# INTERPRETABILITY OF SCANNED AERIAL PHOTOGRAPHS

K.A. Grabmaier, K. Tempfli, R. Ackermann: Scientific Staff, ITC, The Netherlands
Girma Messelu: Head Photogrammetry, Ethiopian Mapping Authority, Ethiopia

Commission IV, Working Group 3

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## ABSTRACT

Digital photogrammetry offers a number of advantages, especially towards automation. One of the major sources of digital images for topographic mapping and data collection for spatial databases are aerial photographs. Although interpretability is an important property of images used for this purpose, there is little known about the loss of interpretability due to scanning of the aerial photographs. We studied the influence of scanning pixel size on the interpretability of wide angle aerial photographs of scales 1:30,000 and 1:60,000. From the specifications for the French topographic maps 1:50,000 we selected some critical point-, line- and area-features. Exclusively for these critical features we compared the stereo interpretation of digital images on a Digital Photogrammetric Workstation (Matra Traster T10) with the one of the original analogue images on an Analytical Plotter (Zeiss Planicomp C120). Interpretability of the analogue originals was clearly superior to their digital offsprings with pixel sizes of 60 μm, 30 μm and even 15 μm. Point features suffered the clearest reduction in interpretability.
To study the influence of pixel size on the usefulness of 1:50,000 orthophoto maps (without annotation), we also produced digital orthophotos from the digital images using different input and output resolutions. We printed them at scale 1:50,000 and tried to interpret from these monoscopic orthophotos the same features as in the stereo interpretation tests, this time with unaided eyes. Point features were not recognizable in this test series, but for line- and area-features the influence of photoscale and pixel sizes was clear.

## KURZFASSUNG

Die Digitale Photogrammetrie bietet einige Vorteile, insbesondere bezüglich Automatisierung. Der Großteil der digitalen Bilder, die für topographische Kartierung und zur Datenerfassung für räumlichen Datenbanken verwendet werden, sind digitalisierte Luftbilder. Obwohl die Interpretierbarkeit von Bildern, die für diesen Zweck verwendet werden, wichtig ist, ist über den Verlust an Interpretierbarkeit durch das Scannen wenig bekannt. Wir untersuchten den Einfluß der Pixelgröße auf die Interpretierbarkeit von Weitwinkel-Luftaufnahmen der Bildmaßstäbe 1 : 30 000 und 1 : 60 000. Von den Spezifikationen der Französischen topographischen Karte 1 : 50 000 haben wir einige kritische Punkt- Linien- und Flächen-Objekte ausgesucht. Ausschließlich für diese kritischen Objekte verglichen wir die Stereo-Interpretierbarkeit der digitalen Bilder an einem Digitalen Auswertegerät (Matra Traster T10) mit der der analogen Originalbilder an einem Analytischen Auswertegerät (Zeiss Planicomp C120). Die analogen Bilder waren ihren digitalen Derivaten mit Pixelgrößen von 60 μm, 30 μm aber auch 15 μm deutlich überlegen in Interpretierbarkeit. Punktobjekte zeigten die deutlichste Einbuße an Interpretierbarkeit.
Um den Einfluß der Pixelgröße auf die Nützlichkeit von 1 : 50 000 Orthophotokarten (ohne Annotation) zu untersuchen, haben wir von digitalen Bildern verschiedener Pixelgrößen digitale Orthophotos ebenfalls unterschiedlicher Pixelgrößen hergestellt. Diese wurden im Maßstab 1 : 50 000 ausgegeben, und wir versuchten von den monoskopischen Orthophotos mit unbewaffnetem Auge die gleichen Objekte zu erfassen wie bei der Stereo-Interpretation. Die Punktobjekte waren in dieser Testreihe nicht zu erkennen, aber bei den Linien- und Flächen-Objekten war der Einfluß von Bildmaßstab und Pixelgrößen deutlich zu erkennen.

## 1. INTRODUCTION

Digital photogrammetry can offer new approaches to topographic data collection and updating for mapping as well as for spatial databases. A key issue in finding cost-effective solutions, however, is to assure the required degree of interpretability of the digital images to be used. This is important for both the presently practicable manual and semi-automatic feature extraction techniques and the future automated change detection and object recognition processes.

There is a whole series of factors influencing interpretability. Obviously, the degree of interpretability that is required is determined by two aspects:
(a) the sizes and nature of the objects to be included (this is strongly influenced by the scale of the map respectively the spatial and thematic resolution of the target database),
(b) the accepted trade off with field completion.

Different from digital satellite images, which offer a fixed spatial resolution, using aerial photographs allows to influence the information content of the images through photoscale and scanning pixel size. In addition to those factors which influence the image quality of the analogue photograph, the scanner properties and most decisively the pixel size determine the interpretability of digital images, which are the input to digital photogrammetric solutions to geo-data collection and revision.

Several investigations have shown that the digital off-springs can compete with their analogue ancestors in geometric accuracy. The interpretability aspect, however, has received little attention yet. We may expect lower interpretational quality due to scanning, certainly when using pixel sizes that lead to manageable data volumes on present systems. A reduction in interpretability implies either a reduction in the information contents of the geo data, or requires an increase of the amount of field completion.

The reduction in interpretability could be counteracted by using larger photoscales than we were used to - as long as the implied cost increase of the total mapping process does not overtake the expected efficiency gain of using digital instead of analytical photogrammetry.

To find proper trade offs for the choosable parameters in a photogrammetric geo-data production line the influence of the image scale and the scanning pixel size on the interpretability of the digital images should be known.

One of the production lines, where digital photogrammetry allows already a far going automation, is image mapping (orthophotography). This gives the possibility to produce image maps quickly and cheaply, and many developing countries see there a chance to get a complete coverage at scale 1:50,000. Here the interpretability of the ortho images plays an important role for the question how much annotation is required to make the image maps a reasonable substitute for the line maps. Extensive annotation however is expensive and time consuming.

We carried out a series of interpretational tests to particularly investigate the impact of photoscale and scan resolution. The tests are related to 1:50,000 topographic map specifications and limited to wide-angle photography. We studied interpretability for stereo observation using a digital photogrammetric workstation (Traster T10 of Matra) as well as mono observation with unaided eye of hard copies at scale 1:50,000 of digital orthophotos (also produced by the T10).

## 2. MATERIALS AND METHODS

### 2.1 Images and test site

We wanted to use good quality images of two different photoscales in the usual range for 1:50,000 mapping (1:25,000 to 1:80,000), preferably from the same site, and the same period. From a site in Southern France we had first generation copies (diapositives) of B/W aerial photographs at scales 1:30,000 and 1:60,000 with a difference of only three years and decided to use them for this test. An area of 6km by 7km was selected, containing varied terrain: flat and hilly agricultural parts up to rugged mountainous forested parts. It does not contain urban or industrial areas. It is contained in a single model of the 1:60,000 images, but from the 1:30,000 photography 4 models are needed to cover it.

### 2.2 Scanning

To make sure, that differences in scan pixel size have a significant influence on the interpretability, at least the largest pixel size had to give a lower resolution than the original images. To guarantee this, a "worst case" estimation for the resolution of the aerial images was done.

With 65% forward overlap and 35% sidelap the maximum radial distance to be used is appr. 110 mm. The camera calibration report shows 40 lp/mm tangential and 49 lp/mm radial resolution. With aerial film the resolution is probably 20% less than with the film used in the calibration, thus only 32 lp/mm (tangential). Usually the resolution is determined using high contrast targets (100 : 1), but for interpretability the resolution at low contrast (1.6 : 1), which may be up to 50% less, is more relevant. To be on the safe side we used for the "most pessimistic" estimate a value of 16 lp/mm, thus all used parts of the original diapositives should have a better resolution than 16 lp/mm. Scanning with 32 pixels per mm can thus not preserve the resolution fully. We could therefor be sure to find a significant difference in resolution between scans with pixel sizes of 60 µm (appr. 17 pixels per mm), of 30 µm (appr. 33 pixels per mm) and of 15 µm (appr. 67 pixels/mm).

Two images (one model) 1:60,000 and six images (four models) 1:30,000 were scanned at GeoRas (Intergraph) with a Zeiss PS1 scanner, using a scanning pixel size of 15 µm. We asked GeoRas not to cut the tails from the histogram. Pixel sizes of 30 µm and 60 µm were obtained by pixel aggregation from the 15 µm images. Considering the principle of the scanner this can be assumed to be a good simulation of actual scans with 30 µm and 60 µm pixel sizes.

### 2.3 Orientation

Geometric accuracy was not part of the study. Only orientation errors, which would make it difficult to relate digitized features and features in the reference data had to be avoided. The available ground control was far from ideal for our images, but this was no problem. Even large errors, if made consistently in all orientations including the reference data, would have been tolerable.

### 2.4 Orthophoto production

Automatic DTM generation and ortho-image production of the Matra Traster T10 was used as much as possible with the default parameters. The digital orthophotos were exported to another workstation, enhanced (3x3 Laplace + original image) and then negatives were produced by an Optronics filmwriter and photographic processing. Finally paper prints were made as photographic contact copies. Five types of orthophotos were produced according to table 1.

| Input (digital image) | | | Output (orthophoto) | | |
|---|---|---|---|---|---|
| original scale | pixel size on | | ortho-photo scale | pixel size on | |
| | original | ground | | orthoph. | ground |
| 1:60,000 | 60 µm | 3.6 m | 1:50,000 | 100 µm | 5 m |
| 1:60,000 | 30 µm | 1.8 m | 1:50,000 | 100 µm | 5 m |
| 1:60,000 | 30 µm | 1.8 m | 1:50,000 | 50 µm | 2.5 m |
| 1:60,000 | 15 µm | 0.9 m | 1:50,000 | 20 µm | 1 m |
| 1:30,000 | 60 µm | 1.8 m | 1:50,000 | 50 µm | 2.5 m |

**Table 1:** Types of Orthophotos

From the 1:30,000 photography four separate orthophotos were produced. To avoid any influence of the mosaicing on the test, those pieces were printed separately and individually oriented for the digitizing. For the orthophoto with 20 µm pixel size the negative was produced with 25 µm pixels and photographic reduction was used instead of contact printing.

### 2.5 Data collection

**Stereo data collections** were done by three operators on the Digital Photogrammetric Workstation Traster-T10 from Matra using Demeter as database software. A "coarse to fine" scheme was used such, that remembering the previous interpretation could not bias the new one. When an operator had to interpret an image part again, which he had interpreted before, the new interpretation was with a much higher resolution.

| scale of original image | pixel size on | | operator | |
|---|---|---|---|---|
| | image | ground | west | east |
| 1:60,000 | 60 µm | 3.6 m | A | B |
| 1:60,000 | 30 µm | 1.8 m | B | C |
| 1:30,000 | 60 µm | 1.8 m | C | A |
| 1:30,000 | 30 µm | 0.9 m | A | B |
| 1:60,000 | 15 µm | 0.9 m | C | A |
| 1:30,000 | 15 µm | 0.45 m | B | C |
| 1:60,000 | original photographs | | another operator | |
| 1:30,000 | original photographs | | C | A |

**Table 2:** Scheme (sequence) for stereo digitizing

To allow some comparison between different operators, the area was split in two halves, and each operator did only either the eastern or the western half for a photo scale / pixel size combination. Table 2 shows the scheme for the stereo digitizing, including the collection of the reference data.

The operators were asked to vary image contrast, brightness and Zoom to be able to interpret the features as good as possible.

For the **mono interpretations** there was only a single operator available, and only small differences were expected, so here biases from "memory" could not be excluded. Digitizing tablets with ordinary cursor (no optical magnification) and Microstation software were used. Proper viewing conditions like glare free illumination and a constant viewing distance of 25 cm were difficult to achieve, but the major problem for the interpretation was the small area, which was visible around the cursor of the digitizing tablet. The operator stated, that he could clearly identify features on the orthophoto, but often "lost" them when trying to set the cursor there "with a finger on the button".

**consistency:** all interpretations were done "ignorance based". Available "other information" like existing topographic maps or higher resolution images were not to be used. The operators were familiar with this terrain type, they had done map completion exercises not far from the site at some time before. To achieve a reasonable consistency they carried out an interpretation training in the neighboring area prior to the actual data collection.

**features:** only critical features were selected from the specifications for the French 1:50,000 map. Features which are probably "always identified" or "never visible" are not considered. Features assumed critical and occurring in the test area were:
- point features: small isolated houses, bridges, reservoirs, towers, monuments.
- line features: foot paths, single lane roads, single track railways, ditches, high tension power lines.
- area features: vineyards, orchards, cemeteries.

All houses up to 120 m$^2$ area had to be digitized. To be on the safe side, slightly larger ones had to be digitized too, but not considered in the analysis.

The same interpretation key was used for the stereo- and for the mono-interpretations.

### 2.6 Reference data

These were digitized from the original diapositives using the Analytical Plotter Zeiss Planicomp C120 and Kork software for the data collection.

The same interpretation key was used as for the test data, only houses were digitized as area features, and the size limit was bigger. This was necessary to limit the test to houses up to 120 m$^2$ without treating a digitized house which is a little bigger as an error.

In addition to the necessary setting of proper viewing conditions (eye base, focussing, image rotation and squint) operators were asked to and to vary the illumination the magnification to get the interpretations as good as possible.

### 2.7 Analysis Method

Data digitized from the orthophotos or on the Digital Photogrammetric Workstation Matra Traster T10 were compared with digitizations from the original diapositives on the Analytical Plotter Zeiss Planicomp C120. Thus the reference data for the two image scales had to be different. This was necessary, because there were obviously significant changes in the three years between the flights.

All data were transferred to ArcInfo, creating separate coverages for each feature in each digitization. After cleaning of the data (e.g. all houses > 120 m$^2$ had to be identified and eliminated from the analysis) matches between the test data and the reference data were identified and counted for point features or the lengths added up for line features respectively. For area features intersections of the polygons were used.

For different sets of test data (6 stereo digitizations from 2 image scales, each with 3 pixel sizes - with and without subdivision in two parts for different operators - and 5 orthophoto types) separate "confusion matrices" for point features, line features and area features respectively were constructed. In the mono interpretations point features could not be identified, so these confusion matrices were not set up. Table 3 gives an example of a confusion matrix for 4 features (1 to 4).

| Inter-preted data | Reference Data | | | | | Total |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | other | |
| 1 | $X_{11}$ | $X_{12}$ | $X_{13}$ | $X_{14}$ | $X_{1o}$ | $T_1$ |
| 2 | $X_{21}$ | $X_{22}$ | $X_{23}$ | $X_{24}$ | $X_{2o}$ | $T_2$ |
| 3 | $X_{31}$ | $X_{32}$ | $X_{33}$ | $X_{34}$ | $X_{3o}$ | $T_3$ |
| 4 | $X_{41}$ | $X_{42}$ | $X_{43}$ | $X_{44}$ | $X_{4o}$ | $T_4$ |
| Missed | $X_{m1}$ | $X_{m2}$ | $X_{m3}$ | $X_{m4}$ | - | - |
| Total | $R_1$ | $R_2$ | $R_3$ | $R_4$ | - | $\Sigma R$ |

**Table 3:** Concept of a confusion matrix

$X_{ij}$: quantity of features interpreted as feature "i" in the test data and as feature j in the reference data.
$X_{mj}$: quantity of features j in the reference data, which have no equivalent in the test data ("missed").
$X_{io}$: quantity of features "i" in the test data, which have either no equivalent in the reference data, or an equivalent which is not one of the features considered here ("other").

As quantity was taken: the number of features for point features, the line length for line features and the area (in m$^2$) for area features .

From these tables were derived:

**Producers accuracy:** $P_i = (X_{ii} / R_i) * 100\%$ (also called "interpretation accuracy".) Gives for feature "i" the percentage of detected and correctly classified features. The opposite of it is **Omissions** ($O_i$ = 100% - $P_i$), which gives for feature "i" the percentage of undetected or wrongly classified features.

**Users Accuracy:** $U_i = (X_{ii} / T_i) * 100\%$ (also called "feature accuracy".) Gives for all features which were classified as feature "i" how many are really "i". The opposite of it is **Commissions** ($C_i$ = 100% - $U_i$), which gives for all features classified as feature "i" the percentage of wrong classifications.

**Missed rate:** $M_i = (X_{mi} / R_i)$ (also called "undetection rate" or "total omissions".) Gives the percentage of features "i", which were not detected.

**Fault rate:** $F_i$ = 100% - $P_i$ -$M_i$ Percentage detected, but misclassified features "i".

**Overall Producers Accuracy:** OPA = $\Sigma(X_{ii}) / \Sigma R$ the weighted mean (by sample size) of the Producers accuracy per feature type.

To distinguish the different operators, the producers accuracy was calculated separately for the eastern and western half of the test area. After eliminating the most obvious gross errors the final calculations were made. For the different digitizations the Producers accuracy (P), the Users accuracy (U) and the Missed rate (M) were tabulated per feature, and the Overall Producers Accuracy (OPA) per feature group added.

## 3. RESULTS OF EXPERIMENTS

### 3.1 Stereo interpretations

A comparison of the stereo interpretability of digitized images and their analogue ancestors is given in table 4. There were no monuments and no powerlines in the reference data and only a few towers, reservoirs and cemeteries. These features are not included in the table, as their sample size is too small to be considered separately. In the "Overall Producers Accuracy" they are however included.

| photoscale | 1:60,000 | | | | | | | | | 1:30,000 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pixel size | 60µm (3.6m) | | | 30µm (1.8m) | | | 15µm (0.9m) | | | 60µm (1.8m) | | | 30µm (0.9m) | | | 15µm (0.45m) | | |
| Feature | P | U | M | P | U | M | P | U | M | P | U | M | P | U | M | P | U | M |
| Is. houses | 24 | 16 | 76 | 36 | 23 | 64 | 54 | 45 | 46 | 38 | 33 | 62 | 56 | 33 | 44 | 68 | 40 | 32 |
| bridges | 44 | 50 | 56 | 43 | 75 | 57 | 46 | 67 | 54 | 60 | 100 | 40 | 67 | 67 | 33 | 82 | 75 | 18 |
| OPA-point | 26 | | | 35 | | | 47 | | | 36 | | | 55 | | | 70 | | |
| footpaths | 0 | - | 100 | 55 | 81 | 45 | 66 | 51 | 34 | 77 | 67 | 16 | 86 | 94 | 14 | 85 | 82 | 15 |
| sing.road | 57 | 66 | 43 | 64 | 53 | 35 | 78 | 71 | 22 | 66 | 90 | 32 | 79 | 95 | 21 | 85 | 92 | 15 |
| sing.railw. | 100 | 100 | 0 | 100 | 100 | 0 | 100 | 100 | 0 | 100 | 100 | 0 | 100 | 100 | 0 | 100 | 100 | 0 |
| ditches | 0 | - | 100 | 73 | 100 | 27 | 79 | 73 | 21 | 58 | 90 | 42 | 81 | 100 | 19 | 86 | 100 | 14 |
| OPA-line | 47 | | | 66 | | | 78 | | | 67 | | | 80 | | | 86 | | |
| vineyards | 0 | - | 91 | 31 | 63 | 62 | 58 | 71 | 42 | 36 | 99 | 62 | 91 | 91 | 4 | 95 | 90 | 4 |
| orchards | 17 | 29 | 83 | 46 | 54 | 52 | 55 | 80 | 40 | 63 | 63 | 36 | 90 | 47 | 6 | 87 | 75 | 11 |
| OPA-area | 6 | | | 42 | | | 57 | | | 46 | | | 91 | | | 95 | | |

**Table 4:** Global results of the stereo interpretations

The comparison between different operators showed considerable inconsistencies. Some of them are easily explainable by the limited experience of the operators, which resulted in inconsistent application of the interpretation key. This is considered as unavoidable noise on the data. There were also gross errors (e.g. in one test an operator had simply forgotten to digitize bridges).

Such data (like the zero for bridges on this half of the test area) had to be eliminated from the analysis. By doing so the sample size for this feature in this test was reduced by approximately 50%, which makes the data less significant.

Fortunately most of these blunders concerned only small samples, so that the OPA for the feature groups are practically not changed by the elimination of those blunders.

The **overall producers accuracy (OPA)** shows a clear increase with a reduction of the pixel size (as can be expected). When looking to the pixel size on the ground we find the following: the results for the 1.8 m ground pixels are practically the same for the two image scales, whereas for the 0.9 m ground pixels the smaller scale photography gives the same result only for line features. It is slightly inferior for point features and clearly worse for area features.

This indicates, that the step in ground pixel size from 0.9 m to 1.8 m has a much bigger influence, than the step in photoscale from 1:30,000 to 1:60,000. Only for the area features the change of photoscale has a significant influence on the interpretability of images scanned with a ground pixel size of 0.9 m.

The **missed rate (M)** is a good measure for the amount of measurements required in the field completion. In our tests it is in most cases 100% - P. This shows, that there was not much confusion between the considered features, as the number of detected but misclassified features is 100% - P - M (See "fault rate" in chapter 2.7). Misclassified features would only require field identification, not measurement.

The **users accuracy (U)** is very low, indicating that many of the digitized features were wrongly included. This is no big problem for the field completion, as it only requires changing the classification or deleting the feature.

**point features** are strongly dominated by the isolated small houses. The missed rate, which varies between 76% (1:60,000, 60 μm) and 32% (1:30,000, 15 μm) shows the considerable amount of additional field measurements needed. The (very low) user accuracy is probably unrealistic. It can be caused by the limitation of the test to houses, which are small and single. Many of the features, which were wrongly digitized as "small single house" may still be houses, but the fact, that they do not qualify for "small" or "single" might have been undetectable. In the reference data houses larger than 120 $m^2$ were digitized, and the corresponding houses in the test data omitted, but this did not catch all of these "errors".

**line features** show very diverse data. The single track railway was always identifiable and the result on single lane roads was also rather good (between 57% and 85%). On the other hand is the interpretability of foot paths and ditches strongly depending on the ground pixel size. The producers accuracy varies between zero for the 3.6 m pixels and 85% for the 0.45 m pixels.

**area features:** vineyards, which are the dominating feature in this group are usually identified by a pattern of tiny parallel lines, less than 1 m wide on the ground (the lines of wines and their shadow) spaced less than 3 m. In this context the success rate of more than 30 % for the 1.8 m ground pixels is more surprising than the zero for the 3.6 m ground pixels.

### 3.2 mono interpretations

The second part of the study, which compares mono interpretation of 1:50,000 orthophotos with unaided eyes to stereo interpretation of the analogue aerial photographs with considerable optical magnification is summarized in table 5.

Point features were not detectable in these tests, this feature group is not shown in the table. From the context can be seen, where single houses and bridges should be found, but they could not be positively identified.

| photoscale | 1:60,000 | | | | | | | | | | | | 1:30,000 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| image pixel size | 60μm (3.6m) | | | 30μm (1.8m) | | | 15μm (0.9m) | | | 60μm (1.8m) | | | 30μm (0.9m) | | |
| ortho pixel size | 100μm (5m) | | | 100μm (5m) | | | 50μm (2.5m) | | | 20μm (1m) | | | 50μm (2.5m) | | |
| Feature | P | U | M | P | U | M | P | U | M | P | U | M | P | U | M |
| footpaths | 27 | 44 | 73 | 44 | 52 | 51 | 55 | 50 | 40 | 53 | 45 | 47 | 43 | 36 | 48 |
| single lane road | 32 | 47 | 68 | 53 | 66 | 44 | 65 | 64 | 33 | 67 | 51 | 33 | 40 | 48 | 59 |
| ditches | 33 | 43 | 67 | 52 | 66 | 48 | 55 | 67 | 45 | 52 | 77 | 48 | 52 | 63 | 48 |
| OPA-line | 31 | | | 51 | | | 62 | | | 63 | | | 41 | | |
| vineyards | 0 | - | 100 | 26 | 61 | 63 | 37 | 51 | 63 | 46 | 55 | 48 | 9 | 39 | 89 |
| orchards | 48 | 43 | 52 | 56 | 43 | 44 | 59 | 55 | 31 | 52 | 43 | 39 | 33 | 39 | 59 |
| OPA-area | 14 | | | 38 | | | 43 | | | 47 | | | 17 | | |

**Table 5:** Global results of the mono interpretations

For **line- and area features** the results are surprisingly close to the stereo interpretations. In the orthophotos prepared from the photography 1:60,000 line- and area-features show, that for the output ground pixel of 5 m reducing the input pixel size from 3.6 m to 1.8 m gives a considerable improvement. This contradicts the assumptions made by Leberl (1992) and by Schiewe and Siebe (1994), that the pixel size on the ground can be the same for the input and the output images, and supports the final suggestion of Schiewe and Siebe to use a smaller input pixel size.

Reducing the output pixel size from 100 μm (5 m) to 50 μm

(2.5 m) gives a modest improvement, while a further reduction of the output pixel size to 20 µm (1 m) improves the result on vineyards only, while it remains unchanged for other features or even getting worse. This indicates, that the limit due to the resolution of the observers eyes is between the 100 µm and the 50 µm pixel size, as suggested by Doyle (1982)

The orthophotos from the **photography 1:30,000** should be compared with the one from the 1:60,000 images of the same input and output resolution on the ground, thus the third case in table 5. The clearly inferior result can be explained from the clearly lower contrast in this photography, which seems to hamper mono interpretation but not the stereo interpretation. Moreover we had no control over the photographic processing, and there were indications, that there were problems in this particular case. New contact prints gave almost the same result as from the photography 1:30,000, but this test was not done under the same circumstances and it was not completed.

## 5. CONCLUSIONS AND RECOMMENDATIONS

Scanning wide angle aerial photography of standard resolution with a pixel size of 15 µm gave a significant reduction in the interpretability, especially for isolated small houses. Pixel sizes of less than 15 µm should be tested too. For high resolution photography, which has a 3 to 4 times better overall resolution, separate tests with much smaller pixel sizes will have to be made.

The test presented here shows the dependency of the interpretability of the tested features on the ground pixel size rather well. Although a generalization to completely different environments can not be made can be used is input to find a good trade off for image scale, pixel size and field completion. Other parameters, like costs of fieldwork and additional costs for larger photoscales and additional time/costs for smaller pixel sizes depend on many circumstances and are not treated here.

The results on interpretations of orthophotos 1:50,000 are obtained by a well trained operator. Interpretation is highly subjective, depends strongly on the experience of the interpreter and can thus not be generalized for the average map user, who depends even more on the resolution of the images. For optimal interpretability the ground pixel size should be smaller for the input image than for the output image. For orthophotomaps 1:50,000 the input images should therefor have a pixel size of less than 3.6 m on the ground, and the orthophotos less than 100 µm at presentation scale. Going to pixel sizes below 1.8 m for the input or 50 µm for the output does not increase the interpretability for observation with unaided eyes.

Orthophoto maps at scale 1:50,000 will need annotation mainly for important point features. For line- and area features this is not so much required if good images and appropriate pixel sizes are used in the orthophoto production.

Extrapolating from our results we would recommend for future tests photoscales 1:80,000 to 1:100,000, scanning with 15 µm to 30 µm and printing with 50 µm pixels. For high resolution photography even smaller scales can be tried, but the scanning pixel size should be less than 2.5 m on the ground.

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