Impact of Softcopy Photogrammetry on Surveying and LIS Activities

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ABSTRACT: The accuracy aspects of softcopy photogrammetry are presented and some of the possibilities of the technology are highlighted, in view of the potential that microcomputer systems present for professionals involved in surveying, mapping and land information system (LIS) data collection. A theoretical model is developed which relates the standard observation error, in planimetry and elevation, to the pixel size. Theoretical values are shown to agree with actual results. The question of accuracy being clarified, specific advantages and characteristics of the technology are shown as well as the possibilities and interest, for surveying and engineering work, of interactive photogrammetry, to which the new systems open the door. Finally, because softcopy photogrammetry is still photogrammetry, there is some discussion of responsibility considerations and the importance of appropriate use—based on appropriate knowledge—of the technology. Examples of incorrect practices are given and some educational adjustments are suggested.

Introduction

In general, it can be stated that increased accessibility—measured in terms of versatility, user-friendliness, and cost—has been a basic objective of the important on-going development of microcomputer softcopy photogrammetry. (Now in common use, the term *softcopy photogrammetry* highlights the fact that photogrammetry is essentially software, and no longer hardware, dependent.) Further, growth in the field of practice of photogrammetry is seen as a natural consequence of increased accessibility.

Characteristics of existing softcopy systems, examined as a function of the objective of greater accessibility, clearly demonstrate that development efforts have been successful. Basic photogrammetric operations are now performed more easily, more efficiently, and with greater flexibility. Combined with the much lower costs of some systems (Welsh 1993), this has facilitated access to photogrammetry for many new users, which, in turn, will lead to the extension of the field of practice. Moreover, softcopy systems have the potential to perform tasks beyond the capabilities of conventional photogrammetric instrumentation.

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Welsh (1992) mentions some of the added features which have helped to make digital systems "powerful instruments for the collection, editing and analysis of spatial data": integration of image and map data, edition, interface with GIS software, generation of digital elevation models (DEMs), production of orthophotos, and so forth. He shows that these features are available with low-cost softcopy systems.

Klaver and Walker (1992), among others, have outlined the potential for growth in photogrammetry, in terms of new applications and new users both inside and outside the traditional surveying and mapping community. Needless to say, this comes at a very appropriate time, given the current huge mapping and data collection needs in both developed and developing countries (Estes and Mooneyhan 1994).

Within the surveying and mapping community, arguably the success of extending the field will depend on, or at least benefit from, some clarification of accuracy concerns, which are often raised in relation to microcomputer low-cost softcopy photogrammetry systems. Some possibilities of the new technology, as well as responsibilities arising out of its use, should also be highlighted.

The Question of Accuracy

With conventional photogrammetric instrumentation, accuracy is a function of the combined effect of diverse physical factors which relate to the quality of the optico-mechanical complex. In this

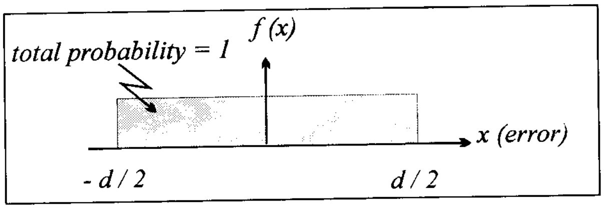

Figure 1. Probability distribution of reading errors.

context, it is the norm for low-cost instrumentation to mean a low level of accuracy. However, the situation is quite different with digital photogrammetry, where accuracy can be tuned to the needs of the user. This is because the accuracy essentially depends on scanning resolution, provided that scanning distortion has been properly accounted for. With digital photogrammetry, accuracy is independent of the system itself, whatever its cost: accuracy is governed by the dimension of the pixel. This assumes, of course, that the software is robust, which should be established and duly documented by the developer or the vendor.

In the case of conventional photogrammetric instrumentation, the practice has been to replace an analytical approach to accuracy evaluation by a global assessment based on empirical tests, because the effects of the different physical factors are difficult to assess properly. Classification of photogrammetric plotters was usually based on such tests, as can be seen, for instance, in Slama (1980). The method was generally considered as only roughly indicative of the actual accuracy of a plotter, and led to general statements such as: "...on the most precise analog plotting instruments, measurement accuracies in the order of 20 micrometers at photographic scale are the best that one can normally expect" (Slama 1980, 704).

With digital systems, however, an analytical approach to assessment of intrinsic accuracy can be taken, because accuracy relates directly to pixel size. The basic image unit being the pixel, the observation data consists of discrete integer154 values: the row and column numbers of the observed elements. Figure 1 demonstrates the results of Blaha (1972), who studied analogous situations (e.g., reading errors of horizontal circles of transits). The figure shows that where d represents the pixel dimension, the reading error—when a given pixel is chosen as the observed point—varies from $-\frac{1}{2}d$ to $+\frac{1}{2}d$. Between this interval, the probability of making an error is the same. Thus the error distribution is uniform, as Figure 1 illustrates.

From basic statistics, it can be seen that the probability density function for a random variable $\mathbf{x}$ uniformly distributed in the interval $-d/2$ to $+d/2$ is

$$f_{\mathbf{x}}(x) = \begin{cases} 1/d, -d/2 < x < d/2 \\ 0, \text{otherwise} \end{cases} \tag{1}$$

and the variance of this random variable is.

$$\sigma_x^2 = \int_{-\infty}^{+\infty} x^2 f_{\mathbf{x}}(x)\,dx = \frac{d^2}{12} \tag{2}$$

which gives the standard observation error

$$\sigma = \pm\frac{d}{2\sqrt{3}} = \pm\, 0.29d \tag{3}$$

From this can be derived the planimetric (σ_p) and vertical (σ_v) errors for the normal case of vertical photography. The value σ_p is the resultant of the model standard deviation errors in the X and Y model directions. Assuming that the model and image scales are the same, a given X error is produced by an equivalent error in the image scale, the equivalent error being from either one or both images. In the Y direction, because the orientation parameters lock the two photographs together, a given error in the image space produces the same error in the model space. In consequence, we have

$$\sigma_X = \sigma_Y = \sigma \tag{4}$$

and

$$\sigma_p = \sqrt{2}\,\sigma = \pm\, 0.41\,d \tag{5}$$

The vertical accuracy, given by (σ_v), depends on the vertical step (vs), or discrete increment in elevation, which is given by:

$$vs = d\,(h/b) \tag{6}$$

where h/b = height/base ratio.

So that we have:

$$\sigma_v = \sigma\left(\frac{h}{b}\right) = \pm\, 0.29 \cdot vs \tag{7}$$

In the case of standard photography (23 × 23 cm, 60% overlap and focal length of 15 cm), h/b = 1.6, so that we have:

$$\sigma_v = 1.6\,\sigma = \pm\, 0.46d \tag{18}$$

As shown in Table 1, results of empirical tests agree with the theoretical model. Test 1 comes from a digital aerotriangulation test organized in 1994 by the European Organization for

	Standard errors			
	Horizontal		Vertical	
	expected	actual	expected	actual
Test 1	4.9	4.8	6.4	6.2
Test 2	—	—	14.8	14.5

Table 1. Accuracy: Comparison of theory and experiments.

Experimental Photogrammetric Research. The test consists of a block of four strips of six models each, flown at the scale of 1/4,000. The actual accuracy was obtained from 77 well-distributed check points. The adjustment results were presented in Agnard et al. (1994). Test 2 refers to an experiment in which 360 tree heights were determined using softcopy photogrammetry. The actual accuracy of these measurements was obtained by comparison with heights determined by field methods. The photograph scale was 1/1,100 and the *h/b* factor was 11. The experiment has been described in Gagnon et al. (1993a). To compute the expected or theoretical accuracies using equations 5 and 7, we have, at ground scale,

- for Test 1, a pixel size of 12 cm and a vertical step of 22 cm, and
- for Test 2, a pixel size of 4.6 cm and a vertical step of 51 cm.

The relationship between pixel size and accuracy being established, the scanning resolution and/or the flying height can be adjusted to meet specific accuracy requirements. Table 2 indicates the accuracy values thus obtained, rounded off to the next centimeter and assuming standard photography. The values are derived from equations 5 and 7, applied to different photograph scales and scanning resolutions (in dots per inch). It is important to note that these figures express the photogrammetry potential. In order to have actual results agree with these figures, proper control and treatment of factors with a possible deteriorating effect on accuracy must be instigated at every operational level: camera and scanner calibrations, field control, orientations, and so on. At 600 dpi, referring to Slama's (1980, 704) statement set out above, the accuracy potential of digital photogrammetry is comparable with that of precision analog stereoplotters: application of equations 5 and 7 gives planimetric and vertical measurement accuracies of 17 and 19 micrometers respectively, at photographic scale.

In conventional photogrammetry, the final accuracy of compiled or collected data is the resultant of the aerotriangulation, set-up and collection stages. Thus, aerotriangulation accuracy standards have had to take into account the fact that the stereomodel has to be set up at the subsequent compilation stage. With digital photogrammetry, however, the set-up stage is unnecessary because data and orientation parameters from the aerotriangulation stage can be used directly. This is a significant advantage because less stringent standards for aerotriangulation are required and time is saved at the collection stage. The range of resolutions presented in Table 2 has been chosen for the reasons mentioned by Welsh (1993): "In fact, for most applications, scanning resolutions of 400 to 1,000 dpi... provide a good compromise between data volume, heighting accuracy, and rendition of small detail." It can be said also that, within that range, good and affordable desktop scanners can be found on the market place.

Possibilities of Microcomputer Softcopy Photogrammetry

On the basis of the preceding results and given the characteristics mentioned in the introduction, it is fair to say that the technology now exists for mass-production mapping and LIS data capture of good quality and at affordable prices. Within the much wider spectrum of people to whom

Scanning resolution (dpi)	Pixel size (m)	Photograph scale					
		1/5,000		1/10,000		1/15,000	
		σ_p	σ_v	σ_p	σ_v	σ_p	σ_v
400	64	13	15	26	29	39	44
600	42	9	10	17	19	26	29
800	32	7	7	13	15	20	22
1,000	25	5	6	10	12	16	18

Table 2. Expected planimetric and vertical accuracies, in centimeters, at different photograph scales and scanning resolutions.

photogrammetry is now accessible, those involved in LIS and GIS database preparation or updating who had previously no direct or easy access to photogrammetry deserve first mention. With softcopy photogrammetry, they are no longer limited to contracting out—with the inherent problems of cost, quality and efficiency control. They now have the chance to become directly involved in the process.

Softcopy photogrammetry also opens the door to interactive photogrammetry. Traditional photogrammetry has proven to be very good at measuring 3-D data. But even though the measurement of such data is very important, the function remains a passive one. It does not allow active or interactive operations in the stereomodel such as, for instance, those operations a surveyor performs in the field for property or construction analysis: direct measurement of angles, azimuths, distances, intersections, resections, parallels, areas, and so forth.

Such operations are possible with the new systems, with COGO computations added to the superimposition and digitizing functions (Gagnon et al. 1993b). With these features, it is possible to determine directly in the stereomodel:

- the distance between two points that are either visible, obtained by COGO computations, or inserted from an existing XYZ or map file;
- the orientation of a line;
- the state coordinates of a property mark that has been tied by simple angles or distances to points displayed on the screen—again, the points can be either directly visible, or computed or inserted from existing data;
- the area of a plot;
- the intersection point of two property lines, defined by visible segments of fences;
- the neighborhood metric relationships brought about by a projected building or road, and so on.

These possibilities are of direct concern and great interest to the surveyor or construction engineer, who will have access to an efficient additional or alternative tool for cadastral and engineering work, or for site and construction planning.

The ability to combine field and photogrammetric operations is a further possibility. That is, the capacity to insert data means that points determined by field methods can be brought to the screen. It is worth noting that, when using field-determined points that have been snapped on, operations done in the stereomodel preserve the accuracy of the field operation. In that respect, softcopy photogrammetry can have a degree of accuracy superior even to that indicated in Table 2.

The nature and importance of the potential impact of softcopy photogrammetry on firms involved in surveying, mapping, and LIS operations is clear. According to Brandenberger (1993), there are some 18,500 such firms in the United States and Canada. Of this number, only 6% (U.S.) and 14% (Canada), respectively, are photogrammetry companies. As awareness of the characteristics and possibilities of softcopy photogrammetry grows, these percentages will doubtless increase significantly and the statistics will change considerably.

Practice and Responsibility Concerns

Increased awareness of the possibilities of the technology must be matched by an awareness of the importance of its appropriate use. It must be understood that—behind the user-friendly software and the exterior easiness of operation—photogrammetry is still photogrammetry. The production of good quality, reliable results is still and always will be dependent on the application of sound knowledge. In conventional as well as softcopy photogrammetry results of good quality are based on respect for the rules of the art—on the application of the established standards. Quality results are based also on the ability to understand the concepts behind the standards: concepts of scale, camera-object geometry, scanning resolution, accuracy, the relationship between pixel dimension and accuracy, error propagation, and so on.

The introduction of softcopy photogrammetry is very recent, the extension of the field is just beginning, and users are still very few. Nevertheless, a lot of incorrect practices have been witnessed already. To name a few:

- the ratio of photograph scale and map scale being completely out of proportion (e.g., producing a 1:1,000 map with 1:15,000 photographs);
- an insufficient number or bad distribution of control points for a model or a block;
- an insufficient number of check points in a block;
- no terrain check;
- a contour interval too small for terrain conditions (1-ft c.i. when grass is 3 ft tall);

- a base/height ratio too small for a given vertical accuracy requirement;
- lack of appreciation of the relationship between pixel size and accuracy; and
- a photograph-coordinate system incorrectly positioned.

Most items in the preceding list refer to principles or subjects that should be familiar to practitioners.

Conclusion

The use of softcopy photogrammetry can be optimized in terms of its multiple possible applications and also in terms of the quality of the product. The importance of quality concerns, in the practice of photogrammetry, has been underlined in a recent series of articles in *PE&RS* (for example, Baezley 1991, Burns 1991, and Quinn 1991), where the authors are talking about traditional photogrammetry practice. Is the subject not much more critical—no matter the degree of software sophistication and user-friendliness—when the field of practititioners is extended beyond photogrammetrists to include, in increasing numbers, people with a different training or educational background? Questions of education and training must be given proper consideration in the new context. As photogrammetry training courses are revised to take account of the new technology, they should reflect the fact that photogrammetry is no longer the preserve of a select few but a discipline accessible to many. Basic courses in photogrammetry, well adapted to the characteristics of softcopy photogrammetry, should be introduced in all curricula leading to professions in which photogrammetry may be a potentially useful tool. The educational response must match the dynamism of the technology expansion. In their description of the present mapping situation, Estes and Mooneyhan (1994) make the comment: "Mapping is an important, complex, expensive, and time-consuming task that, we believe, we are not performing today in an acceptable fashion." The surveying, mapping, and LIS community can contribute to change this situation by taking advantage of the possibilities of softcopy photogrammetry while taking steps to provide an effective educational response.

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