C-Factor for Softcopy Photogrammetry

Donald L. Light

Abstract
The C-factor is an empirical value based on the precision of the photogrammetric instrumentation. The conventional C-factor has been used successfully over the years to determine the flying height required to produce a specified contour interval. C-factors for conventional instruments range from 900 to 2200. Manufacturers commonly state nominal C-factors for their photogrammetric instruments. They vary from 1200 to 2200 depending on the precision of the instruments. Table 1 shows nominal C-factors for some commonly used analog and computer-assisted instruments.

Mathematical Basis for Soft C-Factor
Because the C-factor is basically an expression of precision for the entire system, then it seems important to examine the fundamental parameters that affect precision in stereo photogrammetry.

For decades, photogrammetrists in the United States have relied on an empirical value called the C-factor to determine the appropriate flying height for aerial photography when the desired map contour interval is specified. The C-factor is the dimensionless ratio of the flying height above ground to the contour interval (CI) that can be reliably plotted using the photography. In equation form,

\[ \text{C-factor} = \frac{H}{\text{CI}} \]

where \( H \) is the flying height above ground and \( \text{CI} \) is the contour interval.

Contour accuracy depends not only on the plotting instrument, but also upon the nature of the terrain, the camera and its calibration, the resolution quality of the photography, and the capability of the plotter operator. This has remained true for analog plotters, and is still applicable during the transition years to analytical, computer-assisted plotters. These conditions all combined to yield a total system C-factor, which assumes typical values for all these variables.

Table 1. C-Factors for Photogrammetric Instruments

<table>
<thead>
<tr>
<th>Instrument</th>
<th>C-Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kelsh</td>
<td>1200</td>
</tr>
<tr>
<td>B-8</td>
<td>1300</td>
</tr>
<tr>
<td>PG-2</td>
<td>1600</td>
</tr>
<tr>
<td>AS-11</td>
<td>2000</td>
</tr>
<tr>
<td>Intermap</td>
<td>2200</td>
</tr>
<tr>
<td>LightSys</td>
<td>2200</td>
</tr>
</tbody>
</table>

Changing Equation 3 to use lines/mm (lp/mm) instead of line/mm.


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Presently with Emerge, a Litton/TASC Co., 900 Technology Park Drive, Building 8, 2nd Floor, Billerica, MA 01821.
pairs/mm (lp/mm) for digital terminology, Gardner's Equation 3 can be re-stated as

\[ 0.675 \, m = 1/2.5 \, mm/l \]

so that

\[ m = 0.6 \, mm/l. \] (3a)

If all other errors in the system are assumed to be lumped into \( m \), the contouring ability is directly related to this standard deviation \( m \), because, in the operation of contouring in a stereo model, each point is observed only once as it is passed.

In order to meet the criterion that 90 percent of elevations be correct within one-half the contour interval, National Map Accuracy Standards can be written as

\[ 1.64 \, m = 0.5 \, CI \]

so then

\[ CI = 3.3 \, m. \] (4)

Substituting Equation 2 into Equation 4 yields

\[ CI = 4.7 \times \frac{H}{f} \times \frac{H}{B} \, m, \] (5)

Equation 5 may be related to the usual concept of C-factor defined as the ratio of \( H/CI \). Then an equation for C-factor, as used over the years with analog instruments, can be found from Equation 5: i.e.,

\[ C-factor = \frac{H}{CI} = 0.21 \times \frac{B}{H} \times \frac{f}{m}. \] (6)

Recognizing that the \( B/H \) ratio and the focal length \( f \) are part of the system geometry, it is apparent that variations of C-factor among photogrammetric instruments depend largely upon the capability of the instruments to utilize the resolution of the photography for precision measurement. That is, assume that all other errors are included in the measuring errors \( e_m \), and that \( m \) is directly related to the resolution of the system. Therefore, Equation 6 can be exploited to derive a soft C-factor equation that is applicable to digital photogrammetric workstations.

First, to demonstrate the practical application of Equation 6, consider an analytical plotter utilizing conventional 152.4-mm focal-length mapping photography with \( B/H = 0.6 \). Thirty lp/mm is probably a reasonable estimate of the average resolution which can be utilized by the optical system of the plotter. Then, from Equation 3,

\[ m = 0.3 \, mm/30 \, lp = 0.010 \, mm \]

and, from Equation 6,

\[ C-factor = 0.21 \times 0.6 \times 152.4 \, mm/0.010 \, mm \]

or

\[ C-factor \approx 2.2 \, mm/\text{lp}. \]

It is interesting to observe that the least count on most first-order plotters is 0.010 mm, and this yields a C-factor of 2.2 that is sufficiently close to 2000 as generally claimed by the plotter manufacturers. Utilizing the work of Hallert (1960), Doyle (1963), and Gardner (1932), it has been shown that Equations 3, 3a, and 6 can be used to relate resolution with measuring precision, and measuring precision with a C-factor. Now it seems reasonable to look at the resolution in the softcopy image chain (pixels) and produce an analogous term called “Soft C-Factor” for the coming era in softcopy photogrammetry.

**Soft C-Factor**

The objective is merely to evaluate the components of the softcopy imaging chain and compute a system resolution that the digital workstation is utilizing. Then, enter the softcopy precision \( m \), into Equation 6 and a soft C-factor can be computed.

**Total System Resolution (R)**

Again, recognizing that the C-factor is an empirical value based on precision of measurement, the following expression can be utilized to evaluate each component. Then, using each component of the image chain, compute a total system resolution \( R \), that can be converted to \( m \), by Equation 3a. Finally, enter \( m \), in Equation 6 to arrive at the soft C-factor.

The expression for total system resolution \( R \) (Meier, 1984; Light, 1996) is

\[ 1/R^2 = 1/R^2 + 1/R^2 + ... \] (7)

where all values for Equation 7 must be in l/mm for soft-copy. \( R \), is the resolution of the film in lp/mm converted to l/mm; i.e., 1 lp = 2 l, and \( R \), is scan spot size converted to l/mm.

Example: Assume a modern aerial film camera yields 40 lp/mm (80 l/mm) resolution to the user. Because 40 lp/mm is equivalent to 25 pm/lp, the appropriate scan spot size (SSS) should be 25 pm/lp \( \times \) 1 lp/2.2 l = 11 \( \mu \)m/l = 11 \( \mu \)m/pixel. For converting lp to pixels, the rationale given by Larson and Wertz (1993) shows that 1 lp = 2.2 pixels is appropriate to use when converting analog data to digital data. Eleven \( \mu \)m pixels will approximately preserve the 40 lp/mm (80 l/mm) resolution of the original film. Using the appropriate values for \( R \), and \( R \), in Equation 7, compute the total system resolution \( R \); i.e.,

\[ 1/R^2 = 1/80^2 + 1/90^2 \]

because \( R = 40 \, lp/mm \) (80 l/mm) and \( R = 1000 \, \mu m/mm/11 \, \mu m = 90 \, l/mm \). Then, the total system resolution is

\[ R = 59 \, l/mm. \]

**Table 2. Typical Soft C-Factors**

<table>
<thead>
<tr>
<th>Original Photos (lp/mm)</th>
<th>Scan Spot Size ( \mu )m</th>
<th>Eq (5) ( R_l \mu m/lp )</th>
<th>Eq (6) ( R ) ( \mu m:mm )</th>
<th>Eq (3a) Soft C-Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 (40)</td>
<td>15</td>
<td>0.016</td>
<td>1200</td>
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<td>1200</td>
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</tbody>
</table>

Research to validate these values by experiment should be conducted as soft-copy takes its place in the digital photogrammetry business.
Using the digital Equation 3a,

\[ m_s = 0.6 \text{ mm}/59 \text{ l} \]

\[ m_s = 0.010 \text{ mm} \]

Now, entering \( m_s = 0.010 \text{ mm} \) into the C-factor Equation 6, one obtains Soft C-factor = \( 0.21 \times 0.6 \times 152.4 \text{ mm}/0.010 \text{ mm} \), or Soft C-factor = 1920.

As an additional thought, it is recognized that the photogrammetric workstation’s monitor plays a key role in presenting the stereo-model. Then, it follows that the monitor’s dot pitch should be considered in computing an empirical C-factor. On the other hand, experiments by Wong (1997) show that monitor resolutions are fixed, regardless of scanned resolution or zoom ratios. In view of this and the need to keep computations simple and practical, the monitor’s contribution is considered to be small and, therefore, is ignored in this derivation and is left for further research.

In summary, conventional 15/23 mapping camera photography with 40 lp/mm resolution, which was scanned at an 11-μm spot size, yields a softcopy C-factor that is slightly less than the C-factor for a first-order plotter. Although the soft C-factor is empirical, it can be shown that softcopy photogrammetry is capable of accomplishing precision topographic mapping and the soft C-factor can indicate the proper flying height. Table 2 gives computed soft C-factors for different photography resolution and useful scan spot sizes.

References


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