From Modern Methods of Data Acquisition to New Applications

GPS/INS INTEGRATION

By Jan Skaloud, Swiss Federal Institute of Technology Lausanne (EPFL) and Patrick Viret, VNR Electronique SA, Switzerland, e-mail: jan.skaloud@epfl.ch

This paper presents a new approach to GPS/INS data acquisition and synchronization for the most popular sensors adopted by the mapping industry for direct-georeferencing: the tactical-grade FOG/silicon-based inertial sensors and generic dual frequency GPS receivers. Contrary to most industry solutions, no dedicated timing boards or industrial PCs with real-time OS kernels are needed. The somewhat inconvenient[1] SDLC communication and synchronization of the 400Hz inertial data is handled by a small interface that is connected to a conventional laptop via Ethernet. This PC performs data storage and/or loosely coupled integration with GPS data coming over RS232 serial link. The laptop can use Windows or other standard Operating Systems (OS) as varying processing latency is no longer critical. The same laptop can also handle voluminous (10 kHz) airborne laser scanning data coming over the same Ethernet port or data arriving from high resolution digital camera (fire-wire). Altogether this small-size, low-weight navigation system opens door to new and affordable mapping applications of high precision.

Development History

Integration of inertial and satellite data is the modern approach to airborne navigation. Although both technologies originated as military application, the civilian market quickly followed and initiated development of approaches that allows improving trajectory accuracy by an order of magnitude using the same devices. The disadvantage is usually certain solution latency[2], as it is the case of post-mission filtering and smoothing of Carrier-Phase Differential (CPD) GPS/INS data. This allows obtaining ~0.1m positioning and ~0.01deg attitude accuracy when using strapdown tactical grade Inertial Navigation System (INS) with ~1°/h drift rates. The airborne mapping industry quickly adopted the approach of the precise post-mission trajectory determination for direct orientation/georeferencing (DG) of the imaging sensors. These can be either passive frame cameras (film or digital) and line (pushbroom) scanners or active laser (LiDAR) or radar (SAR) scanners.

The first industrial promoters of DG technology [1], [2] were first retrofitting existing military inertial navigation units (IMU) to existing film-based cameras. Later, first modification of the off-the-shelf military units appeared and sensors were designed to accommodate them. Currently, integrated and compact GPS/INS/Sensor systems are provided by different manufactures. However, the civilian mapping industry still remains small to drive the development of inertial technology at hardware level. Hence, it adopts either the off-the-shelf IMUs or Integrated Sensor Assembly (ISA) from existing aviation or military units. The most popular inertial sensors used in DG are the FOG-based tactical grade IMUs, such as the Northrop Grumman LN-200.

Limitation of Current Approaches

The widespread use of LN-200 and similar FOG systems in civilian mapping has been limited by the cost of the DG-integrated technology that is usually one order of magnitude higher than the cost of the inertial sensor itself. Furthermore, the proposed solutions are usually proprietary in design [1-3] and thus do not allow changes in GPS hardware or further software development. In other cases, specialized timing boards [4] may be adopted requiring the use of desktop-size PC that restricts system portability. Finally, some open-design approaches are limited to particular real-time OS [5] requiring special and expensive development tools.

Constraints

The goal of our development is to provide a solution that is small and modular (e.g. it can accommodate different GPS receivers) with open software architecture in the development of navigation and DG application. The first constraint is the synchronization of the 400Hz inertial data with GPS

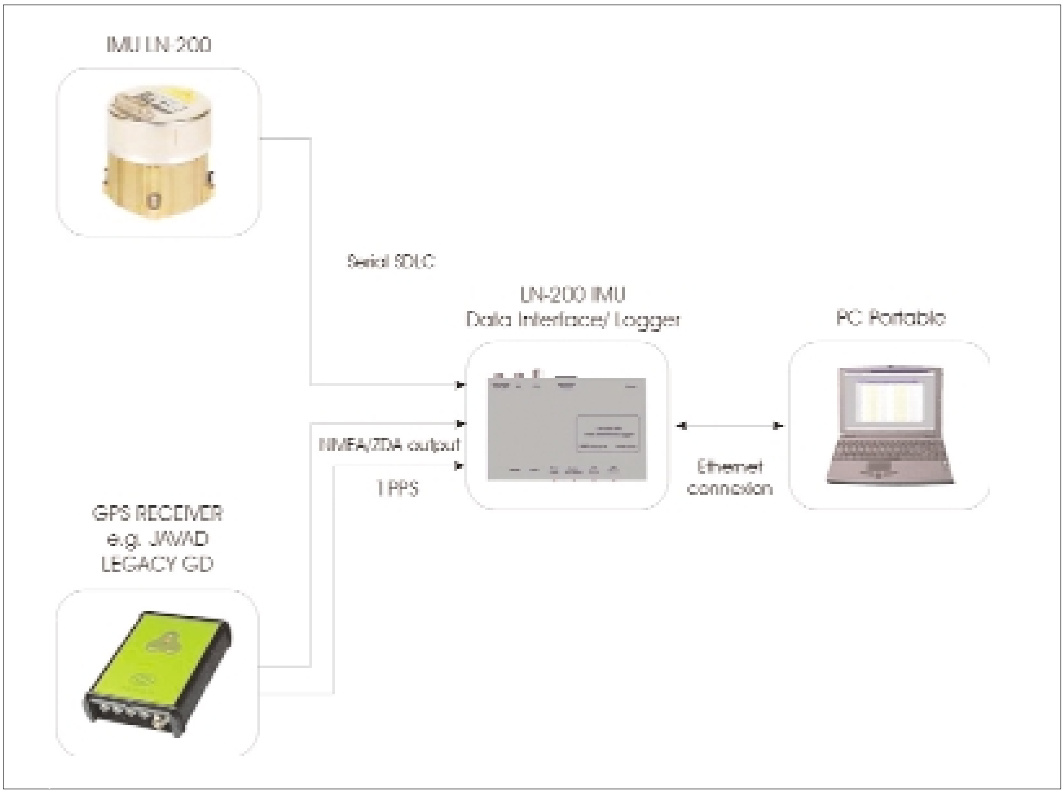

Figure 1 - Adopted modular approach to loosely-coupled GPS/INS integration. Interface size is 170x110x35mm.

time with a maximum error <0.1ms. The hardware constraint is the LN-200 Synchronous Data Link Control (SDLC) protocol that operates at 1.0152 MHz frequency and RS485 physical level. These two constraints require that direct PC implementation has to be able to handle the SDLC protocol and its operating system needs to respond faster than 50µs. Although the open-source OS like RTLinux have sufficiently short response time, their handling of SDLC data stream on a laptop-size computer is more problematic. Even though SLDC⇔PCMCI card exists, its drivers are limited to OS like Windows or Linux and these cannot guarantee fast interrupts.

Solution and Its Advantages

For the above mentioned reasons the direct IMU-laptop connection cannot be realized without difficulties and with dedicating much of the processor resources to communication related tasks. Therefore we propose a hardware-interface solution [6] as is schematically depicted in Figure 1. The IMU sends the SDLC data each 2.5ms, that is at 400Hz frequency. A GPS receiver sends a synchronization pulse (1PPS – available on most high-end receivers) to the interface that time-stamp the inertial data. Once several complete packets of inertial data (26 bytes) are received, the interface resends them to PC via Ethernet port together with the time data. The Ethernet port is a standard on laptops as well as on the small low-cost 8-bits processor adapted for the interface [7]. This processor has no operating system, which assures that the responses to interruptions are fast. The program can either reside in the flash memory or be 'booted' directly from a PC at the start of a data-acquisition program. The later approach is practical in terms of program evolution as it allows common upgrade distribution together with PC-executable. The interface is also connected to a GPS receiver via a serial link that is used to communicate the initial GPS-time bias to an even second. Standard time messages as the NMEA/ZDA defined by National Marine Electronics Association [8] are accepted and can be automatically requested from some type of GPS receivers.

The primary tasks of a PC it to gather the inertial data coming over an Ethernet port employing UDP/IP protocol and store them for post-mission filtering and smoothing with CP-DGPS data. Secondary tasks can be the reception of GPS code and carrier-phase data over the serial link and their integration with IMU data stream to obtain a navigation solution (GPS/INS integrated position and attitude) which is fed to the mapping-mission control unit. As the tasks are no longer time-critical, the lap-

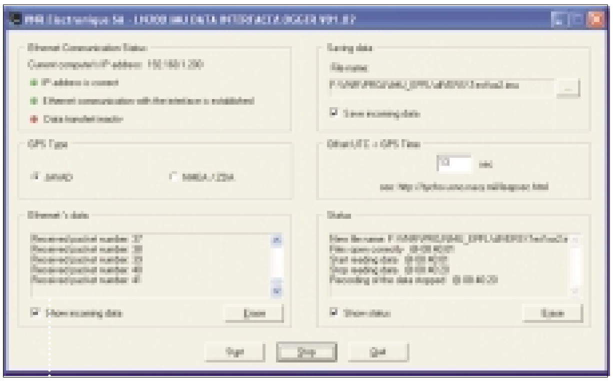

Figure 2 - PC-based integration program (data acquisition window).

top can run a standard operating system such as Windows or Linux. Of course, enough computational resources are needed, but this is not an issue with today's processors. Figure 2 shows the user interface of a data-flow control window. As the UDP/IP protocol does not allow controlling the success of the data flow between two devices, such monitoring is achieved by packed numbering. Should a data-loss due to bad connection occur, a warning message will be issued. Flying experience, however, confirmed the reliability of such approach and the connections. The PC-program also monitors the internal status of the IMU and its environmental variables, as well as internal gyro and accelerometer temperatures, and reports warnings or system failures. These environmental data are also stored separately and some of them are used for post-mission trajectory refining.

Applications

The flexibility and portability of the designed system has proved to be an asset for wide area of GPS/INS applications. These are ranging from navigation and high precision platform orientation (airborne [9] or terrestrial [10]), airborne gravimetry [11] to research in personal navigation and sport telemetry. To emphasize the airborne domain we focus on its further integration with remote sensing devices used in a polyvalent mapping system called HELIMAP [12].

Apart from the GPS/INS sensors, HELIMAP integrates an Airborne Laser Scanner (ALS) and a 16Mpix digital camera. The sensor block is small enough to be handheld by an operator (Figure 3) and thus can be mounted to most types of helicopters within several minutes. The mid-range ALS measure up to 500m flying height and in conjunction with GPS/INS offers an autonomous creation of a Digital Surface Model (DSM) with decimetre-level accuracy. The GPS/INS position and attitude are also used to orient the captured digital imagery.

Therefore an image block formation that is normally required for photogrammetric aero-triangulation is no longer needed nor is the establishment of ground control points. Furthermore, oblique and/or vertical images can be taken during the same flight thanks to the maneuverability of the sensor block. This is important, as sustaining favorable geometry of the ALS and CCD sensors with respect to objects of interest allows obtaining uniform accuracy when mapping steep mountain faces, cliffs, or monitoring avalanche couloirs and other natural or man-made corridors. Finally, the combination of the digital surface model obtained by ALS with the oriented photos permits the automated creation of ortho-rectified images, which are often part of the desired mapping product (Figure 4). The summary of the system benefits is briefly given in Table 1.

HELIMAP: GPS/INS/ALS/CCD
Automation of 3D map generation (DTM, ortho-photo, intensity image)
High accuracy (dm-level), high resolution (<1m^2)
Quick mapping (day or hours) and system deployment (minutes)
Independent from a carrier, no need for system recalibration
Uses custom integration and off-the-shelf sensors ⇒ reasonable cost (<100K €)

Table 1 - Summary of benefits of the helicopter-borne mapping system based on GPS/INS/Sensor integration.

Thanks to the open architecture of the presented GPS/INS, the accommodation of the previously mentioned remote sensing devices used in HELIMAP is relatively straightforward. The laser scanner also employs an Ethernet port for communication and sends its measurements over the TCP/IP protocol. Thus, the same laptop can handle the inertial and laser data streams arriving over the same port. The time scale of the laser data is controlled internally by the ALS device that accepts also synchronization pulses from the GPS receiver. For that reason the 1PPS pulse is split between the IMU interface and the laser scanner. The knowledge of GPS time is attributed to the laser data in the PC that obtains this information from the GPS receiver via a standard NMEA/ZDA message through its serial port. The digital camera data are voluminous and usually require separate storage media. Some manufacturers propose direct storage to optical disks with USB or fire-wire interface, or compact flash cards of large capacity. The data acquisition system thus needs to register only the time of image exposure indicated by the TTL pulse of the camera. This pulse is time-tagged by the GPS receiver to 1ms precision and such information can be stored either internally within the receiver or communicated back to the laptop via the serial link (the same as for the NMEA/ZDA message).

Figure 3 - HELIMAP: Handheld mobile mapping system on a helicopter integrating GPS/INS with high-resolution CCD digital camera and Airborne Laser Scanner (ALS).

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New Perspectives

The development of a GPS/INS system with an open architecture offers new perspectives in associated applications by reducing the cost and complexity while employing standard and 'off-the-shelf' measurement and computing devices. Introduction of a dedicated airborne mapping system (HELIMAP) was given as an example. Its objectives are combination of the state-of-the-art GPS/INS technology with remote sensing devices to provide self-consistent, quickly deployable helicopter-based system for 3D surface mapping and natural hazard monitoring. Evolution of the system followed the emergent technologies used in modern mapping and remote sensing. Further development is expected in the areas of real-time data processing and quality control, direct-georeferencing reliability and mapping integrity.

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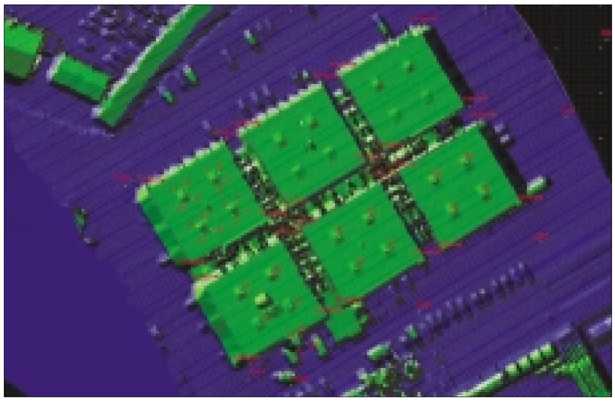

Figure 4 - HELIMAP mapping results. Left: high resolution ortho-rectified image. Right: high resolution digital surface model with point density of 0.2m and accuracy of 0.05–0.15m.

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Notes

[1] Though inconvenient in the sense of modern communication, this protocol is still used by military industry.

[2] Such drawback may be mitigated by modern communication such as GPRS or UMTS.

Biography of the Authors

Dr Jan Skaloud holds a Ph.D. in Geomatics Engineering from the University of Calgary for his thesis on 'Optimizing Georeferencing by INS/DGPS'. Currently, he is a senior research scientist and lecturer at The Swiss Federal Institute of Technology Lausanne (EPFL). He is involved in several areas of GNSS positioning research, GPS/INS integration and mobile mapping.

Patrick Viret graduated from The Swiss Federal Institute of Technology Lausanne (EPFL) with master degree in Computer Engineering. He is working at VNR Electronique SA as a R&D software engineer. His area of expertise includes specialised embedded systems development and object oriented programming.