A Role Played by Airphoto Scale during the Transmission of the Geographic Information

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Abstract

It is not sufficient that photogrammetrists and interpreters merely understand the mathematical meaning of airphoto scale. Inquiring into the role played by airphoto scale during the transmission of the geographic information according to Information Theory not only has a theoretical value, but also gives a clearer guide for the choice of airphoto scale appropriate to the specific aims.

1. General review

The scale of an airphoto, that is the ratio of a distance on the photo to that same distance on the ground, is one of the geometrical parameters used to construct the mathematical model in photogrammetry. It is also a basis for our estimation of the absolute size of features in order to detect their attributes during photographic interpretation. Therefore, to study the properties of airphoto scale has a great significance in both theory and practice.

Since an airphoto is the optical record of terrain scenery under the central projection it complies with the perspective principle which takes a larger image for the near object and a smaller one for the distant object. Consequently, there appears a variation of scale throughout the whole photograph due to that the optical axis of the aerial camera is not exactly vertical and the earth surface is undulate. The dampener devices on the camera mount in the modern airplane for taking aerial photographs has already been able to reduce those tilts of the camera axis into less than 1°, so the effect on airphoto scale resulted from the slight unintentional inclination of the optical axis becomes negligible within the application range of an airphoto. For most elementary measurement applications, these photographs are treated as being vertical without serious error. Relief causes the distance of various objects on the ground to the camera to vary continuously within a certain range, which results in an infinite number of different scales on the photograph. On a photograph, areas of terrain at the higher elevations lie closer to the camera at the time of exposure and therefore appear larger than corresponding areas lying at lower elevations. However, the maximum difference of relief within the limits of an airphoto is usually much less than flying height, thus the scale variation of feature images on a whole photo is less remarkable than that of objects on any picture taken from ground. Therefore, it is often convenient and desirable to use an average scale for an entire photograph to calculate the approximation of the true dimensions for feature images throughout an airphoto. This is a common way adopted during the visual airphoto interpretation.

An aerial photograph is a collection of feature images reduced by optical projection according to the predetermined scale. Photo scale is often considered just as a particular factor of optical reduction by majority of photogrammetrists and interpreters. They analyse it and study various methods of its calculation like discussion of any continuous function with certain limits and keep the examination of airphoto scale on that level.

The author thinks that since the use of airphotos is an important way to acquire the geographic information over a broad scope, it will greatly open up the knowledge about the physical significance of that parameter if one inquires deeply into a role played by airphoto scale during the transmission of the geographic information according to Information Theory. This paper is a tentative attempt at following the above-mentioned idea.

2. The estimation of information content on a single airphoto

We use the popular black-and-white panchromatic film to discuss the estimation of information content on a single airphoto . However, most of its conclusions is feasible to be spread on colour photos.

It is a common knowledge that an airphoto is the record of light energe reflected from features getting into the view field of the camera at the moment of exposure. Images on an airphoto convey interpreters the special geographic information which is sought by them. To some extent image characteristics are similar to the appearance ones of ground objects which are often sensed by the naked eyes. A systematic study of aerial photographs usually involves a consideration of these characteristics such as tone,shape,size,pattern,texture and shadow. (In colour photos there is an add in hue,brightness and saturation as well.) Viewing an airphoto before one's eyes seems to be a simple analogue to look at the distant earth surface from the air. Experience shows that seeing a far scenery has some limitations to identifacation on it only relying upon the appearance characteristics, that is, there exists uncertainty with it. This uncertainty is less for some features and more for the others. Similarly, identification and classification from the image characteristics on airphotos bring out a different reliability. With a statistics standpoint there are the unequal probabilities P_{is} of interpretation for the different image characteristics of a particular feature S. The average geographic information contained by the image characteristics of that feature can be determined by the entropy of S , called $H(S)$, according to Information Theory, i.e.

$$H(S) = -\sum_{i=1}^{n} P_{is} \log_2 P_{is} \quad \text{(bits)} \qquad (1)$$

All larger area features have aforementioned six image characteristics, namely $n=6$; linear features are often short of texture and shadow, so $n=4$. They constitute the prevailing components of classification in airphoto interpretation. If the total number of available or desirable classification on a photograph amounts to m , the information content H extracted from a single photo is equal to the following:

$$H=\sum_{S=1}^{m} H(S)=-\sum_{S=1}^{m}\sum_{i=1}^{n} P_{is}\log_2 P_{is} \quad \text{(bits)} \qquad (2)$$

Unfortunately, at present there is lack of a widespread and profound study to the stochastic behaviour which the image characteristics show in the interpretation performance. Consequently one could not obtain any experimental estimate of P_{is} so that equation (2) has only a theoretical sense. Some investigators adopt an approach to analyse the information content of a given airphoto by means of imitating the scanned images. They use the scanning microdensitometer to digitize photo images line by line and one pixel after another in each line. In this procedure data from a whole airphoto are converted to an assembly of the discrete brightness values or gray levels in number tens of thousands. If the dynamic range to quantify images amounts to m (Up to 256 or more gray levels can be taken with the newest microdensitometer nowadays.), the number of scanned lines is equal to K and each line consists of n pixels, then the maximum information content of an entire photo should be equal to

$$H=nK\log_2 m \quad \text{(bits)} \qquad (3)$$

For ordinary observers the discernible gray range of black-and-white images is about twenty levels, i.e. $m\approx 20$. Suppose the minimum image area distinguishable by naked eyes is a and the efficient image area on a photo is limited to A . Thus the information content from visual interpretation may be estimated by

$$H=\frac{A}{a}\log_2 20\approx 4.32\frac{A}{a} \quad \text{(bits)} \qquad (4)$$

When using airphotos with 23cm square format for interpretation and excluding the marginal parts of photograph due to the poor quality of imagery, let the efficient interpretable area be $A=20\times20\,cm^2$ and assume that the minimum area unit discernible with naked eyes is $a=1\,mm^2$, one can calculate the following result from (4)

$$H=4.32\times\frac{200\times200}{1}\approx 1.73\times10^5 \quad \text{(bits)} \qquad (5)$$

This means the maximum information acquired by visual interpretation from the black-and-white panchromatic film is less than 2×10^5 bits. Table 1 gives information contents provided by (4) for three commonly used airphotos with a condition of $a = 1 mm^2$.

Table 1. Interrelation between information content and format size of airphoto

Format size cm^2	18 × 18	23 × 23	30 × 30
Efficient area A mm^2	22 500	40 000	72 900
Information content bits	0.97×10^5	1.73×10^5	3.15×10^5

3. Relationship between scale and information

As everyone knows the amount of details shown in an aerial photograph is dependent, among other things, on the scale of the photograph. It is easy to make out that situation in comparison with airphotos which all have been taken over the same area but in different scales. Does it imply that the photo taken with a larger scale contains more geographic information than that with a smaller scale provided those two airphotos have the same format? From the familiar formula as follows

$$\frac{1}{M} = \frac{f}{H} \qquad (6)$$

one knows scale $\frac{1}{M}$ is a function of the focal length f of the camera used to acquire the image and flying height above the ground H from which the image was taken. Figures 1 and 2 illustrate the situations respectively. From figure 1 we can see that for a constant flying height the width of the ground area covered by a photo varies inversely with focal length. Consequently, photos taken with shorter focal length lenses have larger areas of coverage than do those taken with longer focal length lenses. For any given focal length lens, the width of the ground area covered by a photo changes directly with flying height above terrain (See figure 2). In a word, the ground coverage of a photograph with smaller scale is broader than that of a photograph with larger scale in the case of using

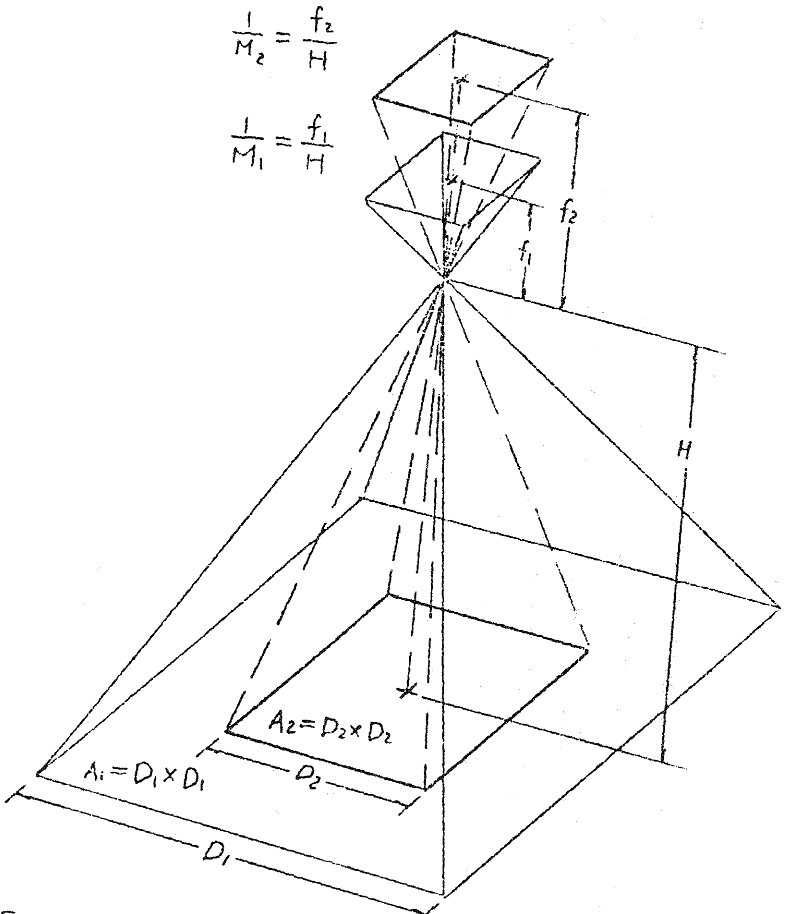

Figure 1. Effect of focal length on ground coverage and scale.

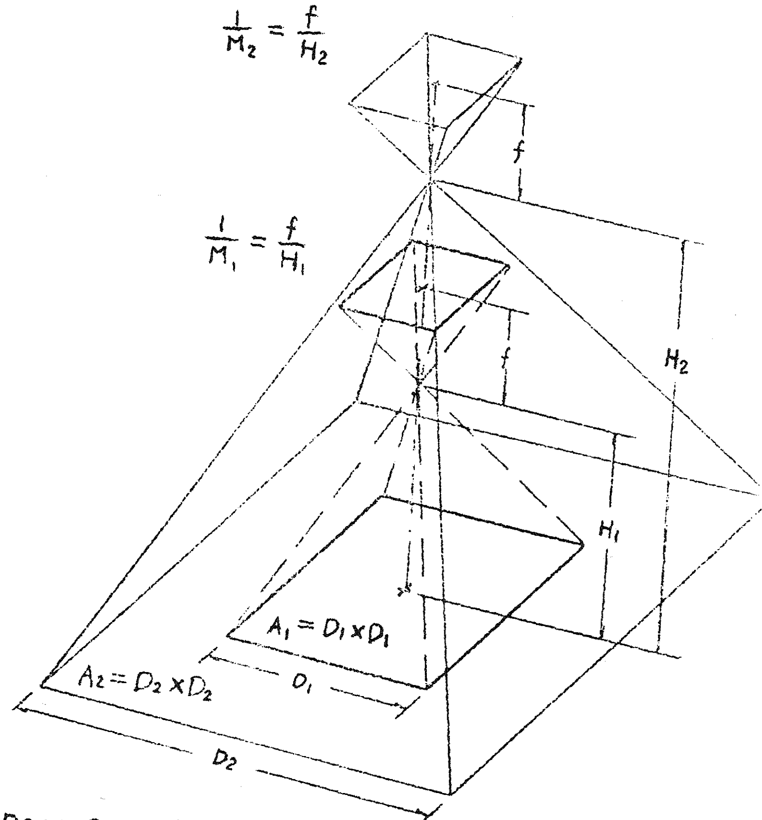

Figure 2. Effect of flying height on ground coverage and scale

any aerial mapping camera with a fixed frame. We have to note the trade-offs between the ground area covered by an image and the object detail available in each of the photographs. Table 2 provides the variations of both scale and ground coverage with flying heights for a single photo based on 152.4mm focal-length camera having a 23cm square format.

Table 2. The effect on photo scale and interpretable ground area due to a variation of flying height

Flying height m	Photo scales 1:M	Interpretable ground areas km^2
610	1:4000	0.64
1143	1:7500	2.25
1524	1:10000	4
2286	1:15000	9
3048	1:20000	16
4572	1:30000	36
6096	1:40000	64
7620	1:50000	100
9144	1:60000	144

The photo scale adopted for extracting the maximum information should meet the user demands on the quality indices of both interpretation and measurement. While selecting it in common practices one needs to compromise with the other factors such as cost, amount of field work etc. on the last decision.

The geographic information carried by airphoto images belongs to the realm of spatial information in a broad sense. The information content computed by means of probability and statistics has taken no account of any concrete demand and sense of users. In fact, the objective information passed on by image characteristics should not be confined just to the outward appearance or grammatical interpretation of features, we need to consider more basic contents such as the relationship between image and its corresponding object (semantic character) as well as the resulted impression on interpreters (use value) during airphoto interpretation. Especially the value of information is directly related to not only how long airphotos have been taken but also how about the professional background and surroundings of interpreters. Moreover, the validity or reliability of the extracted information from airphotos depends on the practical experience of each interpreter. Users of airphoto from different disciplines usually have their own demands of classification in which they are interested. In the inventory of land resources, for example, one requires to recognize any cultivable land. Therefore the minimum area of discernible farmland will become an important reason to select the suitable scale of airphoto.

Furthermore, an obvious difference between the feature images on photographs and the graphic symbols on maps lies in that the former has a continuous variation of gray tone. Quite often it is not easy to find out an accurate boundary between neighbouring features on airphotos. For instance, there is usually a wide transition zone from forest area to grassland where the woods are sparse. Consequently, the total of photo images constitutes a fuzzy set. In order to identify each fuzzy figure as a correct species we have to consider the fuzzy information conveyed by image characteristics. Although there is lack of the unified method to achieve a quantitative analysis of the generalized information at present, one should never forget about it during reseaches for the relationship between scale and information.

Generally speaking, those photo scales proposed by various professional interpreters from their working experience over a long period of time are considered as the ones to satisfy a best extraction of the specific information from images. For example, in general interpretation for the purpose of topographic mapping one of the empirical formulas suggested to select the proper scales has a form as

$$M = 2000 \times A \times R \times \Delta D \qquad (7)$$

where M represents the denominator in the fractional expression of scale; A the minimum length of ground targets in meters; R the compound resolution of the photographic system in lines per millimeter; ΔD the contrast of a given film. One should , in any case, allow for unforeseen circumstances during application of that formula.

4. The influence on transmitting information through images due to a variation of scale

An airphoto itself is an epitome of the ground truth getting into the view field of the camera lens. It has stored some geographic information in an area of the earth surface concerned by its users. When viewing photographs stereoscopically with stereoscopes or directly by eyes at all one has a possibility to detect the necessary information through the various image characteristics.

Experience shows that observing the close scene one can see not only a number of individual small targets but also many details of a large object. However, because of the limit of visual angle the accessible scope of space becomes relatively narrow and small so that we are restricted in recognition of macroscopic scene. On the contrary, when looking ahead and towards the distant mountains one can see a broad green and luxuriant picture, and identify it as a vegetation. However it is much difficult to do a division of that landscape into woodland, shrub, pasture or anything else. Besides the undulate mountain ridges seperating the earth from the sky one can not find out any other clear boundary on the green background.

Airphotos with larger scales provide more possibility to be photographed for tiny features within the view field of the camera and reduce the uncertainty to recognize those features , thus classification may be improved from coarse to fine. Viewing airphotos of large scale is more or less similar to observe the near scene on field. However, owing to a limited ground coverage it is not easy to recognize some geological structures with successive linearments in a narrow range. When photo scale changes from large to small it makes more and more features on the broader scope squeeze in the constant view field of the camera. Because of a finite resolution of the photographic system the number of pixels occupied by each feature reduces rapidly, which leads the entire images on the original photo with a larger scale to be contract into a part of the smaller scale one with the same format. The information content of that part is compressed together with the other ones. However, such a compression of information is not completely analogous to the cartographic generalization during compilation of smaller scale maps based on the larger scale ones. Cartographic generalization is primarily controlled by the artificial rules, but the phenomenons happening on imagery during conversion to the smaller scale where the dimension of all images is reduced in accordance with the same proportion and adjoining images partly are merged as well as some details disappear are due to the decrease of the viewing angle of features themselves to the camera lens and the attenuation of their reflected light energe. For example at very large scales, e.g. 1:1000, the leaves of a tree will contribute to the texture of the branches which are themselves individual visible. At a smaller scale, e.g. 1:20000, the entire crown of the tree contributes to the texture of a forest area. Thus one can find the effect of compression on the geographic information through the textures exhibited by the same feature in different scales.

Though photographs with larger scale have a higher accuracy of measurement than the opposites, with an increase of ground coverage some geographic information of which many photos of large scale are short will gain nodoubtedly on the ones of small scale. Furthermore, the latter provides a wider room for logical reasoning according to site or location of objects in relation to other features during interpretation.

5. Conclusion

Airphoto scale has been considered as one of parameters only for construction of the mathematical model in photogrammetry for a long time past. Its mathematical meaning is well known by everybody as a reduction factor in the perspective projection of ground. However few people had profoundly analysed its physical significance. An increasing application of Information Theory in transmission and processing of remotely sensed data has created an extremely favourable condition for our best understanding airphoto scale. We know that the process from aerial photography to photographic interpretation represents a transmission and processing of the geographic information from the field to the office. It is due to a choice of photo scale that a variety of the geographic information in the extensive earth surface is able to be compressed on photographs with different formats which are convenient to users for management. Therefore, in accordance with the viewpoint of transmitting the geographic information airphoto scale seems to be a compression factor of information.

The previous discussion shows that the information content of a single photo does not solely depend upon a given scale. The format size has also a great influence on the information content of photographs. The geographic information passed on by image characteristics belongs in the ones of broad sense. It is not comprehensive to estimate the information content only by means of probability and statistics. As Information Science is vigorously progressing the author convince that the more efficient method for an overall evaluation of the airphoto information will be found in the near future.

All aerial mapping cameras have a fixed frame size , so the variation of photo scale exerts a direct influence on the ground area covered by a single photo. Airphotos taken with larger scales have smaller area of coverage but provide more information of feature details and possess higher measuring ability. However, airphotos of smaller scales can cover a broader scope of ground and bring much macroscopic information more remarkable than their opposites. Selecting appropriate photo scales should at first meet the requirements for interpretation and measurement of specific purposes, and at the same time give consideration to the other factors such as cost and amount of field work so as to do some modification。 To sum up, we can see that it does not only have a theoretical value but also give a clearer guide for the choice of photo scale appropriate to the special aims to inquire into the role played by photo scale during the transmission of the geographic information according to Information Theory。

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