PPP-RTK : the advantageous result of a hybridization of GNSS accurate positioning techniques

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Abstract. Precise Global Navigation Satellite system (GNSS) positioning is one of the main keys to outdoor positioning. Different technologies exist, each with its own advantages and disadvantages in terms of performance or robustness. This is why the hybridization of two of these techniques is studied; PPP-RTK is the result of the combination of Precise Point Positioning (PPP) and Real Time Kinematic (RTK). This method allows to keep a global approach with a state space representation (SSR) and high performances close to RTK. Using an SSR approach could offer a considerable advantage in precise positioning with telecommunications.

Keywords. Positioning, PPP-RTK, PPP, RTK, SSR

1. Introduction

Precise Point Positioning (PPP) and Real Time Kinematic (RTK) are two different methods for accurate outdoor and Global Navigation Satellite system (GNSS) positioning. Each one has its own way to compute the position. RTK uses a differential positioning technique while PPP has an absolute positioning approach. RTK is the most used method in a lot of applications thanks to higher performances, and uses a network of base stations to collect data to determine the user position. The PPP does not use base stations but a technique of signal augmentation. However, PPP has one main drawback: a very long convergence time.

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First, we will study the two main techniques mentioned above by explaining their characteristics. Then, we will present a PPP-RTK precise positioning hybrid solution. Finally, we will show an example of the advantages of such a technique in telecommunications using Digital Audio Broadcasting (DAB) for example. We will finish by concluding and explaining a possible follow-up to this work.

2. Positining Techniques

2.1. Real Time Kinematic

The main idea of precise positioning method with RTK is the differentiation of phases and codes measurements between two receivers (de Salas & M. Torroja 2016). By this action, some terms will be removed from the GNSS observation equations: the atmospheric errors independent of the receivers and the clock terms have been removed and will not need to be estimated or calculated here. The solution of these equations, used to determine the user's position will therefore be simpler. The biggest unknown is the ambiguity related to the phase. Many techniques to solve the ambiguity exist in this case, like the LAMBDA method (Jokinen et al. 2012). One big advantage of RTK is about convergence: the performance of RTK positioning remains the best (convergence time <1min). However, this application is between two receivers, it is not global. One solution exists : the Network RTK (NRTK).

The main objective is to pool the data of several base stations. This creates an interconnected network. Each station is about 100 km apart in the network. The denser the network, the higher the performance. Indeed, the user will be on average 50km away from a base station. If this distance is respected, the performance of this positioning technique remains as good as that of RTK alone. The mobile receiver will apply the principle of the RTK with the nearest station of the network.

In practice, only one GNSS receiver is needed, the network data is sent to the receivers in corrections messages. There are different types of NRTK implementation: Virtual Reference Station (VRS), Master Auxiliary Concept (MAC) and FläschenKorrekturParameter (FKP) (Retscher 2002). The most commonly used and the one we will apply in our case is the VRS solution. Its principle is based on the creation of an imaginary reference station. The latter is modelled a few kilometres from the receiver. The RTK resolution will be made between this virtual station and the receiver. It is modelled thanks to the network of base stations. The entire ambiguity to be determined can be calculated from the NRTK data.

2.2. Precise point Positioning

PPP is an augmentation technique. It is applied in the context of a global network. The main objective of this technique is to reduce the static side in data processing. Thus, PPP works for a dynamic approach. Its reliability and accuracy is based on the number of satellites, the geometry of the satellites, the availability of the signal and the quality of the measurements. Unlike RTK, this method does not use differentiation. This allows firstly to keep the positional measurement strength of the instrument and secondly to avoid the propagation and correlation of measurement errors. In addition, the PPP uses precise orbital data, precise satellite clock data, from the International GNSS Service (IGS) for example and two frequencies in the GNSS observation equations (Bisnath 2020). Indeed, the double frequency allows to apply the model without ionosphere. This model is the most widely used and allows ionosphere-free combinations of code pseudoranges and carrier phases.

The main factors limiting accuracy in PPP are orbit errors, clock errors and atmospheric variations. The latter is a consequence of multipath: there may be a lack of information on the refraction of the signal in the atmosphere (troposphere, ionosphere). All this will alter the accuracy of the pseudo distance measurements. To compensate for these inaccuracies, the observation equations can take into account several constellations (multi-constellations technique). It is necessary to be careful because errors of counting between the different constellations can appear. Despite these errors, the convergence in PPP will be faster and the accuracy will be improved.

However, the main drawback of this technique is the long convergence time due to the resolution of ambiguities (Jokinen et al. 2012). This is why the RTK explained above is often preferred.

3. A Hybrid Technique : PPP-RTK

3.1. An example of PPP-RTK model

PPP-RTK is an extension of the PPP model, it is a signal augmentation technique but it uses a network of base stations to correct some parameters. Thus, the objective in the GNSS observation equations is the same as in PPP: to make the equations as explicit as possible in order to see the influence of the various parameters. It is an undifferentiated and uncombined model that is implemented (Teunissen & Khodabandeh 2014). There is an inconsistency in the resolution of theses equations: a rank defect. To overcome this, some parameters can be estimated like in the PPP. We can detail the different parameters in *Table 1.*

Parameters	PPP-RTK
Satellites Clock errors	Known precisely (IGS)
Receiver Clock errors	estimated
Bias receiver errors	Estimated
Bias satellite errors	Known precisely (IGS)
Ionospheric delay	Estimated
Tropospheric delay	Known (IGS)
Ambiguity	Estimated
Mapping function	Known (IGS)

Table 1. Parameters in PPP-RTK

Furthermore, in GNSS observation equations for PPP-RTK, a single station principle is applied because it improves the quality of the corrections. The advantages of the PPP-RTK implementation are a positioning system that operates in absolute mode, no mathematical correlation between observables, robustness against errors, and optimal reliability. This hybrid technique can have the same accuracy and performance of RTK.

3.2. An SSR approach

The main advantage of PPP-RTK is that it allows to have an accuracy close to RTK but with a State Space Reprensation (SSR). The SSR approach is opposed to the Observation State Representation (OSR) generally used in RTK and NRTK (Wabbena et al. 2005). The difference between these two approaches is that in OSR the corrections sent to the user are not the same for everyone and depend on the data from the stations closest to the user. On the other hand, in the SSR approach, the corrections are universal and are the same for everyone in the network. They are independent of the user position.

To show the advantage of SSR corrections over OSR-type corrections, we performed tests on the reception of corrections via Digital Audio Broadcasting (DAB). The corrections were put on DAB via a service called "teria" via channel 5B (176.640 MHz). We received this data via a DAB antenna and then transmitted it to a Septentrio GNSS card, connected to a receiver, which uses the corrections to determine its position.

Using the OSR corrections as a first step we noticed a latency of 19sec between the moment when the corrections are received and transmitted (*Figure 1*).

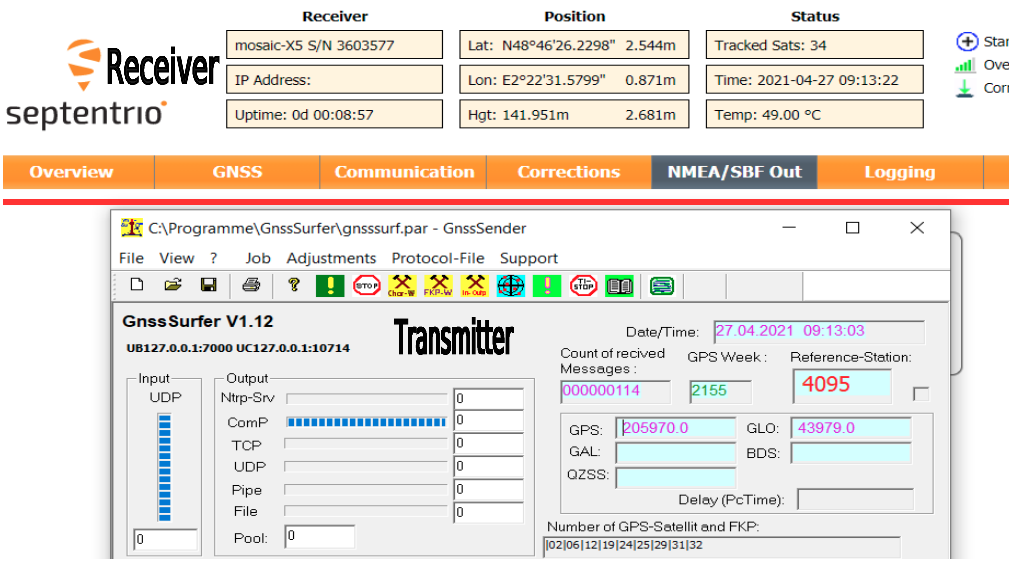

Figure 1. OSR Corrections latency between the received and sent corrections

This latency is a real problem because the receiver cannot take into account the OSR corrections and thus calculate its position. To compensate for this it is possible to use SSR corrections. These are taken into account even with latencies of up to 20sec. Thus, by using SSR corrections the receiver could take into account the corrections and determine its position. This example shows that SSR corrections, are a real asset compared to the latencies that can occur when receiving these corrections via DAB or 3GPP.

4. Conclusion

To conclude, this new approach hybridizing two GNSS accurate positioning techniques shows that having a global positioning method is possible with similar performances to RTK. Indeed, today in many applications, RTK is preferred because it has performances well above PPP. Moreover, RTK remains the standard because it has an OSR approach and devices are calibrated for this type of correction. Very few of them allow the use of corrections with SSR approach. However, in the future, it would be interesting to highlight this approach with an extended version of the PPP: PPP-RTK. Indeed, as shown earlier, having a State Space Representation is an advantage and brings a lot of good results for accurate postioning with telecommunications devices, a smartphone for example. The SSR corrections allow latencies and offer the same performancesof OSR corrections.

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