Mapping Matters

Your Questions Answered

The layman's perspective on technical theory and practical applications of mapping and GIS

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If I have a digital frame sensor such as Intergraph-DMC equipped with an IMU, when can I use the IMU-derived exterior orientation for Direct Georeferencing in mapping without acquiring ground controls or performing aerial triangulation?

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Dr. Abdullah: High end performance Inertial Measurements Unit (IMU) can be used for direct georeferencing in many applications. However, caution should be practiced in applications that require very high accuracy. Although most high-end IMU systems available in the market today are designed to provide high angular measurement accuracy to support the production of high fidelity maps, integrating such IMU into an aerial sensor system such as a camera may change the reliability of these accurate devices. In order to accurately measure the exterior orientation angles of a camera during an aerial imaging mission, manufacturers of aerial cameras strive to mount the IMU in a way that minimizes unwanted motion or torsion between the IMU and the camera body. However, due to some physical constraints in camera design the IMU may not be positioned in the most favorable position. One should understand that the sole purpose of the IMU is to register the exact rotation of the optical path of the camera, or in other words, the lens orientations. As it is impossible to physically mount the IMU on the glass of the lens, manufacturers mount the IMU (or allocate space for it) on the camera's body close to the lens. This results in a sequence of motion detection transfers in order to measure the lens orientation using an IMU. The sequence starts as the IMU (using Gyros and Accelerometers) determines the IMU rotations in reference to the inertia frame, as such rotations are transmitted to the IMU through the camera body. The camera body and the lens should be subjected to the same dynamics generated by the aircraft motion transferred through the fuselage where the camera is mounted. Here we have two sources of mechanical constraints that may degrade the quality of the motion sensing of the IMU. The first one is caused by mounting the lens on the camera, which under turbulent air and excessive vibration may result in some unwanted motion of the lens within that mount. The second contributor to the degradation in the motion sensing is the mounting of the IMU on the camera body. Despite all measures taken by the camera manufacturers to prevent or minimize any type of motion (buckling) between the IMU and the camera body, camera fabrication materials sometimes give way to excessive thermal stresses and severe aircraft dynamics resulting in unwanted loss in the accuracy of motion sensing. Although it is small in magnitude, all these motions may result in a loss in the accuracy of the IMU-measured camera orientation, resulting in a less than perfect model orientation.

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When it comes to evaluating the IMU-performance, I like to look at the aerial acquisition system as a system and not a camera. This is the only way to do justice to the fine technologies of an IMU. In most cases the IMU performance is not the main reason behind a map's inaccuracies or a stereo pair that has unwanted y-parallax. It is the performance of the system as a whole and all the parts together that transfer the motion from the lens to the IMU. To support my argument I would like to offer the example of pushbroom sensors where the IMU is an integral part of the system. No matter how accurate the IMU unit on such a system, the user must always perform aerial triangulation in order to meet the expected accuracy of the mapping products. Aerial triangulation modifies the IMU-derived orientation angles to make up for the accuracy lost due to mechanical instability of the system. No different are the framing cameras, where some users utilize the concept of direct orientation when the product accuracy allows for some frames to be misaligned with adjacent models. But to deliver ASPRS class I accuracy mapping products any time and at all times, users find that a bundle block adjustment (aerial triangulation) is necessary to enable them to deliver accurate products. The same argument goes with current lidar systems. Despite the fact that all lidar systems oper-

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ate with an accurate IMU, some sort of least squares estimation and bundle block adjustment is needed to bring the flight lines together. Most often, lidar users struggle with unstable misalignment angles between the IMU and the lidar body and finding that they need frequent computations of the misalignment angles. It is an example of a system's (as a whole) stability and not necessary IMU under-performance.

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Regarding the part of your question on quantifying the performance of a mapping system equipped with an IMU, it is difficult if not impossible to give an answer to the question as there are so many variables when it comes to putting an IMU on an aerial system and predicting what can happen during the data acquisition mission. An IMU performs accurately on some projects utilizing a direct-orientation concept while the same IMU and aerial system may fail to achieve acceptable results on another project flown a few days later. Producing orthorectified imagery using a direct-orientation concept is more forgiving than stereo compilation when it comes to inaccurate IMU-derived orientation angles. The effect of such inaccuracy in the orientation angles on the orthorectified quality is presented in the form of a mismatch between frames within the ortho tile. Often times, such a mismatch is within or barely outside the accuracy tolerance and users may "Photoshop" shifted linear features such as roads, and fences. While imperfection in the orientation angles presents a serious problem to the compiler, especially if it is excessive. Excessive disorientation in a stereo pair causes y-parallax that results in either eye fatigue for the compiler or it may prevent them from seeing in stereo, making it impossible to produce the map. We can always estimate the effect of IMU accuracy on the resultant map based on the manufacturer's stated accuracy in roll, pitch, and heading. However, and as I discussed above, there are other unpredictable factors affecting system performance. To stand on the effect of errors in the IMU-derived angles alone on the final ground accuracy of the map, please refer to the October 2011 issue of "Mapping Matters" as I gave some useful formulas to compute such an effect, bearing in mind that there are other sources of error that may downgrade the performance of an aerial acquisition system. If you are finding that you can not utilize the IMU-derived orientation angles in direct orientation mode due to instability, you may find that using such angles as initial approximation to the aerial triangulation improves the speed and quality of the auto-correlation of the tie/pass points. In addition, using orientation angles derived from an accurate IMU reduce the amount of ground control points needed for the aerial triangulation if the orientation angles are constrained correctly in the solution.

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Correction: Tables 3 and 4 from the October Mapping Matters Column were printed with errors. They have been corrected below.

Table 3. Errors estimation from different flying altitude.

h (ft)	ΔEω (ft)	ΔNφ (ft)	ΔEκ (ft)	ΔNκ (ft)	ΔEω+ΔEκ	ΔNÐ+ΔNÐ	Circular Error (ft)
1,800	0.087	0.087	0.087	0.087	0.175	0.175	0.247
3,600	0.175	0.175	0.175	0.175	0.349	0.349	0.494
7,200	0.349	0.349	0.349	0.349	0.698	0.698	0.987
14,400	0.698	0.698	0.698	0.698	1.396	1.396	1.975

Table 4. Maps error budget according to ASPRS standard.

h (ft)	ΔEω+ΔEκ	ΔNφ+ΔNκ	Circular Error	ASPRS Class I Accuracy		
				Map Scale	RMSE in E or N (ft)	Circular RMSE (ft)
1,800	0.175	0.175	0.247	1"=50'	0.50	0.707
3,600	0.349	0.349	0.494	1"=100'	1.00	1.414
7,200	0.698	0.698	0.987	1"=200'	2.00	2.828
14,400	1.396	1.396	1.975	1"=400'	4.00	5.657