TOWARDS MAPPING WITH MULTISENSOR INFORMATION: SOME BASIC PROBLEMS IN SENSOR INTEGRATION

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Abstract

Multisensor systems for data acquisition and information fusion systems have already been around for some time. In several application areas the related literature abound [15], there are textbooks covering the topics and there exist succesfully fielded systems. Examples therefrom include military and remote sensing applications. In the mapping community and in her syster communities like photogrammetry the use of multisensor information, with few exceptions, has not been given much attention yet. There is one very good and valid reason behind this, namely that the combination photogrammetric camera-high resolution film has been so far unbeatable in many respects.

Nevertheless, within the last ten years development in the areas of sensor and information technologies has already had a significant impact in some areas of mapping. The use of these new technologies is likely to increase rapidly and it is therefore necessary to understand them and, even more important, to manage their selection, combination and integration. Mapping based on multisensor systems is now an emergent concept and technology.

In this paper some basic aspects related to the use of multisensor systems are discussed with an attempt to derive abstractions for those processes and their related problems.

1 Introduction: current situation and the driving forces

When looking at new technologies for cartographic applications one tends to concentrate on the ones directly related to the imaging-interpretation process particularly, on imaging sensors. The latter are important indeed but one should not forget that many of the "small" revolutions we had recently are also related to technological advances in the related areas. Thus, for instance, in the celebrated corridor mapping systems like the GPSVan (Center for Mapping, Ohio State University and Transmap Corporation) or the VISAT (University of Calgary and VISAT Technologies Inc.) the breakthrough is probably the use of a van as the sensor carrier. Another interesting example has been the use of kinematic GPS for airborne sensor positioning. In this case, the big benefit is not only the cost reduction of ground control but also, if not outperforming it, the cost reduction of the aerial survey itself by means of GPS aided navigation and sensor control. An [incomplete] list of technological factors impacting mapping is: carrying platforms; survey-navigation systems; position and attitude determination sensors; global and local positioning systems; image sensors; range sensors; and information technologies.

There are practical applications based on almost any vehicle available: from satellites of different kinds at different altitudes and manned space stations to ultralight airplanes, to helicopters, to high-altitude aircrafts, to vans and even to airships. The survey-navigation systems are changing the way aerial survey missions are being performed. In some cases there is no need for navigators at all. In other cases they are becoming sensor operators. Satellite geodesy and navigation, inertial navigation, positioning and attitude determination and image processing are complementary and/or redundant techniques for sensor orientation. They are usually dependent on local and global geodetic and navigation additional services. Nearly fully automatic sensor orientation is coming from different technological approaches and the requirements for ground control are being relaxed [19, 26].

New image sensors go digital, either of the pushbroom or frame type and for some applications their overall performance is superior to analog technology. Not to speak about airborne or spaceborne multispectral sensors which were always digital. For some of them orientation with GPS and INS is a must. Range sensors like airborne laser scanners and airborne/spaceborne synthetic aperture radar are already used for practical projects. Both technologies are mature ones as proven by the many new innovative, private companies which offer hardware, software and services. Laser or radar aerial surveys are much less weather dependent than conventional aerial photography and can penetrate forest canopy. There are laser systems which can even detect power lines.

Last, the data acquired by the above mentioned sensors has to be transformed into maps. This involves automatic, semi-automatic and manual procedures. Here new information technologies are instrumental in making the transition from the manual procedures to the automatic ones.

It has been pointed many times that, in our field, technology drives innovation —see [1] for an authoritative discussion— and for innovators this rapid evolution of technology is a challenge in many respects. The problem is not only doing good research and development; the problem is also jumping into the right technological powerhorse at the right moment and leaving it at the right moment as well.

In addition to technology, another important —if not the most one— driving force is market. Many system concepts can be envisioned from the currently and short-term available technological components. Since research and development are expensive and their life-cycles long, it is also a challenge for innovators to identify the main areas of activity and to evaluate their corresponding research and development opportunities.

2 On "our" sensor systems

In geomatic applications sensor systems are designed to explicitely or implicitely capture a number of attributes of objects of our environment with the requirement that they can be referenced in space and in time. The attributes can be many though traditionally our community has mainly concentrated on topographic mapping attributes. [Not so] Recently, environmental monitoring has contributed a long list of additional attributes to map makers. Thus, the information contained in the sensor's acquired data may be interpreted by specialists of different fields, more or less close to geomatics. However, the geo-time referencing is a geomatic task. We will, therefore, refer to sensor systems with geopositioning and timing capabilities.

The above semantic precision made, a way to organize the discussion is to define a model for data acquisition and exploitation in geomatics. A simple model is ANI: Acquisition-Normalization-Interpretation (see the related discussion in [3]).[1] Concerning A, there is an increasing general agreement on the need for flexible data capture systems in order to allow for easy/accurate integration of different sensors as discussed for instance in [4]. The present paper focuses mainly on the N aspect for topographic mapping. By image normalization we will understand here the determination of geometric and radiometric [22] model parameters to allow for transformation from object space to sensor space; where the models must also allow for the reverse transformation when the proper conditions for inversion are met. The N step is completed when the image is oriented in the above general sense. More specifically, given a data set of images, position and attitude observations, radiometric data and time synchronization data, the orientation task will decide what additional information is required (for instance, ground control and photogrammetric observations) and what estimation model is appropiate.

3 Acquisition

Acquisition refers to the data capture step. It is not the purpose of this Section to review the photogrammetric and remote sensing sensors available today but to give some hints on the main trends. The most up to date reference is [10] as for the sensors and their applications. The equivalent in terms of data capture for the normalization step is [2] (see also [5]).

The types of data sensed or measured for our applications are relatively reduced in number: ranges (directly or as time delays), angles, angular velocities, accelerations and images. EDMs, GPS receivers, laser and radar altimeters deliver ranges, inertial measurement units deliver accelerations and angular velocities. Then, there is the large family of imaging sensors in the different spectral bands. INS and GPS have complementary features, INS, GPS, altimeters and imaging sensors independently capture all the information required to georeference any type of panchromatic, color, multispectral and/or hyperspectral images [12, 27, 31]. The analog classical photogrammetric cameras are still supporting almost any aerial surveying missions. The situation is no longer true

[1]Models of the ANI type are often found for scientific data workflows. TFA: Transduction-Filtering-Analisys [28][p. 351], is a similar model for signal processing in an intelligent problem-solving environment. Transduction is the acquisition of signal data, filtering is the "normalization" of the data to make it suited for further signal analysis —feature extraction— and signal understanding —interpretation.

fro industrial photogrammetry as CCD cameras of smaller format are available. Digital video is another promising emerging technology. A higher level of integration is currently being achieved and this will further simplify the acquisition and processing procedures. A particularly interesting case are the imaging/range sensors which integrate images with radar or laser derived ranges [17].

As already mentioned, in practice, as important as the sensor is the platform. Today, sensor systems have been succesfully operated from land vehicles, aircrafts (from lighweight to stratospheric), satellites and even airships (confer also [10]).

The availability of sensors in a wide range of prices and types is an opportunity for the creation of small/specilised companies. One, of many possible examples, is the application of aerial infrared sensors and GPS for the acquisition of thermal imagery (roofs deterioration, underground steam line leaks, chemical likeage, etc.) [7].

4 Normalization

Normalization is the determination of sensor model parameters which allow for transformation from object space to sensor space. The normalization step is accomplished when the sensor is "oriented" in the above sense according to given specifications. The statement "according to given specifications" is important since integrated sensor orientation is not "combined sensor orientation" or "combined adjustment" in the sense of using all information available to compute the most accurate model parameters; "integrated sensor orientation" pursues to fulfill orientation specifications in the "cheapest" way, where cheap stands for some cost function be it related to time, money or whatever operational criteria need to be met.

There are a number of fundamental problems to be kept in mind. An attempt is made here to identify some of them —hopefully, most of them—. They are: the fourth-dimensional orientation and calibration problem, the signal propagation problem, the monosensor correlation problem, the multisensor correlation problem and the sensor-to-model correlation problem. There is also the man-in-the-loop problem —could be viewed as the machine-in-the-loop problem— which is also present in the A and I steps.

Fourth-dimensional orientation refers to the obvious fact that the sensor model parameters or some suitable well defined functions of them must be referred to a common, again well defined, space-time reference system. Particular cases of this problem are time synchronization and spatial eccentricity determination between sensors. Sometimes, datum transformation determination can fall within this concept. Ideally, this problem should be solved at the A stage by a perfectly —or specification compliant— calibrated acquisition system. Since this is many times not the case, the problem, or a mitigated part of it, is passed on to the normalization step and it seems appropriate to call it the fourth-dimansional orientation *and calibration* problem. Examples thereof abound. The solution to this problem is so critical that it can impose strong operational restrictions to the acquisition step.

The signal propagation problem is sometimes introduced as a calibration problem. It is a calibration problem indeed but one of the signal propagation media. In particular, it is one of the most elusive problems in high precision GPS positioning [29] and one which is receiving increasing attention for imaging sensors like photogrammetric cameras when used for high quality orthophoto production [22]. It is interesting to note that "our" signal propagation problem might be viewed by "others" not as a problem but as a means to gain insight in the propagation media properties. A nice example is the use of GPS for ionospheric TEC estimation and, more recently, for tropospheric water vapor analysis and further input to weather forecasting systems.

The sensor-to-sensor correlation problem entails two different problems, the monosensor and the multi-sensor case. Monosensor refers to correlation of data acquired from the same sensor and multisensor to correlation of data from different sensors. Image matching in photogrammetry is probably the best example in monosensor correlation problems. It is still a difficult problem [19, 25, 32] if not approached under restrictive conditions; multiscale matching [30] is, for instance, a whole complex problem in itself which is also present here. (In general, sensor correlation is a low level tool for orientation and calibration but also for the interpretation step.)

Multisensor correlation plays a similar role to monosensor correlation in systems with different sensor types. It is obviously a still more dificult problem than monosensor correlation. The big advantage of multisensor correlation is that it can combine the strengths of the different sensors.

Combination of GPS/INS [20, 26, 33] is a well known case. Combination of range and image data is becoming important [13, 18] and it will even more with the new ongoing developments like the imaging laser altimeters [17].

The sensor-to-model correlation problem refers to the correspondence between acquired data and models of actual objects. Examples are the correspondence between objects stored in a GIS and images (two-dimensional GIS-to-image registration [14]) and the correspondence between cartographic objects and images (image-to-map registration [8]). This type of correlation will also become more important in the future as GIS become more populated of data to be maintained, updated or just used to assist in normalization or interpretation. An example of an ongoing experiment is the new OEEPE project on the use of GIS stored manholes for image orientation or the system developed at the Institute of Photogrammetry of the University of Bonn for the orientation of aerial images. The system is an operative one in use at the Landesvermessungsamt Nordrhein-Westfalen for orthophoto production.

The man-in-the-loop problem refers to the situation where total automation is not feasible and the human expert has to interact with the computer to perform a particular task. A nice example is the operator role in the real-time loop of the photogrammetric stereocompilation process. It is much less evident how the human interaction has to be implemented for other types of sensors (see also [23]). Well solved man-in-the-loop problems lead to performant production lines and the issue is, therefore, of practical importance.

A note on the complexity of normalization for general multisensor systems is here in order. Automation has been achieved to a great extent [19, 32] though not completely. A remarkable partial early attempt has to be mentioned [9]. Nevertheless, it has been pointed out that progress in automation can only be achieved by introducing modern information technology in the normalization process [3, 6, 24]. The field of of intelligent systems for computational science and engineering [16] is an area where tools with a potential for application in geodesy and photogrammetry can be found.

5 A word on interpretation and modelling

As soon as any type of [sensor] data is available in digital form the question of computer aided or automatic information extraction arises. Sometimes the motivation is improved productivity. Sometimes there is no alternative way.

Automatic information extraction when it involves some interpretation process of fitting the data to some predefined models might turn to be a very difficult problem [11]. As a result, photogrammetry is recently shaping itself into a subarea of computer vision, which is a subarea of artificial intelligence.

A case as "simple" as contour line generation for topographic mapping remains unsolved. We are able to [almost] automatically generate elevation models suitable for orthophoto generation. But contour line generation requires a considerable amount of geometrical interpretation which, so far, can only be made by human beings. (Actually, elevation data and orthophoto generation belong to the N step rather than the I step.) If this case of contour line generation, it is clear that the geometrical interpretation required for topographic-map grade contours is much easier to be done from highly dense elevation grids like those obtained from airborne laser and radar altimeters. This is a case where attempts to replicate the human operator procedures with computers fail and where this failure can be bypassed by the introduction of a new technology [12, 21].

6 Conclusions

The examples mentioned in the former sections lead to the main conclusions of this paper: that the difficulties associated with the [automation of the] old processes or the monosensor systems are many times likely to be solved in rather unexpected ways by the introduction of new technologies which break the "rules of the game".

Mapping and, in general, doing geomatics with multisensor systems is an emerging field which is bringing new, imaginative and cheap, solutions to old big problems. Old, rather difficult problems might be bypassed by new systems which, of course, would pose new, hopefully easier to solve, problems to the geomatic scientific and engineering community.

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