Project Study: Tracking Drone Orientation with Multiple GPS Receivers

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Abstract

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I. Introduction

WITHOUT a good awareness of orientation and balance, a drone cannot effectively controll its rotors to achieve desired flying status. A natural response is to install redundant inertial measurement units (IMU). IMU is an electronic device that measures and reports a body's specific force, angular rate, and the magnetic field surrounding the body, using a combination of accelerometers and gyroscopes, sometimes also magnetometers.

IMUs are typically used to maneuver aircraft, including unmanned aerial vehicles (UAVs), among many others, and spacecraft, including satellites and landers. Recent developments allow for the production of IMU-enabled GPS devices.

An IMU allows a GPS receiver to work when GPS-signals are unavailable, such as in tunnels, inside buildings, or when electronic interference is present. Unfortunately, redundancy only addresses unreliable hardware. Various noise sources, including motor vibration, electromagnetic interference, and ambient ferromagnetic influences, create unreliablity for the IMU. Worse even, the errors would accumulate through time and the IMUs are prone to various types of correlated failures.

The SafetyNet is a fail-safe mechanism for IMU failures. The basic idea is using multiple GPS to track 3D orientation of the UAV. The SafetyNet design includes 4 GPS receivers at four arms of the single drone upon IMU failure, we utilize these GPS receivers to estimate the drones 3D orientation. As an alternative to the IMUs, SafetyNet uses GPS signals to estimate the real time orientation of the drone without any inertial or magnetometer assistance. Chanllenge comes that the traditional GPS system iccurs an error around 2 3 meters and the more advanced Differential GPS technology would still have a relative error in the scale of 10 20 centimeters (which equals to 20 degree in orientation). However, opportunities exist in relative GPS signal information and we aim to utilize the spatio-temporal information to achieve better accuracy.

The core additions of the SafetyNet, can be distilled as follows:

- Manipulating measurements across pairs of GPS receivers, satellites, and consecutive time points, capture 3D orientation from two different perspective, which can institute transition model and measurement model of Kalman filter.
- GPS carrier-phase measurements can be used to achieve very precise positioning solutions. Carrier-phase measurements are much more precise than pseudorange measurements, but they are ambiguous by an integer number of cycles. GPS phase measurements are composed of an unknown portion, called integer ambiguity. In attempting to resolve this ambiguity, past work have adopted techniques akin to hard decoding, where the most likely state-estimate is propagated across time. We design the equivalent of soft decoding, whereby top-K possibilities of the ambiguity are propagated, each associated with an inferred probability. A particle filter is used to execute this idea the particle filter degenerating back into the Kalman Filter when the ambiguity is resolved confidently.
- We break away from the classical particle filter approach and adjust the state of the particles based on available measurements. This speeds up convergence of the system, while requiring fewer particles (considerably reducing the computational complexity). As a result, the overall SafetyNet system lends itself to real time operation on todays drone hardware.

II. Problem Formulation

A. Pseudorange

Generally, the GPS operates in measuring the the time difference between transmitter and receiver and the Pseudorange, which is the estimated distance between both ends is formed as in equation 1.

$$Pseudorange = ToF * c \tag{1}$$

where ToF is the time difference and c represents the speed of light.

However, when a satellite transmits a signal, it includes clock error as the starting time of transmission is obtained from its atomic clock. The reception time of the ground receiver is also recorded by less accurate local clock. Because the clock of a typical GPS receiver is not synchronized to the GPS satellites. The resulting error can be up to 300 km. GPS signal can get

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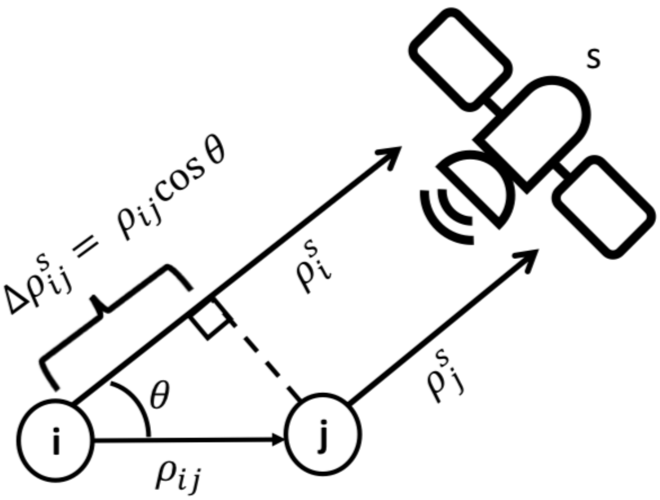

Fig. 1: $\lambda \triangle \phi_{ij}^s = \rho_{ij} \cdot \hat{l}_s + c \triangle t_{ij} - \lambda N_{ij}$

delayed when it enters the Earths atmosphere because of refractions in the Ionosphere and Troposphere. When signal passes through a multipath channel, more errors would be introduced. In our study, we model the error in pseudorange at receiver i from the satellite s as in equation 2.

$$Pseudorange_i^s = \rho_i^s + ct_i - ct^s + A^s + M_i + \epsilon_i^s \tag{2}$$

Here, ρ_i^s represents the real range, t_i and t^s stand for the clock error at the receiver and transmitter sides correspondingly. A models the interference by the atmosphere, M_i stands for the multipath interference and ϵ_i^s represents the hardware noise in measuring.
The operation error from the system would be as large as 1-4 meters which is far from satisfaction. Therefore, the Differential GPS technology is introduced leveraging the difference in signal phase and highly improves the system accuracy.

B. Differential GPS

The differential GPS technology leverages the phase of received GPS signals to improve the accuracy. One advantage of carrier phase is that its changes over time can be tracked reliably by utilizing the doppler shift in the signals.
The phase model is shown in equation 3 by ignoring the multipath and hardware noise error.

$$\lambda\phi_i^s = \rho_i^s + ct_i - ct^s + A^s - N_i^s \tag{3}$$

where N_i^s is the number of full wavelengths in the range which we could not solve from the phase measurement. The unknown property of N_i^s is called as "integer ambiguity" and estimating the integer ambiguity is one of our major concern in the SafetyNet implementation. More discussion on integer ambiguity would come in later sections.
Environmental error sources in Equation 3 are correlated over short time periods and within small geographical areas (200 km). Thus, two GPS measurements across time can be subtracted (or differenced) to eliminate some of these factors. Similarly, simultaneous measurements from multiple GPS receivers can also be differenced. [29] This study propose 4 kind of differentials.

1) Single Differential across Receivers ($SD_{ij}^s(t)$):

$$\begin{aligned} \lambda \triangle \phi_{ij}^s &= \phi_i^s - \phi_j^s \\ &= \triangle\rho_{ij}^s + c \triangle t_{ij} - \lambda N_{ij} \end{aligned} \tag{4}$$

By differencing the phases at different receivers, correlated error sources of atmospheric delays and satellite clock biases disappear.
For further simplification, $\triangle\rho_{ij}^s$ is replaced by $\rho_{ij} \cdot \hat{l}_s$, where ρ_{ij} is the vector between two receivers and $\hat{l}_s$ is the line-of-sight unit vector from the receiver to the satellite. The transformation relationship is shown in figure 1.

The equation then become:

$$\lambda \triangle \phi_{ij}^s = \rho_{ij} \cdot \hat{l}_s + c \triangle t_{ij} - \lambda N_{ij} \tag{5}$$

2) Double Differential across Receivers and Satellites ($DD_{ij}^{sk}(t)$):

$$\begin{aligned}\lambda \bigtriangledown \triangle \phi_{ij}^{sk} &= \lambda \triangle \phi_{ij}^{s} - \lambda \triangle \phi_{ij}^{k} \\ &= \rho_{ij} \cdot (\hat{l}_s - \hat{l}_k) - \lambda \bigtriangledown \triangle N_{ij}^{sk}\end{aligned} \tag{6}$$

With the double differential, the clock error is further removed and the absolute orientation is achieved, but polluted by integer ambiguity. In this study, the spatio double differential forms our measurement model in the filtering process.

3) Single Differential across Time ($SD_i^s(t_{12})$): Similar to differentials across receivers and satellites, we can also perform differentials across time for the same receiver.

$$\lambda \triangle \phi_i^s(t_{12}) = \rho_i(t_{12}) \cdot \hat{l}_s + ct_i(t_{12}) \tag{7}$$

4) Double Differential across Receivers and Time ($DD_{ij}^s(t_1 t_2)$): By taking the difference between the two single differentials across time, we achieved a measurement the change in orientation, totally unpolluted by integer ambiguity. This measurement forms the system transition model in the filtering process.

$$\begin{aligned}\lambda \bigtriangledown \triangle \phi_{ij}^{s}(t_{12}) &= \lambda \triangle \phi_i^s(t_{12}) - \lambda \triangle \phi_j^s(t_{12}) \\ &= (\rho_{ij}(t_1) - \rho_{ij}(t_2)) \cdot \hat{l}_s + c \triangle t_{ij}(t_{12})\end{aligned} \tag{8}$$

C. System Model

III. Conclusion

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Appendix A
Proof of the First Zonklar Equation

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Appendix B

Appendix two text goes here.

Acknowledgment

The authors would like to thank...

References

[1] H. Kopka and P. W. Daly, *A Guide to LATEX*, 3rd ed. Harlow, England: Addison-Wesley, 1999.

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Michael Shell Biography text here.

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