A TOOL TO HELP MAPPING PLANNING IN CLOSE RANGE PHOTOGRAMMETRY

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ABSTRACT:

In Aerial Photogrammetry some tools are available to simplify the aerial mapping planning and make it faster. In particular, once defined the scale of the map, witch is related to the Spatial Resolution (SR), diagrams are available to provide the average scale of photogram and the flying height for different focal length values. Terrestrial Photogrammetry is deficient in this kind of tools, probably because of the greater complexity and the lack of standardization in the parameters of the camera, and because of the presence of constraints on the camera distance and on the angle of view. The basic idea of this work is to obtain some tools to help mapping planning in terrestrial photogrammetry. We establish as project parameters the equivalent focal lenght, the camera distance and the camera resolution, all these variables are function of an assigned SR. We produced two typologies of graphs to help mapping planning: we have assigned or the camera resolution or the equivalent focal length in order to obtain some graphs where the other two parameters are plotted as function of the SR.

INTRODUCTION

In Aerial Photogrammetry (AP) some tools are available to simplify the aerial mapping planning and make it faster. In particular, once defined the scale of the map, witch is related to the Requested Detail Level (RDL), diagrams are available to provide the average scale of photogram and the flying height for different focal length values.
Close range Photogrammetry (CRP) is deficient in this kind of tools, probably for these two reasons:

- CRP is more complex then AP. In fact in AP some parameters are defined, such as the angle of view, the focal distance, etc.. This lack of standardisation in CRP is due to the presence of constraints on the camera distance and on the angle of view.
- Costs of AP are very high so an accurate mapping planning of the survey is necessary.

The basic idea of this work is to obtain some tools to help mapping planning in CRP. In fact an accurate mapping planning is useful also in CRP for the economy of both the survey and of restitution's phase. Digital cameras are usually used in terrestrial photogrammetry, thus in this work is applicated in digital photogrammetry.

In AP the mapping planning includes the following phases:

1. once defined the scale of the map, witch is related to the Requested Detail Level, diagrams are available to provide the average scale of photogram
2. the next step is provide the flying height for the defined focal length value;
3. then the number of flight lines and the number of photographs per night line with sideslap and endslape assigned can be calculate.

Similarly in this work:

1. we first analyse the concept of the scale in terrestrial photogrammetry, essential to assess the relation between the RDL and the scale of digital images;
2. next we analyse all parameters influencing the scale of images, such as camera distance, focal distance and characteristics of the film or the sensor and plot some graphs that evidence the relationship.

The definition of the position of the camera for each photo depends of the particular object of survey so we didn't generalise this phase.
Finally we test the use of graphs in mapping planning with two different cameras.

THE CONCEPT OF SCALE

In photogrammetry, we can find two different concepts of scale (EHASL, 2004):

- the traditional *cartographic scale* (or map scale) is the ratio of map distance to actual distance on the real word. A so-called large-scale map usually covers a smaller area with greater detail.
- the *spatial resolution* (SR) of images or maps which is the size of the smallest possible feature that can be detected. Scale is there described by its grain. In representation of real world the SR is related with the detail level. In remote sensing we often think of SR in terms of the size of the *ground resolution* cell.

The two concepts of scale are related because map data at different scales will allow for different SR. Generally, in a map we can't distinguish two lines as notes if their distance is much narrower than about 1/5 a millimetre. Therefore, we could calculate the SR by multiply 0,2 mm for the scale factor. For example, on a 1:20,000 scale paper map, the minimum distance which can be represented (resolution) is about 10 metres. The SR of Photographs have to be the same of the SR of the representation.

PARAMETERS INFLUENCING SR

The most fundamental metric that forms the basis for estimating SR of photographs is the size of the footprint, or area on the ground captured in a photograph, d_g. The basic geometric variables that influence the area covered by a photograph are camera distance D; focal length of the lens f; actual size of the image on the film s_i, and the orientation of the camera axis relative to the ground (the obliquity or look angle) (Robinson et al, 2002). The relationships among these parameters for a nadir view are illustrated in Figure 1.

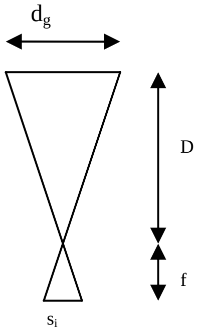

Figure 1. Relation between camera distance (D); focal length (f); size of the image (s_i); area coveded by photograph (d_g)

1.1 Camera distance

The higher the camera distance, the larger the footprint of the photographs. The variation of the scale of photographs taken at different camera distance is illustrated in Figure 2. The two photographs were taken with the same camera and lens, but from different distances. A difference in distance leads to a corresponding difference in the SR of the resulting photographs.

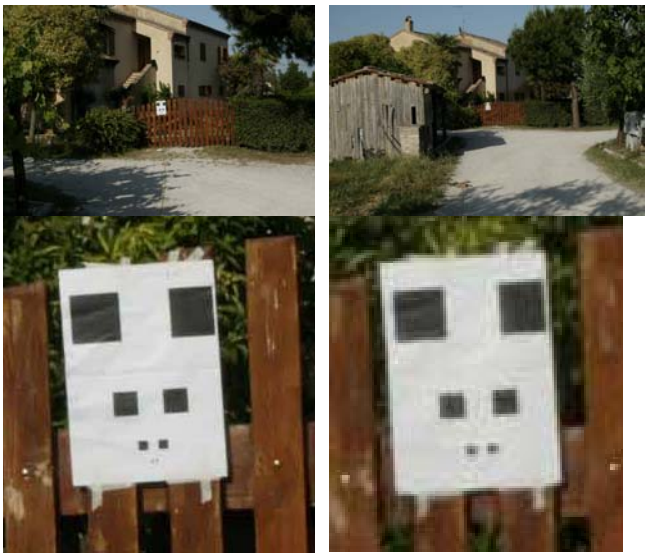

Figure 2. Effect of the distance on SR

1.2 Cameras

After passing through the lens, the photographic image is projected onto film or sensors inside the camera. The size of this original image is another important property determining spatial resolution, and it is determined by the used camera. Traditional camera formats include 35-mm and 70-mm formats. Digital cameras are usually used in terrestrial photogrammetry. In these cameras a CCD (charge-coupled device) is used as a digital replacement for film recording the image projected inside the camera. The format of CCD is not standardised, it's often referred to with a "type" designation. It's defined by the size of CCD and the number of pixels. In Figure 3 we can compare traditional and digital formats.

The cost of the sensor is mostly dependent on the size of the CCD, so designers have crammed more pixels into smaller space by shrinking the pixel size.

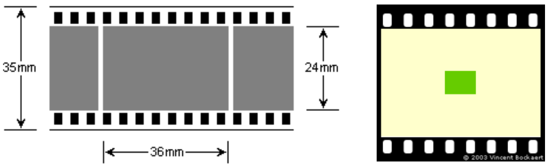

Figure 3. Image Formats 2a) traditional film; 2b)Sensor type 1/3'' compared to traditional film

The size of the pixel is the ratio between the size of the CCD and the number of pixels. A smaller pixel size allows more pixels to fit in a given field size, increasing resolution. However as the pixel size becomes smaller, fundamental physical limits become increasingly important, placing a practical lower limit on pixel size (Merrill, 2000, 2003):

- As the overall size is reduced, the light sensitive area of each pixel gets smaller. As the light-sensing areas become smaller, the signal-to-noise ratios (SNR) decreases, and thus require longer exposure to the light to gather the required information, so the iso speeds get slower, and the iso range they can deliver good images at gets narrower. The larger the pixels are on a sensor, the faster it gathers information, the more sensitive it is, and the more able it is to record the greatest range of tones in a scene. A benefit of this is that it can do this over a greater range of iso speeds than a sensor with smaller pixels, and maintain image quality. So larger pixels will provide higher useful ISO ratings for a digital camera. In terrestrial photogrammetry we can reduce noise using lower ISO ratings. This is possible by use of tripod.
- the ability to resolve features. In a digital image, the resolution is limited by the pixel size: the Nyquist Sampling theorem stipulates that at least 2 CCD pixels must cover the smallest object to be resolved. So the dimension of the smallest feature that can be detected (SR), as illustrated in Figure 3, is projected in sensor in the space cover by 2 pixel size ($2s_p$)
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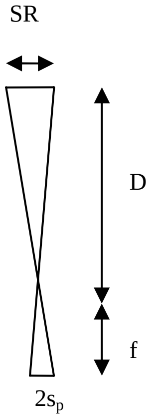


Figure 4. For the Nyquist Sampling theorem the smallest feature that can be detected is projected in sensor in the space cover by 2 pixel size ($2s_p$) .

1.3 Lenses

The longer the lens focal length, the larger magnification, the greater detail, and the smaller footprint. A variety of lenses with different focal lengths are available on the market. The effect of lens focal length on spatial coverage and image detail is shown in Figure 5. The two photos are taken from the same distance with the same camera, using the 50 mm lens and a 100 mm lens. The difference in scale of the photographs is due to the different magnifications of the lenses. Unfortunately, longer-focal-length lenses exhibit poorer performance toward the edge of a frame. There is a greater spatial resolution difference between centre and corner (Robinson et al, 2002).

Figure 5. Effect of the focal length

ESTIMATE SPATIAL RESOLUTION

1.4 Theoric evaluation

For a perfect nadir view, as we can seen in Figure 1, the scale of images can be expressed as its Representative Fraction (RF) by camera distance and focal length or by area on the object captured in a photograph, d_g. and actual size of the image on the film, s_i:

$$RF = \frac{D}{f} = \frac{d_g}{s_i} \tag{1}$$

As we can seen in Figure 4, the ratio between camera distance and focal length is also proportional to the ratio of RS to 2 times the pixel size, as given by:

$$\frac{SR}{2s_p} = \frac{D}{f} \tag{2}$$

From eq. (2) we obtain D as function of SR (Spatial Resolution), f (Focal length), s_p (Size of the Pixel):

$$D = \frac{SR \cdot f}{2s_p} \tag{3}$$

Normally pixels are squares, so the pixel size s_p is done by the ratio between the sensor size in a data direction, i.e. the horizontal direction, and the number of pixel in the same direction:

$$s_p = \frac{s_{s,or}}{n_{p,or}} \tag{4}$$

With eq. (3) we can calculate for a data camera the minimum distance from the object to obtain an assigned SR. For text we have choose two cameras: the Panasonic Lumix FZ20 (pixel size 2.2 µm.) and the Canon Eos D1s (pixel size 8.8 µm.). The Panasonic features a 5-Megapixel resolution, the CCD is 1/2.5'' type; the lens has 12x optical zoom (36-432 mm in 35-mm equivalent); the EOS-1Ds brings ultra-high resolution (11 Megapixel sensor) and full-frame sensor (24x36 mm). We have plotted for both cameras the camera distance as function of spatial resolution for different focal length. Graphs are plotted in $\log_{10}$- $\log_{10}$ scale to see all the range of variables that is very large (e.s the SR covers three orders of magnitude).

We obtain a series of parallel straight-line.

We can find the equation of the straight-line by applying the natural logarithm on both members of eq. (3):

$$\log D = \log \frac{f}{2s_p} + \log_{10}(SR) \tag{5}$$

We have translate the x coordinates so that the y-axes passes through the point SR=0,001 m

The equation (5) became:

$$\log D = c + 3 + \log_{10}(SR) \tag{6}$$

whit values of SR in metres.

The value of intercept will be the minimum distance for distinguish a feature of 1 mm:

$$D_{1mm} = \frac{f \cdot 0{,}001}{2s_p}; \quad c = \log_{10} \frac{f \cdot 0{,}001}{2s_p} = \log_{10} \frac{f}{2s_p} - 3 \tag{7}$$

We can view that the straight-lines has unitary slope, independent from camera parameters. Camera parameters influences only the Y-intercept, as we can see in Figure 6. So we have only calculate the value of incercept c to find the referential straight line, using eq. 7.

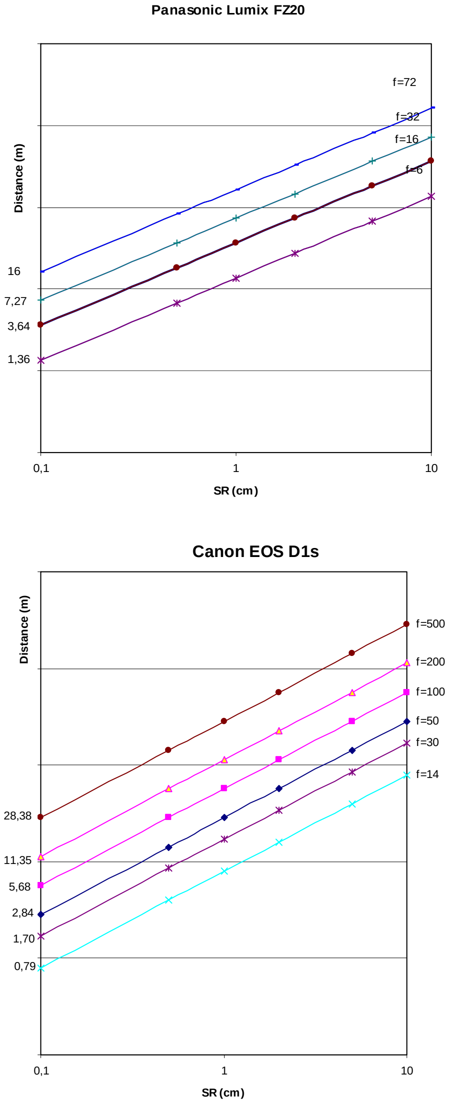


Figure. 6. Distance as function of SR and focal length for two cameras

However parameters in eq. (7) are not so usually known. We can use the so-called "equivalent" focal length (f_e). This parameter, often used in digital cameras instead of effective focal lenght, denotes the focal length (mm) of a 35-mm film camera lens which has the same angle of view (Figure 7). Almost two definitions of equivalent focal lengths exist. The major debate is whether you should consider the angle of view covered by the diagonal across the various formats, which is applicable in some circumstances, or the angle of view along the long side of the formats, which is applicable in other circumstances. The two definitions produces different results because the aspect ratio of CCD, often 4:3, is different from the format 2:3 of the traditional cameras.

We have considered the horizontal angle of view, higher 5% than diagonal one.

The relation between focal length and equivalent focal length is:

$$\frac{f}{s_{s,or}} = \frac{f_{eq}}{36mm} \tag{8}$$

By compare eq. (4), (5), (7) we obtain:

$$D_{1mm} = \frac{f_{eq} \cdot n_{p,or}}{72mm} \tag{9}$$

We can plot graphs similar to these in Figure 6 by using equivalent focal distance. In Figure 10 the straight lines are individuate by the value of intercept.

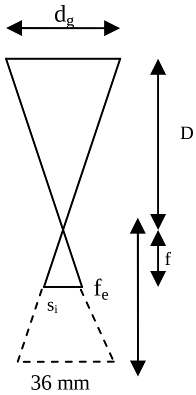


Figure 7 Relation between focal length and equivalent focal lenght

In Tab. 1 the values of intercept are tabulated as function of both the equivalent focal distance and the number of pixel in orizontally direction. Usually in digital cameras the aspect ratio is 4:3 so the number of pixel in a direction is representative of the resolution.

For a data camera, with a data resolution and a data equivalent focal distance we can calculate by interpolation value of intercept, to individuate referential straight line for the camera, in figure 10. This line furnishes the theoric distance for a data SR.

1.5 Empirical validation of the theoric curves

The intrinsic resolution for a data camera, lens and distance can often be degraded by other factors which introduce blurring of the image, such as noise, improper focusing, atmospheric scattering, in dipendence also of the optical quality of the photograph by a particular camera system.

A measurement methodology has been developed to validate the curves obtained in 4.1. This methodology is based on the definition of the *spatial resolution* (SR) as the minimum distance between two features to be distinguished. With an assigned camera and focal distance we have taken photographies at different distances of the grid represented in figure 8. Each feature is represented as a pair of dark squares placed at a distance equal to the dimension of the square. For each feature a minimum camera distance exists to distinguish in the photography each square of the pair. The dimension of the square is the SR of the photograph.

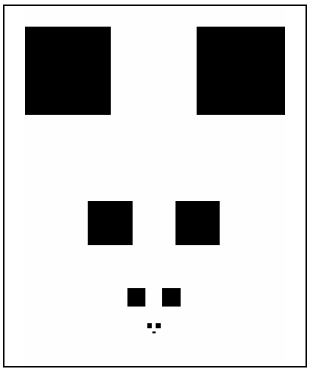
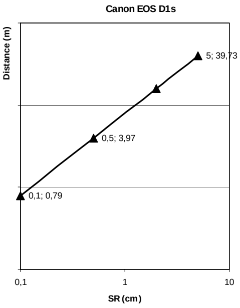
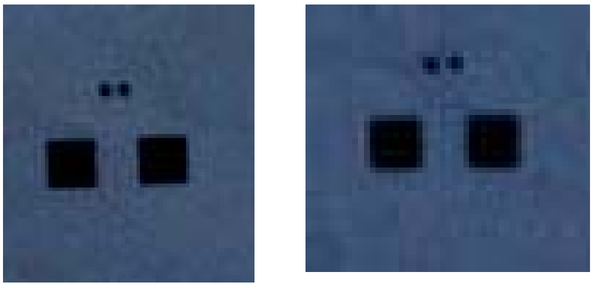


Figure 8. The grid used for the empirical observations

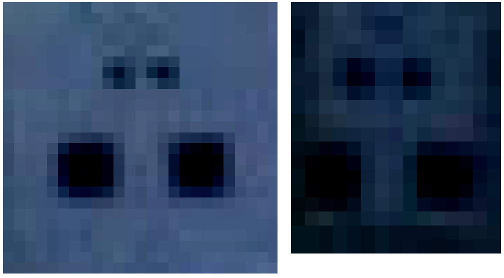
In Figure 9 we show the photographies cut out in correspondence of the feature. Photos are made with the Canon, with a focal length of 14 mm, at different distances. In all photos we can distinguish squares, so the real SR is conform to theoric one; but the contrast gets smaller with growing distance, for the effect of the acutance reduction. For the Panasonic the theoric distance has to be incremented by 20% to distinguish features, probably for the presence of noice.





Feature 0,1 cm
f=14 mm
D=0,79 m

Feature 0,5 cm
f=14 mm
D=3,97 m



Feature 2 cm
f=14 mm
D=16 m

Feature 5 cm
f=14 mm
D=40 m

Figure 9. Empirical observations relatives to points in the graph above

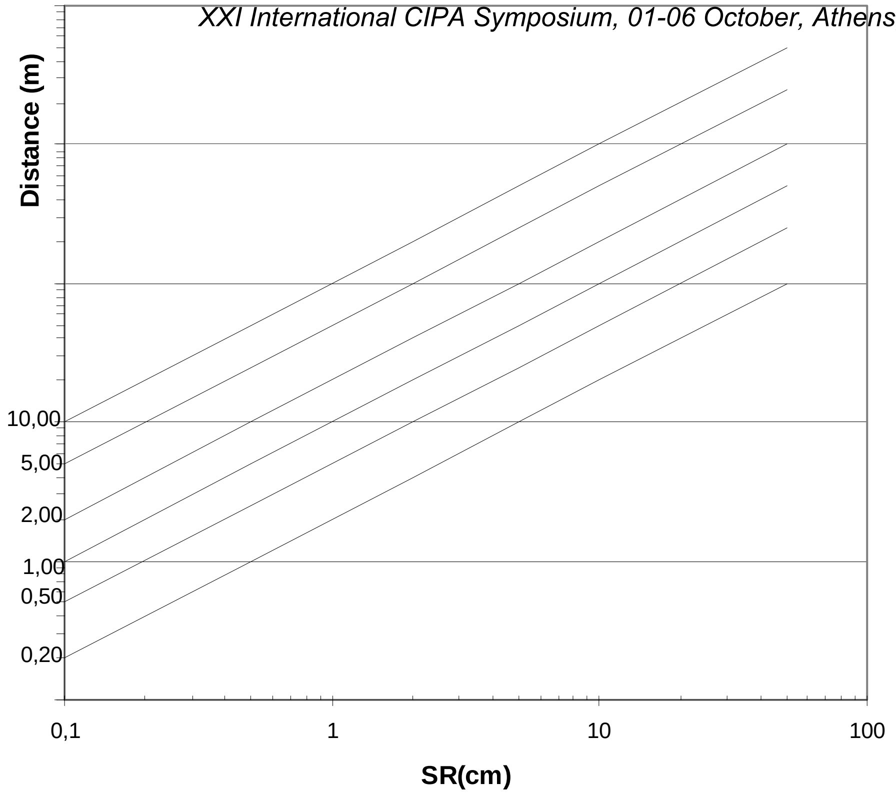


Figure 10. The referential traight line for a data camera is individuate by the value of intercept

Table 1. The value of intercept is tabulate as function of resolution and equivalent focal distance

N. Megapixel		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
n. pixel in or. direction		**1280**	**1600**	**2048**	**2288**	**2592**	**2816**	**3072**	**3264**	**3488**	**3648**
Equivalent focal lenght	**15**	0,27	0,33	0,43	0,48	0,54	0,59	0,64	0,68	0,73	0,76
	30	0,53	0,67	0,85	0,95	1,08	1,17	1,28	1,36	1,45	1,52
	45	0,80	1,00	1,28	1,43	1,62	1,76	1,92	2,04	2,18	2,28
	60	1,07	1,33	1,71	1,91	2,16	2,35	2,56	2,72	2,91	3,04
	75	1,33	1,67	2,13	2,38	2,70	2,93	3,20	3,40	3,63	3,80
	90	1,60	2,00	2,56	2,86	3,24	3,52	3,84	4,08	4,36	4,56
	105	1,87	2,33	2,99	3,34	3,78	4,11	4,48	4,76	5,09	5,32
	120	2,13	2,67	3,41	3,81	4,32	4,69	5,12	5,44	5,81	6,08
	135	2,40	3,00	3,84	4,29	4,86	5,28	5,76	6,12	6,54	6,84
	150	2,67	3,33	4,27	4,77	5,40	5,87	6,40	6,80	7,27	7,60
	165	2,93	3,67	4,69	5,24	5,94	6,45	7,04	7,48	7,99	8,36
	180	3,20	4,00	5,12	5,72	6,48	7,04	7,68	8,16	8,72	9,12
	195	3,47	4,33	5,55	6,20	7,02	7,63	8,32	8,84	9,45	9,88
	210	3,73	4,67	5,97	6,67	7,56	8,21	8,96	9,52	10,17	10,64
	225	4,00	5,00	6,40	7,15	8,10	8,80	9,60	10,20	10,90	11,40
	240	4,27	5,33	6,83	7,63	8,64	9,39	10,24	10,88	11,63	12,16
	255	4,53	5,67	7,25	8,10	9,18	9,97	10,88	11,56	12,35	12,92
	270	4,80	6,00	7,68	8,58	9,72	10,56	11,52	12,24	13,08	13,68
	285	5,07	6,33	8,11	9,06	10,26	11,15	12,16	12,92	13,81	14,44
	300	5,33	6,67	8,53	9,53	10,80	11,73	12,80	13,60	14,53	15,20
	315	5,60	7,00	8,96	10,01	11,34	12,32	13,44	14,28	15,26	15,96
	330	5,87	7,33	9,39	10,49	11,88	12,91	14,08	14,96	15,99	16,72
	345	6,13	7,67	9,81	10,96	12,42	13,49	14,72	15,64	16,71	17,48
	360	6,40	8,00	10,24	11,44	12,96	14,08	15,36	16,32	17,44	18,24

CONCLUSIONS

In digital architectural photogrammetry it’s difficult to define the scale of representation. It’s important for the economy of both the survey and of restitution’s phase to define the Requested Detail Level, which is related on the Spatial Resolution (SR) of the photographies. We first have shown the relations between SR, Distance and other parameters depending on the used camera and lens. Then we have constructed tables and graphs to assess camera distance for a data SR and a used camera system that can have practical utilisation for other possible users.
Otherwise effective resolution could differ on the theoric evaluation in dependence on the camera used. We have to investigate the pejorative factors (in particular the effect of the dimension of the pixel on the noise) by testing more cameras.

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