On-Board Orbit Determination and Modelling for LEO spacecraft

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On-Board Orbit Determination for LEO spacecrafts

Onboard Orbit determination (OD) and modelling for LEO satellite state vectors (PNT) using single frequency GPS code and carrier phase measurements based on Extended Kalman Filter with reduce dynamic methods in ECEF frame

Objective

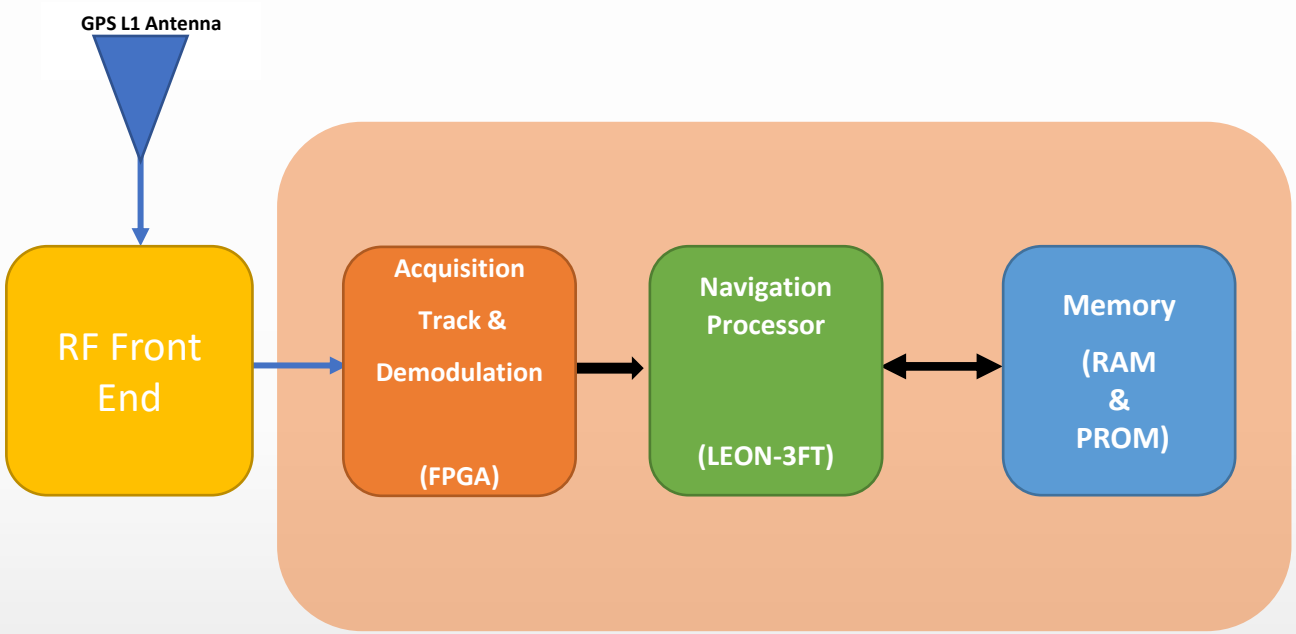
- *Models and Filter to cater to OD requirement, with limited time and resources available on-board for LEO satellites.*
- *Precise State Vectors availability even in the absence of signals for 30 minutes*
- *Precise Clock Information for Spacecraft Time synchronization*
- *Highly precise knowledge of LEO orbit, required for remote sensing and science missions.*

Performance

S.N	Parameter	Estimation Accuracy (3σ)
1	Position Accuracy	3 m
2	Velocity Accuracy	5 mm/s
3	Timing Accuracy	30 ns

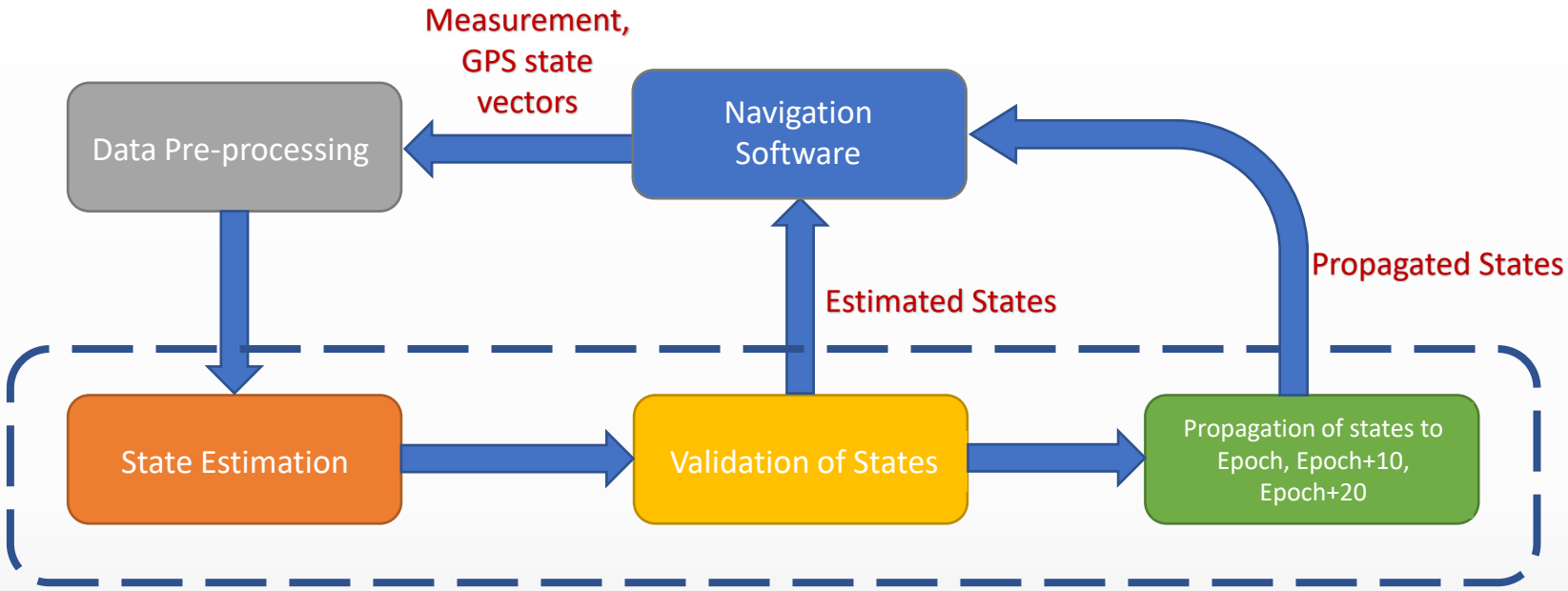
System Architecture

Navigation Receiver using GPS signals provides accurate state vectors and UTC referenced time to spacecraft systems.



- **Antenna** - Single frequency GPS-L1 antenna
- **RF Front End** – L1 Amplifier, Filters, Down-Convertor and ADC
- **FPGA** – Acquisition, Tracking and Demodulation
- **Navigation Processor** – Generates and processes measurements and computes PNT
- **Memory** – Code and Data storage

Navigation Processor Architecture



Core Navigation Software
Frame sync, Navigation algorithm, measurement generation, instantaneous state vectors computation, TM/TC and system manager

Data processing
Smoothening of GPS code and carrier phase measurements.
Detects outliers and cycle slips

Estimation and Propagation
EKF based LEO satellite state vectors and RK4 based satellite orbit propagation

Validation
Successive estimation difference, measurement based validation and flag generation.

- **All the modules are executed, once every second**
- **Estimation and Propagation are time & resource intensive, hence implementation is highly optimized.**

Modelling

Data processing

- *Outlier detection of code range measurements using max & min Range rate bounds, max & min range bounds, SNR*
- *Cycle Slip detection.*
- *Compute Iono error free combination*
- *Smoothening*

Estimation

Estimated parameters (states -X) are

- *LEO Satellite Position, Velocity, Clock Bias*
- *Reflectivity (Cr) and ballistic (Cd) Coefficient*
- *Residual acceleration in 3 R,T,N directions of orbit*
- *Integer ambiguity (at every LOS)*

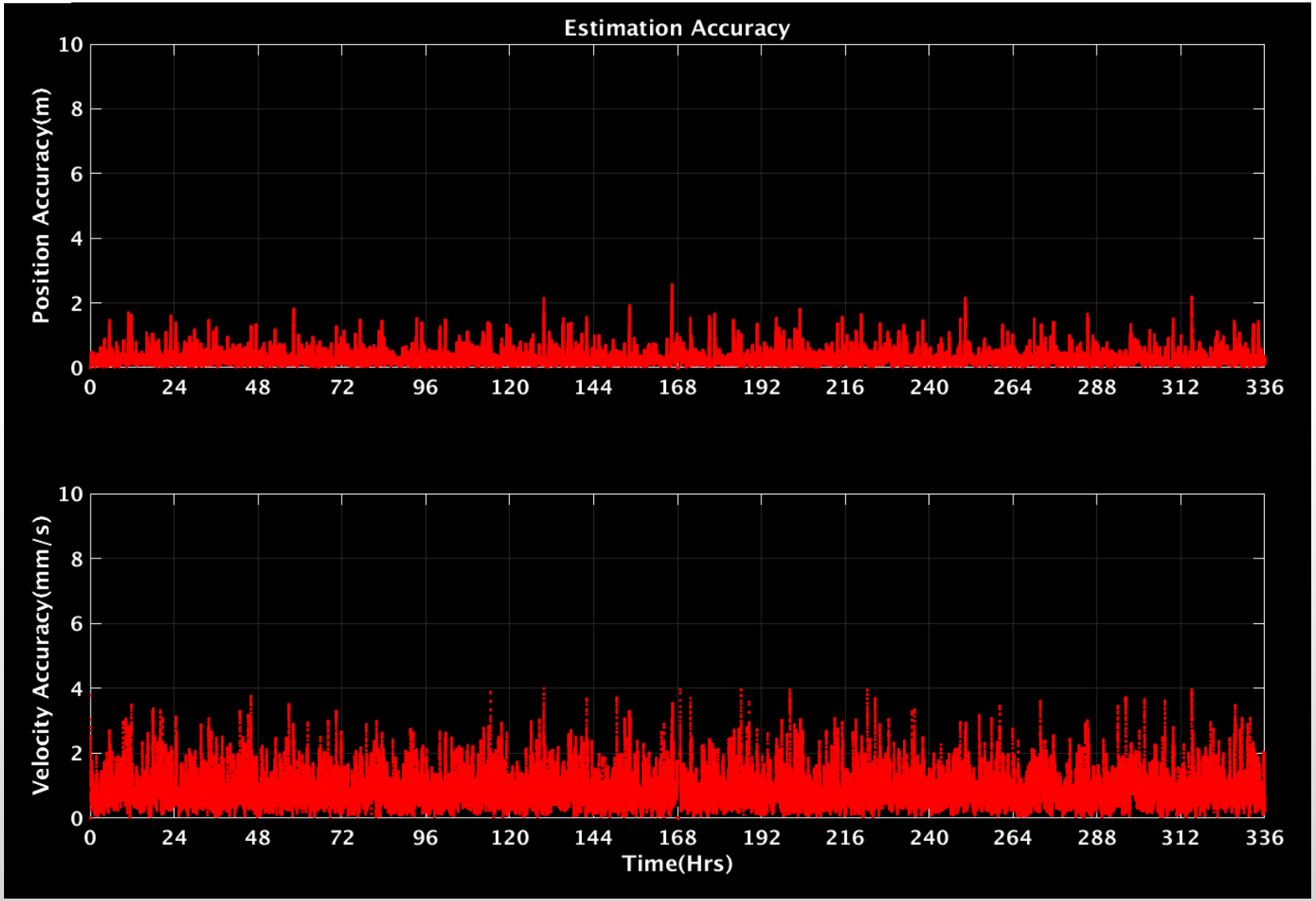
Details of Orbit Model
Reference Coordinate System
Earth Gravity
Third Body Perturbation
Drag Model
Solar Radiation Pressure
Station keeping
Relativistic
Numerical Integration
Additional Forces

Range Modelling

Modelled Receiver , Satellite and Transmission related errors, viz.,

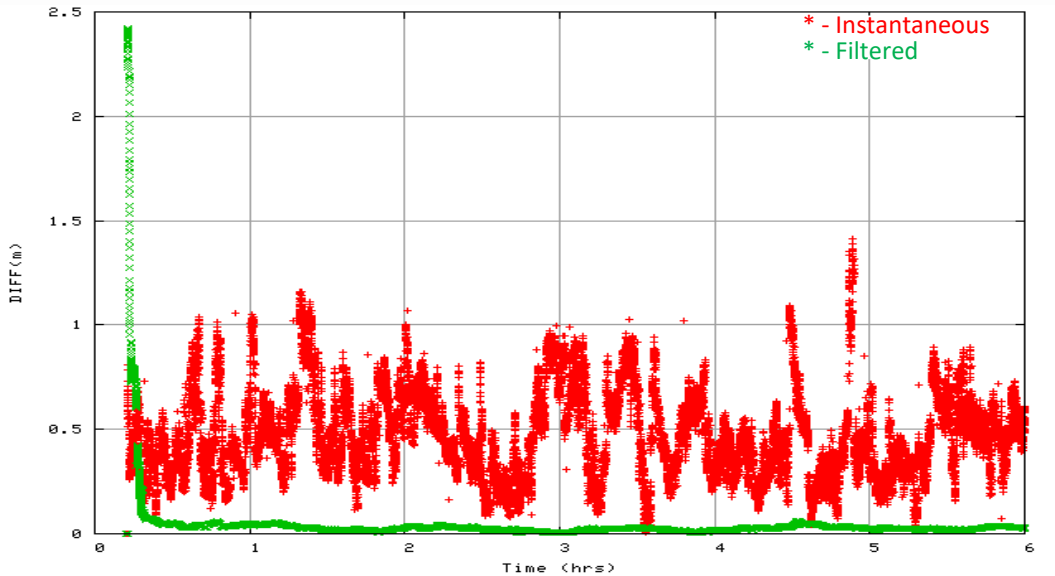
- ✓ *Residual atmospheric errors due to ionosphere refraction (SF-code alone)*
- ✓ *Relativistic errors due to Earth and satellite motion (Sagnac Effect)*
- ✓ *Satellite and receiver side clock offsets, antenna phase centre offsets*

Simulation Results

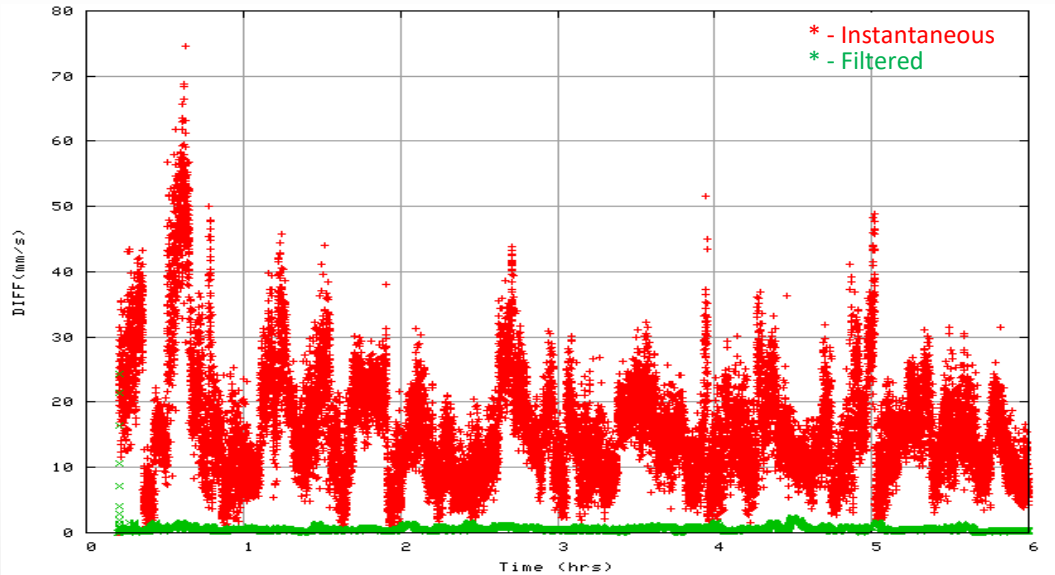


- Orbit determination algorithms executed standalone
- Algorithms verified using Single frequency Code and Carrier measurements available from GRACE-A satellite
- Results
  - Position Accuracy < 2m
  - Velocity Accuracy <5mm/sec

Receiver Results



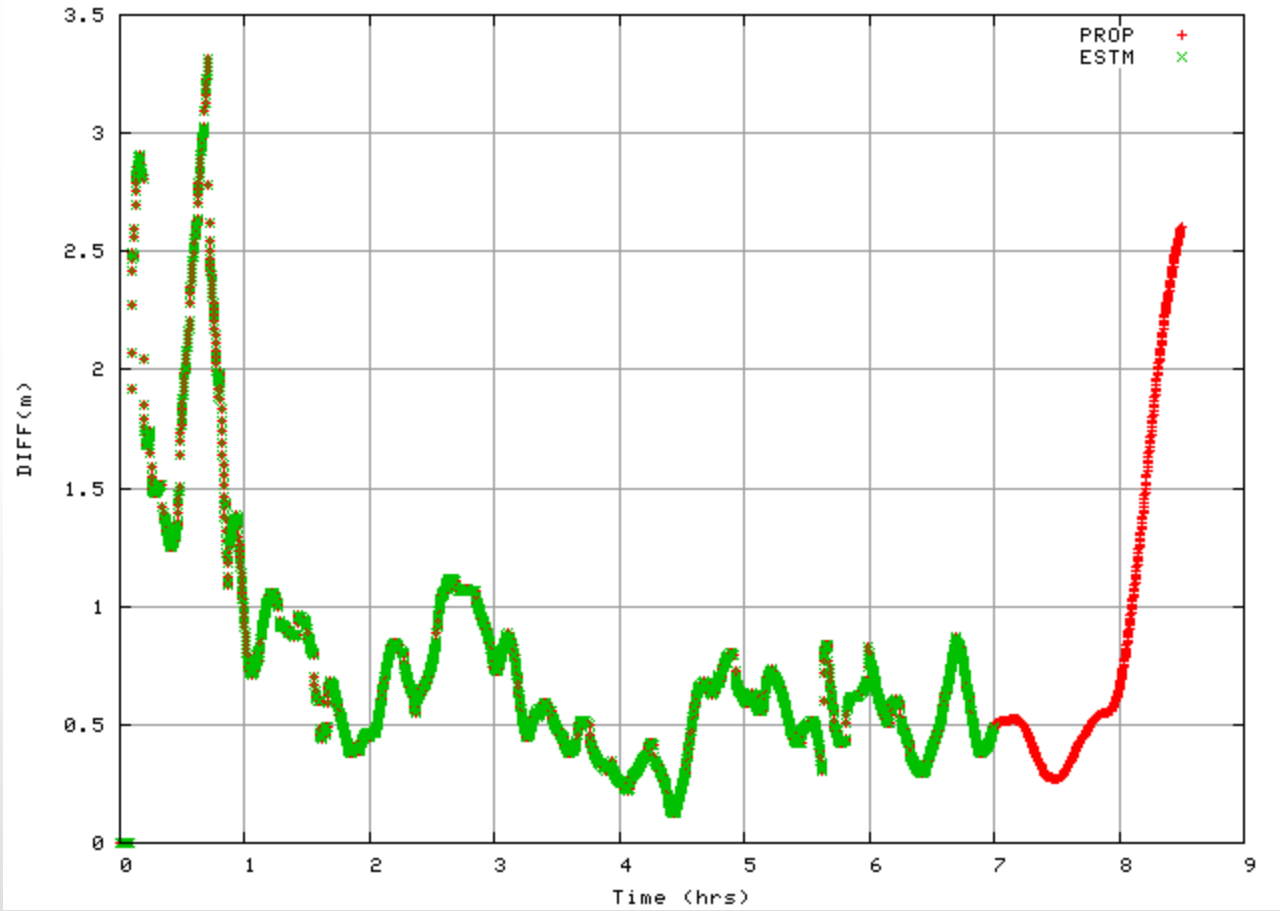
Instantaneous and Filtered Position



Instantaneous and Filtered Velocity

- Signal generated from SPIRENT Constellation Simulator
- Simulated LEO Orbit and signal fed to a receiver executing the orbit determination algorithms
- Results
  - Position Accuracy < 1m
  - Velocity Accuracy <5mm/sec

Prediction Results



Orbit propagated for 1 Hour

Conclusion

- *Models, Methods and techniques optimized to implement the orbit determination and Propagation algorithms on-board, which provides*
  - *Precise Orbit solution*
  - *Continuous smooth on-board orbit solution availability, even when GPS measurements are less than 4*
  - *Outages of up to 30 minutes can be handled with an accuracy of 3 to 4 m, as propagation is part of EKF estimation*
- *System provides the effective on-board autonomy for remote sensing and science mission applications such as altimetry, gravimetry, SAR interferometry, atmospheric sounding etc*
- *System supports absolute navigation as well as relative navigation and formation flying missions, with change of application firmware.*

THANK YOU