Orbital Anomaly Detection and Application of Space Object

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Beijing, China
Summary

- Introduction
- Methodology
- Results & Comparison
- Anomaly
- Further Research
Introduction

☑ Significance:

Detection of space events such as maneuvers, explosions, collisions, fragmentations and sudden changes of space weather are significant.
Introduction

☑ Significance:

Patera: Moving Window Curve Fit method (MWCF)

Swartz: Space Incident Flagging Technique (SIFT)

Kelecy: A maneuver detection method Using TLE Data
Introduction

☑ Research content

- Physical laws
- Mathematical techniques
- Orbital characteristics
- Mahalanobis distance
- Combination

Detection Method Based on SGP4 Secular Forecast Model
Detection Method Based on Moving Window Curve Fit

Comparison

Result
Summary

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Methodology

- Brief Description of Moving Window Curve Fit method

The each processing step of MWCF method is provided by R. Patera.
Methodology

☑ Brief Description of Moving Window Curve Fit method

The each processing step of MWCF method is provided by R.Patera.

a. To fit the practical parameters using polynomial by choosing the size of moving window, it is usually selected the least square method, as following:

\[ p(t) = c_3 t^3 + c_2 t^2 + c_1 t + c_0 \]

and then the dispersion data could be gained by the difference between the practical parameter and the curve value.
Methodology

☑️ **MWCF method**

b. Once the dispersion data is obtained, the mean, variance and standard deviations are computed based on standard methods. The **data threshold** is defined...
Methodology

- MWCF method

c. If a data value exceeds a predefined threshold, an event is declared for that data point. Figure 1 describes the process of MWCF method.
Methodology

☑ SGP4 Secular Forecast method

The change of orbital elements is smooth and continuous in normal situation. Maneuvers, collisions, explosions, and sudden changes of space weather can lead to orbital elements anomaly of the satellite. According to the differences between normal and abnormal situation, this method provide a useful measure to detect space events of the satellite.
Methodology

☑️ SGP4 Secular Forecast method

The detailed steps of this method for LEO satellite are as follows:

a. Select characteristic orbit parameters which can represent the satellite orbit anomaly. As for LEO satellite, the semi-major axis and inclination are taken as characteristic orbit parameters which can reflect the anomaly of in plane and out of plane.
Methodology

- **SGP4 Secular Forecast method**
  
b. Create dispersion data based on SGP4 secular forecast model. The predictable parameters of last TLE to current TLE’s epoch which based on SGP4 secular forecast model are seen as expectant values, and secular parameters of current TLE are practical values.
Methodology

☑ SGP4 Secular Forecast method

Average change rate is selected as relative dispersion due to the nonuniformity of TLE alternation.

\[
\frac{dp}{dt} = \frac{p_i - p_{i-1}}{t_i - t_{i-1}}
\]

A sequence of relative dispersion which include epoch and parameters change rate is obtained.

\[
\left\{ t_k, \left( \frac{\Delta a}{\Delta t} \right)_k, \left( \frac{\Delta i}{\Delta t} \right)_k \right\}, \quad k = 1, 2, \ldots, n
\]
Methodology

- **SGP4 Secular Forecast method**

  c. Detection of orbit anomaly based on Mahalanobis distance. Mahalanobis distance describes the closeness between \( r_i \) and distribution center by disposing these data with a weighting process.

  \[
  d_M^{(i)} = d_M(r_i, \bar{r}) = \sqrt{(r_i - \bar{r})^T C^{-1} (r_i - \bar{r})}
  \]

  Where, the mean of sample is \( \bar{r} = \frac{1}{n} \sum_{i=1}^{n} r_i \), and the covariance matrix of sample is \( C = \frac{1}{n-1} \sum_{i=1}^{n} (r_i - \bar{r})(r_i - \bar{r})^T \).
Methodology

☑ SGP4 Secular Forecast method

The detection threshold $d_M$ is identified by the precision of detection. The magnitude of $d_M$ is generally 3 or 5, and then relative dispersion data can be detected through this threshold. It is considered as orbital anomaly if the Mahalanobis distance is bigger than $d_M$. 
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### Results & Comparison

#### Selection of Space Objects

Terra is selected as example. The TLE used in this study is obtained from [www.space-track.org](http://www.space-track.org).

<table>
<thead>
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<th>Orbit type</th>
<th>Catalog number</th>
<th>Satellite Name</th>
<th>Inclination /deg</th>
<th>Perigee altitude /km</th>
<th>Apogee altitude /km</th>
<th>TLE Sets</th>
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</thead>
<tbody>
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<td>Terra</td>
<td>98.20</td>
<td>701</td>
<td>703</td>
<td>2787</td>
</tr>
</tbody>
</table>
Results & Comparison

- **MWCF method**

Terra’s detection results calculated by MWCF method.
Results & Comparison

**MWCF method**

Two-dimensional distributing of Terra’s dispersion calculated by MWCF method.

![Diagram showing energy dispersion and inclination dispersion calculated by MWCF method.](image)
Results & Comparison

SGP4 Secular Forecast method

Terra’s results of detection calculated by SGP4 Secular Forecast method and the black lines represent the known maneuvers.
Results & Comparison

☑ SGP4 Secular Forecast method

Two-dimensional distributing of Terra’s dispersion calculated by SGP4 Secular Forecast method.
Results & Comparison

Advantage

SGP4 Secular Forecast method:
Based on physical laws,
Analysis the result through orbit character,
Low probability of miss alarm.

MWCF method:
Filters noise,
Processes time varying data,
Efficient and steady.
Results & Comparison

Disadvantage

◊ SGP4 Secular Forecast method:
  Need accurate physical model.
  Data should be modified by error analysis.

◊ MWCF method:
  It is difficult to identify the window sizes, and the curve should not be extrapolated beyond the window.
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Anomaly change of ROCSAT-2’s semi-major axis

For LEO satellite, the semi-major axis should decrease without control as a result of atmospheric drag. According to the TLE date, a strange phenomenon appears that the semi-major axis of ROCSAT-2 is increasing during research, and most altitude keeping maneuvers are used to reduce the satellite’s orbit altitude.

What is the reason?
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Further Research

- **False alarm rate** and **missed alarm rate** can be used to evaluate the detection method of space events, but their **basic concepts and relationship** need further discussion.

- **False alarm rate** and **missed alarm rate** are contrary in math. A novel method, which can balance these two factors, should be studied by analyzing the **orbital laws of physics**.
Thank you!