# ELEVATING GEOSPATIAL PRECISION: THE INTEGRAL ROLE OF RTK, PPK, AND PPP

Advancing Precision with Cutting-Edge Satellite Positioning Techniques

This article delves into the intricacies of Real-Time Kinematic (RTK), Post-Processed Kinematic (PPK), and Precise Point Positioning (PPP) technologies, highlighting their pivotal roles in enhancing geospatial data accuracy across various applications. By examining the operational characteristics, advantages, and integration strategies of RTK, PPK, and PPP, it offers invaluable insights for professionals in aerial mapping, agriculture, and construction seeking to leverage these advanced positioning technologies for improved data precision and efficiency. This guide serves as a comprehensive resource for understanding and applying these cutting-edge solutions in professional geospatial projects

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## RTK vs. PPK and PPP

RTK differs from Post-Processed Kinematic (PPK) and Precise Point Positioning (PPP) primarily in its real-time correction capability. While PPK also offers high accuracy, it requires post-mission processing, making RTK more suitable for applications where real-time data is crucial. PPP, on the other hand, can achieve similar accuracies without needing a base station but requires longer convergence times and precise satellite clock and orbit data.

## Benefits and Applications of RTK-Equipped Drones

Drones equipped with RTK technology are invaluable in several fields due to their ability to capture highly accurate spatial data. This precision is particularly beneficial in:

Aerial Mapping and Geo-spatial Data Acquisition: RTK drones create detailed and accurate maps and collect geo-spatial data critical for land development, agriculture, and urban planning.

## Construction Monitoring: RTK drones provide precise data for monitoring construction progress, ensuring structures are built according to specifications.

## Infrastructure Inspection: High accuracy data from RTK drones aids in inspecting infrastructure, identifying potential issues without the need for costly and dangerous manual inspections.

## Precision Agriculture: RTK drones help in mapping farmlands, monitoring crop health, and optimizing agriculture practices for better yields.

## Operational Insights and Best Practices

To leverage RTK technology effectively, it's essential to maintain a clear line of sight between the base station and the rover to ensure accurate corrections. The technology also relies on robust GNSS antennas and RTK receivers to process the satellite signals accurately. RTK systems can transmit corrections via wired, wireless, or IP network methods, with each having its specific range and setup considerations.

For Certus Aerial Data, implementing RTK technology means adhering to meticulous operational procedures to ensure data accuracy and reliability. This involves careful planning, strict quality control, and utilizing RTK's capabilities to deliver precise aerial data that meets client specifications.

The integration of RTK technology in drone operations represents a significant leap forward in the accuracy and reliability of aerial data acquisition. For companies like Certus Aerial Data, this means delivering unparalleled value to clients across various industries, from agriculture and construction to land development and infrastructure planning. The future of aerial data acquisition is here, and RTK technology is at its forefront, offering precision, efficiency, and cost-effectiveness.

# Real-Time Kinematic (RTK)

RTK is a high-precision satellite navigation technology that significantly enhances the accuracy of position data obtained from GNSS (Global Navigation Satellite System) receivers. RTK operates by using a fixed base station that broadcasts the difference between the positions indicated by the satellite systems and the known fixed position. This information is then used by a mobile receiver to correct its position to a high degree of accuracy, often down to centimeters.

RTK technology involves two key components. The Base Station is a stationary receiver with a known location. It continuously monitors the signals from GNSS satellites and calculates correction factors based on the discrepancies between the observed positions and its known location. The Rover is a mobile receiver (e.g., on a drone, agricultural equipment, construction machinery) that also receives signals from the same GNSS satellites. The rover uses the correction data transmitted from the base station to adjust its calculated position to achieve a much higher level of accuracy in real-time.

The precision of RTK makes it invaluable for a variety of applications requiring high accuracy, such as land surveying, construction, agriculture (precision farming), and infrastructure monitoring. The main advantage of RTK over other GNSS correction methods is its ability to provide real-time, centimeter-level accuracy, which is critical for tasks that rely on precise position data.

The system requires a clear line of sight to a sufficient number of satellites and between the base station and rover to function correctly. Factors such as obstructions (e.g., buildings, trees, or topography) and atmospheric conditions can affect the accuracy and reliability of RTK positioning.

## Here's how RTK works:

Basic GNSS Operation: GNSS receivers, like GPS, rely on signals from multiple satellites in space to determine their position on Earth. These signals contain information about the satellite's location and the time it was transmitted.

Differential Correction: RTK improves accuracy by using a technique known as differential correction. This involves comparing the position data received from satellites with a known, highly accurate reference station on the groReference Station: A reference station is a stationary GNSS receiver placed at a known and precisely surveyed location. This station continuously tracks signals from the same satellites as the mobile (rover) receiver.

**Data Correction:** The reference station calculates the difference between its known position and the position it calculates from the satellite signals. This difference, known as the "correction data," is transmitted to the rover receiver in real-time or near real-time.

**Rover Receiver:** The rover receiver, which is typically mounted on the drone, receives the correction data from the reference station. It then applies these corrections to its own GNSS data in real-time.

**Centimeter-Level Accuracy:** By using the correction data from the reference station, the rover receiver can achieve centimeter-level or even sub-centimeter-level accuracy in determining its position. This is significantly more precise than standard GNSS, which typically provides meter-level accuracy.

**Continuous Updates:** RTK systems continuously update the rover receiver with correction data as the drone moves, ensuring that a high level of accuracy is maintained throughout the flight.

RTK technology is crucial for applications like aerial mapping, construction monitoring, and precision agriculture, where precise spatial data is essential. It allows for more accurate mapping, surveying, and data collection, ultimately improving the quality and reliability of the information obtained from drones equipped with RTK-enabled GNSS receivers.

## Post-Processed Kinematic (PPK)

PPK is a GPS correction technology primarily used in surveying and mapping applications, including drone mapping and land surveying. It improves the accuracy of location data by correcting the data after it has been collected and uploaded, unlike Real-Time Kinematic (RTK) which performs corrections in real-time. PPK requires at least two GNSS receiver units: a static base station (reference receiver) and a moving receiver (rover). The base station records raw GNSS data, which is then used to correct the data collected by the rover, thereby achieving centimeter-level accuracy. This method is particularly beneficial as it reduces the need for ground control points (GCP), saving significant field preparation time and allowing for longer baselines of up to 100 km without the need for a constant connection between the rover and the base station.

The process involves collecting drone data, including raw images, the drone Receiver Independent Exchange (RINEX) file containing raw GPS measurements, and the image timestamp file which records the exact time each image was taken. These elements are

critical for achieving high accuracy in PPK processing. The base RINEX file, collected by the base station, and a navigation file detailing satellite positions are used alongside drone data to correct positioning errors post-mission.

PPK offers several advantages over other methods. It eliminates the need for a live data link between the base station and the drone, making it more reliable in environments where connectivity might be an issue. This method simplifies the setup process and allows for operations beyond the visual line of sight (BVLOS) and in challenging environments. Although the correction happens post-flight, PPK is considered more flexible and, in some cases, more accurate due to the ability to process data around any gaps retrospectively.

PPK technology, by offering easier setup, flexibility, and robust data collection without the need for constant telemetry links, represents a significant advancement in the accuracy and efficiency of drone mapping and surveying, making it a valuable tool in a wide range of applications.

## Here's how PPK works:

**Data Collection:** During a drone flight or survey mission, the GNSS receiver on the drone continuously captures data from multiple satellite signals, including those from GPS, GLONASS, Galileo, or other global navigation satellite systems.

**Data Logging:** The GNSS receiver logs the raw satellite data along with the timestamp at which each signal was received. This data includes information about the satellite's position in the sky and the precise time the signal was transmitted.

**Base Station Data:** In PPK, a reference station, often known as a "base station," is placed at a known location on the ground. This base station also collects GNSS data simultaneously.

**Post-Processing:** After the drone flight is completed, the collected data from both the drone's GNSS receiver and the base station are post-processed together using specialized software. This software considers the known position of the base station.

**Differential Corrections:** The software calculates the difference between the positions determined by the drone's GNSS data and the known position of the base station. These differential corrections account for factors like atmospheric interference, clock errors, and satellite orbit inaccuracies.

**High-Precision Results:** By applying these corrections to the drone's GNSS data, PPK technology achieves highly accurate positioning results with centimeter-level or even

millimeter-level accuracy, depending on the quality of the data and the processing techniques used.

PPK is valuable in applications where high precision is essential, such as aerial mapping, construction monitoring, and land surveying. It allows for the generation of precise 3D models and maps, making it a critical tool for professionals like you at Certus Aerial Data who require accurate spatial data for various applications.

## Precise Point Positioning (PPP)

PPP is an advanced technique in the field of global navigation satellite systems (GNSS) that allows for the computation of extremely accurate positions, often achieving errors as small as a few centimeters under optimal conditions. What sets PPP apart from other GNSS positioning methods, such as Real-Time Kinematic (RTK), is its ability to deliver high-precision results using just a single GNSS receiver, as opposed to RTK which requires both a base and a rover receiver. This aspect of PPP not only simplifies the setup required for high-precision positioning but also broadens its applicability across various industries and applications.

At its core, PPP utilizes a combination of direct observables and ephemerides to refine GNSS position estimates to a high degree of accuracy. Direct observables include carrier phase measurements and the differential delay between GNSS signals of different frequencies. These measurements are critical for mitigating errors caused by the ionosphere, a variable layer of Earth's atmosphere that can unpredictably affect the speed of GNSS signals. By analyzing the difference in delay between signals of different frequencies, PPP algorithms can approximate and correct for these delays, significantly enhancing positioning accuracy.

Ephemerides, which are precise records of GNSS satellites' orbits provided by the geodetic community, play a crucial role in PPP's accuracy. These records are more accurate than the satellite positions broadcast in real-time by GNSS satellites, which can be affected by factors such as micrometeoroid impacts and solar radiation pressure. By comparing raw GNSS observations with these highly accurate ephemerides, PPP can correct for orbital errors, further improving position accuracy. This process, traditionally done in post-processing, can now also be applied in near real-time through services like NASA's JPL Automatic Precise Positioning Service, which publishes improved ephemerides online.

PPP's dependency on satellite clock and orbit corrections, derived from a network of global reference stations, is what enables it to achieve decimeter-level or better positioning

accuracy without the need for a local base station. This system delivers corrections via satellite or the Internet to the end user, who can then apply these corrections for high-precision positioning tasks. The level of accuracy and the time required for the PPP solution to converge depend on the quality of corrections and their application within the receiver.

The main advantages of PPP include its high level of accuracy, the elimination of the need for a local base station, and its applicability to a wide range of industries, including robotics, autonomous navigation, agriculture, construction, and mining. However, it requires significant processing power, access to an external ephemeris correction stream, and some time to converge to full accuracy, which may limit its utility in applications where immediate, centimeter-scale precision is essential.

## OPUS

Opus stands for the Online Positioning User Service, provided by the National Geodetic Survey (NGS), part of the U.S. National Oceanic and Atmospheric Administration (NOAA). OPUS allows users to submit their GPS (Global Positioning System) data to the NGS, where it is processed to give the user a highly accurate position of their GPS antenna. Here's how it works in more detail:

**Data Submission:** Users collect GPS data with their receiver and then upload this data to the OPUS website. The data usually needs to be collected over a certain period to ensure accuracy, often ranging from 15 minutes to several hours, depending on the specific requirements and desired accuracy.

**Processing:** Once the data is submitted, OPUS uses sophisticated algorithms to compare the user's data against a network of reference stations. These reference stations have known, precise locations and provide a baseline for determining the user's position accurately. OPUS uses state-of-the-art models to account for various factors that can affect GPS accuracy, including atmospheric conditions, satellite orbits, and more.

**Report Generation:** After processing, OPUS generates a report for the user that includes the precise latitude, longitude, and height of their antenna. This report may also include other information, such as the quality of the data and an estimate of the positional accuracy.

**Applications:** OPUS is widely used in surveying, engineering, and other fields requiring precise geographical positioning. It's particularly valuable because it provides access to

high-accuracy GPS positioning without the need for the user to own and operate an extensive GPS reference station network.

Advantages: The primary advantage of OPUS is its convenience and the high level of accuracy it can provide. It's a free service, accessible to anyone with a GPS receiver capable of collecting the necessary data. This makes it an invaluable resource for professionals and enthusiasts alike who need precise positioning data but don't have access to more extensive surveying equipment or networks.

OPUS democratizes access to high-precision GPS data, offering an essential service for various applications where accurate geographical positioning is critical.

## Setting New Standards in Precision: How RTK, PPK, and OPUS Are Changing the Game

RTK provides real-time, centimeter-level accuracy during data collection. It relies on a base station with known coordinates that transmits correction data to your GNSS receiver in real time. The corrections are applied to your drone's position in real-time, allowing for precise positioning during the flight. RTK typically achieves horizontal accuracy within a few centimeters.

After your drone flight is completed, PPK comes into play. It further refines the accuracy by post-processing the collected GNSS data along with base station data. PPK can achieve even higher accuracy levels, typically within millimeters or centimeters, depending on the quality of data and processing techniques. It corrects errors introduced during the flight, such as atmospheric effects and clock discrepancies.

OPUS can serve as a final accuracy check or verification step. It allows you to cross-check your PPK-derived coordinates with highly accurate reference data provided by the National Geodetic Survey (NGS). OPUS can provide coordinates with centimeter-level accuracy, and it's especially useful for confirming the quality and reliability of your PPK results.

To understand how combining Real-Time Kinematic (RTK), Post-Processed Kinematic (PPK), and the Online Positioning User Service (OPUS) can create a robust geospatial workflow yielding extremely accurate positioning data, it's essential to delve into each component's unique contributions and how they interact to enhance overall precision in applications like aerial mapping, land surveying, and infrastructure inspection.

## RTK: The Foundation for Real-Time Precision

RTK technology provides centimeter-level accuracy by using a fixed base station to broadcast real-time corrections to a mobile receiver. This system effectively compensates for the most significant GNSS errors caused by atmospheric interference, satellite orbit inaccuracies, and clock errors. The real-time nature of RTK is its most significant advantage, allowing for immediate precision during data collection, crucial for dynamic environments and when immediate results are required.

## PPK: Refining Accuracy Through Post-Processing

While RTK offers real-time accuracy, PPK technology steps in to refine this precision further through post-processing. Unlike RTK, PPK doesn't require a real-time link between the base station and the rover. This means data collected in the field can be processed afterward, using corrections from either a local base station or a network of reference stations. PPK's flexibility makes it especially useful in environments where real-time communication is difficult or in projects where data collection outpaces real-time processing capabilities. By carefully correcting the data post-collection, PPK ensures that even minor inaccuracies not corrected in real-time are addressed, enhancing the dataset's overall precision.

## OPUS: Validation Against a Known Reference System

The Online Positioning User Service (OPUS) provides users with access to a network of continuously operating reference stations (CORS). By submitting GNSS data collected from a single receiver to OPUS, users can receive position information with centimeter to sub-centimeter level accuracy. This is achieved by comparing the submitted data against the known positions of the CORS network, effectively validating and further refining the accuracy of data processed through RTK and PPK. OPUS serves as a final check, ensuring the highest possible accuracy by anchoring the collected data to a well-established, highly accurate reference system.

## Integrating RTK, PPK, and OPUS into a Unified Workflow

By integrating RTK, PPK, and OPUS, geospatial professionals can leverage the strengths of each method to create a comprehensive and robust workflow for achieving unparalleled accuracy in their projects. The workflow typically follows these steps:

Real-Time Data Collection with RTK: Initial data collection is performed with RTK, providing real-time corrections and immediate precision.

Post-Processing with PPK: The collected data undergoes post-processing using PPK, refining accuracy by addressing any discrepancies or errors not corrected in real-time.

Validation with OPUS: The refined dataset is then validated against the CORS network through OPUS, ensuring the data aligns with a known, highly accurate reference system.

## Factors Influencing Accuracy

The effectiveness of this integrated approach depends on several factors, including the quality of the GNSS equipment, the environmental conditions during data collection, the duration of the data collection period, and the specific processing techniques employed. High-quality equipment can significantly reduce initial errors and enhance the effectiveness of RTK corrections. Meanwhile, optimal data collection and processing techniques, tailored to the specific conditions and requirements of the project, are crucial for maximizing accuracy.

When executed correctly, combining RTK, PPK, and OPUS offers a powerful method for achieving centimeter-level accuracy in geospatial data collection and analysis. This integrated approach meets the demanding standards of professional geospatial applications, enabling precise mapping, surveying, and inspection tasks across a wide range of industries and projects. The synergy between real-time precision, refined post-processing, and final validation against a known reference system provides a comprehensive solution for obtaining the most accurate positioning data possible.