 (colour-neg.)	S1	14 µm
Company A	92	SWE	Kodak 2444 (colour-neg.)	S2	14 µm
Company B	96	FIN	Kodak 1443 (CIR-pos.)	S3a	20 µm
Company B	911	FIN	Kodak 1443 (CIR-pos.)	S3b	20 µm
Company B	608	FIN	Kodak 1443 (CIR-pos.)	S3b	14 µm

Table 1. Histograms used.

Scanner	Model	Bits	Owner
S1	Zeiss SCAI	10	Company A
S2	Leica Geosystems DSW600	12	Company A
S3a	Leica Geosystems DSW600	10	Company B
S3b	Leica Geosystems DSW600	12	Company B

Table 2. Scanners.

For the study of the tone tuning procedures and their influence on radiometric quality, 20 tuned CIR ortho images were received from three Finnish image producers and two Forestry Centres. Company A, Company B and Company C delivered three types of images: the original orthophoto, one tuned to be used in forest interpretation and one tuned to be used in land parcel interpretation. Forestry Centres delivered images tuned to be used in forest interpretation. Company A also delivered 41 scanned CIR images (Kodak 1443 CIR-negative film, Leica Geosystems DSW600 12bit scanner). 40 of the images were taken in different parts of Finland (10 from Central Finland, 10 from Northern Karelia, 10 from Northern Ostrobothnia, 10 from Lapland) and in different seasons (from each area: 5 in the beginning of summer 2002 and 5 in the middle or end of the summer 2002). In addition, one image from southern Finland taken on the summer 2003 was delivered.

3.2 Methods

Preliminary studies of histograms were made with Matlab 6.5 and Erdas Imagine 8.5 –softwares. Based on these results, a program named HISTOQC was coded with C++ -language for collecting histograms and statistics of scanned aerial images. It runs in Windows-based operating systems in DOS-prompt and can be used either interactively or from the command line. HISTOQC calculates the statistics described on chapter 2.2. The black borders of images, resulted from surrounding film clear base, were excluded from the calculations of histograms. Statistic-files were imported to Excel and several charts and diagrams were created and analysed.

Experimental image enhancement was made with Adobe PhotoShop 7.0 –software. Effects of these enhancements to image histograms were followed using HISTOQC.

4. RESULTS

4.1 Histograms

Different types of films produced clearly distinguishable image histograms. In all images investigated, RGB-histograms were typically unimodal, i.e. they had a single peak. In colour films

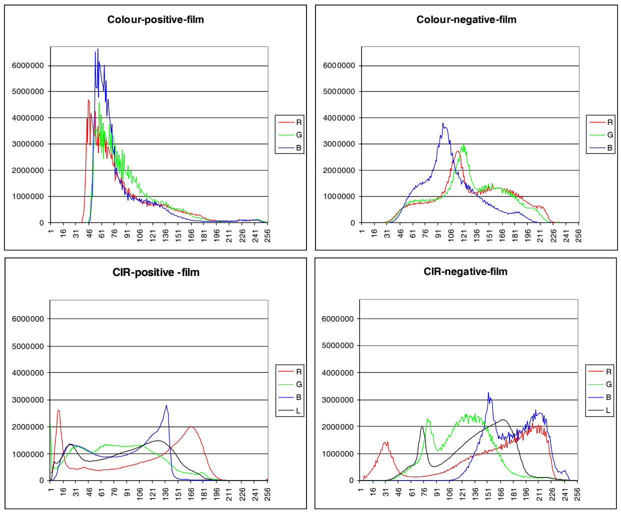

Figure 2. Histograms of different types of films.

this peak was often situated on the darker half and in CIR-films on the brighter half of histograms. The latter could be explained by the strong near-infrared and green reflectance of vegetation. In CIR-films bimodal histograms may appear if there are large water areas on the image. Example histograms of different types of films are presented in figure 2.

4.2 QC of Scanned images

Data from the Company A image server were calculated with the first version of HISTOQC-program, so only R, G and B –histograms and their statistics were gathered. Data from the Company B image server included also the L-histograms.

In the analysis the histogram material was classified to image-detailed (Figure 3), flight-detailed (Figure 5) and film- and scanner-type-detailed data (Figure 4). According to studies of these histograms, the most important statistics for the QC were efficiency, saturation (0% & 255%) and 99%-efficiency. In the ideal situation, efficiency of all histograms in 8-bit data would be 256 and there would be only a small amount of 0 and 255 DNs. Because the scanning process is such that several images are scanned using the same parameters, some compromises have to be accepted, and full utilization of histogram cannot be obtained. Also the averages and standard deviations of

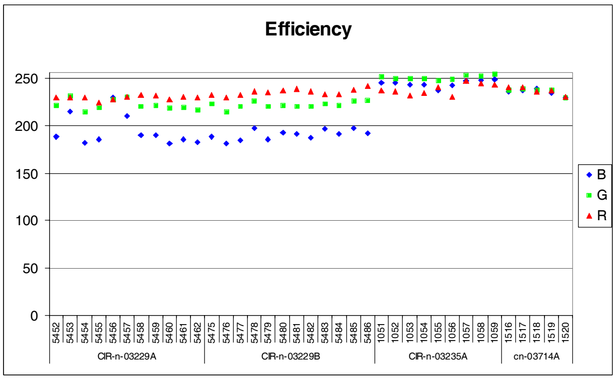

Figure 3. Example of image-efficiencies of four flights. n=negative, cn=colour-negative.

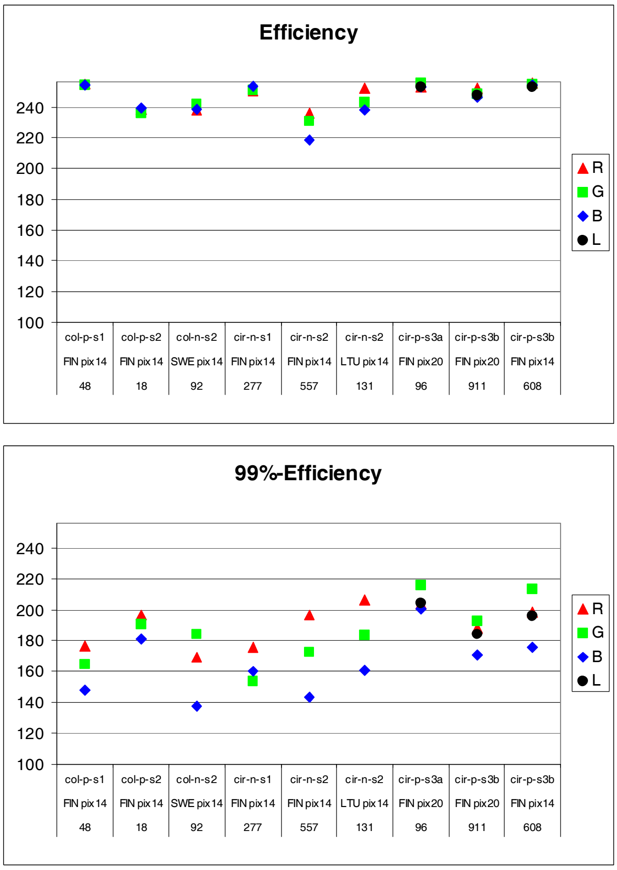

Figure 4. Averages of efficiency and 99%-efficiency per film-type and scanner. p=positive, n=negative. s1, s2, s3a and s3b refers to scanner type, FIN, SWE and LTU to countries where images were taken, pix14 and pix20 resolution used in scanning and the number refers to the amount of images.

histograms were found to give valuable flight-specific information of images (Figure 5). Example of the affect of different scanners and film-types can be seen in Figure 4.

In the CIR-negative-films and both kinds of colour-films the efficiency of R, G and B-channels varied from 157 to 256 and average of efficiencies was 228. For 99%-efficiency the corresponding numbers were 75, 230 and 170. Saturations (0% and 255%) in light and dark end of histograms were 0 for all channels. So even though the luminance was not calculated, it

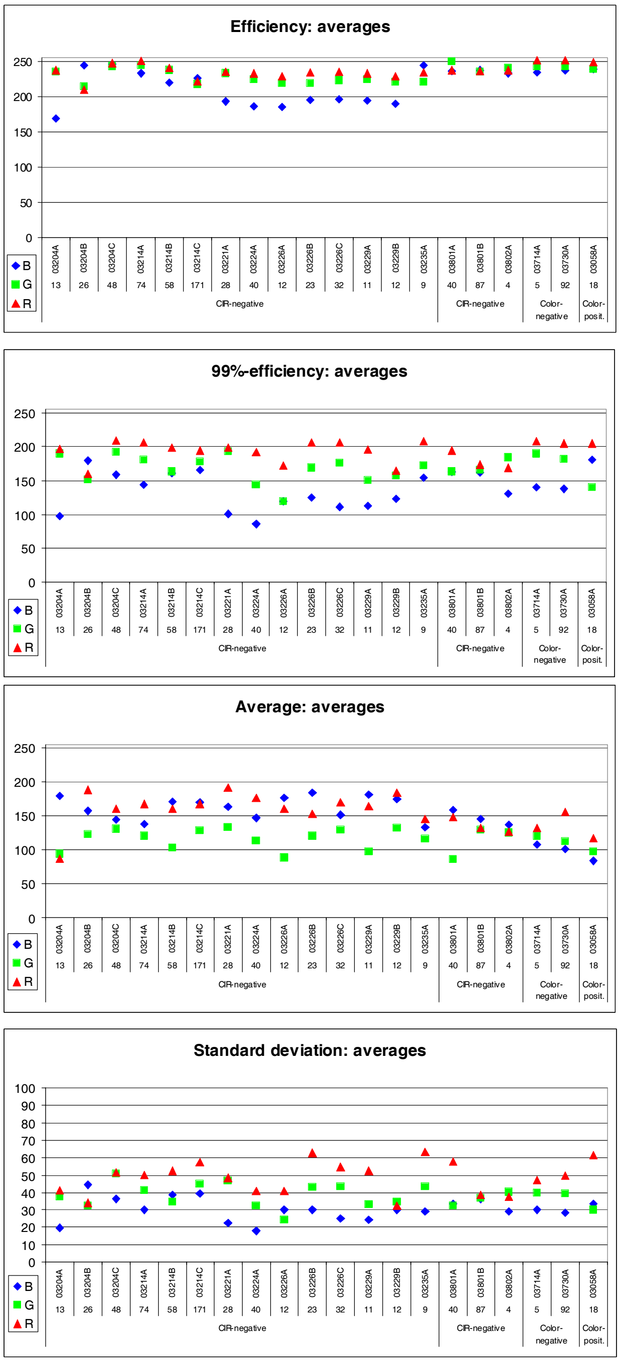

Figure 5. Averages of efficiency, 99%-efficiency, averages and standard deviation of several flights. Number in the x-axis below the block name describes the amount of images taken on that flight.

is clear that there were no totally black or white pixels in these images (Figure 5).

In the CIR-positive-films the efficiency of R, G, B and L-channels varied from 178 to 256 and the average efficiency was 254. For the 99%-efficiency the corresponding values were 124, 253 and 195 (Figure 5). The 255% saturation was almost 0 for all channels; the maximum single value was 0.35% for Blue. For 0% saturation the maximums were 18% for R, 61% for G, 25% for B and 25% for L, and averages were 0.7%, 3.3%, 0.7% and 0.4%, respectively. The high saturation values of some images were explained by large water areas, which

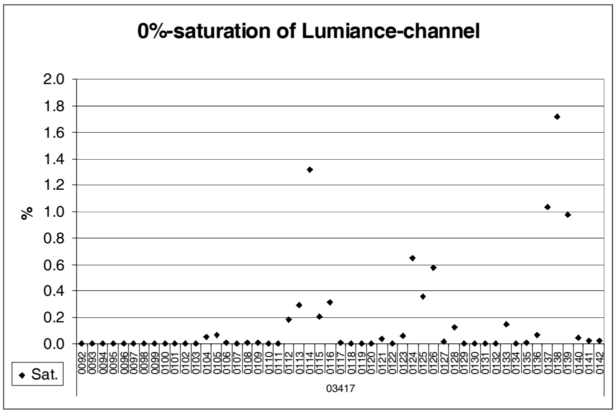

Figure 6. 0%-saturation of luminance-channel of CIR-positive images.

were black. Example of image-detailed-data of 0%-saturation of luminance-channel can be seen on figure 6.

In general, the statistics of images of single flight were quite uniform, even though scanning parameters were determined using only a few images of the flight (Figure 3). From the image-detailed efficiency plots of all the flights a few flights with exceptionally low efficiency could be found. This indicates that tuning of the scanning parameters using statistics calculated from a few sample images will probably lead to acceptable scanning statistics of the whole flight.

4.3 Radiometry of enhanced orthophotos

To determine optimally enhanced CIR-image suitable for visual forestry and agricultural applications, preliminary investigations of enhanced orthophotos were made using 20 images received from three image producers and image users (two Forestry Centres). R, G, B, L, I, H and S-histograms and their statistics were calculated from the images. Different kinds of areas (fields and various forest objects) of size 100x100 pixels were cropped from the original images and the same histograms and statistics were calculated. According to these statistics, all images were considered to have good radiometric quality, even though in visual analysis every image appeared different, so also their interpretability varied.

After these studies and response received from co-operative partners, a decision was made that the optimally enhanhed CIR-image would not be defined by numerical factors but rather a radiometrically and visually high quality image would be created from the scratch. A scanned CIR-image from southern part of Finland from summer 2003 was chosen as a basis for this work.

The criteria's for the radiometric enhancements were:

- To get coniferous and deciduous trees separated from each other and at the same time set the balance of red and green colours so that the composition of stands of mixed forest would be interpretable.
- To seek optimal tone for open rock- and other inorganic areas.
- To avoid dark forest shadows to get saturated.

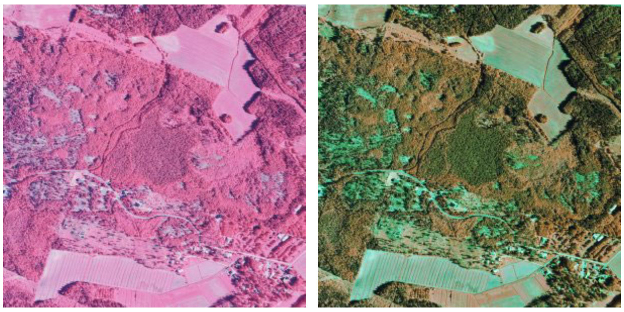

Figure 7. Original aerial image and tone-model-image.

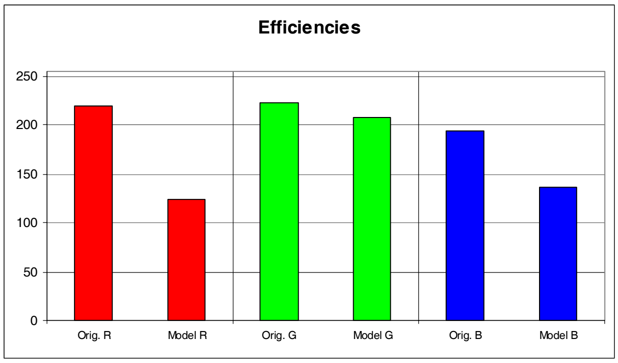

Figure 8. Efficiencies of original image and tone-model-image.

For justifying the preliminary adjustments a field control was made with two forest interpretation specialist from the Forestry Development Centre Tapio. After this final enhancements were made. The result, tone-model-image, is presented in Figure 7. For the fine-tuning also larger scale model images of various object types were extracted.

The usability of the model-image was tested with several CIR-images taken on various stages of growing season around Finland. Excluding Lapland, all images were possible to be adjusted to match visually with the model-image.

Even though the enhancement procedures were made in such a way that the efficiencies of all histograms were followed, some loss of information especially in the near-infrared-channel (red) could not be avoided. The efficiencies of original and final image are presented in figure 8.

5. DISCUSSION

5.1 Histogram QC

The purpose of the 100%-QC of scanned images is to ensure the suitability of the images for further use. The most descriptive statistics for QC are efficiency, 99%-efficiency and saturation. Efficiencies and saturation monitor the histogram from opposite directions; if efficiency is at its maximum, saturation may exceed its tolerance values. The difference between efficiency and 99%-efficiency is that efficiency is more easily controlled during the scanning process, but the 99%-efficiency describes the utilization of the histogram better. Efficiency may contain some insignificant amounts of DNs that are excluded in 99%-efficiency.

Optimally the image contains as much information as possible i.e. the efficiency of its histograms should be high. At the same time saturation of bright and dark areas should be avoided. Based on the studies made, following recommendations were established:

- Efficiency of R, G, B and L-histograms should be at least 230 DNs i.e. 90%
- 99%-efficiency of R, G, B and L-histograms should be 160-254 DNs
- 0% and 255% saturation of L-histogram should not exceed 0.5%
- 0% and 255% saturation of R, G and B-histograms of CIR-positive-film should not exceed 2.0%
- 0% and 255% saturation of R, G and B-histograms of other film-types should not exceed 0.5%

The same recommendation for saturation of L-histogram is also given by European Commission (2004). Scanner- and film-type-detailed data as presented in Figure 4 can be used to improve these recommendations after the 100%-histogram-QC has been taken to full operational use.

Because the image-detailed statistics were in a flight level quite uniform, excluding exceptional images, it can be assumed that the calculation of histogram statistics in scanning parameter selection phase would lead to good result in scanning of the whole flight.

5.2 Tone model image

The created tone-model-image is one alternative that can be used in the tone tuning for forest interpretation purposes. It is not optimal for all purposes, but it is a scientifically justified and radiometrically good quality alternative for images based on subjective criteria. The information loss mentioned in chapter 4.3 is a consequence of high contrasts required for forest interpretation and was expected. Because of this, MAF decided not to use the tone-model-image (Figures 7. and 8.) in the image enhancements for land parcel identification.

6. CONCLUSIONS

A 100%-histogram control of scanned images is highly recommended. Calculating histograms and statistics after scanning is an efficient process. Histogram-control should be implemented directly to scanning software for the maximum ease of use. For each scanned film diagrams presenting efficiencies, 99%-efficiencies and saturation of every image should be created and summary statistics should be calculated. Separate alarm should be given of the images that exceed the given tolerance values. The central data should be archived; in a long run these statistics give valuable information of the development of scanning process and they can be used for optimization of scanning parameters. The histogram control can also aid in the selection of scanning parameters.

Recommendations of tolerance values given in chapter 5.1 are not in any way final; they will be improved when the 100%-histogram-QC is taken to full operational use. In addition to 100%-histogram-QC, thumbnail images of every scanned image should be created. The complete QC-system should contain also visual inspection of a sample of final images, because all the radiometric errors cannot be detected by histogram control.

Interpretations of forests and land parcels have conflicting requirements for radiometric enhancement of orthophotos. Specifying numeric recommendations for image enhancement procedures appeared to be difficult. The most practical way for defining the desired radiometry with the existing commercial systems is a model image. One image cannot be optimal for all purposes, thus various applications and even various user may require different model images. In this article a tone-model-image suitable for forestry applications was presented.

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