The Applanix SmartBase^{TM} Software for Improved Robustness, Accuracy, and Productivity of Mobile Mapping and Positioning

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Introduction

Applanix, along with the Trimble GNSS Center of Excellence, developed the Applanix SmartBase^{TM} software to reduce the current limitations of using high-accuracy carrier phase differential GNSS for airborne mapping.

Mobile Mapping using GNSS – The Limitations

Atmospheric Errors and Short Base Lines

The efficient use of carrier phase differential GNSS positioning is restricted primarily by the effects of the atmosphere (ionosphere and troposphere) plus satellite clock and orbital inaccuracies that cause systematic errors in the observations. The further away the rover is from the reference station, the more these errors are de-correlated, and hence not cancelled out in the differences. The error is often expressed as a part-per-million (ppm) on the base-line separation between the rover and the reference station. For the highest accuracy results (ie at the cm level), the base-line length between the roving receiver and the reference station must be limited to no more than 30 km in order to reduce the errors to an acceptable level.

One of the advantages of mapping from the mobile platforms is the ability to cover large areas in a short amount of time, thus increasing productivity. However the full extent of this productivity is difficult to achieve using carrier phase differential GNSS for high-accuracy applications due to the short base-line restriction; a dense infrastructure of reference stations must be put in place as the mapping mission is conducted, which greatly increases the cost.

The Applanix SmartBase Software – The Solution

Post-processed Virtual Reference Station

For land-based applications a significant productivity improvement in Real-Time Kinematic (RTK) positioning has been achieved using the concept of a "Virtual Reference Station" or VRS [1]. Here observables from a dedicated network of GNSS reference stations are processed to compute the atmospheric and other errors within the network. These are then interpolated to generate a complete set of GNSS observations as if a reference station was located at the rover. There are a number of significant benefits to this approach:

- the distance to the nearest reference station can be extended well beyond 30 km
- the time to fix integer ambiguities is significantly reduced
- the overall reliability of fixing integer ambiguities in increased
- the cost of doing a survey is reduced by eliminating the need to set up dedicated base stations.
- no special processing is required in the RTK engine, as it is the case for a centralized multi-base approach

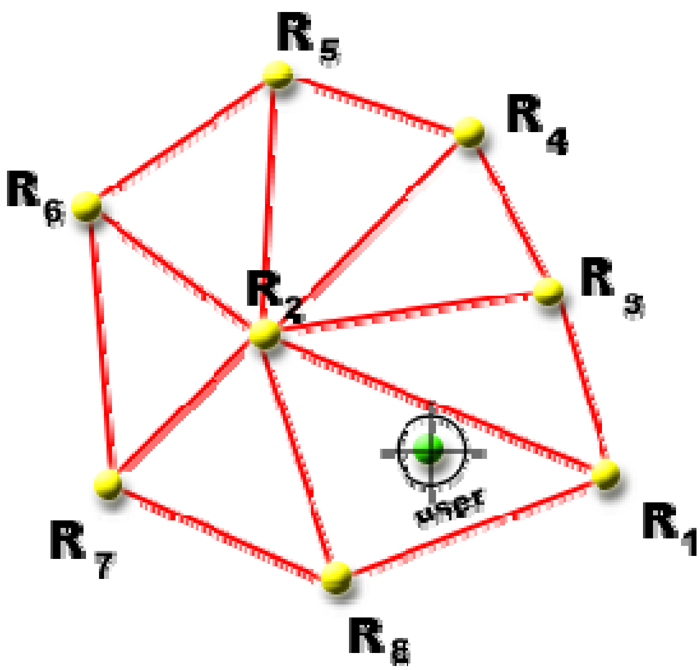

Figure 1: Virtual Reference Station Concept

The Applanix SmartBase software is a post-processed version of the Virtual Reference Station concept designed to work in a mobile mapping environment. Based upon the industry leading Trimble© VRS™ technology, the Applanix SmartBase software has been optimized for large changes in altitude by the rover, and extended to work with reference stations separated over very large distances. It has also been tightly integrated into the Applanix IN-Fusion™ technology implemented in POSPac Mobile Mapping Suite.

The Applanix SmartBase software processes the raw GNSS observations from a network of 4 to 50 reference stations to compute the atmospheric, clock and orbital errors within the network. These are then used to correct for the errors at the location of the POS GNSS receiver at each epoch, as it moved throughout the network.

The SmartBase concept is illustrated in Figure 2. The green area represents the zone in which the atmospheric and other errors have been estimated to a level such that the ppm effects always remain equivalent to that of a short base-line (ie less than 30 km). This is despite the fact that the reference stations themselves could be separated by up to 100 km or more.

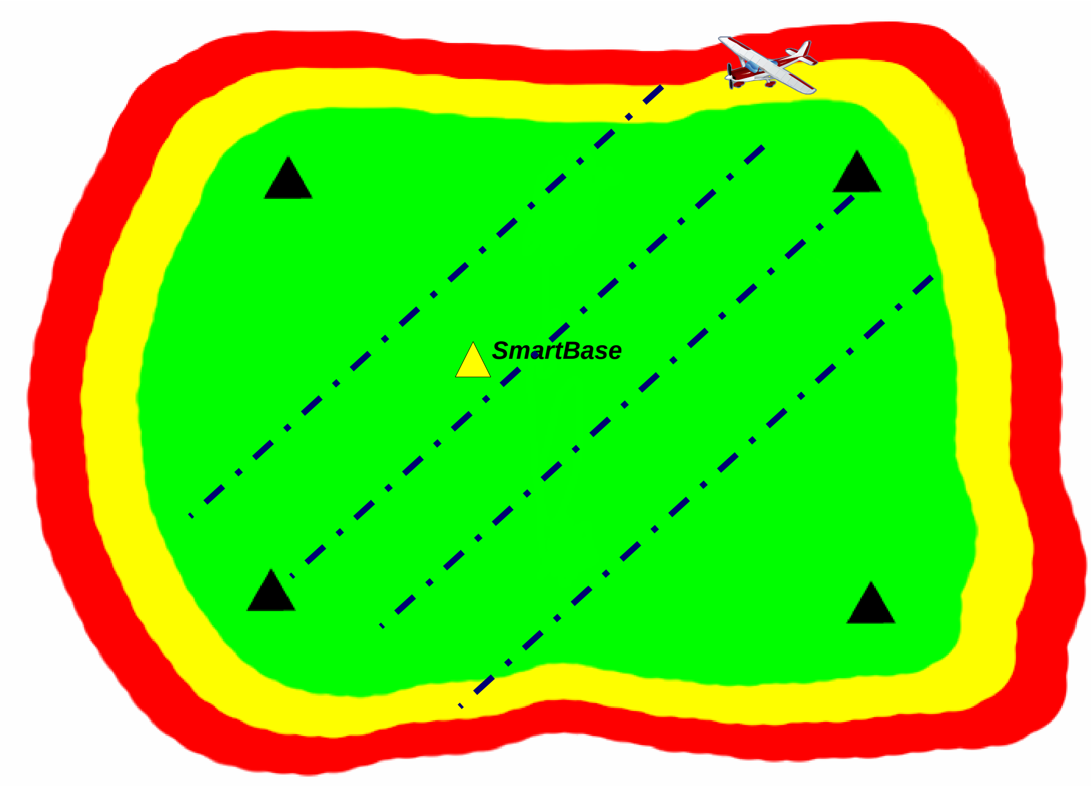

Figure 2: Applanix SmartBase Concept

The homogeneity of the "green" zone within the network of stations is a function of the density of the network, the accuracy of the reference station co-ordinates, the quality of the reference station observations, and the atmospheric activity during the survey.

A typical reference station network used in Applanix SmartBase processing is shown in Figure 3.

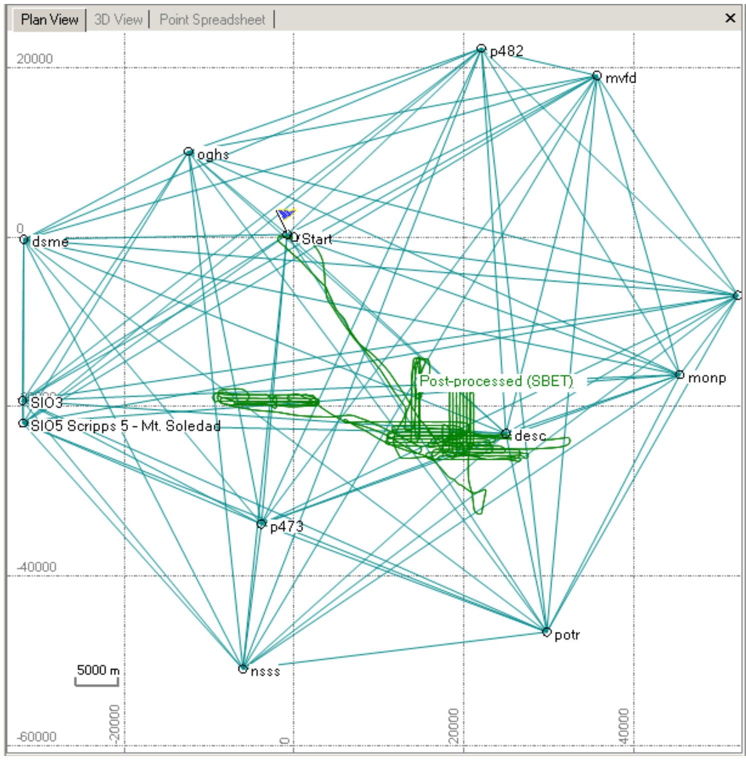

Figure 3: Example Network used in Applanix SmartBase

Higher Accuracy over Longer Base Lines

Tests conducted by Applanix have shown that it is possible to achieve the same accuracy (3 – 10 cm RMS) as using a dedicated reference with a base-line separation of less than 30 km, as long as the maximum distance from the rover to the nearest reference station in the network is no more than about 70 km. Furthermore, when integrated with the IN-Fusion technology in POSPac MMS, it is also possible to achieve this accuracy while flying turns at greater than 20 deg bank angles, or mapping under obstructions such as bridges. The 70 km guideline implies a triangular network with a distance of approximately 100 km between stations.

If the highest accuracy results are not necessary and there are no obstructions or flat turns are still acceptable, it is possible to extend the maximum distance to the nearest base station to beyond 70 km and still maintain integer ambiguities. To do this, part of the trajectory must be within 70 km of the nearest base station for several minutes in order initialize the correct ambiguities. These can then be carried through the solution for distances to the nearest reference station of well up to 100 km, with an accuracy be closer to 10 - 15 cm RMS. Beyond 100 km to the nearest reference station, the accuracy of the solution will degrade towards that of a floated solution.

Figure 4 shows plots of the differences between two trajectories, one produced by the Applanix SmartBase and the other produced by POSGNSS using a dedicated reference station. The Applanix SmartBase solution used a network of 4 reference stations with rover distances to the nearest reference station varying from approximately 77 km to 95 km. The dedicated reference station solution had a maximum base-line separation of 45 km, with an average separation of approximately 25 km.

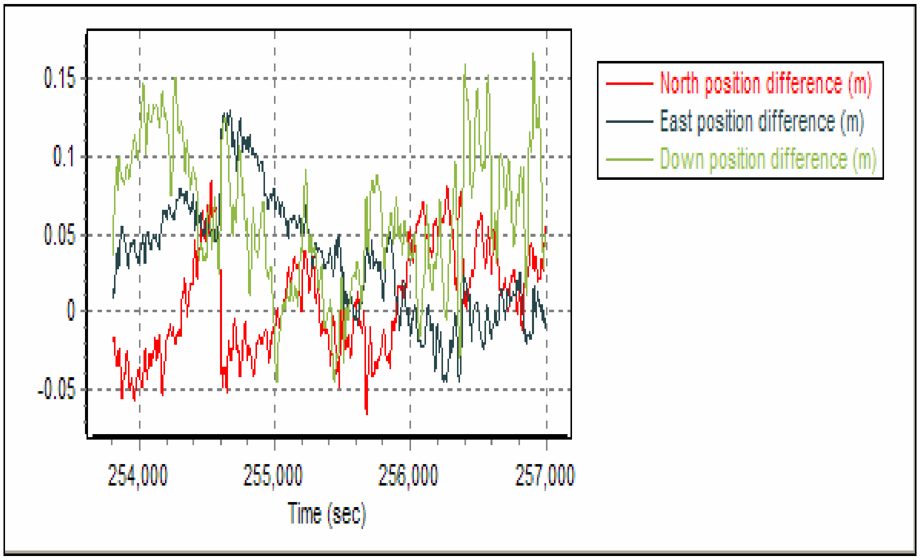

Figure 4: Differences, POSPac Air 5.0 using Long Base-line SmartBase vs Short Base-line Dedicated Base

The plots show that the Applanix SmartBase solution is consistent with the solution using a dedicated base station, even though the distances to the closest reference station were more than double that of the dedicated base.

The Use of Existing Reference Station Networks

There are typically 3 sources of reference station data that can be used with Applanix SmartBase software: The Continuously Operating Reference Stations (CORS), permanent pay-per-use real-time VRS networks that also make available the observables for post-processing, usually for a charge, and non-permanent dedicated reference stations set up by the user.

Nowadays permanent networks are continuously expanding around the world and offer the ability to perform high accuracy differential GNSS airborne mapping with little or no reference station infrastructure costs. Depending upon the region of the world, the stations can sufficiently dense and reliable to achieve high-accuracy results without the need to set up any dedicated infrastructure.

Figure 5 shows a map of the CORS coverage in the United States. In many States the density of the CORS is more than the 100 km inter-station guideline required to achieve high accuracy results using the Applanix SmartBase software without the need to add extra dedicated stations. This is especially true around urban areas (which is typically where the highest accuracy is required). Figures 6 and 7 show similar coverage maps for networks in the UK and Germany. Again, the density is more than sufficient to meet the 100 km guideline. Other networks that are available for use include the EUREF network covering much of Europe, the GSI network in Japan, the Australian Regional GPS Network, and the International GNSS Service (IGS) network, covering many parts of the world.

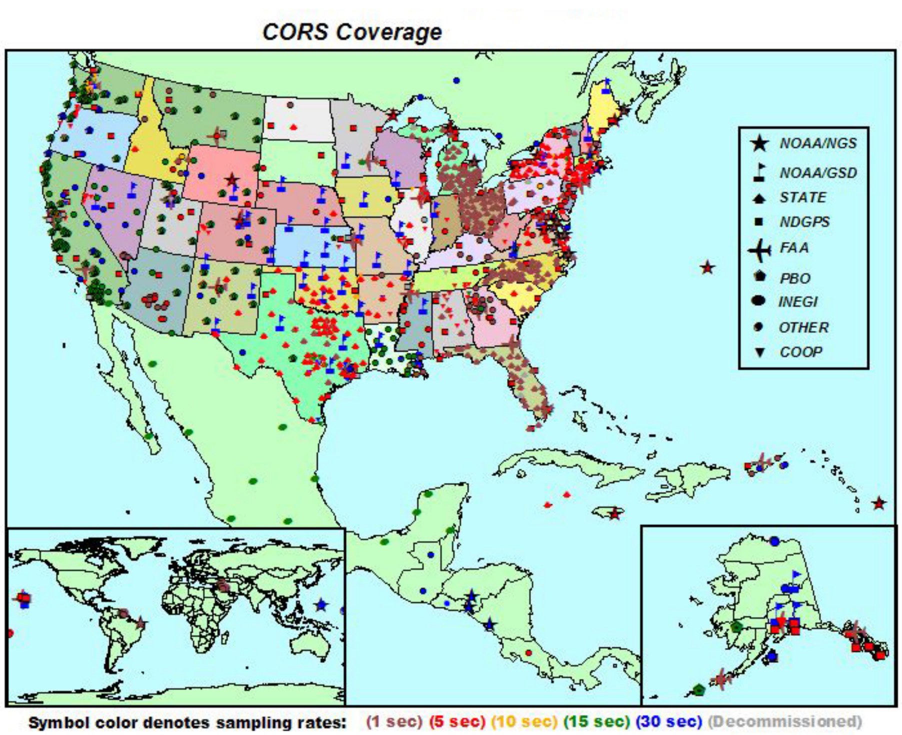

Figure 5: CORS Coverage, United States, (Courtesy USGS web-site)

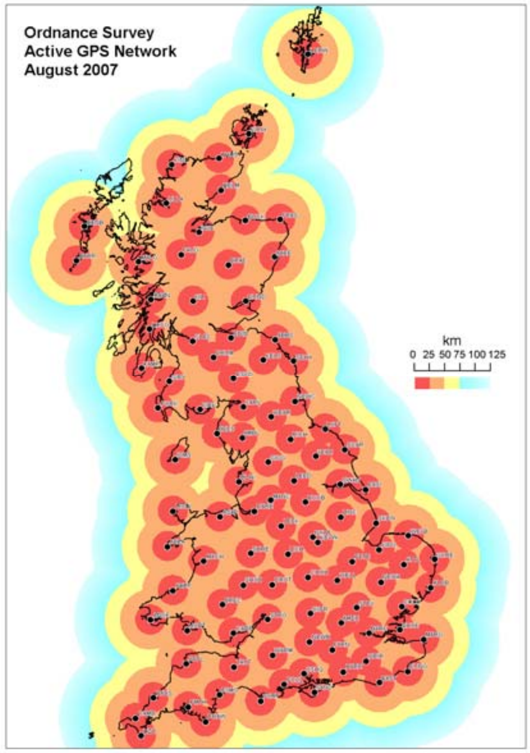

Figure 6: Coverage Map, UK, (Courtesy http://www.ordnancesurvey.co.uk/oswebsite/gps/)

Figure 7: Coverage Map, Germany, (Courtesy SAPOS, German State Survey)

Automatic Download

The Applanix SmartBase software includes an automatic download feature for many of the publicly available reference stations. The software automatically searches a database for any reference stations that are within a desired radius from the project area and displays these on the plan view. The user then chooses which stations to use and the software automatically connects to the corresponding websites to download and import the reference station files along with the precise ephemeris data from the IGS website.

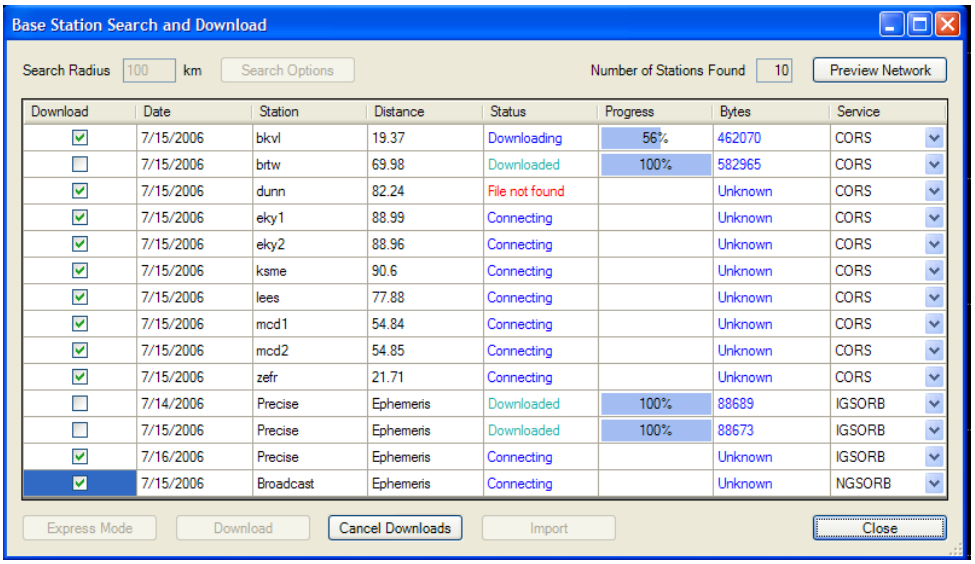

Figure 8: Applanix SmartBase Automatic Reference Station Download

Robust Quality Check

In order to achieve high accuracy over such long base-lines, Applanix SmartBase requires that the reference station coordinates must be land-surveyed in very accurately, and the observables from the reference stations must be of good quality and free of data gaps.

When using the freely available reference stations, there is always a concern about data integrity, particularly with respect to the accuracy of supplied coordinates, the possibility of missing data, and the possibility of a physical damage to the antenna that might have occurred just before or during the mission.

In most cases the coordinates and data from the reference stations are checked in an ongoing fashion. However, to reduce the risk of poor results and to provide a means of built-in quality assurance on the accuracy of the overall positioning, Applanix SmartBase includes a SmartBase Quality Check module that performs an extremely accurate network adjustment on all the base-lines and reference stations in the network. The Quality Check module uses 18 to 24 hours of reference station data to accurately compute the base-lines between one station set as the control and the rest of the stations. The long

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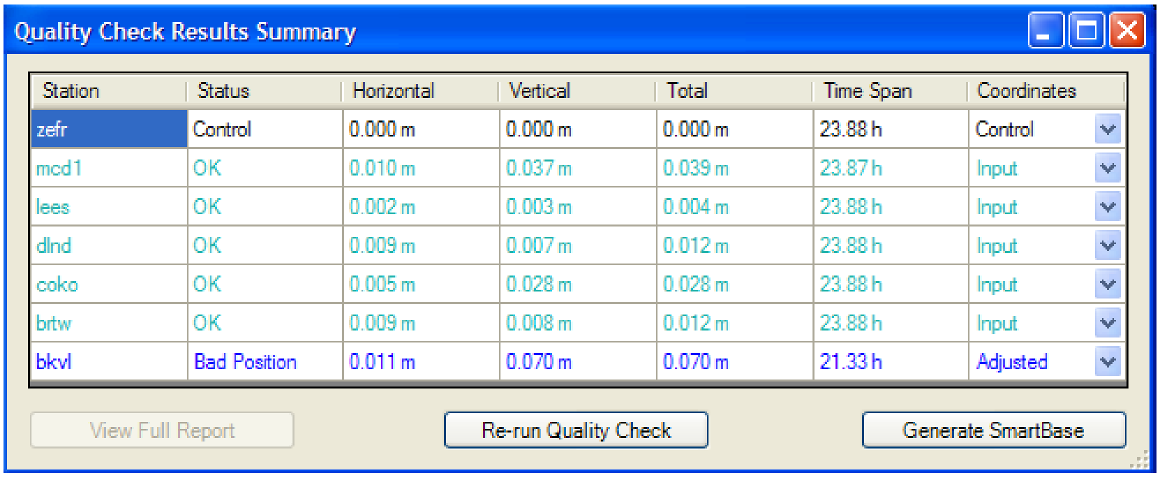
duration of data is used to ensure that all multipath variations due to changes in satellite positions are averaged out as much as possible.

The output of the Quality Check module is a table indicating the estimated error for each reference station coordinates. If the estimated error is larger than 5 cm, the coordinates are flagged as bad meaning that the input coordinate cannot be trusted. In that case the user has the option of using the adjusted coordinates instead of the input coordinates, or not using the reference station at all in the Applanix SmartBase computations.



Station	Status	Horizontal	Vertical	Total	Time Span	Coordinates
zefr	Control	0.000 m	0.000 m	0.000 m	23.88 h	Control
mcd1	OK	0.010 m	0.037 m	0.039 m	23.87 h	Input
lees	OK	0.002 m	0.003 m	0.004 m	23.88 h	Input
dlnd	OK	0.009 m	0.007 m	0.012 m	23.88 h	Input
coko	OK	0.005 m	0.028 m	0.028 m	23.88 h	Input
brtw	OK	0.009 m	0.008 m	0.012 m	23.88 h	Input
bkvl	Bad Position	0.011 m	0.070 m	0.070 m	21.33 h	Adjusted

Figure 9: Applanix SmartBase Quality Check Module

Additional quality checks are done on the individual reference station observation files before the Applanix SmartBase is computed. The final result of this process is that the integrity of the used reference station data and coordinates are known completely before the airborne data are even processed.

If a dedicated reference station or stations are added to the network, the user has the option of logging their data for 18 hours and including them in the Quality Check process, or can simply add these to the network after the check is done on the downloaded stations.

If reference station data are downloaded from a pay-per-use service, running the Quality Check process is optional with the assumption that a similar process has already been run on the reference stations by the provider (hence one of the reasons for paying for the data!).

Conclusions

The Applanix SmartBase software represents a major increase in productivity for GNSS mobile mapping by providing the following features and benefits:

- The use of existing reference station infrastructure to achieve higher accuracy over longer distances reduces deployment costs

- Increased robustness and accuracy minimizes production costs and re-work

References

[1] Landau H., Vollath U., and Chen X. (2002) Virtual Reference Station Systems, Journal of Global Positioning Systems, Vol. 1, No. 2, 2002