Contribution ID: **37** Type: **talk**

Doppler Based Orbit Determination with Optimization

Sunday, 13 December 2020 15:10 (20 minutes)

Space Situational Awareness (SSA) is becoming more and more important as the number of satellites is increasing. The body of knowledge for SSA relies on the tracking data to determine the orbit of artificial objects in Earth orbit. Determining orbit is basically obtaining the state vector, that is the position and velocity vectors, or equivalently obtaining the classical orbital elements at a specific time. The state vector uniquely determines the orbit of a satellite, and the accuracy of this orbit determination is important to pursue a successful space mission. There are different kinds of orbit determination techniques which relies on different kinds of tracking data. In this study, the Doppler data of a single pass are used to determine the orbit of a satellite.

Guier and Weiffenbach discovered the potential of the Doppler effect to determine orbit of a satellite. It was the very beginning of the Space Era with the launch of Sputnik in 1957. They published their first paper, Theoretical Analysis of Doppler Radio Signals from Earth Satellite, on Nature in 1958. They searched for orbits of the Sputnik 1 and Explorer 1 in the paper.

Doppler shift is a fundamental phenomenon for the waves. It can be summarized as the change in the frequency due to the relative motion of the source and the observer. The change in the frequency can be calculated as $\Delta f = \frac{\Delta v}{c} f_0$ where c is the speed of light, Δv is the difference between the velocity of the source and the receiver, and lastly f_0 is the transmitted frequency. Thus, Δv gives the rate of change of the distance between the source and the observer, and it can be represented as $\dot{\rho} = \vec{v} \cdot \left(\frac{\vec{\rho}}{\rho}\right)$ where $\vec{\rho}$ is the relative position vector of the source with respect to the receiver. This means that Δf equals 0 for the case when the $\vec{v}$ and $\vec{\rho}$ vectors are orthogonal. This happens at the maximum elevation of the satellite with respect to the observer which is the configuration corresponding to the closest distance between the satellite and the observer.

In this study, the Doppler data are obtained from the observations and also generated from the TLE data. To generate artificial Doppler data from TLE, a two-body propagator is used to simplify calculations. Then, the Doppler data are used to determine the orbit. We aimed to determine the orbit by using minimum information of the observed satellite. Simply, we just "heard" the satellite. Under this uninformed situation, it is convenient to apply optimization techniques. For this application, there is a need for having some constraints on the parameter space of the possible orbit. Mainly, the satellite is assumed to be in the low Earth orbit. Thus, the altitude is constrained to be between 200 km to 2000 km. This conraint provides the domain of the semi-major axis and the upper bound of the eccentricity. Actually, these assumptions decreased the search space of the optimization and made the application affordable in terms of computation time.

To have the preliminary orbit determination from the Doppler data, the optimization technique that we used is the particle swarm optimization (PSO). After having the preliminary orbit determination with PSO, a gradient based optimization is further used to increase the accuracy of results. Then, differential correction is also used to further increase the accuracy.

We applied this approach for both the generated artificial data and the real data. In the real data that we obtained from our ground station #510 in the SatNOGS network, there was a difference between the received transmitter frequency and the specified transmitter frequency of the satellite, and this fact decreased the accuracy of our results.

To conclude, we studied the Doppler data based orbit determination for uniformed situations of the satellite orbit. For the cases of near circular orbits, the results become more accurate. In addition, if the exact transmitted frequency info is known, it is possible to obtain fairly accurate orbit determination results.

Primary author: Mr ERTÜRK, Mehmet Fatih (Istanbul Technical University & University of Turkish Aeronautical Association)

Session Classification: Room #2