THE SEMANTIC INFORMATION OF IMAGES ACQUIRED BY AERIAL DIGITAL SENSORS IN CARTOGRAPHIC AND ENVIRONMENTAL APPLICATIONS

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Commission IV, WG VI/9

KEY WORDS: Digital, Cartography, Mapping, Analysis, Information , Accuracy

ABSTRACT:

Aerial digital cameras were first presented on the occasion of the ISPRS International Symposium in 2000. Since then, several papers that analyse the geometrical accuracy of digital camera have been presented. These works have underlined the fact that the geometric accuracy obtainable with the digital sensor is significantly higher than the accuracy achieved with scanned analogue cameras. Nevertheless, this accuracy is usually obtained considering predefined markers which allow higher geometric precision than the other points required in the Technical Specifications at a certain map scale, whereas precision (during tests) in map productions is focused on common map entities required in Technical Specifications. Furthermore, good geometric precision in triangulation does not guarantee easy stereoplotting of all the map entities with the required precision. However, it is obviously wrong (and simplistic) to consider, without any logical proof, that digital camera products are comparable, from a semantic point of view, with traditional photogrammetric camera products acquired approximately at the same nominal scale.

The semantic information of digital images is accurately analyzed in this paper, and the geometrical aspect is neglected. In particular, the semantic information is considered both from a qualitative and quantitative point of view and the image quality and information content of several digital sensors (*ADS40 Leica Geosystems 1st and 2nd Generation, DMC Intergraph Z/I, UltraCamD Vexcel Corp., 3-Das-1 Wehrli & Associates*), which are commonly employed in the map production at different scales, are evaluated. In this analysis, particular attention is paid to the handiness of the interpretation of the entities that are requested in modern technical specifications (at several scales) for map production.

1. INTRODUCTION

Aerial digital cameras were first presented on the occasion of the ISPRS International Symposium in 2000. Since then, these cameras have become ever more popular and will eventually replace analogue film cameras. Traditional cameras are destined to drop out of the market in a few years, as some of largest film manufacturers in the world have discontinued production and the majority of camera producers have decided to only develop digital sensors (Casella, 2007).

During these years several papers that analyse digital camera geometric accuracy have been presented. These works have underlined the fact that the geometric accuracy obtainable with the digital sensor is significantly higher than the accuracy that can be achieved with analogue cameras. Nevertheless, this precision is usually obtained considering predefined markers which allow geometric precision from 3 to 5 times higher than the other points (Kraus, 1997) required in the Technical Specifications at a certain map scale, whereas precision (during tests) in map productions is focused on the common entities that are required by the Technical Specifications. Furthermore, good geometric precision in triangulation does not guarantee easy stereoplotting of all the map entities with the required precision.

However, it is obviously wrong (and simplistic) to consider, without any logical proof, that digital camera products are comparable, from a semantic point of view, with traditional photogrammetric camera products acquired approximately at the same nominal scale.

As a consequence, a comparison of the semantic content of (scanned) analogue and digital images must be performed. In this analysis, particular attention must be given to the ease of interpretation of map entities which are required in modern technical specifications (at different scales) for map production.

Some papers have already described these differences, analysing the geometric accuracy and the noise effects through testing and measurements (Becker et al. 2006; Kölbl, 2005; Casella et al., 2004; Cramer, 2004; Leberl, et al., 2003; Reulke, 2003). Other papers have detected in the Ground Sample Distance (GSD), the fundamental parameter in the flight specifications for digital cameras (Casella, 2006). One [Jacobsen, 2007] has already compared images acquired by two frame cameras (*DMC* and *UltraCamD*) with scanned analogue images. A multiplicative factor of 1.5 between the GSD of digital images and scanned analogue photos was proposed in this work, in order to obtain the same object detail; this factor, however, only referred to one particular map scale and there was no clear reference to technical specifications.

In this present paper, this comparison between scanned analogue and digital cameras is performed in a more systematic way; these differences are in particular analysed only from a semantic point of view, disregarding the geometrical aspect and a comparison between different cameras. This evaluation is performed considering the image quality and information content of several digital sensors which are produced by leaders in this field such as Intergraph Z/I (DMC), Leica Geosystems (ADS40 1st and 2nd Generation), Vexcel Corp. (UltraCamD) and Wehrli & Associates (3-DAS-1), which represent over 90% of the world's photogrammetric digital sensors. In addition, as is well known, these cameras have different internal geometries (frame camera and pushbroom) and, as such, they have been considered representative of all digital cameras actually on the market. Furthermore the performed analysis has considered different flight images, acquired at different altitudes and over different kinds of landscape, in order to obtain the most complete set of data possible. This analysis considers from 1:500 to 1:10000 map scales. A complete analysis of smaller scale maps cannot be performed considering only aerial sensors. It is necessary to considers also satellite ones (Boccardo et al., 2005).

The technical features of the sensors and available flight features are reported in the following table.

Sensor	Internal geometry	f [mm]	Flight height [m]	Nominal Scale 1:	GSD [m]
ADS40 1st	Pushbroom	62.8	6000	100000	0.62
ADS40 2nd	Pushbroom	62.8	2000	32000	0.1-0.2
UltraCamD	Frame	101.4	900	9000	0.08
DMC	Frame	120	1200	10000	0.12
3-DAS-1	Pushbroom	110	900	8000	0.08

Table 1. Available flight features

The technical specifications in map production usually define the main features of photogrammetric flights in order to realize a digital map at a certain map scale. However these specifications refer to analogue cameras and consider these cameras equivalent to digital ones. For this reason, starting from practical equations and custom usage adopted in analogue flights, new practical equations for digital flights are presented. The used methodology to achieve these results is described step by step in section 2.

In the performed tests, Ground Sample Distance was considered the Fundamental parameter in the flight specifications for digital cameras (Casella, 2006). Each digital camera in fact has a different internal geometry and it is actually impossible to find a "standard" for digital cameras. For this reason, the comparison was performed considering comparable flights with the same value for this parameter. The GSD of analogue images was obtained scanning these photos with a 20 µm pixel size because, with a smaller pixel size, no more details can be identified and accuracy is not appreciably improved (Jacobsen, 2007; Lingua et al., 2007; Perko et al.,2004, Baltsavias, 1999).

Finally the achieved conclusion are presented in Section 3, and a new table is proposed which relates the map scale to the GSD of digital photogrammetric flights.

2. TESTING METHODOLOGY

The traditionally nominal scale of analogue camera images is linked to the achievable map scale through practical equations and tables (Italian Geodetic Commission, 1973; Kraus, 1993).
As known analogue cameras have reached a certain "standard" in internal geometry. As a consequence, considering a focal length of 150 mm (wide-angle camera), it has been possible to link a GSD (obtained by scanner) to a nominal scale and, through these tables (Italian Geodetic Commission, 1973), to an achievable scale map, as shown in figure 1.

The equivalent GSD and the requested accuracy for each map scale is shown in figure 1. As shown, the Ground Sample Distance and accuracy differs by a non constant value: in some ways, handiness of interpretation influences the GSD size at large map scales (particularly in 1:500 and 1:1000 map scales) and the difference between these parameters decrease.

The established link between GSD of (scanned) analogue images and the achievable map scale was used as a starting point. In other words, available digital flights were initially analyzed considering cartographic details required at a map scale with the same GSD; then the evaluation as to whether a larger scale was achievable using the same digital images was performed. As already proposed in [Giulio Tonolo et al., 2007] and in [Lingua et al., 2007], particular attention was paid to the ease of interpretation of the map entities which are required in Technical Specifications (at different scales) for map production, verifying whether it was possible to recognize and plot these details. In particular, the required map entities were detected in reference to the INTESA GIS technical Specifications which are the Italian application of the European INSPIRE Directive.

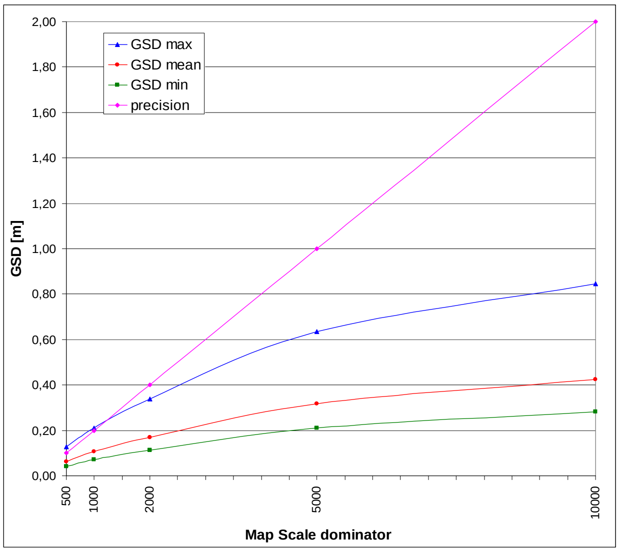

Figure 1. Scale map and GSD in scanned analogue Cameras

The map entities were analysed and judged for each available flight. This work was summarized in tables. An example is shown in the following in table 2.

In order to define an achievable map scale for each flight, the requested map entities were initially grouped into 7 different levels (e.g. roads, buildings, etc.): for example, streets and pavements were inserted into the road category, rivers and channels in the water category, and so on.

Then, in each level, the entities were classified in three different groups:

- group A: it was possible to plot the entity;
- group B: the entity was visible on images, but it was not possible to plot it;
- group C: the entity was not neither visible.

The percentage of entities belonging to each group is reported, as example, in table 2. According to this percentage, it was possible to classify this level in:

- Metrically plotted, if at least 95% of the cases belong to Group A (P);
- Visible, if only 60% of the case belong to Group A and 35% to Group B (V);
- Not visible (NV).

A map scale was chosen if all the levels were in the P category. This final subdivision is shown in the last column in table 2. These procedure were repeated, for each available flight, and, in each case a map scale was chosen.

2.1 ADS40 1st Generation

The available images were taken by this sensor at an altitude of 6000 m, with a GSD of about 62 cm. In spite of this, the quality of images is good, especially coloured ones. Two different areas were acquired with the same GSD: one over the city of Turin (Italy) and the other over the Susa Valley, the location of the 2006 Winter Olympic Games.

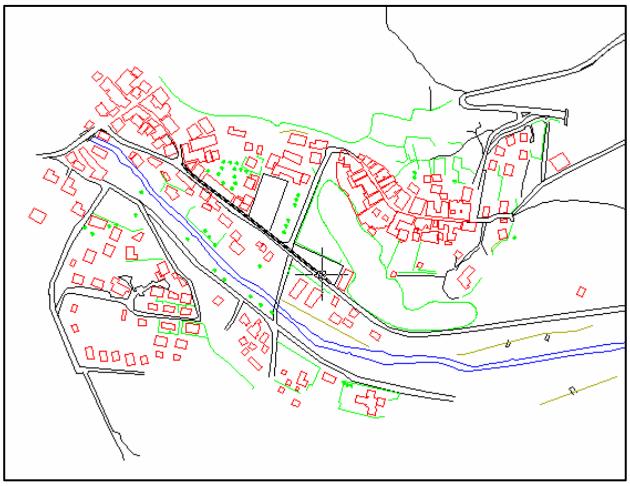

Figure 2. An Example of the map entities stereoplotted from the ADS40 1st generation of the Susa Valley

According to our methodology, it was expected that a 1:10000 map scale (figure 2) would be extracted from these images.

Map entities	*Group A*	*Group B*	*Group C*	
Road and railway	96%	4%	0/9	P
Buildings, urban furniture, technical buildings	100%	0%	0%	P
Water, rivers, channels, water works, etc.	100%	0%	0%	P
Energy, material, fluid pipelines	95%	5%	0%	P
Man-made Territorial divisions	100%	0%	0%	P
Break lines	100%	0%	0%	P
Vegetation	100%	0%	0%	P
TOTAL %	*98%*	*2%*	*0%*	*P*

Table 2. Map entity levels and sub-levels

The analysis of the results is summarized in table 2. The performed analysis has confirmed the expectations. The colour images helped to detect different objects and to distinguish, according to their colour, different entities, such as stone walls from brick walls.

However some map details were not metrically plotted as requested in technical specifications because of their reduced dimensions in the images. For example the sky-lift pylons in figure 3 are shown as they appeared at zoom 1:1: this kind of entity is obviously difficult to detect and even more difficult to plot.

The GSD 0.62 m can, to a certain extent, be considered the maximum suitable dimension in 1:10000 map production. In general, a maximum GSD of 0.60 m is suggested for this map scale.

Figure 3. Sky-lift pylons in a ADS40 image (zoom 1:1)

2.2 ADS40 2nd Generation

This sensor acquired images during two flight performed at different altitude over the city of Romanshorn (Switzerland). One flight was performed at about a height of 1000 m and with a GSD of 0.10 m. The second flight, which was flight at an altitude of 2000 m, instead had a GSD of 0.20 m.

Both flights acquired good quality images. An example of the images from the first flight images is shown in figure 4 while an example of the 0.20 m GSD images is given in figure 5.

Figure 4. Urban area acquired by ADS40 2nd generation, GSD=0.10 m (zoom 1:1, 4:1)

It was initially expected to extract a 1:500 map from the first flight images, as all the entities requested by technical specifications were clearly visible. Nevertheless details larger than 0.5 m must be metrically described, at this map scale. However, these details were sometimes hard to correctly represent; an example of this is the small chimney (shown in figure 4) that can only be plotted by zooming onto it. For this reason an attempt was made to realize both a 1:500 and 1:1000 map scale: the achieved results are summarized in table 3. As shown, it is however possible to map at a 1:500 scale, just by zooming a little onto some details. In some ways, a GSD equal to 0.10 m can be considered the maximum suitable dimension for this scale mapping.

Map Scale	***Group A***	***Group B***	***Group C***	
1:500	96%	4%	0%	P
1:1000	100%	0%	0%	P

Table 3. Comparison between 1:500 and 1:1000 map scale

It was expected to extract a 1:2000 map scale in the second flight (GSD=0.20 m).

The possibility of extracting a 1:1000 map scale was evaluated but, as shown in table 4, too many entities, even though visible, could not be correctly plotted. An example is shown in figure 5 where small pavements obviously appear very narrow even when large zooms are used. For this reason, it was decided to extract a 1:2000 map scale.

Map Scale	***Group A***	***Group B***	***Group C***	
1:1000	90%	10%	0%	V
1:2000	100%	0%	0%	P

Table 4. Comparison between 1:1000 and 1:2000 map scale

Figure 5. Urban area acquired by ADS40 2nd generation, GSD=0.20 m (zoom 1:1, 4:1)

2.3 UltraCamD Vexcel

This flight was performed over the city of Graz in Austria, at an altitude of 900 m. The GSD dimension was about 8 cm and it was therefore expected to generate a 1:500 map scale from these images. All the map entities required for this scale map were recognized correctly and stereoplotted. The quality of these images was very high, as it is possible to see in figure 5. Small windows and chimneys on roofs are clearly shown (also in a stereoscopic view).

This GSD dimension can be considered the optimal dimension in the 1:500 map scale.

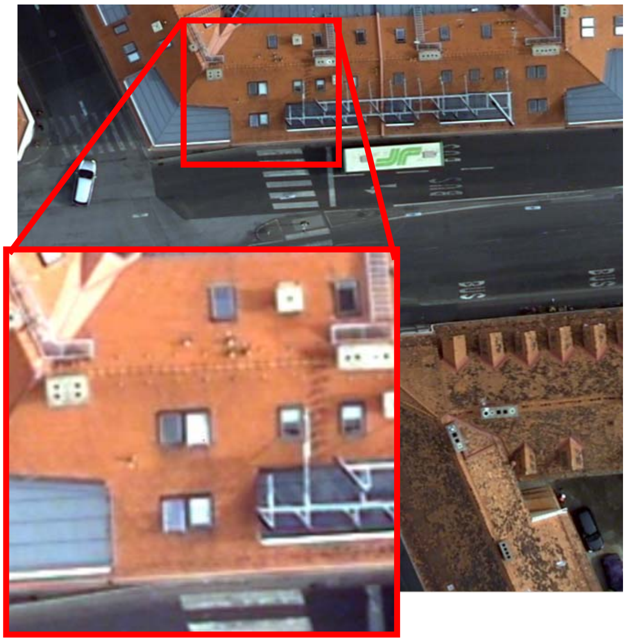

Figure 6. Urban area acquired by UltraCamD (zoom 1:1, 4:1)

2.4 DMC Z/I

These images were acquired during a flight which was performed at a height of 1200 m over the city of Lauria in Italy. The Ground Sample Distance was 0.12 m large.

All the required map entities in the 1:500 map scale were recognizable in a first analysis. Nevertheless their dimensions, as in the previous case, were too small to be correctly plotted in a digital map even thought a 4:1 zoom was employed (see figure 6). A comparison between 1:500 and 1:1000 is made in table 5. As shown, it was not possible to metrically represent too many entities.

For this reason, the semantic analysis was performed in reference to the 1:1000 Technical Specifications. All the required map entities were detected and plotted with the necessary precision.

2.5 3-DAS-1 Wehrli & Associates

This flight was performed at a height of 1000 m. The GSD is about 8 cm and according to the adopted methodology, it was expected to extract a 1:500 map scale.

As in all the previous examples the image quality was very high as shown in figure 8. Each map detail was in fact easily recognizable and could be easily plotted.

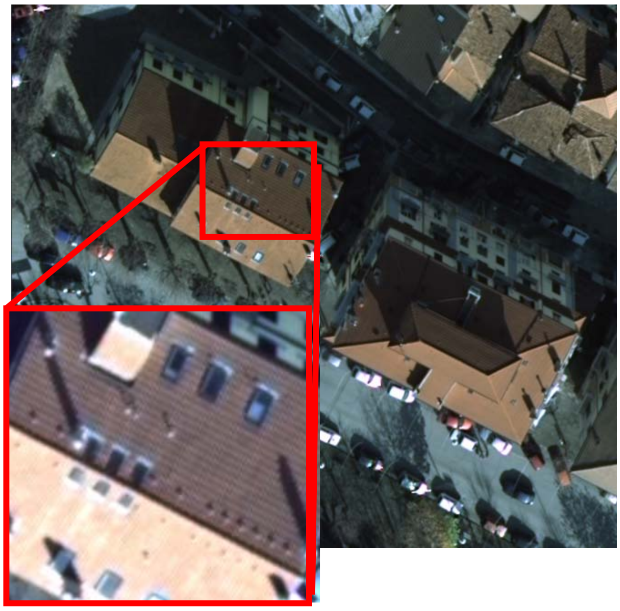

Figure 7. Urban area acquired by DMC (zoom 1:1, 4:1)

Map sale	***Group A***	***Group B***	***Group C***	
1:500	87%	13%	0%	V
1:1000	100%	0%	0%	P

Table 5. Comparison between 1:500 and 1:1000 map scale

Figure 8. Urban area acquired by 3-DAS-1 (zoom 1:1, 4:1)

3. CONCLUSION

In this paper digital images acquired from several digital sensors were analyzed from a semantic point of view in order to evaluate the differences with scanned analogue cameras and to propose new GSD values for different map scale production.

According to the performed analysis, digital cameras seem to give better quality images than scanned analogue images.
In order to realize a certain map scale, digital cameras allow flights with a larger GSD to be performed. In particular, the following equation is suggested:

$$GSD_{CD} = g\ GSD_{AI} \qquad (1)$$

where GSD_{DC} =GSD in digital cameras
GSD_{AC} = GSD in scanned analogue cameras
g = gain factor, g>1

In general, it was noticed that digital images allowed stereoplotting of the same map scale using a GSD 1.1 up to 1.6 times greater than the GSD of scanned analogue images.

Map scale	***GSD_{AC} [m]***	***GSD_{DC} [m]***	***g***
1:500	0,064	0.010	1.56
1:1000	0,106	0,120	1,13
1:2000	0,171	0,200	1,18
1:10000	0,423	0,62	1,46

Table 6. Gain factor between scanned and digital images in the performed tests

As shown in table 3 the gain factor is not a constant but changes according to the scale map and increase in value in smaller scale maps. The maximum reached GSD value for each map scale is reported in this table, according to the performed test; in particular, the reported GSD in 1:500 and 1:10000 map scales could be considered the maximum suitable values.

In general, the g-value 1.6 must be considered a limit which is difficult to exceed because of the small size of the map entities to plot. On the contrary, g-values of about 1.1 or 1.2 should be considered very moderate. A compromise can be reached if a g-value of about 1.4-1.5 is considered.

According to this issue, a new GSD has been proposed for each mapping scale (see table 7). This table, which summarize the conducted work, could be considered a valid aid to adapt Technical Specifications to the performances of new digital sensors.

Map scale	Scanned analogue camera GSD [m]	Digital camera GSD [m]
1:500	0.06	0.09
1:1000	0.11	0.15
1:2000	0.17	0.24
1:5000	0.32	0.45
1:10000	0.42	0.60

Table 7. GSD comparison analogue - digital camera

Starting from this value, it will be possible to determine the flight features of each digital camera, according to its internal geometry. An example is shown, considering the internal geometry of the 3-DAS-1 camera, in table 8.

A geometrical check of all the stereoplotted map entities has not been performed so far. In the future this methodology will be improved by checking, where possible, this geometrical precision in stereoplotted entities with the direct surveys using GPS-RTK techniques.

1:	GSD [m]	Flight Height [m]	Nominal scale 1:	Swath width [m]
500	0.09	1100	10000	720
1000	0.15	1830	16700	1200
2000	0.24	3000	26700	1920
5000	0.45	5500	50000	3600
10000	0.60	7300	66700	4800

Table 8. Flight feature for a 3-DAS-1 flight

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ACKNOWLEDGE MENTS

This work was carried out as part of the research activities of the National Research Programme PRIN05 “Use and integration of high resolution digital images acquired by aerial or satellite platforms for cartographic and environmental applications”. The person in charge is Prof. Sergio Dequal.

The authors would like to thank C.G.R for proving the ADS40 1st generation images, Geotop s.r.l. for providing UltraCamD images, Geoworks s.r.l. for providing DMC images, Leica Geosystems for providing the ADS40 2nd generation images and RATI s.r.l. for providing the 3-DAS-1 images.