Near Real-Time Global Density Estimation Using Satellite Precision Orbit Ephemerides

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Outline

- Background
- Paper Structure
- Research strategy
- Experiments and simulation study
- Conclusion

Backgound

- Background

  A predominate source of dynamical model uncertainty for low Earth-orbiting (LEO) spacecraft is incapable of properly modelling all of the density variations in the Earth's upper atmosphere.

  Jacchia-Roberts or MSISE-90 can only approach 10% accuracy in quiet conditions and 20%-30% in high solar activity.

  Improved knowledge of upper atmospheric density will allow for improved orbit determination, which will help prevent collisions, as well as improve prediction of satellite life-spans.

- Concerning Research

  Recently, Dynamic calibration of the atmosphere (DCA) and onboard accelerometers derived densities methods are popular.

Backgound

- Dynamic calibration of the atmosphere (DCA)

  Cefola used TLE data to creat corrections to Russian GOST model, which are made for a one day grid using the TLE data as well as solar and geomagnetic activity data as inputs with hundreds of satellites in LEO are examined from April 2002 to January 2003.

  Storz utilized 75 inactive payloads and debris to solve for a global correction to density that changes dynamically in the thermosphere and exosphere every three hours, which is called the High Accuracy Satellite Drag Model (HASDM).

  Doornbos used TLE data to calibrate the neutral density of the thermosphere, and improvements were made in error from around 30% for the base models to around 15% using a single daily parameter.

Backgound

- Onboard accelerometers derived densities

  Bruinsma and Biancale first derived density from CHAMP accelerometer data, and Schlegel used [6] the CHAMP accelerometer to characterize thermospheric density structures in polar regions.

  Collaboration between the Centre National d'Études Spatiales (CNES) and the University of Colorado researchers produced several publications using accelerometer data from CHAMP and GRACE.

  Bruinsma and Forbes further examined the use of the STAR accelerometer aboard CHAMP to identify density variability.

Backgound

DCA also models the atmosphere discretely based on the intervals of input data. Finally, the use of TLE data by most DCA schemes limits the accuracy of the results. And, these approaches are limited temporally by the use of daily solar flux or averaged geomagnetic indices.

A weakness of the accelerometer density method is the low number of spacecraft and limited altitude ranges and spatial coverage.

DCA on the other hand, possesses many satellites and a great deal of data but is not nearly as accurate.

James R. Wright , Eric Dale Fattig, and Andrew Timothy Hiatt demonstrated the simultaneous real-time estimation of both atmospheric density and ballistic coefficient with simulated range data and with real range data.

Paper Structure

This paper firstly introduces the research strategy briefly including processing strategies, data, and results analysis.

Then, based on the strategy various scenarios are selected as experiments by EPOS-RT for simultaneous real-time estimation of both atmospheric density and ballistic coefficient.

Finally, the results of experiments are analyzed in detailed before the conclusions are drawn.

Research strategy

- Orbital drag acceleration,

$$a_D = -\frac{1}{2}\frac{C_D A}{M}\rho V^2$$

- The estimation errors in LEO air-drag accelerations are due most significantly to random errors in modelled atmospheric density ρ and ballistic coefficient B,

$$\Delta a_D = (\frac{\Delta B}{B} + \frac{\Delta \rho}{\rho}) a_D$$

- The baseline atmospheric model chosen generates a density, ρ. Corrections to the density, Δρ/ρ, and corrections to the ballistic coefficient, ΔB/B, are generated from the estimation process.

Research strategy

- Given x = x(t) is a dynamic scalar random variable, which in this case is either density or ballistic coefficient, the following equation is satisfied for an exponential Gauss-Markov sequence,

$$x(t_{k+1}) = \Phi(t_k, t_{k+1}) x(t_k) + \sqrt{1 - \Phi^2(t_{k+1}, t_k)}\, w(t_k)$$

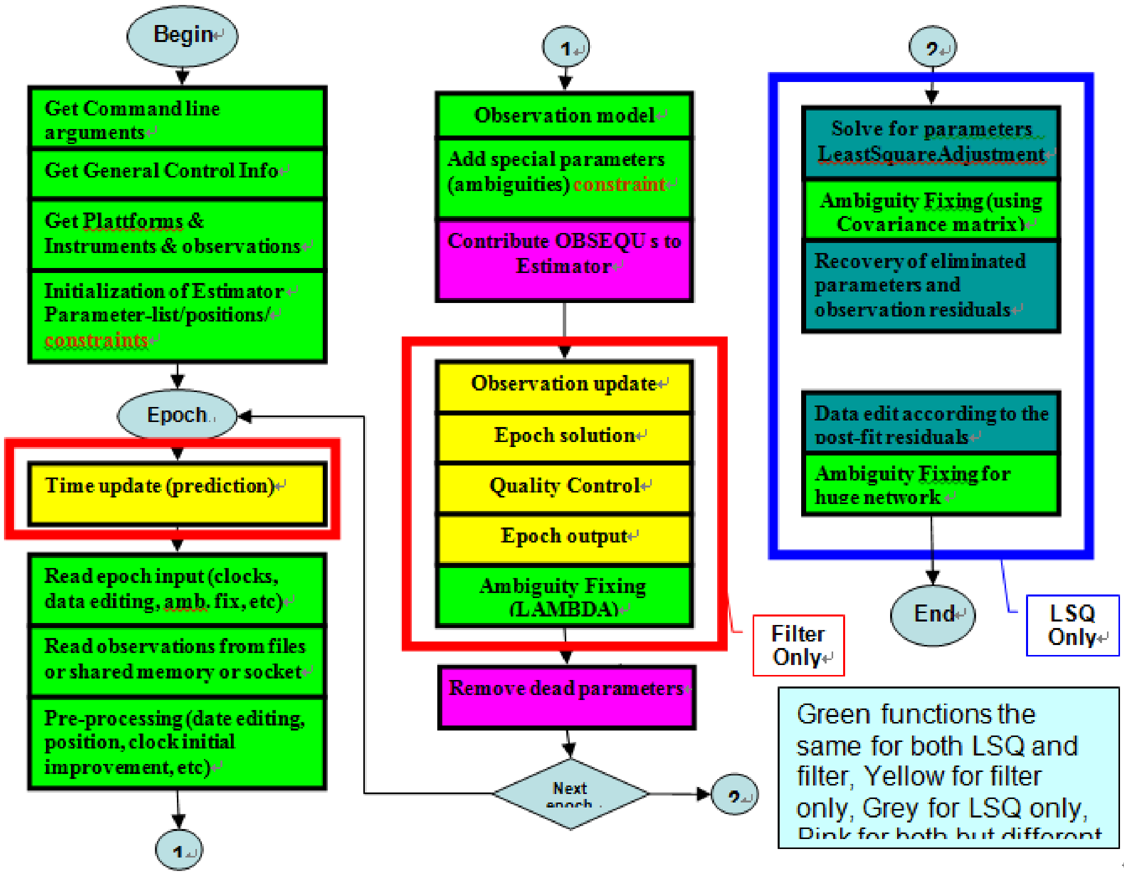
$$\Phi(t_k, t_{k+1}) = e^{\alpha |t_{k+1} - t_k|}$$

$$\alpha = \ln(1/2) \big/ \tau$$

- The half-life, τ, is the half-life input by the user.

Research strategy

- EPOS-RT is designed and developed recently at GFZ for real-time applications with the capability of integrated adjustment with GNSS data, accelerometer data, K-band range and range-rate data, and ground-based SLR data.



Research strategy

- we compare the POE derived densities to accelerometer derived densities with cross correlation coefficient, which is a non-dimensional number which can be between -1 to +1 and is to quantify how two signals correlate.

$$CC = \frac{\sum_{i=1}^{N}\left[(x(i)-\overline{x})(y(i)-\overline{y})\right]}{\sqrt{\sum_{i=1}^{N}(x(i)-\overline{x})^2}\sqrt{\sum_{i=1}^{N}(y(i)-\overline{y})^2}}$$

Experiments and simulation study

- Data sets

  GRACE-A POE on day 001 in 2010, GRACE-B POE on day 001 in 2008, and accelerometer derived densities from Version 2.2 densities .

- Based atmospheric models

  Multiple atmospheric models are examined, including Jacchia 1971, Jacchia-Roberts , the Committee on Space Research (COSPAR) International Reference Atmosphere, CIRA 1972 , and the Naval Research Laboratory MSISE model (NRLMSISE 2000).

- The nominal ballistic coefficient of GRACE is 0.00687 m2/kg

Experiments and simulation study

- The satellite force models

Satellite force models	Description
Mean earth gravity	EGM96 120×120
N-body	DE 405 (SUN MOON MERC VENU MARS JUPI SATU)
Solid earth tide	IERS 2003
Ocean tide	CSR 4.0
Solar radiation	Computed for all panels
Relativity	IERS 2003
Atmospheric drag	DTM94
Empirical force	2 parameters in each ACR directions
Integrator	Step: 5 s, Adams order: 7
Atmospheric density half-life	180 min [15]
Ballistic coefficient half-life	1.8 min [15]

Experiments and simulation study

- The surface properties of GRACE for computing the solar radiation pressure

Panel	Area(m2)	Unit Normal			Emiss	Absorp
		X	Y	Z		
Front	0.9551567	+1.0	0.0	0.0	0.62	0.34
Rear	0.9551567	-1.0	0.0	0.0	0.62	0.34
Starboard (outer)	3.1554792	0.0	+0.766044	-0.642787	0.81	0.65
Starboard (inner)	0.2282913	0.0	-0.766044	+0.642787	0.62	0.34
Port (outer)	3.1554792	0.0	-0.766044	-0.642787	0.81	0.65
Port (inner)	0.2282913	0.0	+0.766044	+0.642787	0.62	0.34
Nadir	6.0711120	0.0	0.0	+1.0	0.75	0.12
Zenith	2.1673620	0.0	0.0	-1.0	0.81	0.65
Boom	0.0461901	——	——	——	0.62	0.34

Experiments and simulation study

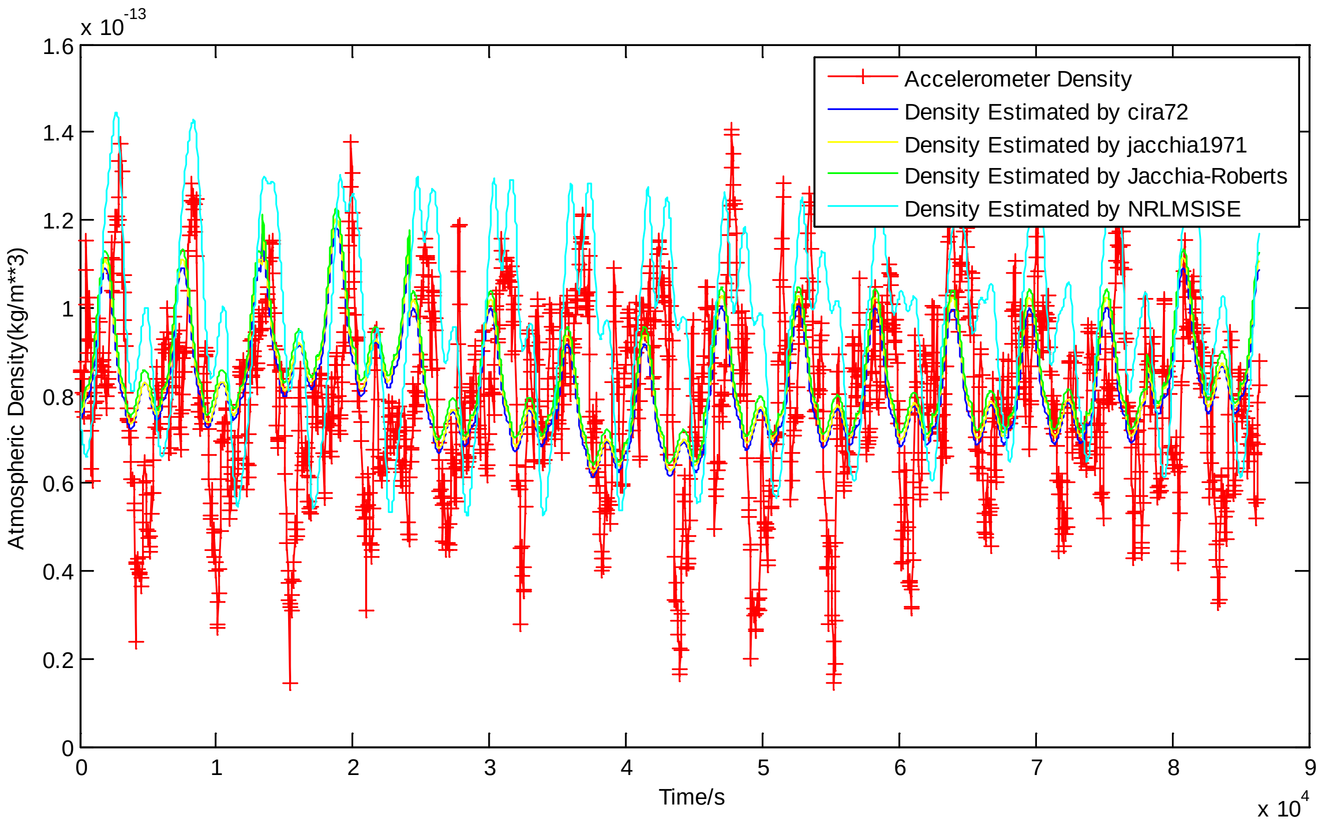


Figure 1 POE Estimated Density Based on Jacchia 1971, Jacchia-Roberts, CIRA 1972, NRLMSISE 2000 Model Density and Accelerometer Density of GRACE-B Satellites for Jan. 1, 2008.

Experiments and simulation study

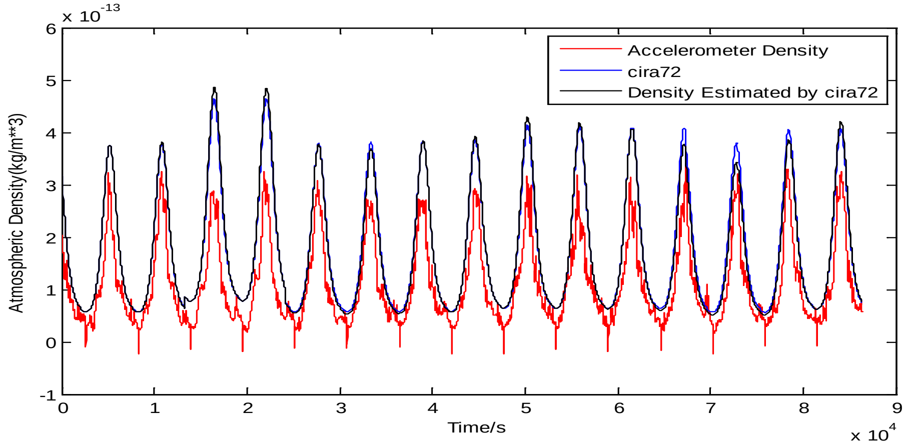


Figure 2 POE Estimated Density Based on CIRA 1972, CIRA 1972 Model Density and Accelerometer Density of GRACE-A Satellites for Jan. 1, 2010.

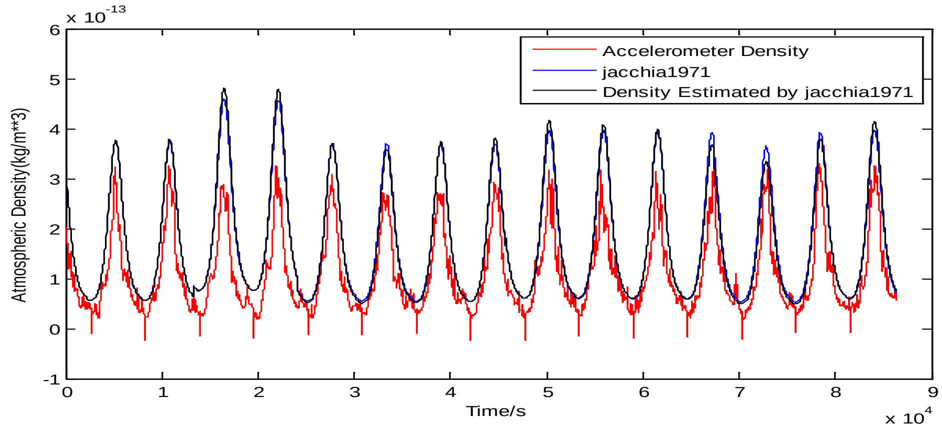


Figure 3 POE Estimated Density Based on Jacchia 1971, Jacchia 1971 Model Density and Accelerometer Density of GRACE-A Satellites for Jan. 1, 2010.

Experiments and simulation study

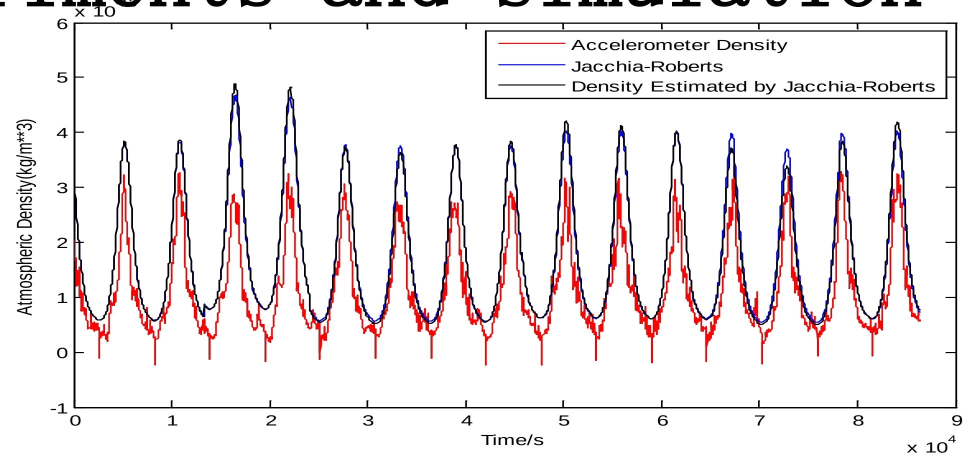


Figure 4 POE Estimated Density Based on Jacchia-Roberts, Jacchia-Roberts Model Density and Accelerometer Density of GRACE-A Satellites for Jan. 1, 2010.

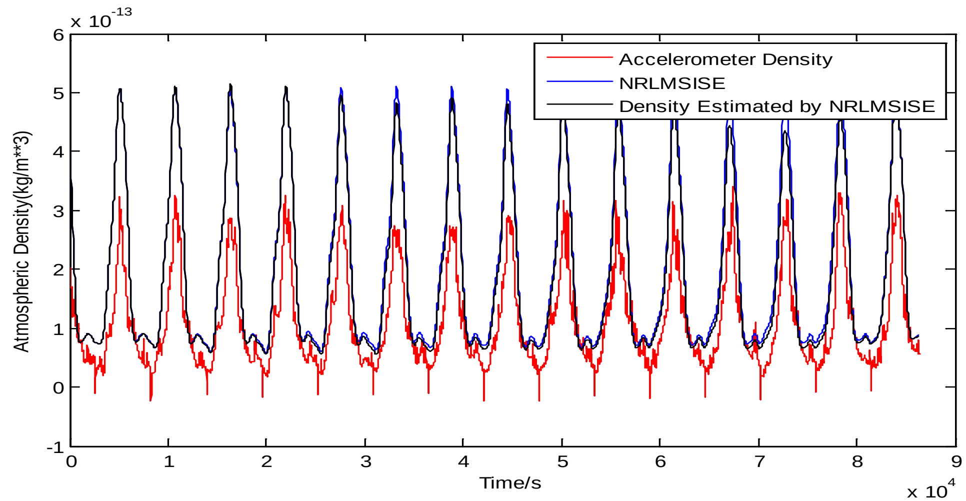


Figure 5 POE Estimated Density Based on NRLMSISE 2000, NRLMSISE 2000 Model Density and Accelerometer Density of GRACE-A Satellites for Jan. 1, 2010.

Conclusion

		Cira72	Jacchia 1971	Jacchia-Roberts	NRLMSISE 2000
GRACE-A	Model	0.9488	0.9482	0.9483	0.9604
	Estimated	0.9576	0.9566	0.9568	0.9618
GRACE-B	Model	0.8011	0.8014	0.8010	0.8094
	Estimated	0.8189	0.8214	0.8188	0.8282

- First the POE estimated densities are superior to model density in comparison with accelerometer density.
- Secondly, the CIRA-1972, Jacchia 1971, Jacchia-Roberts, and NRLMSISE 2000 based POE density estimates all have very similar results with very slight differences between them.
- The preliminary research shows that the processing stragies is feasible and build up a good basis for simultaneous real-time estimation of both atmospheric density and ballistic coefficient.
- However, there are many jobs to do in the future, including specifying the ballistic coefficient correlated half-life and density correlated half-life, investigating the effect of solar activity and geomagnetic activity on atmospheric density estimates, and considering the sensitivity of the density estimates to the initial ballistic coefficient.

Thanks !

Questions ?

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