Workflow Oriented Sensor Management Systems

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ABSTRACT

Historically flight management systems have been considered separately from the photogrammetric workflow. In fact, many times vendors of photogrammetric production systems have left the development of flight management systems to enterprising photo flight companies who commercialized an in-house development. Here we present a new approach to the overall concept of sensor management and demonstrate the gains in both productivity and comprehensiveness that can be realized by elevating the sensor management tools to the level of the remainder of the production system.

1. INTRODUCTION

In many cases, Flight Management Systems (FMS) have played a secondary role to the remainder of the photogrammetric workflow process. This has probably been the result of the specialized nature of data capture as compared to the photogrammetric workflow and the lack of domain expertise by the traditional developers of production tools. In fact, many times the FMS has been developed by an enterprising photo flight company who has attempted to commercialize an in-house development. This lack of cohesion between the planning and acquisition of remote sensed data with the follow-on workflow results in a loss of both efficiency and production quality right at the beginning of the production process. Indeed, as more and more functionality moves aboard the sensor platform, the division between actions performed on board the aircraft and those relegated to the ground processing systems is becoming blurred. Therefore, we feel that it is essential for the FMS to become an integral yet "modular" portion of the overall production system.

2. PROCESSING CONCEPTS

In order to fully understand our various foci in developing a new Sensor Management System, it is necessary to review some concepts that we feel are important in any modern production design.

Systems

In adding any new design to our product portfolio, we always consider a *systems* approach as opposed to simply developing a point solution. A systems approach considers how the new component will fit into the overall production workflow from both a data and a workflow point of view. Without a systems approach, one is faced with unnecessary steps in the workflow such as translating the ancillary flight data recorded during image acquisition to a format compatible with the project planning system, waiting on the results from the FMS prior to any downstream data population or production planning and, in general, a very disjoint approach to project management.

Accelerating Processing

As the photogrammetric business becomes ever more competitive, we are pressured to increase the productivity of the workflow with its ensuing improvement in the ever-important Return on Investment (ROI). While quantum steps are made by introducing new technologies such as automatic terrain and geopositioning processes, it is important not to ignore general efficiencies in the production process. We are all familiar with parallel processing in which the same task is preformed on multiple data simultaneously. In the production environment, we often implement a parallel processing workflow by simply adding a new operator position. For example, we can roughly double the rate of feature extraction by doubling the number of technicians who are performing the task. Allowing the production workflow to proceed in parallel often requires sophisticated additions to the techniques in which project data is managed to allow safe *concurrent* access. However, we often ignore the improved efficiencies that can be realized through *pipelining*. Pipelining a set of processes means setting them up in such a fashion that step B can commence prior to the completion of step A and so forth down the entire processing chain. A relevant example of this is the ability to begin the aero triangulation process prior to the completion of image scanning. Pipelining the production flow requires a complete and tight integration of both the data flows within the process and the processing tools. Obviously it is not possible to pipeline mission planning and data acquisition if these tools are not tightly integrated into the overall production system.

Modularity

Modularity is a design principal that primarily addresses *customization* and *scalability*. Customization allows one to couple various components to address specific workflow issues or to accommodate the skill levels of the technicians. Of course as a systems vendor, we would like customers to select modules only from our company but this is not always their desire! Therefore, an important element of modularity is an open systems approach to designing the various components of the system. Users of photogrammetric systems would like to be able to select the scanner of their choice and interface this to downstream processing systems without the need to introduce unnecessary steps such as data translators or data reformatting. This is an obvious need that has been apparent for many years, driving any number of data standardization movements. A second important issue addressed by a modular approach is scaling the system. One can think of a basic example of this with a multiprocessor-capable workstation that ships with a single Central Processing Unit (CPU). The operating system automatically detects and adapts to the installed number of processors such that when a second processor is added, the system scales performance with no perturbation in the applications. In the case of a flight management system, customers want a fully capable system to which they can add an IMU without reworking the existing system or changing their user interface. Thus *scaling* may mean capability as well as throughput.

3. THE SYSTEM CONCEPT

Our primary goal in the development of a next generation sensor management system was to ensure that we created a workflow solution rather than a point approach. A workflow solution ensures that maximum use is made of data created in the planning phase as well as feedback information from the mission itself. Such a systems approach ensures that there is a minimum of data flow problems during production as well as provides a very good overall quality management system. In block diagram form (figure 1), the system resembles our current generation of product, the T series.
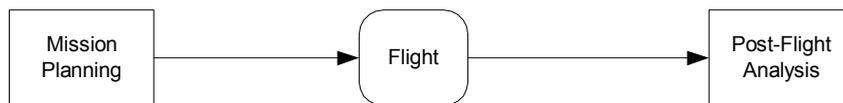
Figure 1 - Overall System

Mission Planning

The *Mission Planning* phase of sensor management involves planning the mission using a ground processing station, actually just a simple workstation equipped with a PC card reader/writer. The mission planning system provides a rich data environment such that scanned raster maps, vector mapping data and even digital orthophotos can be used in the planning of the flight lines. Eventually the system will include full three-dimensional planning such that elevation information is figured into the flight line algorithms. The system addresses the usual expectations such as flying a particular azimuth, planning the most economical mission for a given region of interest and so forth. These features, with the exception of three-dimensional planning, are standard in modern flight management systems.

The true systems approach is evident through the immediate availability of the planning information in the overall data management of the production system. If the user has deployed a basic management tool such as ImageStation™ Photogrammetric Manager (ISPM), the planning information will automatically populate flight lines, anticipated photo centers, photo names, camera name and so forth. This ensures a smooth post-flight workflow in that this data will not have to be manually entered. For users who have deployed a robust production management system such as TerraShare™, the benefits are much greater. Following mission planning, all TerraShare clients will have immediate access to the overall mission parameters in a graphical user interface. The image footprints (or swath in the case of a push-broom sensor) with associated metadata are populated into a normal TerraShare project. Symbology such as line styles and weights depict the status of individual images; e.g. red dashed footprints meaning the image is planned but not collected or or-line. Introduction of this level of data early in the process allows pipelining of the production workflows. A production manager can begin the process of planning the assignment of data segments to production operators; an aero triangulation operator might segment the project into blocks and so forth. Most importantly, the production manager has a synoptic view of the project and its status much earlier in the production cycle than is usually the case. A typical TerraShare view of a project is depicted in figure 2.

The Mission Planning portion of the system provides a rich candidate for "Quantum Services" (Graham, 2001) in which, through connectivity to various data providers over the Internet, additional planning data can be used. For example, the planning could connect to a provider of elevation data, a second provider of digitized raster graphics and so forth. This would allow the mission planner to make use of a wide, distributed collection of data without the overhead burden of actually maintaining the collection; in other words, collaborative computing. Obviously, the providers of data must be paid and therefore the system will have to include a mechanism for *metering* services.
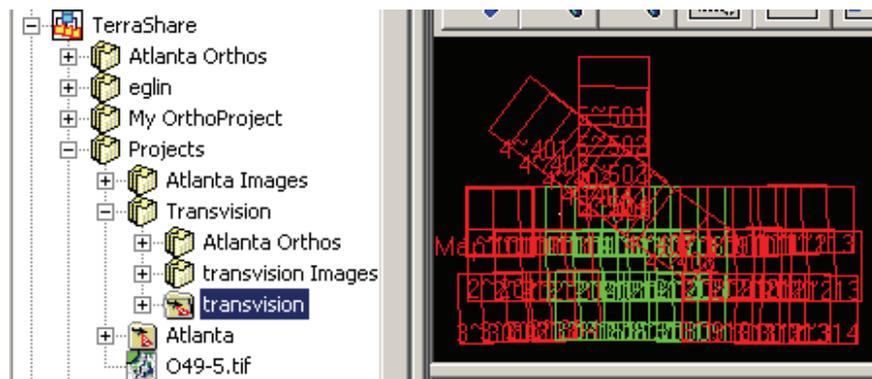
Figure 2 -TerraShare Project

Flight Management

The *Flight Management* segment of the system manages the sensor environment during the actual data acquisition process. We have moved this technology to the next generation as well through more fully integrating the on-board systems and providing a modular architecture that allows the integration of additional sensors (for multi-sensor platforms) and ancillary mission support sensors such as an Inertial Measurement Unit. The flight management portion of the system is fully described in the next major section.

Post-Flight Data Processing

There are two primary objectives in the design of the post-processing section of the system; a quick analysis of the success of the mission and seamless flow of the data acquired during the mission into the workflow process.

Mission data is transferred to and from the on-board system thorough the use of a solid-state memory card. This format is not only the most rugged Commercial-Off-The-Shelf solution for airborne systems but also provides very rapid data access. Therefore, even though comprehensive mission data may be recorded as part of the overall digital data that was collected (for example in LIDAR and digital camera systems) including these data on the mission card allows a rapid post-flight analysis of the results without the need to read tapes or other lower speed data collection devices.

The analysis portion of post-processing allows the user to view the actual acquisition waypoints relative to the planned mission waypoints. Although unacceptable mission parameters should be detected and corrected during flight, this is not always the case. The post-flight quick look analysis allows an early decision on whether or not a reflight of portions of the mission will be required.

The most significant aspect of the systems approach to the design is that the project management system is automatically populated with the actual mission data. The planned data within the management system is updated with the actual mission parameters (for example, planned photo centers are updated to reflect true photo centers). The true value of an integrated workflow becomes apparent at this time. As the actual images are introduced into the system (through scanning, for example, in the case of an analog aerial camera), the data management system will graphically indicate the status of the project through a symbolic representation. This allows the production manager to assign operators to the project in a phased manner. Digital measurement in support of triangulation or input into an automatic triangulation process can immediately proceed

rather than delaying the start of production until the entire project has been scanned.   As discussed earlier, this approach is mandatory for pipelining the production process.

4. MODULAR SENSOR MANAGEMENT SYSTEM

The primary architecture of the airborne components of the system is denoted in figure 3 below. The primary components of the system and their functions are listed in table 1.

Table 1 - Sensor Management System Components

Subsystem	*Functions*
System Controller (SC)	• Overall control of the in-flight system
Sensor Interface Module (SIM)	• Personalizes the generic SC to a particular sensor • Provides Sensor Management User Interface
Real Time Controller (RTC)	• Performs functions that must execute in real time
Pilot Display	• Provides real time sensor and flight line information to pilot
Sensor	• The actual data acquisition module (e.g. RMK TOP, DMC, RC-30, etc.)
Video Camera	• Provides quick look data, V/H computation data
Inertial Measurement System (IMU) – Optional	• Provides 6-DOF sensor monitoring
Active Mount – Optional	• Actively stabilizes/points the sensor

Among our design goals was to architect a system that could easily support the Z/I Imaging 6 month software update release cycles. Since embedded systems tend to require more time for both development and testing than do general-purpose programs running on standard computers, we allocated the minimum of functionality to the Real Time Controller. This design often required the segmentation of a single function between the two computers within the on-board system (the System Controller and the Real Time Controller). Another driver for segmenting the on-board programs between a general-purpose computer and the custom Real Time Controller is the rapidity with which computer processing power advances. An off-the-shelf ruggedized laptop computer is used as the System Controller, allowing a user to upgrade this central element of the hardware as often as is desired. The processing requirements allocated to the Real Time Controller are quite modest with sufficient headroom to preclude the need to update the hardware within this custom portion of the system over the next several years.

System Controller

The System Controller (SC)) is actually a set of programs running on a conventional Off-The-Shelf laptop computer. The SC accepts the mission plan on a PC Card and controls all aspects of the sensor(s) while the mission is being flown. The SC program is divided into two major user interface views; the sensor management console and the mission view.

The sensor management console provides the operator with an interface to all sensors within the system. Not only does this include the image acquisition sensor but also the auxiliary sensors such as GPS, Stabilization mount, IMU and so forth. For example, if the operator wished to control the camera in a manual mode, he would select exposure time and iris setting through this interface.

The mission monitor console provides the graphic view of the flight lines, waypoints, waypoint status, aircraft attitude, speed and so forth. In addition to the normal informational display, sensor status indicators are visible. This assures the operator that the various sensors are operational, eliminating the need to switch displays to the sensor management console unless a parameter change is needed or an error is indicated. A subset of this view is transmitted to the Pilot Display.

Maximizing the reliability of the overall system was a very important design goal. The customization of conventional computers such as laptops with special interfaces has historically proven to be problematic. To overcome this issue, we use only the standard single RS-232 to drive the Pilot Display and the integral Ethernet to communicate with the Real Time Controller. Signal routing hardware and software is contained within the RTC to interface with the various other hardware components within the system.

Sensor Interface Module

The Sensor Interface Modules (SIM) allows the system to support a variety of sensors without the need to change code within the System Controller itself. The SIM coverts a generic command (such as *set exposure time*) originating from the SC to a sensor specific command. This concept is much like the Hardware Abstraction Layer (HAL) used in the design of Windows NT™ to allow easy porting of the operating system to different processors and multiple processors (Solomon, 1998). The interface between the SC and the SIM is open and defined. With a SIM software development kit, a third party sensor developer could, in theory, develop an interface to their sensor and plug it in to the overall system without us needing to make changes in the System Controller.

Real Time Controller

The real time controller (RTC) contains a microprocessor with the surrounding support devices and provides the functions within the system that must execute in *real time* or *predictable time*. By real time, we mean within a deterministic time (relatively short) of the occurrence of an event. Functions that must be responded to in real time include triggering the sensor at the closest approach to a waypoint, recording the GPS coordinates of the mid-point of the exposure and similar events. The functions contained within the RTC have been kept to a design minimum for easier maintenance of the system and to allow long hardware refresh cycles on the RTC. Many functions that must be executed in real time have been split between the RTC and the System Controller to accommodate our minimization design goals. For example, the closest approach to a waypoint algorithm is divided between the RTC and the SC such that the bulk of the algorithm executes within the SC. The partitioning of the real time functions presented a very engaging design challenge to the team. As a side note, it is interesting to realize that the design of a system is profoundly affected by considerations such as system maintenance, not just functional allocations.

The Real Time Controller provided us with a single container within which to integrate all of the custom hardware aspects of a Sensor Management System. The hardware components and/or functions within the RTC include:

- The Real Time Single Board Computer with its ancillary I/O subsystems

- The Video Frame grabber
- Interface converter (converts the Ethernet interface between the RTC and the System Controller to the various signals needed by other components within the system)
- A Navigation quality GPS
- T/AS (stabilization mount) interface for the Z/I Imaging TA/S
- Hardware connectively to subsystems such as sensors, IMU, Video camera, etc.

The RTC and its subsystems are housed in a standard 19" rack-mountable cabinet.

Pilot Display

The Pilot Display provides an uncluttered, easy to read guidance display for the pilot. While this display is also available within the user interface of the System Controller itself, the pilot should not have to be concerned with information of use to the sensor operator such as sensor status.

Sensor

Obviously, the sensor itself is the central concern within the system. Our system is designed to accommodate a variety of sensors, initially in framing acquisition mode. A framing sensor is characterized by acquiring the image as a single *snapshot* at the programmed point of exposure. Eventually we will expand the capabilities of the system to include push broom designs, which are characterized by a *continuous on* mode. In addition to accommodating a variety of sensors, the system is designed such that it can accommodate multiple sensors operating in parallel. This type of configuration will become important for missions such as LIDAR operating in conjunction with a camera.

Video Camera

The video camera is an intrinsic part of the base system and provides the input for several functions. First, it serves as the input device to provide real time feedback to the camera operator on the ground coverage of the sensor. The video frame grabber (physically located within the RTC cabinet) can be synchronized with the sensor trigger to acquire a low-resolution video image of the area of coverage. A second function of the video image is to provide input to a computation algorithm within the SC that, combined with input from the GPS, performs a Velocity to Height ratio computation used for Forward Motion Compensation (FMC) input for the sensor. A third function of the video image is to provide input to the SC for a platform yaw computation. This yaw compensation is used to drive the drift control of the sensor stabilization mount (if present).

Inertial Measurement System (IMU) – Optional

The IMU performs the obvious function of providing precise pitch, roll and yaw data for *a priori* Exterior Orientation (EO) data. Modern IMUs are typically integrated systems that incorporate a high precision differential GPS, providing full 6 degree of freedom EO information as well as accuracy estimates in the form of standard deviations that are input to the aero triangulation system (Cramer, 1999). A degree of integration not present in current generation flight management systems can be realized by interfacing the IMU with the Sensor Management System. The most useful integration is perhaps that of supplying the full post processing information as a single integrated data volume on the SC PC Card. Currently most systems provide the IMU data separately (both physically and logically) from the FMS information. Higher levels of possible

integration include the use of yaw data from the IMU to control the yaw drive of the stabilization platform and quite possibly use of the full pitch, yaw and roll information of the IMU to control a servo mount that does not incorporate position sensors. This would permit a reduction in the complexity and expense of the stabilization mount.

Active Mount – Optional

The optional stabilization mount maintains the sensor in the optimal orientation for data acquisition. In the case of an aerial camera, this is nadir. Most platforms provide real time correction for roll and pitch. The Z/I Imaging TA/S provides full correction of pitch, roll and yaw. Thus yaw is set at each waypoint (or when the bearing line of waypoints changes) and is maintained by the active mount until a new yaw command is received. Some active mounts (such as the TA/S) have the ability of providing real time readout of their current roll, pitch and yaw angles. Such information can be used to determine the position of the aircraft relative to the sensor. In theory, this data could be used for antenna offset correction although we do not know of a current implementation of this application.
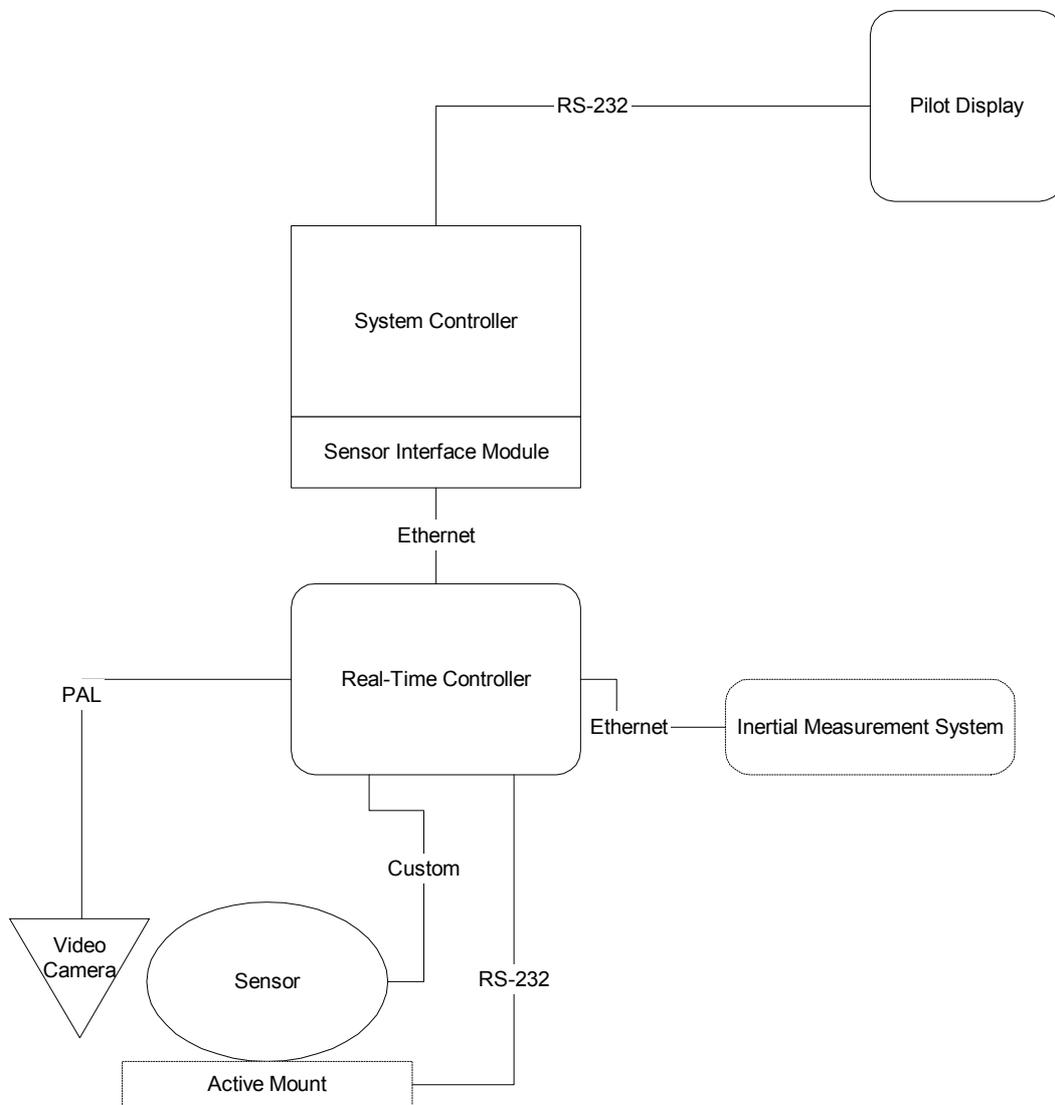
Figure 3 - Sensor Management System

5. SUMMARY

Sensor management has been one of the last aspects of the photogrammetric workflow to become tightly integrated into the overall production process. We believe that significant productivity gains can be realized by a complete integration of this aspect of mission planning and execution into the workflow process. The exploitation of ancillary data during image acquisition is in its infancy and offers significant opportunities for additional research and process improvements.

6. REFERENCES

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