Research on observation method of along the contour of China coastline based on CASEarth Satellite

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Abstract: Facing the rugged complicated coastline in China, three ways including data smoothing algorithm based on Third-Order Bezier Curve, High-order Bezier curve fitting algorithm and curve fitting algorithm based on least squares method are used to generate a smooth contour of coastline by analysing coordinate of coastal city. In the meanwhile, setting a series of leading point that meet the constraints of performance of CASEarth satellite to guide the satellite's centre of view to move along the contour, and giving best solution among the three methods by the comparison.

KEYWORDS: CASEarth satellite; smoothing coastline; Bezier curve; curve fitting;

1. Introduction

1.1. Background
As a new-type national strategic resource, big earth data has become a hot topic in the world. "Big Earth Data Science Engineering", strategic science and technology project of Chinese Academy of Sciences, specially set up the project of Science Earth Satellite (CASEarth Satellite) with camera of wide width. The project focusing on the detection of “human traces”, carrying out detection for energy consumption of densely populated area, structure of human settlements and offshore coastal environment. Among them, the detection of offshore and coastal ecological environment in China is an important scientific application target. Facing the reality of the rugged coastline and large latitude and longitude span, how to plan the smooth trajectory of the coastline and satellite field of view is an important research to enhance the value of the satellite application.

1.2. Main technical parameters of CASEarth
CASEarth is a reconnaissance satellite with wide width and low angular velocity, the following table gives the performance parameters associated with this study.
Table 1. Technical parameters of CASEarth.

| Parameter                        | Value   |
|----------------------------------|---------|
| Type orbital                     | sun-synchronous orbit |
| Orbital altitude (km)            | 505     |
| Multispectral resolution (m)     | 10      |
| Imaging width (km)               | 300     |
| Local time of descending node    | 9:30 am |
| Angular velocity                 | 60°/300s |

* Near the center of the field of view have higher resolution. Consider quality of resolution, only observe data that are within 45 degrees of deviating satellite point.
* In reality, CASEarth have faster angular velocity.

1.3. Structure of paper
Simulation modeling environment is introduced in 2.1, the evaluation function is defined in 2.2 and the modeling of attitude maneuver is shown in 2.3. Section 3 mainly introduce Bezier curve and its application. In section 4 experimental result is given. In the end of this paper we discuss which method is more appropriate based on agile satellite’s parameters.

2. Simulation modelling and evaluation function

2.1. Map modelling
Satellite Tool Kit, an analytic software, is used to obtain data of satellite orbit in this paper. And it is convenient to make map with the help of M_Map, a mapping package for Matlab. For analysis in this background, we choose an orbit of CASEarth that passes over the Chinese coastline, and mark the coastal city point. Curve fitting is based on these points. Using the function of M_Map, we can calculate the distance between points by the coordinate of latitude and longitude on the map, so that we can ultimately and approximatively calculate satellite pitch and roll angle.

![Map Modeling](image)

Figure 1. Map modeling

2.2. Evaluation function
We think excellent solution is that the center of field of view should be as close as possible to the coastline. Because this will generate the data of higher resolution if it is closer from the center of the
field of view. In order to quantify this evaluation criterion, we only need to consider shortest distance from the center of field of view to each coastal city. Of course, the distance should be associated with resolution. For the convenience of research, we simply set the following table to express relationship between the distance and resolution, and then finding the sum of these coefficient generated by the distance in scope of observation to compare which solution is better one.

| Distance Range | Coefficient |
|----------------|-------------|
| 0~10km         | 1.0         |
| 10~30km        | 0.9         |
| 30~50km        | 0.8         |
| 50~100km       | 0.7         |
| 100~150km      | 0.5         |
| >150km         | 0           |

* Not observed over 150km.

2.3. The modelling of attitude maneuver

It is important to determine the guidance law of attitude between adjacent leading points, which is essential to estimate whether the guidance point setting is consistent with the constraints of satellite performance. The following describes the detailed method.

![Figure 2. Attitude modeling](image)

$l$ represents the ground trajectory of satellite. We decompose the distance $D_{AB}$ along the satellite’s forward direction and latitude direction. Then we can approximate the change of pitch and roll angles.

$$\theta_{roll} = \tan^{-1}\frac{D_A}{505} - \tan^{-1}\frac{D_B}{505}$$  \hspace{1cm} (1)

$$\theta_{pitch} = \tan^{-1}\frac{l_A}{505} - \tan^{-1}\frac{l_A-V_{satellite}\times t_{AB}+\frac{D_{AB}\times \cos\theta}{\cos(\theta+\phi)}}{505}$$  \hspace{1cm} (2)

$l_A$ represents the distance between sub-satellite points and point A along the satellite’s forward direction, $D_{AB}$ is the distance between point A and point B. For convenience, setting $t_{AB}=1s$. Note that the variation trend of yaw angle should be consistent with the trend of the change of the field of view curve.

3. Algorithm used

3.1. Bezier curve\(^{[1]}\)

Bezier curve is a mathematical curve applied to a 2D graphics application. The following is its equation.

$$B(t)=(1-t)^nP_0+\sum_{i=1}^{n-1} n t^i (1-t)^{n-i}P_i + t^n P_n$$  \hspace{1cm} (3)
B(t) is a group of time series data, starting at $P_0$ and ending at $P_n$, its trajectory is affected by the control point $P_i$.

![Figure 3. four-order Bezier curve 1](image1)

![Figure 4. four-order Bezier curve 2](image2)

Obviously, the trend of the curve will be close to the position of the control point. We will try to use this feature to find the contour of coastline.

### 3.2. Data smoothing method based on third-order Bezier curve

This method is an application of Bezier curve. We can use it to obtain a smooth curve as below.

![Figure 5. Unsmooth curve](image3)

![Figure 6. Smooth curve](image4)

The specific approach is divided into three steps. 1) Finding and connecting the median point of each adjacent line segment. 2) According to the ratio of the length of two adjacent line segments, dividing the connection of median point. 3) Moving the line and make the break point coincide with the corresponding inflection point. And then we can use Bezier curve to smooth line segments based on obtained control point. Of course, we can also change the camber by adjusting the length of distance between control points.

### 3.3. Curve fitting based on Least squares

Least squares method is a mathematical optimization technique. It finds the best matching function of data by minimizing the sum of the squares of the errors. Curve fitting is a classic application for this algorithm. Fifth-order polynomial fitting is used in this project.
4. Results and summary
For convenience of comparison, setting observation range of CASEarth is from Lianyungang to Quanzhou for all three methods. The figure below shows that if satellite don’t make attitude maneuver, it can’t observe the coastline.

4.1. High-order Bezier curve test results
Although the field of view obtained by high-order Bezier can cover coastline, the centre of field of view is biased to inland.
Figure 9. The curve of view 1

Under the evaluation function, its value is lower. In order to maximize the range of observation, in Figure 8, P1 is the starting point of observation, P2 is the ending point of observation, this is caused by the attitude maneuver of pitch angle. More detailed information about pitch angle will be given in Figure 10.

Figure 11. Angular speed information 1

The x-axis represents the sequence of leading points, and units of y-axis are degree. Set a leading point every second.

4.2. Test results of Least squares method.

Figure 12. The curve of view 2

Figure 13. Angular speed information 2

Obviously, the centre of field of view is closer to the shoreline, and the trajectory is centred relative to the previous method. Note that when you use this solution, it is indispensable to ensure monotonicity of longitude or latitude coordinates.

4.3. Test results of third-order Bezier curve

Compared to the Least square method, the solution based on third-order Bezier curve is closer to real contour of coastline. Note that it is important to treat the entire trajectory as a whole to set leading point, otherwise the change of rolling angular velocity is discontinuous.
5. Summery

The above methods all can obtain approximate coastline contours. From the value of the evaluation function, the ground path obtained by third-order Bezier curve is optimal, and the trajectory is closest to the real. Meanwhile, this way can make full use of the ability of attitude maneuver of CASEarth to observe densely populated cities with better resolution, it also meets the requirements of some scientific goals.

Observation of the coastline is just one task of CASEarth among many others, but the range of observation is limited by angular velocity. In fact, this task is more suitable for agile satellites. With the rapid development of agile satellites, its angular velocity can reach 4.5 (°) /s[5], which is more conducive to observe remote sensing data of non-satellite points. If we use agile satellites to achieve the observation of coastline, it is easy to implement to observe most of coastline once. Under this premise, the advantages of data smoothing method based on third-order Bezier curve will be more obvious.

6. References

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