3D-Map Aided Multipath Mitigation for Urban GNSS Positioning

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Global navigation satellite system has been widely used in the personal and vehicular positioning for safety and convenience purposes.

Especially in urban environment, the multipath effect is a critical issue.
Recently, with the arrival of 3D map information, it can be used to enhance the satellite positioning performance since multipath effect is an environment-dependent issue.

We would like to mitigate multipath effect by applying the ray-tracing technique to obtain a database about the relation between the multipath-induced delay and the distance from the receiver to the building, and under the assistance of 3D map to correct the position solution.
A variety of approaches have already been proposed in order to detect and mitigate multipath effects on GNSS positioning.

- **Improvement of receiver hardware**
  - Using antenna arrays to distinguish multipath signals
  - Using additional sensors such as an infrared camera to detect whether the direct signal is blocked and then exclude the pseudorange measurements of the invisible satellites

- **Algorithmic method**
  - Using Receiver Autonomous Integrity Monitoring (RAIM) algorithm to provide an alert by assessing GNSS measurement residuals

- **Correlator technique**
  - Narrow correlator technique
  - Strobe correlator technique
  - Multi-correlator architecture

- **Estimation technique**
  - Utilizing multipath estimating delay locked loop (MEDLL) to estimate each parameter of multipath signals
Flow Chart

- Satellite position
  - Doing the ray-tracing analysis
    - Measuring the relation between the multipath-induced delay and the distance from the receiver to the building
      - Multipath-induced delay database
  - 3D map information
    - Finding the accurate distance between the receiver and the building
      - Correcting the rough position solution
GNSS positioning is based on the time-of-flight principle.

Generally, at least four measurements are needed to solve the three-dimensional position solution and the receiver time offset.

The raw measurement namely pseudorange is the speed of light multiplied by the time shift required for a replica generated by local code generator to correlate with the code transmitted from the satellite.

A mathematical model of multipath signal is modeled as

\[ s(t) = \sum_{i=0}^{M} a_i(t) C \left[ t - \tau_i(t) \right] \cos \left[ \omega t - \theta_i(t) \right] \]

Since multipath signal takes longer distance to travel compared with direct signal, it is more prone to signal delay and power attenuation.
Compared with direct line-of-sight signal, the reflected signal is delayed and attenuated.

Multipath effect on correlation function:

In the presence of multipath signal, the resultant correlation function is distorted.
A discriminator is used in the code tracking loop to provide an error signal so that the local replica can be aligned to the incoming code.

Multipath effect on discriminator output result:

- Multipath leads to a shift, so called multipath-induced delay, of the zero-crossover point in the discriminator output S-curve.
- Consequently, the pseudorange error is resulted in.
Ray-tracing technique is applied to obtain the reflecting point and the path difference between the direct signal and the reflected signal.

From the ephemeris data, the position of the satellite is calculated in order to determine the elevation and azimuth angles of the satellite seen from the receiver.

According to optics and geometry theories, the reflecting point on the reflecting surface is computed.

As a result, the path difference between the direct signal and the reflected signal is estimated; so is the propagating time delay caused by the environment.

\[ s_1 - s_0 = \text{path difference} \]
Establishment of Multipath-induced Delay Database

- Having the path difference information, the multipath-induced phase error and multipath-induced delay can be estimated based on the concepts of correlation function and discriminator output.

- Through simulation, the relation between the multipath-induced delay and the distance from the receiver to the building is measured and observed.

- The multipath-induced delay database is represented as

  \[ \varepsilon = f(\theta, \varphi, d) \]

  where \( \varepsilon \) is the multipath-induced delay
  \( \theta \) is the elevation angle of the satellite
  \( \varphi \) is the azimuth angle of the satellite
  \( d \) is the distance between the receiver and the building
The variation of the path difference between the direct signal and the reflected signal:

![Graph showing the variation of path difference with distance between receiver and building.](image)
The variation of the multipath-induced delay by using the correlator spacing of 1 chip:
- Distance between the receiver and the building from 0(km) to 0.05(km)
- Distance between the receiver and the building from 0.3(km) to 0.36(km)
The variation of the multipath-induced delay under three different correlator spacing circumstances:

Using smaller correlator spacing in the code tracking loop can improve the positioning accuracy.
Correction of the Position Solution

- In the positioning process of the receiver, the composite effect of multipath signals can be obtained, that is to say, the multipath-induced delay is known.
- With 3D map information, the surrounding environment of the receiver can be realized.
- From the ephemeris data, the satellite positions can be calculated.
Correction of the Position Solution

Through the multipath-induced delay versus distance between the receiver and the building diagram, we can get a set of corresponding distances for a given multipath-induced delay and satellite position.

For a different satellite which generates multipath signals, we can get a different set of corresponding distances.

Finding the intersection of these sets, we can obtain the accurate distance between the receiver and the building.

As a result, the position solution can be corrected and the positioning accuracy can then be improved.
Gratitude

- Clear and detailed lectures
- Useful practices and interesting demos
- Friendly participants and kind teachers

Especially my group members!!!