RTK/PPK Implementation for TAS Mapper Series

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Introduction

Navigation has become an integral part of our daily lives. Global Positioning System (GPS), has now become a commonly used term. We often confuse ourselves with the terms GPS and GNSS, which is an abbreviation for Global Navigation Satellite System. In the general sense, GPS is the name for a constellation of satellites launched by the US for the purposes of navigation. GNSS as a whole, consists of all the available constellations that can be used for the same purpose.

Blewitt[1], states that GPS Positioning, in our case, GNSS positioning is based on the principle of trilateration. This method makes use of three known coordinates to determine the desired position. GNSS Point Positioning however, requires four “Pseudoranges".

Pseudorange can hence be defined as the distance between the satellite and the GNSS receiver and is calculated as the product of the time difference (between transmission and reception of a signal) and the speed of light.

Pseudoranges can vary due to the presence of clock errors, which result from the measurement of time difference. A nanosecond of clock errors can result in an error of approximately 30 centimeters[2]. Satellite clock error is just on of the factors that cause errors in measurement. The other possible factors are listed below[3].

- **Dilution of Precision (DOP)** - Availability of satellites for a three dimensional lock.
- **Ephemerides Errors** - Errors pertaining to the positioning of satellites, relative to each other.
- **Ionospheric and Tropospheric Delays** - Delays and distortions in signals when they pass through the various atmospheric layers.
- **Phase Center Variation (PCV)** - Variations in the pseudo-ranges measured by the satellite and the receiver antenna.
- **Foliage and Rain** - Due to the presence of trunk, branches and leaves and also distortions in signals during heavy downpour.
- **Multipath** - Reflection of signals from high rise buildings.

The figure below shows an approximate accumulation of error before the signal is received by the user.

Table 2 Standard error model—no SA

	One-sigma error, m		
Error source	Bias	Random	Total
Ephemeris data	2.1	0.0	2.1
Satellite clock	2.0	0.7	2.1
Ionosphere	4.0	0.5	4.0
Troposphere	0.5	0.5	0.7
Multipath	1.0	1.0	1.4
Receiver measurement	0.5	0.2	0.5
User equivalent range error (UERE), rms[a]	5.1	1.4	5.3
Filtered UERE, rms	5.1	0.4	5.1
Vertical one-sigma errors—VDOP= 2.5			**12.8**
Horizontal one-sigma errors—HDOP= 2.0			**10.2**

Figure 1. **List of Standard GPS Errors[3]**

For the purposes of mapping and surveying, corrections need to be applied for accuracy and further post processing. One such method of corrections is by the use of a Differential Global Navigation Satellite System (DGNSS).

Principle of Operation

DGNSS is a GNSS augmentation system that provides corrections for GNSS errors. DGNSS uses the fact that the receivers in close vicinity (upto 150kms) experience common errors and hence utilizes this fact to provide accurate corrections[3]. The corrections are usually transmitted from a base station which is an accurately surveyed location. The user and the base station receive the signals from the same set of satellite vehicles.

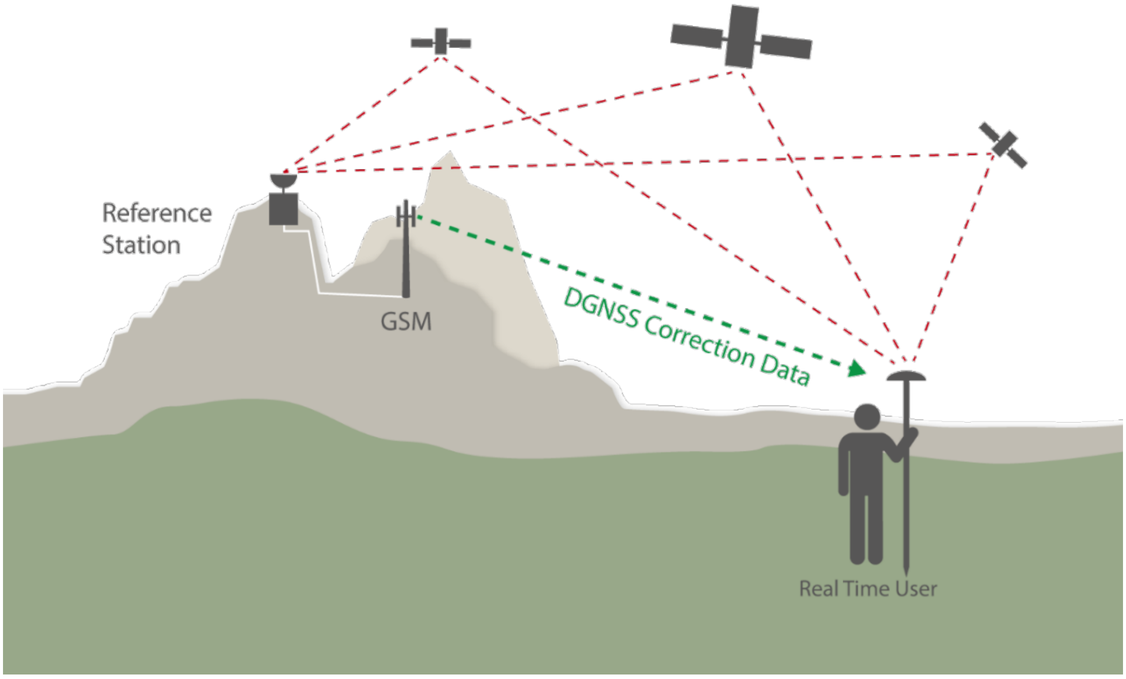

Figure 2. **Differential Global Navigation System[4]**

Let us assume the following[5]:

- $[x_{sat}, y_{sat}, z_{sat}] \rightarrow$ are the coordinates of the satellite vehicle transmitting the signals.
- $[x_{Rx}, y_{Rx}, z_{Rx}] \rightarrow$ are the coordinates of the user recieving these signals.
- $[x_0, y_0, z_0] \rightarrow$ are the coordinates of the referenced base station.

If ρ is the pseudorange between the satellite and the receiver and R_0 is the pseudorange between the satellite and the base station then these pseudoranges can be calculated as follows:

$$\rho = \sqrt{(x_{sat} - x_{Rx})^2 + (y_{sat} - y_{Rx})^2 + (z_{sat} - z_{Rx})^2}$$

$$R_0 = \sqrt{(x_{sat} - x_0)^2 + (y_{sat} - y_0)^2 + (z_{sat} - z_0)^2}$$

These pseudoranges are compared and then necessary corrections are applied. Information is sent from the reference station to individual receivers The information includes[6]:

- Corrections to pseudoranges, satellite clock and ephemeris data.
- Raw measurements of pseudoranges and carrier phase.
- Data verifying the integrity of the signals received
- Auxiliary Data - Location, health and meteorological data of the reference station.

The corrections drastically improve the accuracy of the position. Normally, GNSS positions are accurate upto 0.5m. However, with GNSS augmentations such as DGNSS, one can obtain centimeter level of accuracy as close as 2cms.

Real Time Kinematics GNSS (RTK-GNSS)

Satellites usually transmit a carrier signal in the form of a sine wave with a certain phase. When the signal is received by an antenna, the signal exhibits a different phase. The receiver also generates a similar copy of the signal and compares this copy with the original signal sent by the satellite to obtain a phase observation. At this point, the integer number of wavelengths 'n' is unknown and hence is termed as integer ambiguity[7]. If an attempt is made to resolve these ambiguities in real time, then this configuration of DGNSS is termed as Real Time Kinematic (RTK) configuration. In simpler words, RTK primarily deals with collection of real time data and simultaneously applying corrections to the data collected. The quality of a RTK position estimate can be divided into 3 categories[8].

- **Single** - Precision similar to a single receiver configuration.
- **Float** - A decimeter level of precision obtained after the integer ambiguities are resolved as real valued numbers.
- **Fixed** - A centimeter level of precision obtained after the integer ambiguities are resolved as integers.

Elimination of Ground Control Points

Ground Control Points (GCPs) are physically marked locations with x, y, z coordinates. These points are precisely determined and hence serve as reference points for applying corrections. However, even with GCPs, geolocations can be off by approximately 1%. For a larger area, this translates to several meters of offset. Accurately mapping a location requires multiple GCPs, clearly marked with contrasting colors and equally laid out with approximately 1000 to 1500 feet of separation. RTK solves this problem by completely eliminating the need for GCPs. Using one properly georeferenced station, necessary corrections can be applied on board the aircraft via a real-time data link, hence improving the accuracy of the locations recorded[9].

Need for Real Time Data Link

Like every system, RTK also has a certain disadvantage. An RTK-GNSS requires a continuous real-time data link to continuously apply corrections to the UAS. A loss of connection would directly result in a loss of data and hence inaccuracies. RTK is sensitive to obstructions in its path and to agile manoeuvres. If the system loses sight of even one satellite from the constellation, integer ambiguity needs to be determined again to generate a fixed solution[8]. Real time corrections are also dependent on the RINEX files that are generated for corrections. A Receiver Independent Exchange (RINEX) file contains corrections for errors such as PCV and Ionospheric/Tropospheric delays. According to International GNSS Service (IGS)[10], only 5 RINEX generating facilities are available in India at the following locations:

- Indian Institute of Science (IISc), Bangalore
- Indian Space Research Organization (ISRO), Lucknow - 2 Stations
- Indian Space Research Organization (ISRO), Port Blair
- National Geophysical Research Institute (NGRI), Hyderabad.

To alleviate this issue of RINEX generation, modern systems are capable of recording data and then converting them to RINEX files which can then be later used to apply corrections. However, there is still a risk of losing data due to an unfortunate loss of data link.

Post Processed Kinematics(PPK)

Post Processed Kinematics (PPK), in simple words, is data correction after a mission. PPK uses the same equipment as RTK, with one small difference. The data is independently recorded at the base station and also, on board the UAS. The base station data can be converted to a RINEX file, that can later be used as a reference for applying any set of corrections that were missed during the mission. PPK, though time consuming, has a set of advantages to itself[11]:

- In the event of a loss in data link, the data is still recorded. Any missing data can be approximated using the past and the future values.
- Forward and reverse solutions can both be used to check and improve accuracy of the location. Errors such as PCV can hence be eliminated using PPK.

People might still argue that RTK is more feasible as it is less time consuming and performs corrections "on the go". However, several UAV manufacturing organizations such as Altavian, and Event38 have already upgraded their on board systems to support PPK as a method post processing and have achieved better results with PPK, when compared to RTK[11][12].

Conclusions

RTK has already proven to be a breakthrough technology when it comes to survey grade mapping. RTK, though having its own set of disadvantages, if implemented for Post Processed Kinematics seems to prove beneficial as it provides the users complete control of rectification process, thereby satisfying the needs and requirements of the end user. We are currently revamping our existing drones with RTK systems to comply with your existing needs and quality standards.

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