feature

A new type of direct georeferencing for a new type of photogrammetry

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Small unmanned aerial systems (SUAS) are emerging as an alternative method of acquiring photogrammetry data to the traditional systems using full-size manned aircraft. These SUAS have evolved from relatively low-cost RC electric model aircraft technologies into purpose-designed autonomously guided sensor platforms that are capable of cost-effective image acquisition suitable for photogrammetry processing over small areas. The first generation photogrammetric SUAS as exemplified by the Trimble Gatewing X100, a 'bird-sized' flying wing constructed of carbon fibre and plastic foam with a wingspan in the range of 1-2 metres and an airframe designed to be light, rugged and portable. It carries as payload a high-end commercial 'point and shoot' camera that looks down through the bottom of the fuselage. The aircraft flies a 'low and slow' survey trajectory lasting in the order of 30 minutes while the onboard flight controller triggers the camera to shoot images and record them to an internal memory card. The operator determines the area to be surveyed and the landing point using a mission planning application running on a tablet computer, and then transfers the en-route survey and landing trajectory information to the on-board flight controller. The operator either launches the aeroplane by hand or from a compact catapult, and then waits while the aircraft flies its programmed survey grid and lands at the designated landing position. A typical survey mission is limited by the capacity of the lithium polymer (LiPo) battery that powers the motor and payload. An 8 amp-hour battery can provide approximately 30 minutes' flying time. This is enough to generate overlapping images of a 1-5 square kilometre area at flying altitudes of around 30-100 metres, required to be well below civil aviation minimum altitudes.

Aero-triangulation software running on a PC or in the cloud can then be used to produce an orthomosaic map and digital surface model (DSM) via bundle adjustment from the acquired images, provided they have the required along-track and cross-track overlaps and georeferencing information available. The current georeferencing information used for SUAS photogrammetry is a sufficiently dense field of ground control points, the same technique that was employed by aerial photogrammetry with manned aircraft up until about 20 years ago.

Is big or small better?

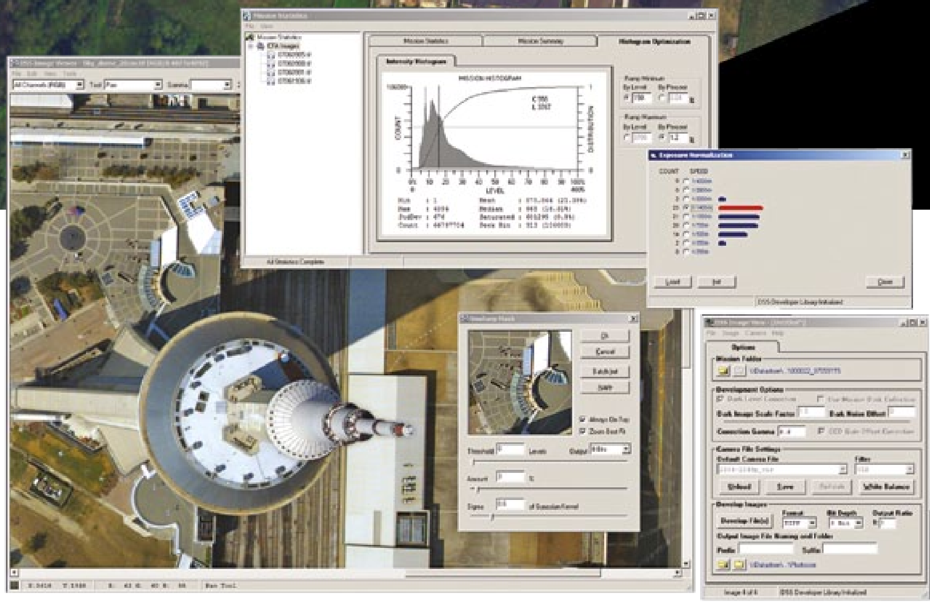
The ultimate success of the SUAS for small-area photogrammetric applications will depend in part on how well they compete with small, single-engine full-size aircraft such as a Cessna 172 carrying a medium format aerial camera system such as the Applanix DSS 500. Two key value propositions of the photogrammetry SUAS versus manned platforms are the ability to produce very large scale map products through their low flying heights, and low cost on-demand photogrammetry of single small areas that don't warrant the flight-hour cost of a full size aircraft. The operator of a full-size photogrammetry platform can serve this market profitably only by accumulating several such job orders and flying them in a single mission. The SUAS operator by contrast can set up and execute a single small photogrammetry mission inside of an hour, and their low capital cost and ease of use mean it is feasible to place an SUAS at each site that requires frequent repeat surveys. This admits cost-effective applications such as local terrain profiling, excavation volume estimation and farm crop stress mapping that would not be feasible with a full size photogrammetry system.

Setting aside civil aviation regulations for SUAS that vary from country to country, the photogrammetry SUAS value proposition is challenged on several fronts. For one, a single crash due to a flight control failure leading to the destruction of the airframe and the payload can wipe out any cost advantage the SUAS may have had. This risk can be managed with safety-of-vehicle reliability engineering and testing. The SUAS airframe typically has a finite lifespan of around 50 missions due to the wear and tear of hard landings (essentially shallow glidepath collisions with the ground) in unprepared terrain. This is an operational

expense that the manufacturer typically alleviates by offering replacement airframe components at low cost. Ground control surveying required for orthomosaic georeferencing and DSM construction is another operational expense that can undermine the SUAS value proposition. This discussion is concerned with this last expense and how to deal with it.

Direct georeferencing

A method of cost-effective direct georeferencing (DG) of the images is desired in order to reduce or eliminate ground control expenses. This cost-benefit tradeoff between direct georeferencing and ground control surveying emerged some 20 years ago in traditional airborne photogrammetry, and appears to be repeating for SUAS. The DG solution that has become a standard in wide area photogrammetric mapping is a GNSS-aided INS comprising an inertial measurement unit (IMU), a GNSS receiver, and a processing engine that implements a GNSS-aided INS solution both in real time and post-mission via post-processing software with optimal smoothing running on a PC. The post-mission DG solution has a dynamic camera position accuracy of a few centimetres and a camera orientation accuracy of 20 arc-seconds, thus providing decimetre mapping frame accuracies from several kilometres flying altitudes. The cost of such a DG system is close to $100k, driven mostly by the cost of the IMU containing accurate and high-priced sensors such as fibre-optic gyros and precise mechanical accelerometers, which are necessary to achieve the required orientation accuracy. However, this is still a small fraction of the cost of the mapping cameras and aircraft, and is significantly lower than the cost of acquiring ground control over large areas, thus making for a strong value proposition.



A DG system for SUAS photogrammetry has a completely new set of requirements. One key difference is the significantly lower cost of the SUAS (a few tens of thousands of dollars) and the finished data that it generates, and hence the allowable cost of a DG system that fits this cost model. Another key difference is the high sensitivity of the SUAS to size, weight and power consumption of additional payload components. Every additional ounce of payload increases the wing loading and hence the power consumption required to fly the aircraft, which in turn reduces the mission duration and hence the area surveyed. On the other hand, the low survey altitudes of a few hundred metres makes the required orientation accuracy for a given mapping frame accuracy significantly lower than that of a higher flying full-size photogrammetry system. The position accuracy requirement will depend on the particular end data product, and may well be the same centimetre-level requirement as with full-scale photogrammetry.

The emerging technology that appears to meet the challenging and sometimes conflicting requirements of DG accuracy, size, weight, power consumption and cost is a new generation of GNSS-aided INS products using micro-electro-mechanical system (MEMS) accelerometers and gyros. A MEMS device is an extremely small mechanical device whose parts are etched out of a silicon wafer using integrated circuit fabrication methods. The first generation MEMS accelerometers and gyros were fairly crude but good enough for automotive applications such as air bag deployment detection and vehicle stability control. Subsequent generations have exhibited increasing accuracies, and as of recently MEMS inertial sensors with fairly low-noise characteristics have emerged for applications such as camera stabilisation, general aviation instruments and short-term inertial navigation.

A DG system for SUAS photogrammetry requires as sensors a survey-grade dual frequency embedded GNSS receiver and antenna to achieve RTK position accuracies of a few centimetres, plus MEMS accelerometers and gyros of sufficient quality to obtain orientation accuracies on the order of a few tenths of a degree in post-processing. The DG system that meets these requirements is essentially a small precision GNSS receiver with onboard MEMS inertial sensors plus post-mission processing software that computes an optimally smoothed best estimate of position and orientation at the camera exposure times. In fact, one can envision an even smaller hardware form factor, comprising a single silicon wafer containing all inertial and GNSS sensing and computing resources, similar in size to the current GNSS receiver chips found in automobile navigation systems and cell phones. Such chip-level GNSS receivers currently do single-frequency code phase tracking only and hence do not generate the dual frequency carrier phase measurements required to compute a precise RTK position solution. To date, precision GNSS receivers continue to require discrete components assembled on a printed circuit board, which in turn defines the smallest achievable DG system hardware implementation.

The airborne photogrammetry and mapping landscape is undergoing a fundamental change with the arrival of a new player, the photogrammetry SUAS. It won't displace medium and large format cameras on full-size manned aircraft because it is incapable of efficient volume production that the larger cameras are capable of. The SUAS does, however, fill a niche that the larger platforms can't address. Direct georeferencing again offers a compelling value proposition to this new breed of photogrammetry system, and as a result a new generation of smaller, lighter and cheaper DG systems driven by every improving MEMS inertial technology is emerging. It appears that history is repeating itself.

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