Guidance, Navigation, and Control (GNC) of a Quadrotor Drone

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Motivation & Theory

Motivation

- Accurate guidance and navigation are crucial to the functionality of any autonomous aerial system. Modern platforms commonly rely on the Global Navigation Satellite System (GNSS) for real-time state estimation.
- GNSS navigation works by using pseudorange measurements derived from satellite positions and time stamps, enabling a receiver to compute its position.

Theory & Expections

- This lab utilized a motion-capture (MOCAP) system to simulate a GNSS-like pseudolite setup, aiming to study how measurement noise and satellite geometry affected real-time position estimation.
- Due to the experiment occurring indoors with a clear line of sight to all pseudolites, minimal multipath and no atmospheric propagation delay were expected.
- The estimated trajectory was predicted to closely match the true drone path as a result, with variations mainly expected to be a result of the time-varying geometry dilution of precision (DOP) rather than environmental effects.

$$P_i = \left\|\bar{\mathbf{r}}^{R} - \mathbf{r}^{S_i}\right\| + c\,\delta T_R$$

Equation 1. Pseudorange equation with clock error

$$\sigma_{\text{pos}} = PDOP \cdot \sigma(\delta P)$$

Equation 2. Position error grows with PDOP and the pseudorange noise level

Flight Trajectories

Guidance Trajectory Flight Tests

- Drone Lab's testing apparatus included a MOCAP system and a quadrotor drone.
- The MOCAP software was altered to simulate a set of six GNSS satellites, each providing time stamps, pseudoranges, and satellite positions.
- The quadrotor flew a predetermined guidance trajectory while data was recorded.
- Static measurements were also collected at known locations to quantify pseudorange noise.
- MATLAB script GPS_NA_3D.m was used to compute trajectories and generate visuals.

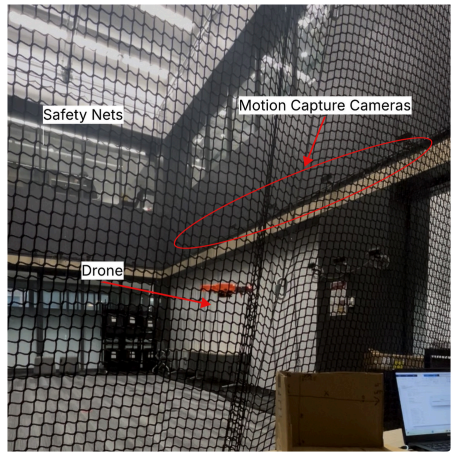
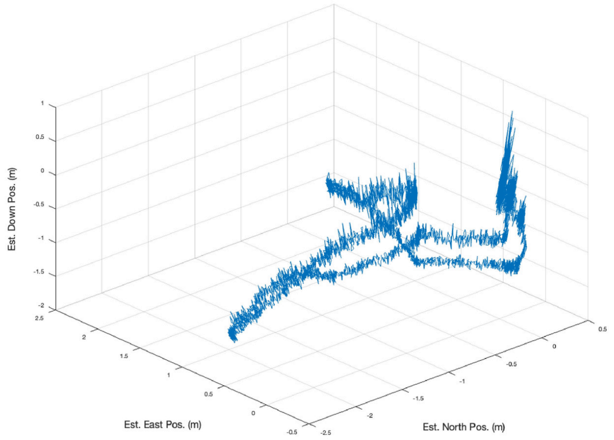


Figure 1. Drone Lab

Figure 2. Estimated 3D flight trajectory obtained from pseudolite pseudorange data using Newton's method and Eq. 1. The reconstructed path forms the expected T-shaped pattern flown during the experiment.



Error & Conclusion

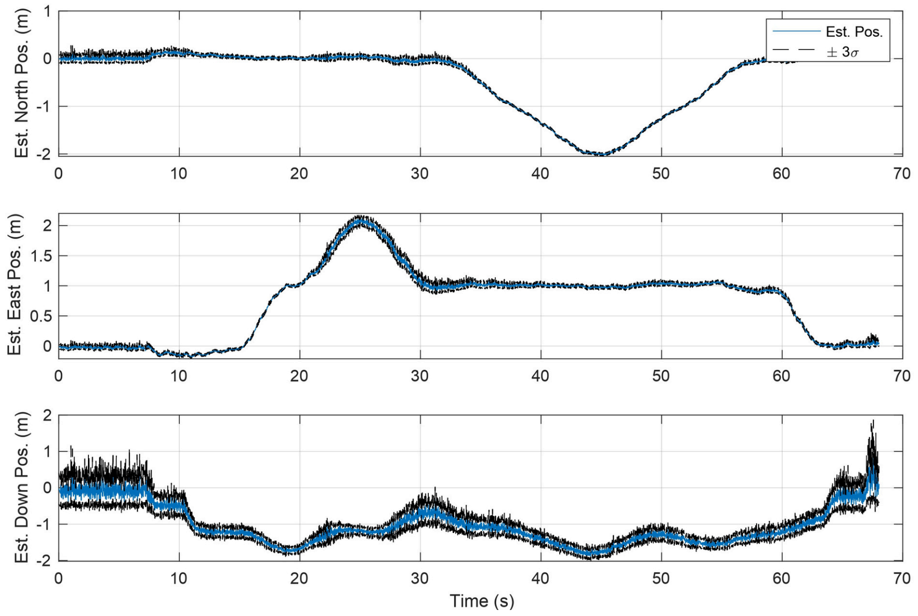


Figure 3. Estimated north, east, and down positions with ±3σ uncertainty bounds (99.7% confidence interval) computed using Eq. 2. The uncertainty is largest in the down direction, indicating weaker vertical geometry (higher DDOP).

Conclusion

- The quadrotor's position was successfully estimated using pseudorange data generated by the MOCAP system configured to emulate a GNSS-like pseudolite network.
- The largest uncertainty appeared in the down direction. This result diverged from the initial expectation of uniformly low error and was primarily attributed to weaker vertical camera geometry (higher DDOP).
- While the north and east directions had full 360 coverage the down direction only had cameras at two sets of heights
- To improve this test environment, more cameras at varying heights would reduce the DDOP related uncertainty.