T.O.P. CONCEPTS FOR SENSOR ORIENTATION

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ABSTRACT

Airborne sensor orientation, particularly for photogrammetric cameras, is of interest because orientation is a key step, between acquisition and iterpretation, which determines the quality and even the interpretability of images. In this paper, a global approach to sensor orientation is presented with emphasis on aerial photogrammetric cameras. The situations where a pure INS/DGPS solution suffices and where a combination INS/DGPS/AT is required are discussed as well as their global and local aspects. The discussion is linked to the current progress in GPS technology and the future development of the European Galileo system.

1 INTRODUCTION

In the late eighties, the first successful AT/DGPS (Aerial Triangulation and Differential GPS) experiments were completed. Today, a decade later, direct sensor orientation by INS/DGPS has become the dominant orientation technology for all airborne sensors with the exception of metric aerial cameras. In this particular area, the success of automatic digital terrain model generation for orthophoto production has encouraged the development of AAT (Automatic AT) by digital image matching. As a result, in addition to standard AT/DGPS, two different technologies, INS/DGPS and AAT/DGPS, are available. In parallel, satellite geodetic positioning has made enormous progress. If we look at all these developments and compare them with current practices, the idea of their optimal combination for photogrammetric camera orientation comes naturally. The name Total Orientation Procedures (Colomina, 1999) intends to reflect this approach which is qualitatively discussed in the rest of the paper.

2 ON TWO-STEP ORIENTATION

Sensor orientation is only a step, a “technicality” in the process of image exploitation whose ultimate goal is image interpretation.

The mapping and cartographic pattern acquisition-normalization-interpretation is not a particular one in the area of geosciences and Earth observation. In all cases, between raw data acquisition and data exploitation or interpretation, there is an intermediate step which has to correct raw data from instrumental errors and external influences before data is amenable for specific domain interpretation. In physical geodesy interpretation is geoid determination, in mineral exploration interpretation is mineral location.

Normalization serves therefore interpretation. Normalization is technology-dependent; much more than interpretation is. Interpretation sets the requirements for normalization or, in our context, sensor orientation. The requirements are of many different kinds, from operational to geometrical, from technical specifications to time and cost constraints.

Within the technical requirements both the precision, accuracy and reliability figures as well as the more qualitative aspects like consistency with local reference frames or parallax-free stereo models are found.

Traditionally, the photogrammetric orientation task is usually performed in two separate steps: in the first step (aerial triangulation or INS/DGPS trajectory determination) the long wavelength components [or global solution] of position and attitude are solved for; in the second step (stereo model set-up) the short wavelength components [or relative local solution] are resolved. The first step delivers orientation at accuracy levels which meet project geometric specifications. It guarantees the overall block consistency. In an orthophoto project, for example, this is enough since there is no stereoscopic interpretation task at the end of the production line. In a standard topographic mapping project, orientation has to serve another task, namely, stereoscopic image visualization and interpretation. In this case, the short wavelength components of orientation are required at high accuracy levels. Any global solution, be it AT/DGPS or INS/DGPS based direct sensor orientation, will, in general, not resolve the short wavelength components at the accuracy degree desired for they are "global optimizers." These are obvious facts. Nevertheless, many times, they are overlooked when trying to stereoscopically interpret images oriented by INS/DGPS.

3 ON DIRECT VS. INDIRECT

Direct versus indirect, or INS/DGPS versus AAT/DGPS, is one of the current holy wars in photogrammetry. This section is not one of its battles. For the reader interested in comparative analysis there are a number of papers dealing with the topic (Colomina, 1999, Cramer, 1999, Škaloud, 1999a, Škaloud, 1999b). Inertial trajectory determination is a well established, known procedure (Savage, 1998a, Savage, 1998b) whose integration with DGPS has already been transferred to commercially successful systems for sensor orientation (Scherzinger, 1997). However, there is still some confusion on the global performance of the concept, mainly because the global INS/DGPS orientation picture is not well understood. One of the "troublesome" behaviours of INS/DGPS based orientation is the stereo model residual parallax issue, which is addressed next.

Whatever the choice of orientation technology is and whatever the orientation convictions are, there are some generally accepted *pros* and *cons* of the available technologies. INS/DGPS has yet to solve the calibration family of problems. This includes the fact that image selfcalibration is lost. AAT —rather AAAT (Assisted AAT) in the author's opinion (Colomina, 1999)— depends on image texture and slaves block geometry to the orientation task.

The criticism that INS/DGSP does not guarantee parallax-free stereo model setting is just not fair, for aerial triangulation suffers from the same drawback. The only difference being, that not too many were curious enough or had the SW to set-up a stereo model directly from aerial triangulation. Since stereo model set-up was —is— mainly based on the coordinates of ground point determined in the aerial triangulation, the second orientation step is always performed. Any residual parallax introduced by the global solution is just not seen.

After the discussion of the above section, it is apparent that the solution to the INS/DGPS orientation parallax problem is as simple as it is for aerial triangulation (see figure 1): identify homologous points on both images, then compute a local bundle adjustment optimization with two sets of observations, their corresponding weights and the associated models. The first set contains the six plus six orientation parameters based on the INS/DGPS direct solution. The model is the obvious one. The second set contains the image coordinates of the homologous points, their weights and either coplanarity or colinearity observation equations. In other words the second step is a standard relative orientation determination constrained by observations of the exterior orientation elements. If the exterior orientation elements' observations are correctly weighted, the final solution will be parallax-free and still acceptable as a global one.

4 ON SATELLITE KINEMATIC POSITIONING

It is a misunderstanding that the limiting factor in precise direct sensor orientation, specifically in metric aerial camera orientation, is inertial technology. Contrary to that, the limiting factors are long range satellite kinematic positioning and the stability of the mechanical assembly between the IMU (Inertial Measurement Unit) and the camera. This is known. In this section we will comment on two ongoing developments which will have a major impact in the way trajectory determination is performed: the European Galileo system and GPS modernization; and the progress in ionospheric modeling.

In spite of the US Congress' rejection of the $ US17 million budget request for GPS civil modernization —on both the Block IIR and Block IIF satellites—, it seems that GPS modernization will take place whatsoever, even if the US DoD (Department of Defense) has to become the modernization funding agency. The benefits of GPS modernization have been summarized by K.D. Mc Donald in (Mc Donald, 1999). It includes C/A code on L2, and a third civil frequency L5 with precision F code. With modernized GPS, stand-alone L1/L2 C/A code positioning will be at the 5 m level and precision stand-alone L1/L2 C/A and L5 F code positioning at the 0.5 level. For geodetic applications, the third civil frequency will allow for 5 cm RTK (Real Time Kinematic) positioning and for 5 mm after post-processing. Galileo will provide, as well, three signals to the civil community with an even better signal-to-noise ratio. A comparative analysis of three carrier phase positioning for Galileo and modernized GPS and the impact on integer ambiguity resolution is made in (Joosten et al., 1999).

While we await modernized GPS and Galileo, new approaches in GPS ionospheric tomography have already been used for cm level trajectory determination (Colombo et al., 1999) with ground reference stations located at hundreds of km.

Although less accurate (0.40 m horizontally, 1.03 m vertically, at the 1-sigma level) absolute —non-differential— C/A code positioning (Ovstedal, 1999) is a relatively straightforward procedure likely to become of real practical interest in

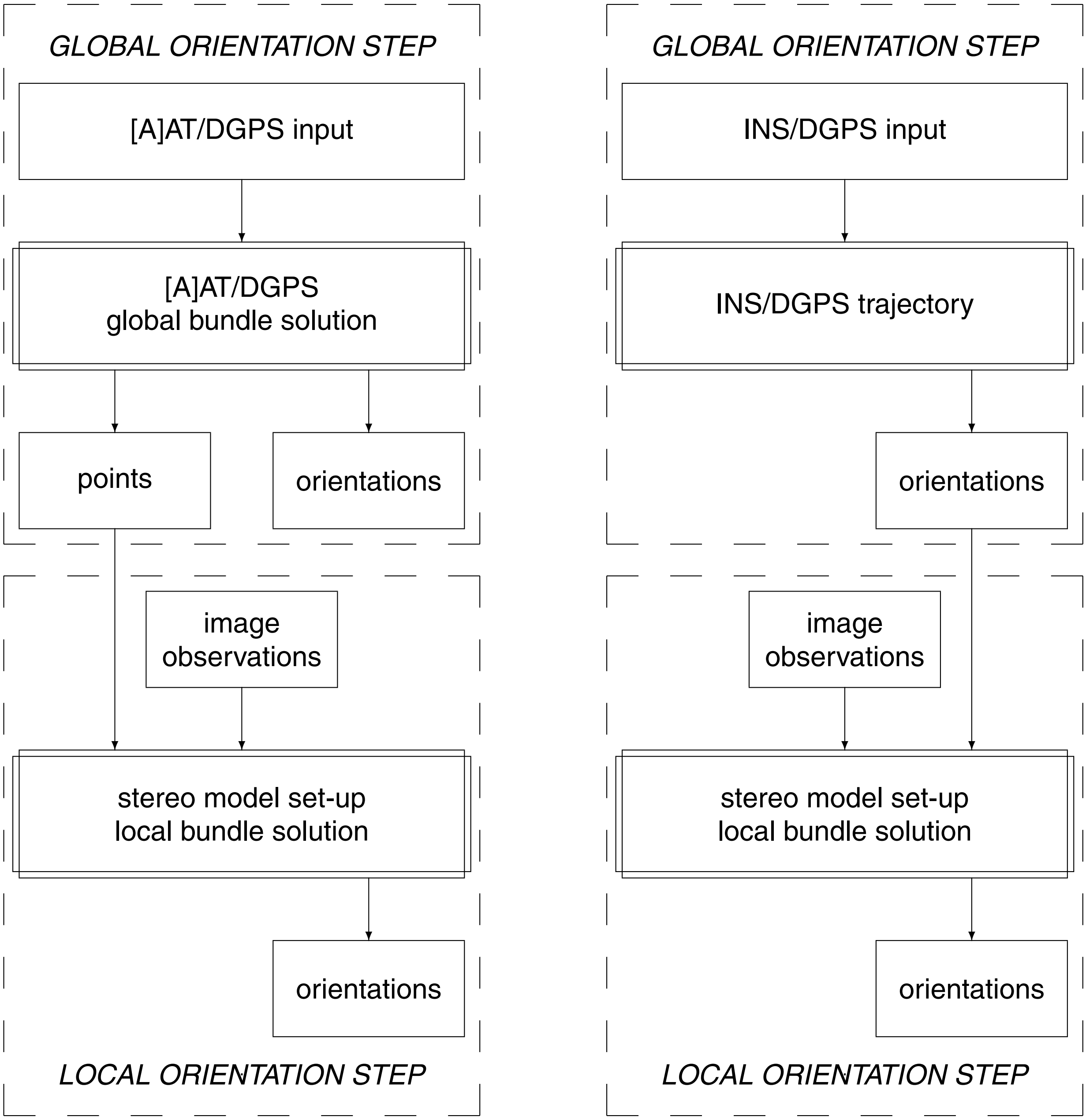

Figure 1: Two step AT/DGPS and INS/DGPS orientation.

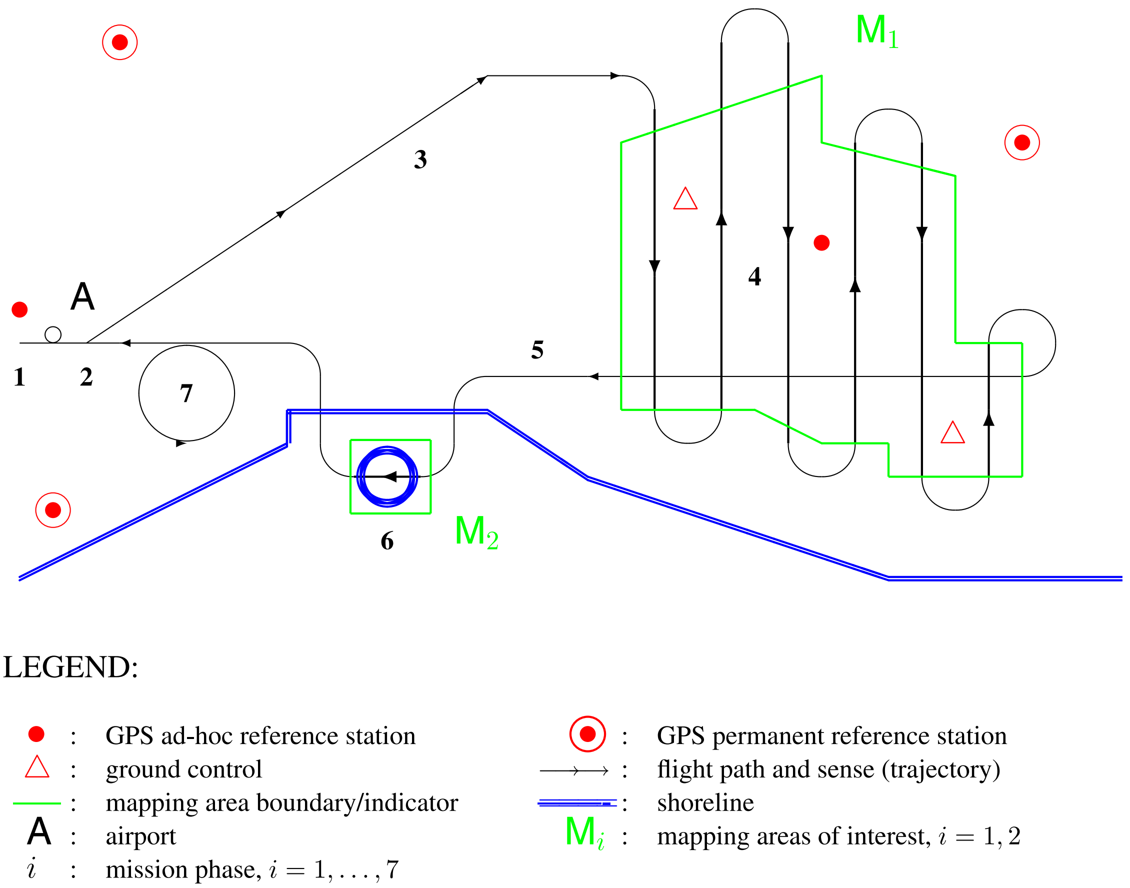

Figure 2: General aerial mission layout.

kinematic applications when GPS SA (Selective Availability) is discontinued. See also (Witchayangkoon and Segantine, 1999) for a discussion of absolute phase positioning with the PPP (Precise Point Positioning) service of NASA's JPL (Jet Propulsion Laboratory). All the mentioned achievements (Colombo et al., 1999, Ovstedal, 1999, Witchayangkoon and Segantine, 1999) are based on the raw data and derived products collected by the tracking reference stations of the IGS (International GPS Servive; see section 6.2).

The bottom line for trajectory determination is that within the next decade, without SA, with a modernized GPS, with Galileo, and above all with IGS, precise absolute positioning will become a reality.

5 TOTAL ORIENTATION PROCEDURES

We start with an example and then generalize. The example scenario is schematically depicted in figure 2. Let us assume a standard aerial photography flight mission for mapping purposes. Let us assume, as well, that the airplane has its base at airport A and has to cover two mapping areas of interest, M_1 and M_2. M_1 is the main mapping area whereas M_2 is of secondary relevance but it has to be covered. To illustrate a not so uncommon situation we assume that M_2 is an island. It could be any piece of land away from and not connected with M_1.

We further assume that the company that does the survey has installed two reference, ad-hoc, GPS stations; one close to the airport, the other close to the main mapping area. Furthermore, there are a number of GPS permanent reference stations operated by some geodetic or mapping agencies. It would also be possible that the surveying company establishes a third GPS reference station at M_2.

Now assume that the airplane is equipped with geodetic GPS receivers and has one or more IMU attached to its imaging sensors. Under normal flying conditions and air traffic regulations a typical mission process would be as follows. The airplane spends some time roaming at the airport platform before heading for the runway (1) and taking off (2). After take off the airplane will head to M_1 (3), fly stripwise (4) and go to M_2 (5). It will then fly M_2 (6) and then fly back to A, possibly after some waiting circles before landing (7).

So far, nothing new. Let us ask ourselves this question: when to switch on and off the trajectory and attitude related instruments like GPS receivers and inertial units. The T.O.P. approach answer to the question is that GPS and inertial observations should be collected from take off to landing, as opposed to the current practice of switching the position and attitude instruments on/off a few minutes before/after the image acquisition process starts/ends. Apparently, this is inconsistent with the results presented in (Colombo et al., 1999) where GPS integer cycle ambiguities are solved on-the-fly epoch-by-epoch. This is actually not the case as it is described next when re-reading the mission process.

During phase 1, sensor positioning can be performed at a few cm accuracy level because of a close GPS reference station. Also, during phase 1, the IMU will be able to align with the help of GPS. After phase 3, the IMU will be calibrated and some GPS tropospheric modeling process will have been started and stabilized. During phase 4, the imaging phase, the airplane will fly over M_1 and, while in there, a few times close to where the second ground reference station is. This will allow, again, for an independent check/determination of the GPS integer cycle ambiguities. (In phase 4, the actual imaged area on the ground is restricted to the mapping area of interest since sensor orientation is performed primarily by INS/DGPS.) Phase 6 is, again, an imaging phase whose “short” trajectory is better dtermined as a subtrajectory of a longer trajectory, which is accomplished by phases 5 and 7. Note that with the current GPS constellation, the integer cycle ambiguities, which we assumed to be reliably estimable in phases 1 or 4, are likely to be maintained for some period of phases 3 and 5. The situation will improve in the future if the GPS modernization initiative prospers (Mc Donald, 1999). And it will be further improved by the simultaneous use of a modernized GPS system and the future European GALILEO system.

So far we did not mention the permanent GPS stations. They are likely to be located not exactly in the mapping areas but they can provided either additional raw GPS observations or derived products if they are related to networks like those of the IGS (http://igscb.jpl.nasa.gov/) or EUREF (http://homepage.oma.be/euref/). The derived products include precise ephemerides, satellite clock corrections, coordinates for the stations themselves referred to well defined geodetic reference frames, and periodic ionospheric models. The above information seems to be enough not to use the ad-hoc GPS reference stations (Colombo et al., 1999). This is a major step forward. Even for some medium to small scale applications the straightforward absolute positioning techniques described in (Ovstedal, 1999) are likely to be sufficient.

The INS/DGPS post-processed trajectory transferred to the sensor instrumental reference frame is optimal in the trajectory sense but not in the sensor orientation sense since correct interpretation requires a well calibrated system. Calibration is a rather general term and, in the case of traditional photogrammetric cameras, includes the calibration of the fundamental camera constants —a must— and selfcalibration —an option—. With INS/DGPS the fundamental camera constants are calibrated and checked periodically. Selfcalibration is largely mission/time dependent and if there is a need for it, then the INS/DGPS process has to be followed by homologous point matching and a bundle adjustment. This does not necessarily mean that we are back to digital AAT since, given the image orientation parameters, the number of homologous points that have to be matched is relatively small. For the same reason, the robustness of the estimation of 10 to 40 additional selfcalibrating parameters is high. A lightweight AAT package or even manual, traditional measurement of a few points would compare favorably to the quality-checks and editing of digital AAT.

The above methodology corresponds to the ideas given in (Colomina, 1999): concentrate the efforts in developing methods to fully exploit the potential of INS/DGPS and then, if needed, complement INS/DGPS technology for orientation with image processing technology and bundle adjustment for fine calibration; in any case, keep the existing bundle programmes or a lightweight version for sensor calibration.

6 THE T.O.P. PROCESS

In section 5, a concept for an optimal combination of INS/DGPS and lightweight AAT has been described. Nevertheless, for a concept to be brought into actual practice a decision making process is needed. Contributions to this are discussed in the next subsections.

6.1 Define the project quality parameters

It is said that business is about making money out of satisfying customers. The project quality parameters are the weights to balance the relative importance of technical specifications, time to market and cost of the service. Those three main parameters are then modulated by market, external factors and by corporate, internal factors. Once this becomes clear, what the customer wants and how it is to be delivered (progressively, at once, etc.), then the technology options to do the orientation are likely to show up naturally.

6.2 Consider using IGS data and derived products

The mission of the International GPS Service "is to provide a service to support, through GPS data products, geodetic and geophysical research activities." Beyond that, the IGS is providing the general geodetic, mapping and Earth Observation community, with an extraordinary, daily data set at no cost. There are many sources of IGS related information. The IGS web site is worth the visit of anyone in the photogrammetric community.

The IGS products are: high accuracy GPS satellite ephemerides, Earth rotation parameters, coordinates and velocities of the IGS reference tracking stations, GPS satellite and refernce station clock corrections, ionospheric information and tropospheric information. All this products can be dowloaded from the IGS web sites and are formatted according to well documented and stable formats. The IGS file formats are supported by all major GPS SW and HW manufacturers.

Before deploying an expensive ground GPS infrastructure, have a look at the IGS web site and see how much you can "steal" from it. The same holds for reginal similar services like EUREF in Europe and for local services like those maintained by the local geodetic agencies.

6.3 Fix a policy for sensor calibration

With INS/DGPS as the primary tool for orientation the calibration of the system becomes critical. Depending on external and internal factors one could go for a small test field nearby the company headquarters and check the calibration periodically. Or one could go for calibration blocks tailored to projects. One should have a policy for when (2-3 times per season), where and how to check calibration.

6.4 Fix a policy for quality assurance

In the early stage and because of INS/DGPS is relatively new in this activity sector and because of the calibration uncertainties, define and measure a small set of GCPs (Ground Control Points). The GCPs can be further entered into a bundle adjustment involving just their images. (Note that with a suitable calibration model, a connected bundle network is defined so the measurement of a few GCPs can be used for an optimal estimation of calibration parameters. Note as well that this does not require any particular block geometry.)

6.5 Account for the second orientation step

This has been discussed in sections 2 and 3.

6.6 Develop and/or select the right set of tools

If one wants to stay on the safe side of the process, one needs a few more SW pieces than those offered by the manufacturesrs. There is still a gap between the INS/DGPS SW packages and the photogrametric ones. This gap includes calibration, geodetic reference frame transfers, and IMU-camera missalignment determination. These tools are only available at universities and at some companies. The situation is even worse for creative users who might be interested in implementing their own strategies like those proposed in this paper.

7 THAT ALL IMPORTANT SW FLEXIBILITY

Software development is a rather complex and expensive task. Manufacturers of software systems are forced to make decisions on what to support and what not. It would be naive to ask that every "brilliant" idea is implemented. However, a high degree of flexibility and efficiency is proven to be feasible (Navarro, 1999, Navarro, 2000). This development at ICC (Institute of Cartography of Catalonia) is an example of how medium sized organizations can benefit from SW development and integration. The Socet Set of LH Systems is another example of a flexible approach. On the other side, there are stereo model set-up modules in photogrammetric workstations that do not allow for the introduction of exterior orientation elements as observations. The same holds for some AAT packages. Both the systems and their users will benefit from a slightly more open SW interfaces.

8 CONCLUSION

Much progress has taken place in geodetic positioning and attitude determination since the introduction of GPS in aerial triangulation in the late eighties. In the next decade, the GPS modernization and the Galileo initiaves will bring additional accuracy and reliability to satellite RFR positioning. Progress has also taken place in the automatic generation of terrain models by image matching —if not to produce acceptable contour maps at least to produce acceptable heights for orthophoto generation—. The relative success of automatic terrain model generation launched the idea of AAT. Unfortunately, INS/DGPS skills and knowledge have been in short supply within the photogrammetric community and both technologies, INS/DGPS and AAT, have gone parallel, separate ways. Beyond the brute force approach of integrating the two technologies as they exist today. a global, total procedure, has been proposed which combines the strengths of both. The T.O.P. concept leans heavily towards taking full advantage of modern geodetic INS/DGPS trajectory determination and relegates AAT to calibration and selfcalibration tasks (lightweight AAT). (Though the spirit of this paper was not to participate in the ”direct vs. indirect” holy war, the author has to admit that, while not being a fanatic, has his own, strong convictions.)

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