WHERE ARE WE?

IN THE THIRD OF HIS SERIES LOOKING AT GETTING THE MOST FROM UAVS, LEWIS GRAHAM REPORTS ON HIS EXPERIMENTS IN USING ON-BOARD TECHNOLOGIES TO OBTAIN SURVEY-GRADE POSITIONING INFORMATION

In the second part (*GeoConnexion International,* January 2015) of this series on experimenting with small unmanned aerial vehicles (sUAVs), I discussed our trials and tribulations with adapting prosumer cameras to sUAV mapping missions. Since that time, we have settled on the Sony NEX-5. The difference in image quality and hence accuracy compared with the smaller Canon consumer cameras well compensated for the additional cost and mass of the Sony.

We have also, at least for surface mine work, switched from a fixed-wing platform to a multi-rotor. We so frequently encountered environments, such as the site depicted in Figure 1, that the fixed wing just became too limiting. We have settled on the S900 frame from DJI, heavily modified by us to accept the Pixhawk realisation of the PX4 autopilot.

We have become very adept at placing photogrammetric targets for controlling our models. We moved from painting targets and collecting static positions (20 minutes per target) to a nice real time kinematic (RTK) surveying base/rover, with collection times reduced to several seconds as a result. However, we still have to walk the mine site, deploying targets and then retrieving them following the flight mission (we now use large ceramic tiles for our targets). Thus we have been highly motivated to research on-board RTK technology.

A brief diversion to discuss global navigation satellite system (GNSS) positioning is in order so that you can appreciate the various options we have explored. Each GNSS satellite transmits time information, its position, health and other data on a modulated carrier. The signal is below the ambient electrical noise level and so can only be extracted because of a known encoded message (so-called gold codes). Receivers determine their location by determining their ranges to several satellites. Due to a variety of error contributions, this broadcast position accuracy is on the order of 3m to 5m. Using a satellite-based augmentation system (SBAS), this position can be improved to about 1m to 3m.

SBAS-assisted GNSS is pretty much the standard for the navigation system on board an sUAV. For example, we use a U-blox GPS/GNSS receiver on our AV-900 that routinely provides 1m-3m of absolute accuracy. This is certainly more than adequate for navigation and landing a vertical takeoff and landing system. However, it is not anywhere close to the survey-grade accuracy we would like for camera positioning. This led us to investigate an on-board, high accuracy GNSS solution.

A common trick used for improving GNSS-derived accuracy is to place one receiver at a known location (the base station) and compute the error at this station. The error is the GNSS-derived location as

Figure 1: Canyon environments such as this force the fixed wing/rotary wing issue!

compared to the known placement location. A second receiver close to this base station will exhibit error that is highly correlated with the error of the base. Thus if you sent this error vector from the base to the 'rover', you could very accurately correct the rover position. This is the basic principle of RTK GNSS (see Figure 2).

Our AV-900 mapping system equipped with a differential GNSS system is shown in Figure 3. The Tallysman multi-frequency TW3870 RTK antenna is the grey, short dome at the base of the navigation GNSS mast. It is very important to place a lager ground plane (essentially a metal disk) at the base of the antenna.

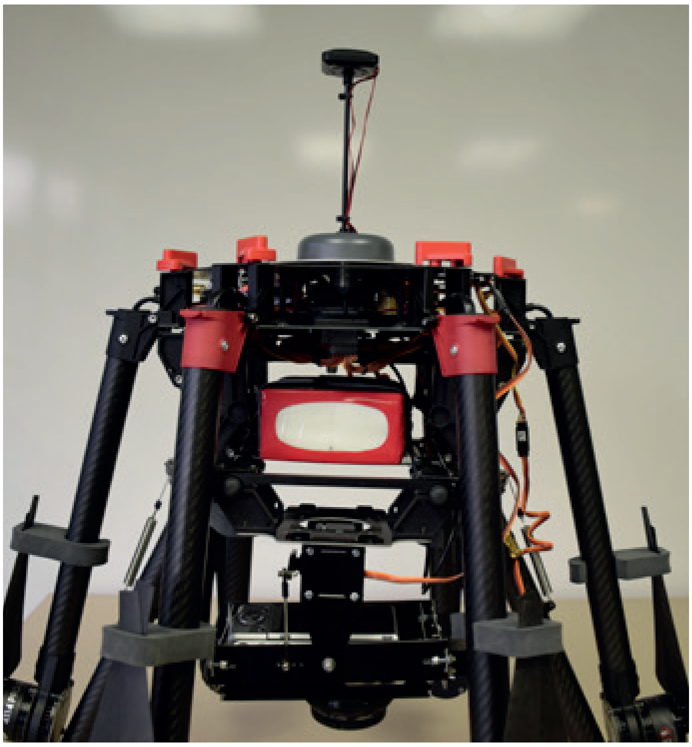

Figure 3: The AV-900 with an on-board RTK system

All the difference

We have discovered that the antenna used in the GNSS rover makes a huge difference in the accuracy of the result (a factor of three or more) and the rover's ability to maintain a 'fixed' solution. Naturally, the better antenna has a mass five times greater than the lesser antenna's. I would caution you against using commercial, off-the-shelf RTK-equipped mapping sUAVs – most use the inferior antennas to save on mass. An example of an RTK-grade, multifrequency antenna is shown in Figure 4 (see page 33).

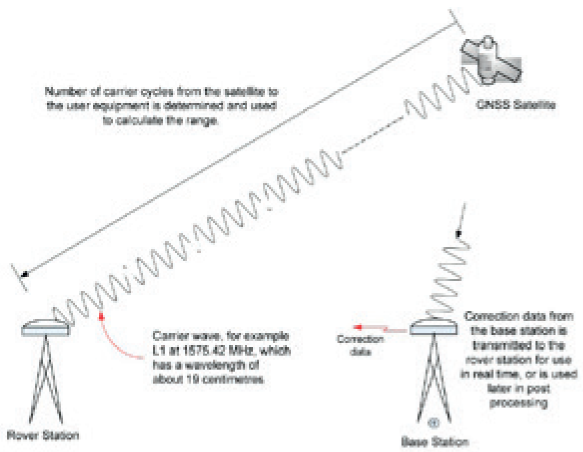

Figure 2: The RTK scheme (courtesy NovAtel)

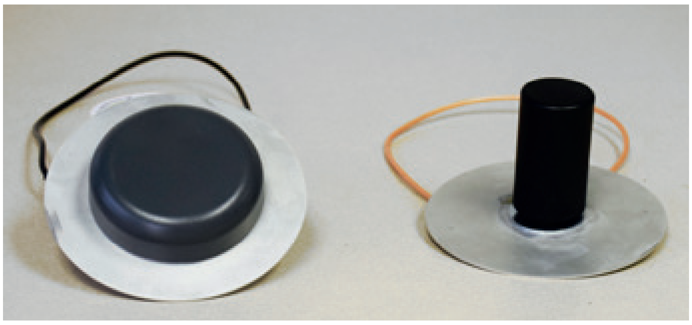

Figure 4: GNSS Antennas with ground planes - the preferred Tallysman is on the left

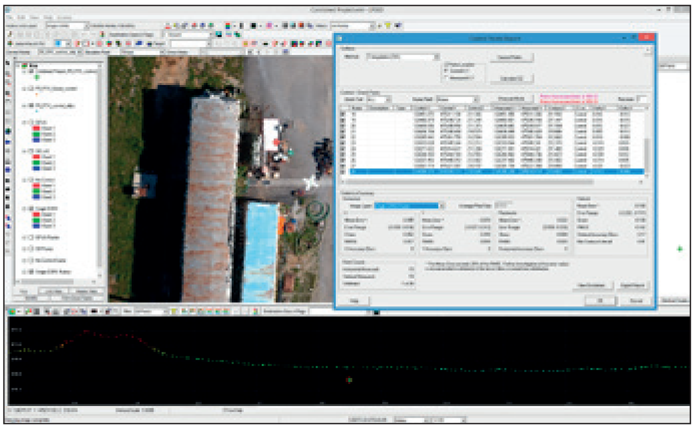

Figure 5: PPK Accuracy Assessment

An RTK system deduces corrected position in real-time. This is very useful for applications where position is immediately needed (for example, in precision navigation such as injecting fertiliser at previously recorded seed planting locations). But in our work, getting the precise location of the sUAV at the time of each camera exposure is not needed in real-time. Therefore, we do not need to communicate the correction vector from the base station to the AV-900 – we simply record both for later processing (we use a custom single board computer with an SD memory card on board the AV-900). This approach is referred to as post-processed kinematic (PPK) and is the scheme most often used in airborne photogrammetry.

Complications

There is a bit of a complication (isn't there always?). Since the aircraft pitches, yaws and rolls during flight, the position of the GNSS antenna with respect to the focal node of the camera (the location to which we must transform our location information) is dynamically changing. This is termed 'dynamic lever arm'. We used our navigation gyroscopic angles in a bit of home grown mathematics to dynamically correct for this.

In theory, we can now place a base station and fly the mission with no control. This is a huge increase in productivity since it can often take a half hour or so to place, RTK and retrieve photogrammetric control tiles. In reality, however, we are finding that you may need one photogrammetric control point to de-bias the vertical (z).

In one of our studies (see Figure 5), we established 20 control points at a fairly small stockpile site, establishing their positions with an RTK survey instrument tied to an on-site base station. We used one of the US's National Geodetic Survey's continuously operating reference stations (NGS CORS), approximately 10km from the test site, as our operational base station for the PPK experiment. Post-processing of our PPK data was achieved using the open source RTKLIB software package.

While the results in planimetric are great at less than 2cm root-mean-square error (RMSE) and less than 1cm in bias, the z is not as good. We note a bias of 16cm and RMSE of 16cm. The vertical error range is a bit over 8cm, centred on -0.16cm. We have consistently achieved similar results for z of about cm of error centred on a bias in a variety of experiments. Thus the z can be improved by simply using a single control point to remove the bias.

It is often the case that a base station from systems such as NGS CORS is not sufficiently close to the site to provide the necessary accuracy. In this case, you could set a survey base station at the site. An alternative is to subscribe to a virtual reference station (VRS) service. A VRS creates a virtual base station at a location that you designate, interpolating corrections based on corrections from a network of circumscribing real stations. This scheme is shown in Figure 6.

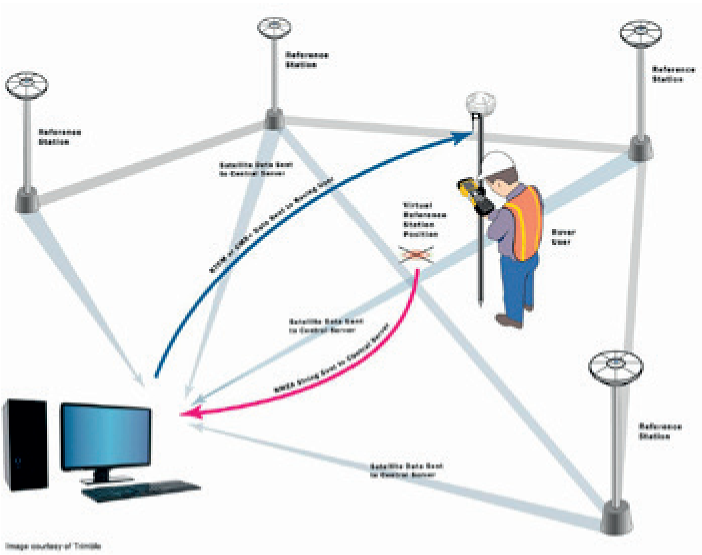

Figure 6: A virtual reference station scheme

OUR FINDINGS

Our summary from all of this is:

- You need surveyed control for extreme accuracy project (~2cm or better range).
- Post-processed kinematic (PPK) offers a real-time savings when lower accuracy (a factor of two to three) will do.
- Antennas matter – a lot! Plan to invest a minimum of US$500 for a good rover antenna.
- The virtual reference station scheme is another big time savings.

Impressive time savings

We have done extensive tests with the SmartBase cloud solution from Trimble with quite satisfactory results. The VRS is great because, since we are doing PPK processing, we can define the VRS after the flight. This means we can simply take the AV-900 out of its case and fly! It does not get any faster than this.

We are so impressed with the time savings from on-board PPK that we will begin to offer this as a standard technology on our AV-900 multi-rotor. Our next investigations will be with positioning and orientation systems where we get not only position but also attitude. The additional input of an a *priori* attitude is required for sensors, such as LIDAR and line scanners.

Stay tuned for more of our adventures!

WE ARE SO IMPRESSED WITH THE TIME SAVINGS FROM ON-BOARD PPK THAT WE WILL BEGIN TO OFFER THIS AS A STANDARD TECHNOLOGY

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