Extended Kalman Filter Based Onboard Orbit Determination Using GNSS Receiver For LEO And GEO Satellites

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Introduction

Objective

Instantaneous smooth and precise estimation of LEO/GEO satellite position and velocity in near real time using single/dual frequency code and carrier phase GPS measurements based on Extended Kalman Filter (EKF) with reduced dynamic method for onboard implementation

Scope

- ✓ *Precise knowledge of LEO orbit required for remote sensing missions and in science mission applications*
- ✓ *ECEF based reduced dynamic EKF to cater to this requirement, with limited time and resources available on-board of LEO satellites*
- ✓ *Extension of this technique to autonomous precise orbit estimation of GEO satellites*

Accuracy

Using dual frequency code and carrier phase measurements (LEO)

Instantaneous accuracy: 1-2 m (position) and < 4-5mm/s (velocity)

Prediction Period: < 2-5m Position Error (LEO) in 1 hour

Using Single frequency code and carrier phase measurements (LEO)

Instantaneous accuracy: 2-3 m (position) and < 5-6mm/s (velocity)

Prediction Period: < 5-7m Position Error (LEO) in 1 hour

Methodology

Data processing

- Outlier detection of range measurements
- Cycle Slip detection using rate of L4 & L6 measurements.
- Dual - Compute P3 and L3 Iono error free combination
- Single – Compute Iono error free combination (P1+L1)/2
- Smoothening of P3

Estimation

Estimated parameters (states -X) are

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

$$X(t)_{44} = \left(x, y, z, v_x, v_y, v_z, b_0, Cr, Cd, R, T, N, \ldots\right)^T$$

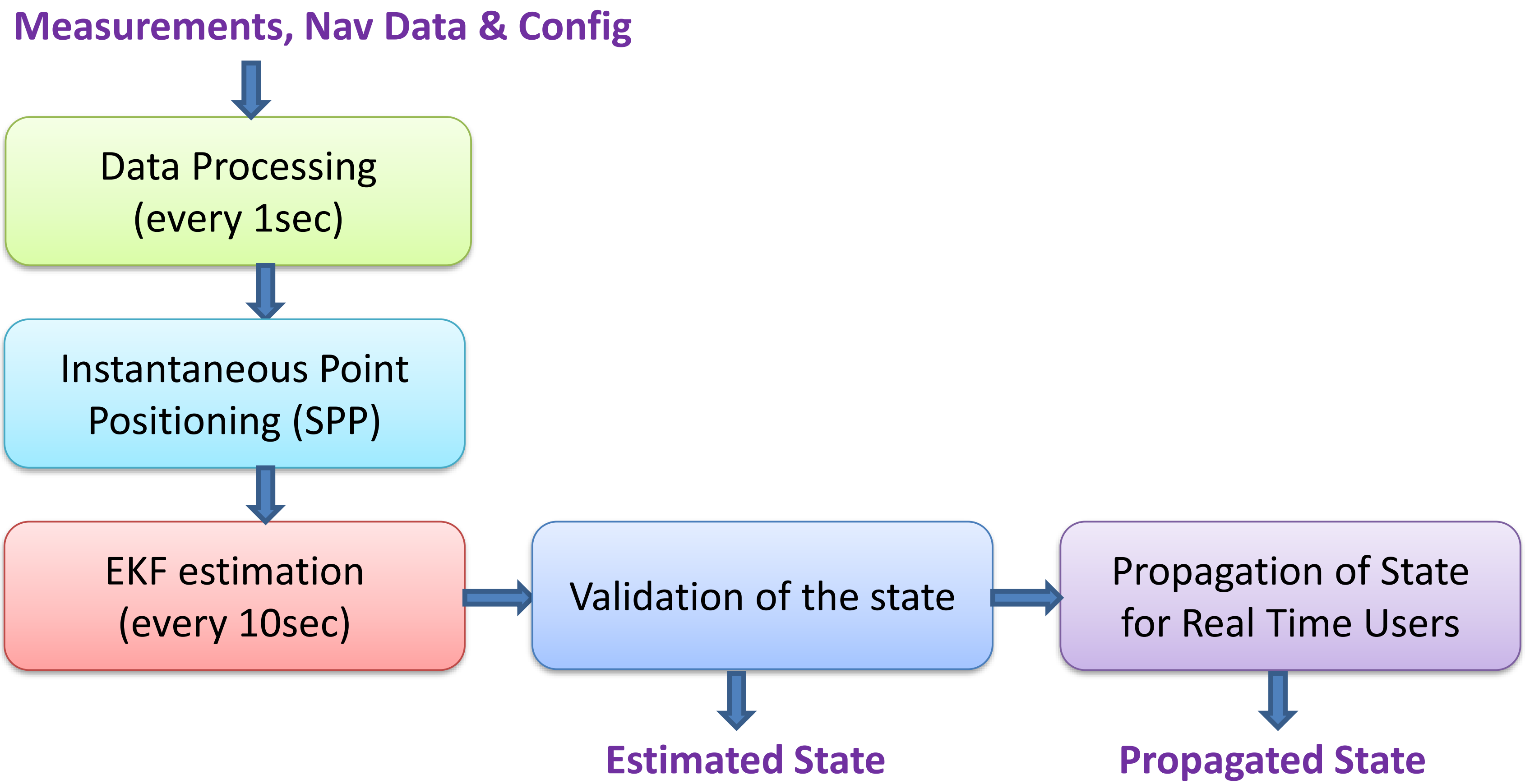
Details of Orbit Model	
Reference Coordinate System	ECEF
Earth Gravity	EGM 2008
Third Body Perturbation	Sun, Moon Empiricial Formula
Drag Model	Harris-Priester
Solar Radiation Pressure	Empirical SRP model
Relativistic	Mathematical formulation
Numerical Integration	Runge-Kutta (4th order)
Additional Forces	Coriolis, Centrifugal

Range Modelling

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

- ✓ Relativistic errors due to Earth and satellite motion (Sagnac Effect)
- ✓ Satellite and receiver clock offsets
- ✓ Antenna phase centre offsets, variations and biases

Software Design

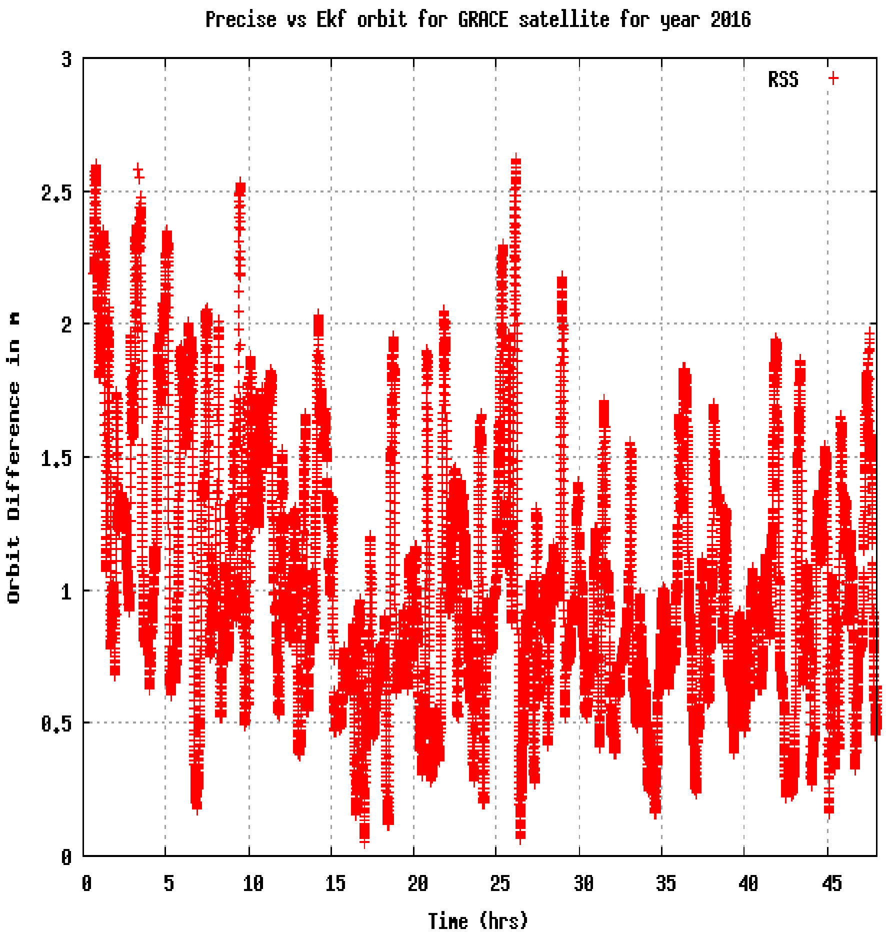


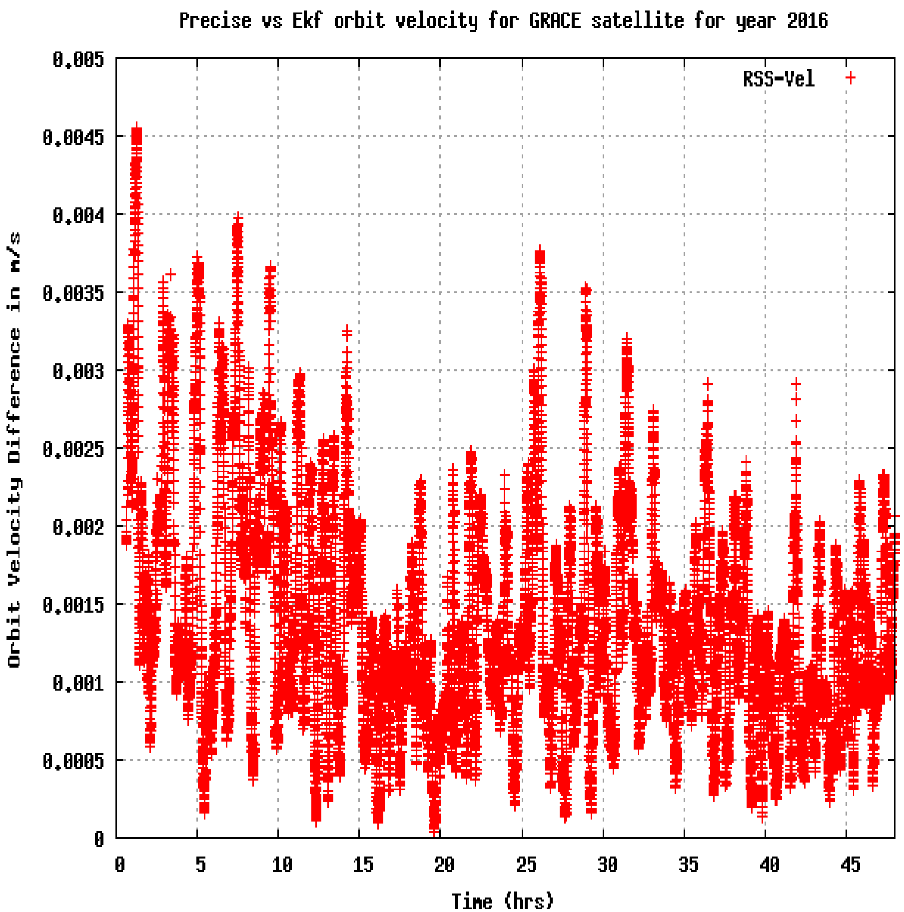
Environment:

TSIM Simulator Evaluation used for onboard environment simulation

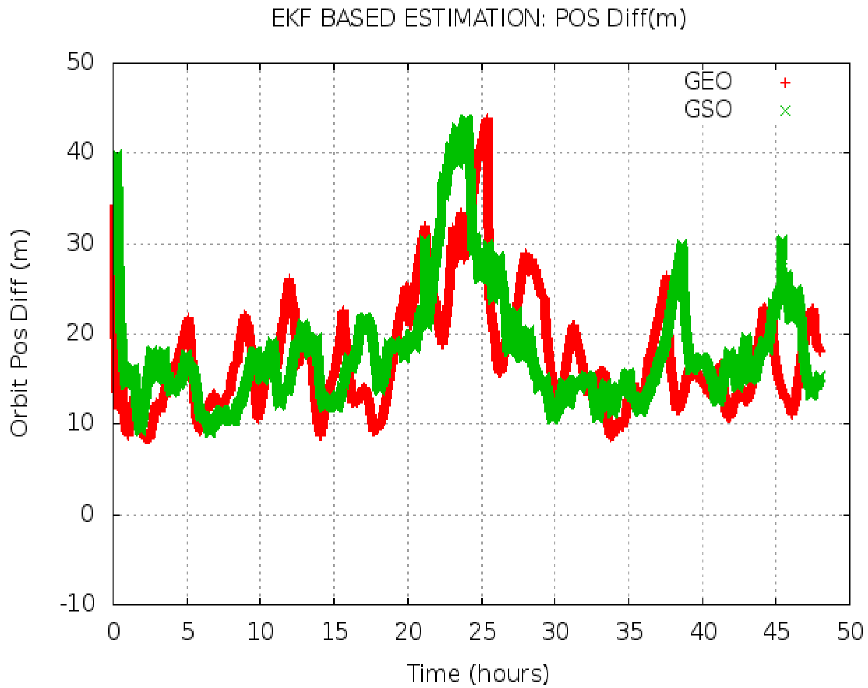
Software execution with 40MHz Proc Speed, 4MB RAM & H/w FPU

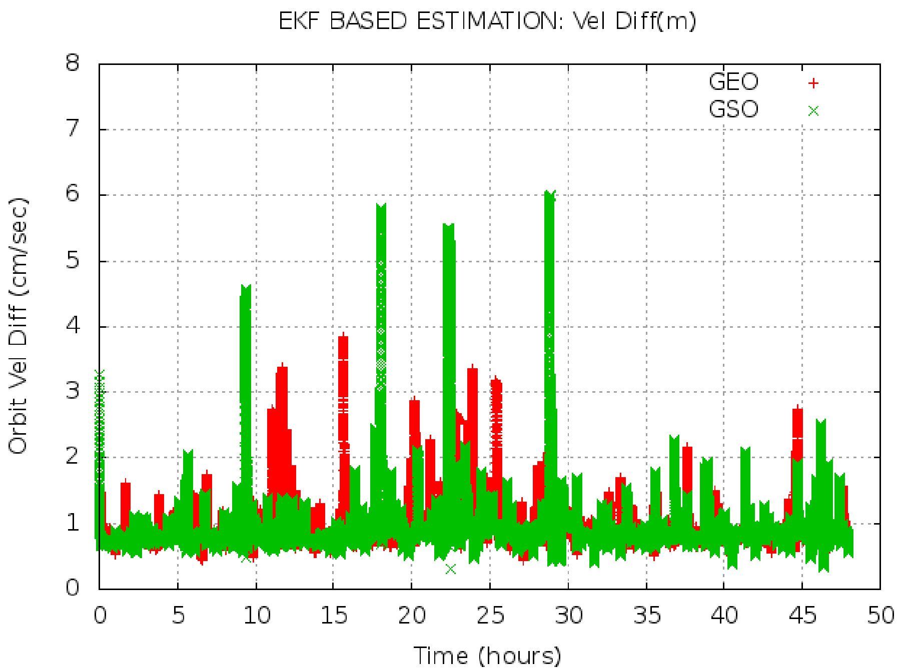
EKF Vs Precise Estimated orbit of GRACE satellite using dual frequency carrier phase measurements





Sample Results (GEO/GSO Satellite)





Summary

Spacecraft	Single (Code +Carrier)	Dual (Code + Carrier)
GRACE	Pos.: 2.1m Vel.: 3.5 mm/s	Pos.: 1.2m Vel.: 2.5 mm/s
COSMIC	Pos.: 1.8m Vel.: 3.5mm/s	Pos.: 0.8m Vel.: 1.6 mm/s
NAVIC GEO	-	Pos.: 12.1 m Vel.: 0.9 cm/s
NAVIC GSO	-	Pos.: 12.4 m Vel.: 1.1 cm/s

Advantages of Proposed Algorithm

- *Continuous smooth orbit solution availability, even when the number of GPS measurements is less than 4 (which is the minimum requirement for SPS solution)*
  - The measurement update have been done sequentially at every Line of Sight (LOS)
  - Filter initialization will be happen with Onboard solution or SPP solution(with velocity derived using multiple points interpolation)
  - Estimation have been done at an interval with best smooth measurements
  - Validation of the filter estimated state using SPP and onboard solution
- *Outages of up to 60 minutes can be handled onboard LEO satellites with an accuracy of 2 to 5 m*

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