Detection of Thermospheric Density Variations via Spacecraft Accelerations Observed Using the CASSIOPE GAP Instrument: Initial Investigations

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Introduction

As one of eight instruments of the Enhanced Polar Outflow Probe (e-POP) payload on the Canadian CAScade, Smallsat and Ionospheric Polar Explorer (CASSIOPE) small satellite (Figure 3), the GPS Attitude, Positioning, and Profiling experiment (GAP) can employ one or more of the four GAP-A dual-frequency GPS receivers and associated zenith-facing antennas (Figures 2 and 9) to provide high-resolution spatial positioning information, flight path velocity determination, and real-time, high-stability timing. Preliminary processing of raw GPS data acquired from the GAP-A GPS receivers using the University of New Brunswick’s (UNB) CASSIOPE Atmospheric Profiling and Positioning Software (CAPPS) and International GNSS Service (IGS) precise products has produced sub-decimetre root-mean-square positions and correspondingly-accurate velocities for the CASSIOPE spacecraft. Spacecraft acceleration can also be determined by subsequent processing of the velocity estimates.

Methodology

The CAPPS utility is a specially-designed low-Earth-orbit (LEO) processing engine capable of providing highly-accurate estimates of LEO spacecraft orbits as well as correspondingly-accurate spacecraft velocities and accelerations. The current software implementation utilizes the point precision positioning (PPP) technique using dual-frequency ionosphere-free GPS observables and IGS final orbit and clock products to perform a purely-kinematic approach to precise orbit determination (POD) at a sub-decimetre RMS level with future goals of achieving centimetre-level accuracies. Following the estimation of spacecraft position, time-differenced carrier-phase (TDCP) observables are used to determine spacecraft velocity and acceleration at a mm/s and mm/m²/s level, respectively (Serrano et al., 2004). Equations 1 and 2 illustrate the observables and observation equations used in CAPPS’ velocity and acceleration estimation algorithms. Figure 4 summarizes CAPPS’ current position, velocity, and acceleration estimation workflow.

\[
\begin{align*}
\mathbf{\hat{r}}_{k+1} &= \mathbf{\hat{r}}_k + \mathbf{v}_k \Delta t + \mathbf{a}_k \frac{\Delta t^2}{2} \\
\mathbf{\hat{v}}_{k+1} &= \mathbf{\hat{v}}_k + \mathbf{a}_k \Delta t + \mathbf{\xi}_k
\end{align*}
\]

\[\text{Cycle-slip/outlier/data-gap detection}\]

\[\text{Process IGS Final orbits and clocks}\]

\[\text{Dual-frequency pseudorange-only point positioning estimation}\]

\[\text{Dual-frequency ionosphere-free carrier-phase/pseudorange PPP POD}\]

\[\text{Combined TDCP velocity and acceleration estimation}\]

Initial Results

While the CAPPS utility remains a work in progress, initial processing results provide insight into the feasibility of the PPP-POD algorithm as well as the achievable accuracies of its initial spacecraft position and velocity estimations. Unfortunately, a majority of the available GAP-A GPS observation data has random data gaps most likely attributed to a boisterous-keeping of high-volume receiver information. As seen in Figure 5, these data gaps necessitate regular resets of carrier-phase float ambiguity estimates and subsequent re-convergence of estimated parameters. A solution to avoid future data bottle-necking issues is currently being investigated with the assistance of the University of Calgary. Figure 6 illustrates the behavior of data gaps observed for CASSIOPE GAP-A receiver 1 on October 1, 2016.

![Figure 6: Observed gaps in observation data for CASSIOPE GAP](image)

Despite the occurrence of these data gaps, preliminary results demonstrate the achieveability of sub-decimetre RMS accuracies for CASSIOPE orbit determination. Figures 7 and 8 show 3-Hz spacecraft position estimates (represented in Keyhole Markup Language format using Google Earth) and associated position component standard deviations (1-sigma) for CASSIOPE GAP-A receiver 1 on May 5, 2017.

![Figure 8: Estimated magnitude of spacecraft velocity for CASSIOPE GAP-A receiver 1 on May 5, 2017](image)

References


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