GNSS LOCALISATION

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1. Review of GNSS Localization Techniques

a. Differential GPS (DGPS)

***Differential GPS (DGPS) enhances the accuracy of standard GPS by using fixed ground-based reference stations. When you use GPS, your device, like a smartphone, connects to satellites orbiting Earth to determine your location. However, the signal from the satellites can be slightly distorted by factors like the atmosphere, which can cause minor inaccuracies in your location—sometimes up to several meters off.
DGPS improves this accuracy by employing reference stations on the ground. These stations are in fixed, known locations. They receive signals from the same GPS satellites, but because they already know their exact position, they can calculate any errors in the satellite signals. The reference station then broadcasts these error corrections to nearby GPS devices. When your GPS device receives these corrections, it adjusts its calculations, resulting in a much more accurate location—often down to just a few centimetres.
In simple terms, DGPS acts like a local guide that knows the exact location and helps correct any errors in your GPS device's readings, making your location tracking much more precise.**

***DGPS greatly improves the accuracy of standard GPS, reducing location errors to just a few centimetres, which is essential in many precise applications. It provides more reliable and accurate positioning, even in challenging environments like cities or forests.
In real-world applications, DGPS is used in agriculture for precision farming, allowing for efficient planting and harvesting. In marine navigation, it helps ships travel and dock safely. In construction and surveying, it ensures buildings are constructed with pinpoint accuracy. Aviation benefits from DGPS by enhancing aircraft navigation, especially during takeoff and landing. Autonomous vehicles, like self-driving cars and drones, rely on DGPS for safe and accurate navigation. Emergency services use it to quickly and precisely locate people during rescue missions. Overall, DGPS enhances safety, efficiency, and precision across various industries.**

b. Real-Time Kinematic (RTK)

***Real-Time Kinematic (RTK) is a technology that makes GPS much more accurate, often down to just a few centimetres. It works by using a base station at a known, fixed location and a moving receiver, like the one in a drone or tractor. The base station knows exactly where it is, so it can figure out the tiny errors in the GPS signals it receives. It then sends this correction information to the moving receiver.
RTK achieves its high precision by focusing on the carrier waves of GPS signals, which are like the "fine details" of the signal. Instead of just measuring how long it takes for the GPS signal to travel from the satellite, RTK looks at the wave patterns themselves. By comparing these patterns between the base station and the moving receiver, RTK can pinpoint the receiver's location with very high accuracy. This is especially useful in activities like mapping, construction, and farming, where being off by even a few centimetres can make a big difference.**

***RTK and DGPS are both techniques used to improve GPS accuracy, but they differ in**

several ways. RTK offers higher accuracy, often down to a few centimetres, compared to DGPS, which typically provides meter-level accuracy. However, RTK is more complex, requiring a reference station and real-time communication with mobile receivers, as well as more advanced equipment.
In terms of use cases, RTK is ideal for applications where extreme precision is necessary, such as in land surveying, autonomous vehicles, and precision farming. DGPS, while less accurate, is simpler and sufficient for tasks like general navigation, marine operations, and agriculture where exact positioning is not as critical.

c. Assisted GPS (A-GPS)

***A-GPS, or Assisted GPS, enhances the performance of standard GPS, especially in reducing the time it takes to find your initial location. Normally, GPS needs to connect to several satellites, which can take a while, especially if you're in a place with a weak signal, like indoors or in a city with tall buildings.**
A-GPS speeds this up by using information from your mobile network. When you try to get your location, your phone connects to nearby cell towers or Wi-Fi networks, which helps it quickly figure out which GPS satellites to connect to. This network assistance dramatically shortens the time needed to get your initial position, so you can get accurate location data faster, even in challenging environments.

***A-GPS, or Assisted GPS, enhances regular GPS by using additional information from nearby cell towers or Wi-Fi networks, which helps to get a location fix faster and in challenging environments like inside buildings. However, it still relies on satellites and might not be as accurate in very dense urban areas. DGPS, or Differential GPS, improves accuracy by using a fixed ground-based reference station that corrects satellite signals, but it requires nearby base stations and can have limited coverage. RTK, or Real-Time Kinematic, provides extremely high precision by using multiple ground stations and complex algorithms to correct signal errors in real time, making it ideal for tasks that need very precise positioning like surveying. However, RTK systems are expensive and complex, needing a clear line of sight and reliable communication between stations. In summary, while A-GPS is good for quick and general location fixes, DGPS and RTK offer higher accuracy but come with their own challenges.**

d. Precise Point Positioning (PPP)

***PPP, or Precise Point Positioning, is a technique used to determine your exact location using just one GNSS (Global Navigation Satellite System) receiver, like a GPS device. Normally, finding your location with GNSS can be a bit off, usually within a few meters. However, PPP improves accuracy by using more detailed information from the satellites and correcting errors like those caused by the atmosphere or clock discrepancies. This allows the GNSS receiver to pinpoint your location very precisely, often within a few centimetres, without needing any extra equipment or reference stations nearby. It's like giving your GPS a superpower to be incredibly accurate on its own.**

***PPP (Precise Point Positioning) and RTK (Real-Time Kinematic) are two methods used to improve GPS accuracy, but they differ significantly in how they work, their accuracy, cost, and what they need to function.**
PPP is a technique that uses satellite data and advanced calculations to provide highly accurate location information, typically within a few centimetres. It doesn't

require a nearby reference station, making it more flexible and easier to use over large areas. However, it can be slower to deliver accurate results, sometimes taking several minutes, and it often requires expensive equipment and access to correction data, which can add to the cost.
RTK, on the other hand, involves using a local reference station in addition to satellite data to provide almost instantaneous high-precision positioning, usually within a few centimetres or even millimetres. This method is extremely accurate and fast, but it requires a nearby reference station or a network of them, which limits its range. It’s generally more expensive due to the need for additional infrastructure and equipment.
In summary, PPP offers high accuracy over larger areas but can be slower and costly, while RTK provides faster, more precise results but requires nearby reference stations and is also expensive.

2. Methods to Improve GNSS Localization

a. Kalman Filter and EKFs

*The Kalman Filter is like a smart guessing tool that helps you track and predict the position of something, even when your measurements are noisy or uncertain. Imagine you're trying to follow a car's movement using GPS, but the GPS data isn't perfect and has some errors. The Kalman Filter takes in these imperfect GPS readings and combines them with what it knows about the car's previous positions and how it typically moves. By doing this, it makes a better guess about the car's current position and even predicts where it will be next. It's like having a map that gets more accurate as you go along, making sure you stay on the right track even when your data isn't perfect. This is especially useful in GPS-based systems, like the ones used in phones or cars, where having accurate location information is crucial.

*The Kalman Filter helps improve the accuracy of Global Navigation Satellite System (GNSS) data by smartly filtering out noise and correcting errors. Imagine you're trying to figure out your exact location, but the information you get is a bit shaky or uncertain. The Kalman Filter acts like a smart prediction tool that constantly updates your position by considering both the data it receives and what it already knows. It predicts your location, compares it with the noisy data, and adjusts the prediction based on how trustworthy the new data seems. This way, it smooths out the inaccuracies and gives you a more reliable and accurate location over time.

*The Kalman Filter is like a smart guesswork tool that helps in making sense of noisy data. Imagine you’re trying to track the position of a moving object, but the data you get, such as from a GPS, isn’t always accurate because of errors or noise. The Kalman Filter helps by taking these noisy data points and estimating the most likely position of the object. It does this by predicting where the object should be based on its previous position and correcting this prediction using the new, but noisy, data it receives. Over time, it adjusts its estimates to become more accurate. In GNSS localization, this means it can smooth out the errors in the position data and provide a better estimate of where something is, like where your phone or a car is located, even if the GPS signal is a bit off.
The Extended Kalman Filter (EKF) improves accuracy in systems like GNSS by handling situations where the data or system behaviour isn't straightforward or

linear. Imagine you're trying to figure out your location, but the path you're on is curved or involves complex movements. The EKF, like a smarter version of the regular Kalman Filter, adjusts its predictions even when the situation is complicated. It takes the same approach of predicting and correcting, but it also accounts for the curves and twists in the data. This allows it to provide accurate results, even when the data or the system is not perfectly straightforward.

b. Particle Filter

***The Particle Filter is a method used to estimate the position or state of something that is difficult to predict accurately, especially in systems that don’t follow simple patterns. Think of it like trying to track a person in a crowded room using a bunch of tiny robots. Each robot makes a guess about where the person might be. Over time, as the robots get more clues (like seeing the person’s shadow or hearing their footsteps), they adjust their guesses. Some guesses get closer to the actual position, while others are discarded. This process helps narrow down the person’s exact location, even if the room is noisy and chaotic.**
In the context of GNSS (Global Navigation Satellite System) applications, where you're trying to determine the precise location of something (like a car or a drone) in a world full of uncertainties, the Particle Filter is particularly useful. It works well in situations where the environment is complex, and the data you get is not straightforward, meaning it doesn’t follow a simple or predictable pattern. This makes the Particle Filter a good choice for handling non-linear, non-Gaussian systems, where the relationship between variables isn’t straightforward, and the errors or uncertainties don’t follow a normal distribution.

***The Kalman filter and the particle filter are both used to estimate the state of a system, like predicting the position of a moving object. The Kalman filter is simpler and faster because it assumes everything follows a normal distribution, making it less computationally demanding. However, this assumption can limit its accuracy in more complex situations where the reality doesn't fit neatly into a normal distribution. The particle filter, on the other hand, doesn't rely on this assumption and uses a large number of random samples (particles) to represent possible states. This makes it more accurate and robust in handling complex, nonlinear, or non-Gaussian problems, but it also requires more computational power. So, while the Kalman filter is quick and works well for simpler, predictable scenarios, the particle filter is more powerful but slower, especially for complicated, unpredictable systems.**

c. Sensor Fusion

***Sensor fusion is a technique where data from different types of sensors, like GPS, Inertial Measurement Units (IMU), and LiDAR, are combined to get a more accurate and reliable understanding of location. Imagine trying to find your way using just a GPS, which tells you where you are based on satellite signals. However, sometimes these signals can be weak or blocked, like in a tunnel or dense forest, making your location uncertain. By adding information from other sensors, like an IMU that tracks movement or a LiDAR that maps surroundings, sensor fusion fills in the gaps and corrects any mistakes from the GPS alone. This combination leads to more precise and stable positioning, especially in challenging environments.**

***Sensor fusion enhances GNSS (Global Navigation Satellite System) performance in**

challenging environments, such as urban canyons or indoors, by combining data from multiple sensors to provide more accurate location information. GNSS signals can be weak or blocked in these areas, leading to poor accuracy. By integrating data from sensors like accelerometers, gyroscopes, and magnetometers, which measure movement and orientation, the system can fill in gaps when satellite signals are unreliable. This approach allows for a more consistent and reliable determination of position, even when GNSS signals alone would struggle to provide accurate results.