GEOREFERENCING REQUIREMENTS FOR AIRBORNE PHOTOGRAMMETRY AND REMOTE SENSING

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ABSTRACT

Air survey methods are generally moving towards multi-sensor systems, made possible by the recent technology development. Of particular importance is sensor orientation by GPS (position) and INS (attitude). Different levels of specifications are distinguished, reaching from the stabilisation and internal consistency of imaging or laser sensors to the demands on absolute orientation data for the purpose of direct georeferencing. Finally, the accuracy requirements of orientation data in combination with other sensors are reviewed.

1. CONVENTIONAL PHOTOGRAMMETRY, A MONO-SENSOR SYSTEM

Aerial photogrammetry has been a mono-sensor system, for a long time, being limited to aerial photography. Because of that it was not autonomous at all, had to rely on external **ground control** in order to solve for the free system parameters (contrary to terrestrial photogrammetry). The application of aerial surveys has adapted to those conditions by successfully developing operational standards. The established technique and performance of aerial triangulation in particular has provided system consistence, with clear command of accuracy, reliability and economy.

Various auxiliary camera orientation data from additional airborne sensors have repeatedly been considered and applied in the past, in order to ease the generally costly dependence on ground control. The efforts had only temporary success and could not basically alter the general conditions.

2. TOWARDS AUTONOMOUS MULTI-SENSOR SYSTEMS

2.1 New Technology

The great advances in technology of the last two decades have started to thoroughly alter the fundamental concept and structure of photogrammetry, amounting to truly **revolutionary** changes. Photogrammetry is moving towards multi-sensor systems for digital information acquisition, possibly becoming nearly autonomous, i.e. practically independent of external parameter fixing. In the course of this development photogrammetry and remote sensing merge together in terms of methods, techniques and extended applications.

There are 2 groups of **sensor development** to be distinguished, as far as photogrammetry and remote sensing are concerned:
(1) Sensors providing orientation data, especially GPS, INS, and laser or radar altimeter;
(2) Sensors providing multi-data about the objects, especially Laser Scanner, SAR, MS Scanner, in combination with photographic sensors or not, which in turn may become digital or linear array cameras.

We concentrate here on sensors which provide **orientation data**, i.e. on GPS and INS in particular.

2.2 High Precision Kinematic GPS Positioning of Airborne Sensors

2.2.1 GPS flight navigation. First, it is to be mentioned that the C/A code pseudo-range positioning in real time has gained great influence on the navigation of air survey flights. It is practically standard, the advantages being evident. Survey flight navigation now goes by coordinates, not any more by visual navigation. As a result the photo-coverage or the flight lines of other sensors become extremely regular, with all subsequent advantages.

2.2.2 Phase Observations, Signal Loss of Lock. The real fundamental contribution of GPS concerns the high precision kinematic sensor positioning, not necessarily in real time, by differential phase observations with regard to one or more GPS ground receiver stations on known points. Prime application, so far, has been camera air station positioning for aerial triangulation, in post-processing mode.

The general conditions for the application of kinematic sensor positioning are well known. They are highly favourable in general terms, advocating wide application. However, there is the problem of signal loss of lock, especially during flight turns, because the lines of sight to satellites can be interrupted by wings and fuselage. Attempts to fly turns more carefully cannot sufficiently be relied upon, and are not acceptable in operational terms. Interruption of GPS signals destroys the previous ambiguity solutions. Practicable solutions to restore or re-establish ambiguity solutions were not available, for a long time. Instead, approximate solutions were applied, based on C/A code positioning, resulting in biased ambiguity solutions, as consequence of which the following parts of the GPS trajectory showed systematic errors, called **GPS drift errors**. Fortunately, the drift errors turned out to be about linear for short subsequent time intervals.

On that basis successful applications of kinematic GPS sensor positioning were developed, especially for aerial triangulation. The systematic GPS drift erros would be assessed and corrected for by using external information, for instance via **combined adjustment** in combination with photo-blocks. That type of solution and application in aerial triangulation has worked very well in practice, although some ground control points were mandatory for a datum transformation, and additional cross strips had to be applied in order to avoid system singularities. The relative precision of GPS positioning has been more than sufficient for application in all photo-scales, reaching magnitudes of < 10 cm, even < 5 cm. The limitation of the method was, however, that no absolute GPS positioning could be obtained. In combination with photo-coverage that was acceptable, but other, non-imaging sensors would require absolute GPS data.

2.2.3 Fast OTF ambiguity solutions. The recent hardware and software development for kinematic GPS positioning has started to basically alter the situation. Fast OTF (on the fly) ambiguity solutions are capable, in principle, to bridge signal interruptions and **restore** interrupted **trajectories**. That development is of greatest importance, also from a concept point of view, making combined sensor systems practically autonomous, at least with regard to the GPS reference system (WGS 84). There are, however, some problems implied which are being studied, at present. OTF ambiguity solutions can be subject to constant or **systematic errors**, depending on satellite constellations and distance to the GPS ground receiver station(s). With regard to that distance the **reliability** of the method is not yet safely established.

With fast OTF ambiguity solutions the kinematic GPS positioning of airborne sensors is absolute, in principle, with regard to the GPS coordinate refernce system. This is a fundamental step in photogrammetry which cannot be overestimated. In combination with **absolute GPS trajectories** the integrated aerial triangulation (i.e. orientation of photos and photo-blocks) can do without ground control at all, except for the GPS ground station(s). Experience and tests give reason, however, to issue a general **warning**: In an absolutely referenced system all systematic errors must be under strict control. This is particularly true also for systematic photogrammetric errors which did not show up in the conventional approach, being either not visible (at air stations) or compensated by ground control. The conclusion for multi-sensor systems must be that on-the-job **system calibration** becomes mandatory, unless some essential parameters are left free for subsequent fixing by external information, e.g. by ground control points.

2.3 Sensor Attitude Data

Sensor orientation includes attitude determination, in addition to positioning. The combination of GPS with aerial triangulation can do without attitude sensors, but in general they are needed for absolute sensor orientation.

2.3.1 Multi-Antennae GPS. An interesting possibility to directly measure the attitude of an airborne sensor is the use of 3 or 4 integrated GPS antennae on wings and fuselage of the aircraft and interferometric data processing. The special advantage is the direct relation to the GPS reference system. There are, however, various problems, also because the measurements refer to the carrier, not to the sensor itself. It implies integrated calibration and, in this case, also dynamic modelling of the system. The obtainable attitude accuracy seems to be in the order of 1 milli-radian, for the time being, which is not sufficient for high precision applications.

2.3.2 Attitude determination by INS.

Inertial systems have never been much applied in photogrammetry. Their positioning performance had too large drift errors, and has effectively been replaced by GPS positioning. The attitude determination by INS, however, is gaining ground. The internal precision of INS is very high. It can externally be maintained if drift errors are controlled in **combination with GPS** positioning. In that combination INS is also capable of helping bridge GPS signal interruptions. Laser scanning and SAR systems depend directly and in absolute terms on the accuracy of INS attitude data. It is again to be mentioned that inertial systems require thorough initialisation and total system calibration.

2.4 Application of Orientation Sensors

Orientation sensors like GPS and INS are no stand alone systems. Their purpose and application is always in combination with other sensors which provide object information. These are especially imaging sensors (aerial camera, digital linear array camera, SAR and multispectral scanners), but also laser scanning systems.

The different systems have different requirements, depending on the actual application. We may distinguish **3 levels** of performance: (1) Orentation data for **stabilizing** only parts of a trajectory (flight lines, strips), without absolute reference. (2) The same as (1) but extended continuity and **consistence** for a whole flight mission (block), absolute reference still provided by other means (ground control). (3) The same as (2) but with reference to a given coordinate system. In that case we speak of **absolute** orientation data resp. of **georeferencing**.

Photogrammetric block triangulation, for instance, gains great economic benefit from GPS camera positioning, by the vast reduction of ground control, whose accuracy functions are taken over by the GPS data. A photo-block has consistent geometric strength in itself. Therefore the GPS data need **not** necessarily to be absolute nor completely consistent. Stripwise consistency is sufficient for still obtaining a block solution the absolute orientation still being provided by some few ground control points (see 2.2.2). If the complete GPS trajectory is continuous and consistent (2.2.3) the combined system is geometrically stronger, its application therefore preferable, still relying on some ground control points for datum transformation. Whether a separate datum transformation for georeference is required depends on the absolute reference of the GPS data and on condition that constant or other system errors are either not existent or have been calibrated. Attitude data for aerial photographs are not mandatory in the case of block adustment. If available and applied, however, they strengthen the total system and are advantageous even if of moderate accuracy only. The specific geometry of single strips, however, needs attitude information in any case, whether derived via ground control or by INS data.

All **other sensor systems** mentioned which provide object information depend to a higher degree on directly measured orientation data, as without them no consistent object description is achievable, in different degrees. The terrain points derived from a **laser scanner**, for instance, depend absolutely on GPS for positioning and on INS for the attitude of the sensor. There are little possibilities to check or correct for geometric stability and datum of the resulting data sets. Instead, a on-the-job system calibration is essential. In a similar way attitude data are mandatory to obtain rigid image-geometry with digital **linear array cameras**. The function of GPS positioning thereafter is the same as with conventional photo-blocks. Also **multi-spectral scanner** data or SAR scanning depends in absolute terms on attitude and position data, taken during the flight, unless ground control can be brought in.

The general tendency concerning position and attitude sensors is twofold. On the one hand **high accuracy** is essential to make such sensor data really useful. But increasingly also **absolute reference** is wanted, leaving open the necessity for overall **datum orientation**. In all cases we deal with multi-sensor systems. And the necessity for thorough system calibration is stressed again.

Remark: It has been speculated, at various occasions, that the provision of position and attitude data by GPS and INS could make **aerial triangulation** in photogrammetry **obsolete**. This is certainly a valid consideration in general and may first be applied in cases of reduced accuracy requirements. There are, however, 3 considerations which have to be kept in mind: (1) A photo-block which refers entirely and in absolute terms on orientation sensor data has reliability zero. The orientation data reference cannot be checked at all, the resulting system relies on them absolutely. (2) As soon as a system depends on absolute data then also all other circumstances must meet absolute requirements. It means that all systematic errors (interior photo-orientation, camera-GPS synchronisation etc.) must be under absolute control and must be relied upon. This is quite a difference against conventional photogrammetry, the good results of which are only obtained because many errors are compensated or neutralized by certain degrees of freedom. (3) If aerial triangulation proper is abandoned some local homogenisation might still be applied.

3. ACCURACY REQUIREMENTS FOR ORIENTATION DATA

The above considerations mainly referred to the principal importance and application of orientation sensor data in relation with other imaging or non imaging sensors. It remains to consider the required accuracy. There is no general answer to that question. The accuracy requirements which orientation data shoud meet depend very much on the sensor combination and the envisaged application.

Possibly the highest requirements are set by high precision **photogrammetric application**, in terms of aerial triangulation. Conventional high precision aerial triangulation, at any scale, achieves attitude accuracies for the images in the order of 3 resp. 5 or 6 mgon (for κ resp. ϕ and ω) or about 0.05 - 0.1 mrad. It is said that (expensive) INS systems can achieve such accuracy results, required with regard to absolute reference, but applications in aerial photogrammetry are not known. Attitude accuracies in the order of 2 - 0.2 mrad are easier to obtain. They are quite useful for strengthening combined aerial triangulation, and can suffice directly for the photo- or orthophoto-rectification. Also, they can provide initial approximations for other purposes (like automatic aerial triangulation).

The requirements for GPS camera positioning depend on the photo-scale. Large scale aerial triangulation reaches standard errors of perspective centres of a bout 3 -4 cm. That would require GPS coordinate precision of 5 cm, or better (not in terms of absolute accuracy but of internal consistency only). The extension of such blocks is usually < 10 km. For smaller photo-scales the GPS precision requirements drop to more convenient magnitudes of 10 - 20 cm, and can go to 0.5 m or more for medium and small scale topographic mapping. It can be said that the performance of kinematic GPS positioning is sufficient for application within the full range of photogrammetric photo-scales. If, however, the GPS positioning is to be absolute, then all systematic errors (GPS and images) must be kept to the same order of magnitude, which is a completely new situation for photogrammetry.

The **laser scanning** systems on the other hand depend practically in absolute terms on the positioning and attitude data provided by GPS and INS. The requirements can be specified in general to be about 10 cm (or better) for positioning, and 0.1 mrad in attitude. Combined system calibration is essential.

In the field of **remote sensing** the multi-spectral scanners also depend entirely on position and attitude data, unless merged in conventional ways with maps or previous scenes. The requirements are usually not as high as in photgogrammetry proper, as precise geometry is often secondary. The direct and accurate orientation of such imagery has given airborne remote sensing a great push, in terms of extended applications and much greater practical convenience. A special case is radar imagery (SAR). Here again the dependency on orientation data is direct. And high accuracy INS systems, combined with kinematic GPS positioning, mark the performance.

In general, the application of GPS positioning and attitude determination by INS in combination with various airborne imaging or non-imaging sensors has given all aerial information technology a **great impetus**. The potential of application has been greatly widened and the conditions of application have become much easier and more economic. Of vital importance is the fact that the orientation data are obtained digitally for direct computer processing. The implications have just started to be realized. It is a great **challenge** for the near future to exploit the potential of multi-sensor systems.

As a last remark it is mentioned that the availability and the performance of the orientation sensors also have successfully widened applications in fields which previously have not been open to airborne methods, but which quickly gain importance. Examples are helicopters or low flying light aircraft, equipped with various also non-imaging sensors for sensing environmental pollution under and on the ground or in the air. For such applications the direct and documented positioning is essential.