THE N.O.S.A. PROJECT AND CONCEPT FOR SENSOR ORIENTATION

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1 Introduction

NOSA is a project of the ICC which was established in 1994 and which has recently received additional funding from the DGR-CIRIT (Direcció General de Recerca - Comissió Interdepartamental de Recerca i Innovació Tecnològica, Generalitat de Catalunya) and from the DGICYT (Dirección General de Investigación Científica y Técnica, Ministerio de Educación y Ciencia). NOSA (Navegació i Orientació de Sensors Aerotransportats) stands for Navigation and Orientation of Airborne Sensors. The goal of NOSA is to develop concepts and, eventually, systems for the integration of imaging, position, attitude and other geophysical sensors and data in order to allow for aerial survey navigation and precise orientation in real-time, fast or conventional post-processing. In particular and more specifically, a concept for a SISA (Sistema Integrat de Sensors Aerotransportats) —an integrated system of airborne sensors— and fast algorithms are pursued. Since data is the most expensive component of mapping and GIS projects, primary data acquisition —in particular, sensor systems— is a key aspect of our projects, hence the relevance of NOSA. The NOSA project is related to the GeoTeX [4] software development project and to production projects ranging from aerial triangulation to environmental monitoring [1].

The ICC aerial survey department currently operates two types of sensor systems. One type consists of a GPS geodetic receiver and a metric camera. The other type consists of a CASI 501 multispectral scanner [1], low cost gyros and a GPS receiver of the geodetic type. A CCNS-4 navigation system for conventional photographic aerial surveys is currently being installed. An IMU (Inertial Measurement Unit) is being purchased. There are plans for testing airborne digital panchromatic cameras and thermic sensors in 1995. And this is only an example to illustrate the general trend for the next years: sets of different sensors will be installed on airborne platforms. The more integration between the sensors, the more performance of the acquisition-normalization-interpretation (ANI) cycle in photogrammetry and remote sensing. (Sensor data fusion is not only a challenge in geomatics but a broad problem in the many branches of remote sensing like the surveillance or military ones.)

The two former concepts —the ANI cycle and its performance— and their relation to a sensor system deserve some remarks. The ANI cycle is a data processing general model for photogrammetric and remote sensing tasks [3]. The performance is measured by the costs, the time and the technical specifications. The features of the individual sensors and their level of integration determine the performance of one or more components of the ANI cycle. For instance, a time-synchronized GPS receiver contributes to navigation (acquisition) and to orientation (normalization) on the cost and time aspects but not on the technical specifications part since precision is kept to a similar level.

Depending on the project, the relative importance of cost, time and technical specifications (including the type of sensor data) may change. Therefore, a sensor system must be flexible enough to accommodate different sensor configurations as well as to serve different performance requirements.

2 Fast and real-time mapping for environmental purposes

Fast and real-time mapping are of interest when a fast response is needed which is based on some cartographic document. The situation is found when monitoring natural disasters as floods, forest fires, vulcanism, and other catastrophic events, which PUTS special time requirements of information delivering to respond to emergency. One aspect of fast mapping, fast sensor orientation when high accuracy is achievable, is also of general interest because it simplifies post-processing and data handling.

An important example to illustrate the concept of real-time mapping is the application to fire fighting and wildfire management in the Mediterranean area. GIS and traditional remote sensing techniques provide knowledge of ecological parameters and distribution of fuel available to fire which can be input to fire models for propagation prediction. When a fire is expanding rapidly under dry and windy conditions, the model has to be updated as often as possible. Also, for safety reasons, fire fighter teams need very accurate information on time. One of the first remote sensing systems applied to data acquisition on wildland fires is the thermal infrared scanners. There, maps from images with heat sources become the foundation of tactical plans for the suppression teams.

The above example is a very demanding one. In general, it can be stated that environmental monitoring require, indeed, fast delivery of accurately georeferenced thematic information. A related example to illustrate the concept of fast mapping is the Brazilian PREVFOGO system where images —in this case from satellites— are daily normalized by the INPE (Instituto Nacional de Pesquisas Espaciais) and handed over to IBAMA (Instituto Brasileiro do Meio Ambiente e Recursos Naturais Renováveis).

Actually, real-time mapping is a well formulated concept since some years ago. Its relation to emergency situations is apparent. At the ICC, though the bulk of our work is conventional topographic mapping where time is less critical, the concept of fast mapping is also being formulated because of the increasing relevance of many environmental applications

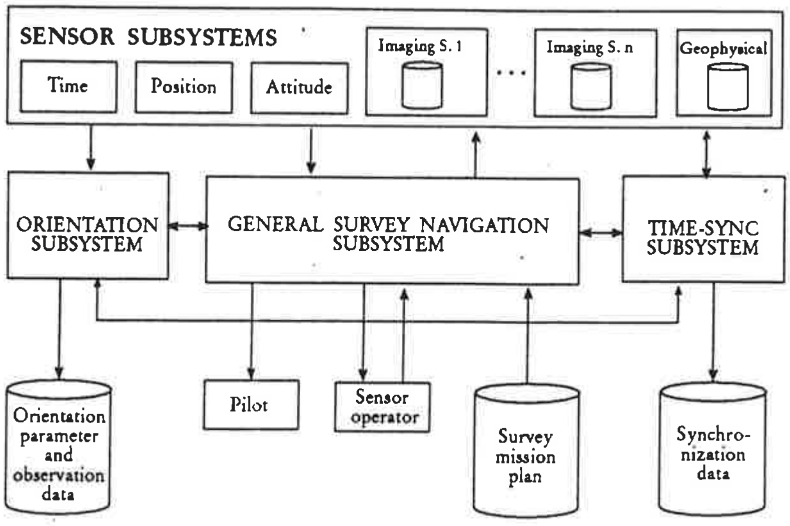

Figure 1: Sensor system schematic layout.

of airborne remote sensing. In the next section we describe an ideal SISA according to our needs and discuss some limitations of most sensor systems currently available. In the rest of the paper we discuss some critical aspects more related to the fast orientation aspect.

3 General requirements for airborne sensor systems

In our context, an airborne sensor system is a computer based hardware and software system which allows for the precisely synchronized recording of imaging, ranging, position, attitude, geophysical and other auxiliary data during aerial survey missions. In an integrated system, the sensors cooperate in the realization of the mission tasks like survey navigation or sensor orientation.

Ideally, a system should accept both analog and digital sensors and should be expandable in a similar manner as an ordinary computer is; adding a new sensor to the system should be nothing else than connecting a new peripheral to the sensor system computer. Unfortunately, most sensor systems available are dedicated ones; i.e., systems tailored for a particular type of aerial survey mission. The reasons behind this situation are the rapid technological development and the small size of the corresponding market. However, the availability of fast processors, fast and high capacity storage devices, new multitasking operating systems and new software engineering tools claims for a revisiting of the existing sensor system concepts.

There are a number of problems related to the realization of such a system. One general problem is related to hardware and software systems' design. There are some critical

No. of visible GPS satellites	RTCM SC-104 message type 1	RTCM SC-104 messages type 1 & 9
4	7 s	5-10 s
7	11 s	7-14 s
11	18 s	11-22 s

Table 1: Average transmission time for RTCM SC-104 Type 1 and Type 9 Differential GPS messages at 50 bps (bits per second).

aspects to this point: the real-time requirements for navigation and time-synchronization to a common time reference system —usually, the GPS time—; the large amount of image data to be stored and transferred internally between imaging sensors and local storage (Figure 2 illustrates this aspect). As mentioned, all that is a systems' design problem which cannot be discussed here.

A second general problem is the external wireless data transfer: the radio up-link from GPS permanent stations to the sensor system and possibly the radio down-link from sensor systems to ground-based monitoring or decision centers. Table 1, borrowed from [7], shows typical average transmission intervals of the differential corrections to GPS pseudorange observations for a transfer data rate of 50 bps (bits per second). This would allow real-time positioning below 10 meters which is excellent for navigation but not for our purposes in most cases.

A third general problem is the rapid computation of optimal orientation parameters with data and time constraints. In the following we discuss the last two problems in the context of fast mapping.

4 Communication aspects for fast orientation

Fast orientation requires that post-processing be done during the aerial survey and sometimes nearly in real-time. Therefore, GPS reference station data in form of differential corrections [7] has to be sent to the aircraft receiver. The Radio Technical Commission for Maritime Services of the U.S. has defined the so called RTCM SC-104 standard format for Differential GPS services which is widely used to transmit this data. In particular, the data may be phase corrections as some message types (18-21) of the standard are designed to allow for high accuracy real-time kinematic positioning. A major problem is that for high accuracy "continuous" —say, approximately 1 Hz— positioning in a dynamical envi-

NOTATIONS:

n_b : number of bands per frame
n_p : number of pixels per band
f_I : frequency of image recording (frame / time)
v_a : aircraft's velocity
m_I : image scale
p_I : pixel size (image)
p_g : pixel size (ground)
r : overlap (for matrix images)
V : transfer rate

FORMULAS:

$$V = n_b \cdot n_p \cdot f_I \quad \text{(general)}$$
$$V = n_b \cdot n_p \cdot v_a \cdot p_g^{-1} = n_b \cdot n_p \cdot v_a \cdot p_I^{-1} \cdot m_I \quad \text{(pushbroom)}$$
$$V = n_b \cdot n_p \cdot v_a \cdot p_g^{-1} \cdot (1 - r)^{-1} \quad \text{(matrix)}$$

TABLE:

Sensor	case	n_b	n_p	p_I	m_I^{-1}	r	V
CASI 501	1	14	512	15	666000	–	52 kb/s
	2	15	512	15	226000	–	166 kb/s
3-line camera	1	3	12000	10	30000	–	9 Mb/s
	2	3	12000	10	5000	–	52 Mb/s
matrix camera	1	1	5000^2	10	30000	0.6	3 Mb/s
	2	1	5000^2	10	5000	0.6	18 Mb/s
	3	1	17000^2	10	30000	0.6	10 Mb/s
	4	1	17000^2	10	5000	0.6	61 Mb/s

($v_a = 72m/s$, p_I in microns)

Figure 2: Data transfer rates generated by imaging sensors.

ronment, high data transmission rates of the order of 1200 bps are required. We summarize the situation according to [6] (see also [5]).

In general, differential GPS data links to transmit pseudorange corrections or pseudorange/phase corrections can be set up in different frequency bandwidths depending on the coverage, data rate, equipment costs, and frequency availability. Transmission rates of at least 1200 bps required for sending phase corrections for "continuous" positioning can be reached by VHF, UHF —30 to 3000 MHz—. At these frequencies the transmission is limited to the line-of-sight and data integrity is affected by multipath. The use of these frequencies over large areas using ground transmitters requires a network of repeaters. The network of transmitters and repeaters may be dedicated or already existing. (A system for existing networks is the RDS (Radio Data System), a European standard for distributing data over broadcast FM subcarriers. In U.S. the equivalent of RDS is RBDS (Radio Broadcast Data System). The system broadcasts information along with conventional radio programs. The combination of GPS and RDS will allow to transmit differential GPS corrections at low cost over a large part of the country.)

On the other side, at lower frequencies, rates above 200 bps are not recommended. Pseudorange corrections can still be sent at these rates providing "continuous" navigation and positioning consistent with the pseudorange observable noise; high accuracy navigation and positioning with carrier phase corrections is not possible. At low and medium frequencies, from 30 kHz to 3000 kHz, limiting factors are atmospheric noise and skywaves. Coverage ranges between 50 km and 400 km depending on the Earth surface local features. At high frequencies, from 3 MHz to 30 MHz, the signal is reflected on the ionosphere and the transmission range can be more than 1000 km. Irregularities on the ionospheric propagation decrease the signal consistency and frequency diversity is necessary. With the exception of governmental agencies, spectrum frequency allocation may be a problem.

Satellite communications are also used to transmit GPS data. These systems offer a wide coverage and high reliability and transmission rates allow differential phase GPS [5][p. 47]. However, operating cost can be quite high.

In short, finding a suitable differential GPS radio datalink for fast and real-time mapping is a key issue.

5 Algorithmic aspects of an on-board fast orientation subsystem

The fundamental requirement for position and attitude determination for sensor orientation in mapping and GIS data capture is that the obtained orientation parameters allow for a consistent construction of a 3 dimensional model of the Earth surface and its objects.

In other words [for consistent]: global, rigid motion and scale uncertainties are acceptable because they can be easily corrected and preserve first order geometric relationships; local uncertainties and errors are only acceptable below a given set of precision thresholds which are critical project specifications. The above simple principle has been the basis for many photogrammetric procedures over decades and is still the idea behind the most popular approach to modern GPS aerial triangulation. In fast orientation determination, this capability of seamless local object reconstruction has to be added to the operational conditions in which surveys are many times performed: the reference GPS stations may be several hundreds of km apart from each other, the aerial survey may take several hours, line-of-sight between the survey aircraft and the reference station may not exist, complex or sudden aircraft maneuvers may be necessary, discontinuities in data recording may happen, and the like.

The maximum set of observables available for the subsystem will be: GPS carrier phases and [smoothed] code pseudoranges with their respective differential corrections, IMU derived positions and attitudes.

The above considerations translate into a set of technical problems and requirements. If the radio link allows for the broadcast of phase differential corrections at, say, 1 Hz frequency, then correct integer ambiguity solution may still be difficult (long baselines, tropospheric effects [2]). If phase differential corrections are only available at a sparse set of epochs then, in addition, lower accuracy gaps between accurately determined epochs may occur if an IMU is not installed. In summary, the system under development has four operating modes: pure phase positioning (1) and phase positioning at a limited number of epochs with different interpolation techniques: drift corrected IMU on-board observations (2); on-board interpolated carrier phase corrections for the reference station (the carrier phase corrections not being transmitted are interpolated) (3); and transmitted phase smoothed pseudorange differential corrections (like in the former mode pseudorange corrections could be also interpolated) (4). If there is no real-time request, a global approach to the solution of phase range ambiguities will be adopted; i.e., the best estimate will be based on a multiple epoch residual minimization. (Note that high precision fast orientation is also of interest since it would eliminate a part of post-processing.) While the above strategy for the selection of appropriate observables is almost standard, the algorithm —or rather the subsystem— is more complex than an epoch-by-epoch monolithic solution algorithm. It must keep track of the time spots when an orientation solution is needed, a number of observational events like cycle slips, and finally it must be able to compute the optimal global solution before landing.

So far, only the positioning aspect has been discussed. For the orientation aspect we will start by solely relying on the IMU unit.

6 NOSA plan of activities

The first step will be the acquisition the acquisition of a Novatel GPS Card. The second step will be the acquisition of a strapdownn INS and its integration with the CASI sensor. The third step will be the acquisition of a radiolink and the integration of a fast/global orientation subsystem. In the last step we will integrate the INS with the former system. Concurrently to these activities a truly integrated sensor system will be either developed or purchased.

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