REFRACTIONAL EFFECTS IN PHOTOGRAMMETRY

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ABSTRACT

A brief description of photogrammetric procedures are made to show how it has been and today is possible to make correction to photogrammetric measurements for the effect of refraction.

Then a review of how refractional effects have been calculated is made.

Finally some suggestions are made of how to meet the demands for improved accuracy in photogrammetric measurements.

WHAT IS PHOTOGRAMMETRY ?

Photogrammetry is a tool for determining 3-dimensional,object-coordinates from two 2-dimensional photographs, preferably taken with a metric camera.
A metric camera is a camera that has a fixed and known inner orientation which means that the principal point and principal distance must be determined. This is done in a calibration. The basic unit for measurement is the photograph coordinates x' and y'.
From the photograph coordinates and the inner orientation we then try to reconstruct the rays between the projection centre and the objects at the moment the photograph was taken. These angles or rays are used to make a resection of the projection centre in space in the first place. This is a standard method for two overlapping photographs which is performed with a relative orientation and an absolute orientation. When we know the exact situation for the projection centre we can continue to compute coordinates for all other points using intersection. One big difference between photogrammetric and geodetic measurements, however, is that we only get one observation for our computations. This means that we must have a very good control over all possible errors that affect our observations if we want to achieve a good accuracy in our final results. Calibration of photogrammetric instruments and procedures leading to accurate adjustments and good correction-functions is therefore of great importance.

E. Tengström and G. Teleki (eds.), Refractional Influences in Astrometry and Geodesy, 321–325.

Such error-functions are for example
- radial and tangential lens distortion
- film shrinkage
- refraction and earth curvature.

HOW IS PHOTOGRAMMETRY USED?

Photogrammetry is used for many different purposes. The classical area is of course mapping from aerial photographs, from the beginning only for small scales 1:50 000 - 1:20 000 but today also for large scale mapping up to 1:400.

In ordinary civil engineering photogrammetric methods also find a place for deformation measurements and volume computations etc. Here terrestrial cameras are used and the distance between camera and object is much smaller than in aerial photography.

Another increasing area is the densification of the net of known ground points used for absolute orientation of stereomodels. It is in this field of photogrammetry most efforts are spent to get the highest possible accuracy today.

WHEN IS CORRECTION MADE FOR REFRACTION?

Photogrammetric computations can be made with analogue or analytical methods.
In the first case a stereoplotting instrument is used and we get a drawn map or 3-dimensional coordinates as primary products. Because we do not measure the coordinates of the picture directly we have very limited means of introducing corrections.
One way is to include corrections plates in the copying process from negative to diapositive or put correction plates in the image-holder in the stereoplotting instrument. These glass-plates can only be made for standard heights and standard atmospheres.
Antoher way is to compute the effects on the model-coordinates and make corrections to these. (Tham)
But with analytical methods we have other possibilities. Here we use comparators to directly measure the photograph-coordinates and numerical methods for reconstruction of the central projection and both relative and absolute orientation.
The introduction of any type of correction to photograph coordinates can of course be done very easily in the computations.

HOW HAS REFRACTION BEEN TREATED?

The influence of refraction on photogrammetric measurements was outlined in a basic work by Leyonhufvud in 1950.
In this work the following assumptions were made
- only rays that have nadir-distances between 0 and 60 degrees are treated
- atmosphere consists of concentric shells

- flying heights lie between 0 and 10 km
- ICAN standard atmosphere
- linear temperature gradient.

The following conclusions are drawn concerning the use of a standard atmosphere:
- variations in absolute temperature, humidity and pressure is of minor importance
- only variations in temperature gradient can be of importance
- linear temperature gradient can be assumed since photogrammetric flights always take place on a clear day below a thin cloud-cover.

Errors caused by using the observed angle as true and by assuming a flat earth is neglected.
The astronomic refraction is computed for different nadir-distances and from that the photogrammetric refraction is computed for different flying heights and terrain heights.

For near vertical photographs the influence on coordinates can be assumed as radialsymmetric around the principal axis.

Later works in this field by for example Bertram and Schut do not add much new to solve the problem. They make the same assumptions of radialsymmetry and only tabulated densities for other standard atmospheres are used that extends up to 80 km.
Bertram states that refraction must be corrected for, an example is given where it causes a distortion of 10 microns which is very much compared to the measuring accuracy of 1 micron for a comparator.

PHOTOGRAMMETRIC HANDBOOKS

If we look into different handbooks for photogrammetry there is not much more to be found.
In Handbuch der Vermessungskunde methods are given for computation of the refraction angle using numeric integration or a simplified summation.
The values of n as a function of height H must be given and an example is shown where $n(H) = 1 + 0.000226\sigma(H)$, where the σ-values are taken from the ARDC-model-atmosphere.

The Photogrammetric Guide by Albertz/Kreiling gives a method for computation of refraction using the ICAO-standard atmosphere with temperature-gradient of 0.65 K/100 m up to 11 km and then constant temperature up to 32 km and pressure $p = 1013.25(1 - 0.022557696\ H)^{-5.2558}$ mb between 0 and 11 km and $p = 226.3204\ e^{0.15768852(H - 11)}$ mb up to 32 km.
The radial distortion due to refraction is computed with observed nadir-distance and astronomic refraction angle
$\Delta\tau_0 = T - 6366200(Q_0 - Q_p)/(H_0 - H_p)$.
T is derived from a 4-degree polynomial in H_0 and Q_0, Q_p with a 5-degree polynomial in H_0, H_p respectively. This is perhaps the most commonly

used formulae.

In Ackermann/Schwidefsky are references made to Leyonhufvud and Schut for the computation of the refraction angle.

HOW IS ACCURACY BEING IMPROVED TODAY?

The results achieved with numerical photogrammetry today are very excellent, however, methods are tried to further improve accuracy. In block-adjustment, for example, parameters for the inner orientation are included as unknowns in the computations, this is called self-calibration.
If parameters for radial lens-distortion are included the effects of refraction must to some degree be included in these.
This could be one way to compensate for the actual atmosphere.

Another method to improve accuracy is to use the discrepancies in known points after block-adjustment to compute parameters in a correction polynom separate for x- and y-coordinates. These polynoms are then used to compute corrections for all new coordinates.

CONCLUSIONS

- Today only model-atmospheres are used to compute the refraction for aerial photogrammetry.
- Traditional methods for photogrammetric measurements offer limited possibilities for corrections of photograph coordinates.
- There is a demand for more accurate photogrammetric measurements for point densification.
- With modern computing methods where comparator measurements are used it is easy to introduce corrections.
- Refraction, among other errors, must be fully controlled using inflight registrations of actual conditions if accuracy is to be improved.

SELECTED REFERENCES

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Bertram, S. Atmospheric Refraction. Photogrammetric Engineering no 1 1966

Jordan/Eggert/Kneissl. Handbuch der Vermessungskunde

Leyonhufvud, A. On Photogrammetric Refraction. Photogrammetria 1952-53

Schut, G H. Photogrammetric Refraction. Photogrammetric Engineering no 1 1969

Tham, P H. Addition to Leyonhufvud's Article: On Photogrammetric Refraction. Photogrammetria 1952-53.

DISCUSSION

J. Saastamoinen: During this elapsed 19 years period, there have been two shocking things for photogrammetrists. One was the earth's curvature, and the other had to do with refraction. I don't remember exactly - was it 15 years ago or so - there was an international test of photogrammetry, and our office was trusted the treatment of the results Everybody was extremely surprised when at the center of the picture the measured elevations were very good, but going off the center, a few kilometers, the elevations were very bad. And someone said that maybe the earth is curved. Now, the second shock came in analytical photogrammetry with these refraction corrections. There was a Russian paper, written by - I think - Dr Kushtin. He was the first to point out that in modern airplanes, when the camera is mounted behind a port-glass in a heated and pressurized cabin, the optical system is no longer an ordinary lens but there will also be refraction between layers of different densities separated by the port-glass. And these effects happen to have the opposite algebraic sign to the ordinary refraction correction. At a certain flying height - about at 6000 meters - the effects cancel out each other. So, in analytical photogrammetry, it might be better not to apply any refraction corrections at all. A third remark is on the papers by Bertrand and Schut in "Photogrammetric Engineering" - if you look a couple of years later, you will find that the solution for the actual atmosphere is very simple, as simple as the refraction correction computed from standard atmosphere.

J. Larsson: I would say, that in standard procedures of photogrammetry of today we don't try to measure the actual atmosphere. We don't compensate for it. But we should correct for the actual atmosphere to further increase the accuracy of the analytical photogrammetric procedures.

J. Saastamoinen: You need only the pressure at the ground and the pressure at the camera.

J. Larsson: These measurements should be made at all flight missions when analytic procedures such as a block-triangulation shall be used.

J.C. de Munck: In photogrammetry the scale is normally kept free. So the greater part of the refraction is not important. Only second and higher order terms are of interest for the photogrammetrist.

J. Larsson: That is certainly true. The greater part of the refraction may be thought of as a scale difference, which is eliminated in the absolute orientation.