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OPTIMUM PLANNING AND SCHEDULING FOR AGILE REMOTE SENSING SATELLITE

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ABSTRACT:

The high flexibility of the agile satellite can significantly improve its ability to obtain data. Compared with ordinary satellite so the planning process become very complicated, so we introduce an algorithm which allows efficient management of the operations concerning optical acquisitions. this algorithm will start from receiving the request from customer with it's all parameters and flight dynamics data of the satellite ,first the algorithm make a geometric classification of the areas of interest and a partitioning of these areas into stripes which develop along the optimal scan directions according to the mode of imaging ,the second step is computes the succession of the time windows in which the acquisition operations of the areas of interest are feasible, taking into consideration the potential restrictions associated with these satellite maneuverability , the geometric and stereoscopic constraints. The results and the performances of the proposed algorithm have been determined and discussed considering the case of the Periodic Sun-Synchronous satellite.

KEYWORDS: planning and scheduling, agile satellite, cutting up, feasibility study.

1.INTRODUCTION:

Earth observation missions are an important topic in aerospace where the goal is to scan the Earth's surface with the help of satellites. Earth observation applications include among others geodesy, cartography, climatology and weather forecast. Depending on the desired application, different sensors from radar over infrared to visual sensors are used.

The areas of interest are may be spot targets, polygon, straight stripes or curved strips that have to be scanned at a constant scan velocity which depends on the sensors used. The satellite has many restrictions like storage capacities and maneuverability. The areas of interest change over time, and weather influences the visibility of interesting areas.

Satellites with imaging or radar instruments, which equipped with gyroscopic actuators instead of flywheels, which the satellites are able to move freely around their inertial three axes (yaw, pitch and roll angles).

The Control Moment Gyros principle relies on the gyroscopic effect to rapidly and instantaneously generate an important output torque by using the spin axis' rotation of a momentum wheel thanks to a card an gimbaled mechanism. The CMGs are used both for the maneuver guidance to ensure transitions between image acquisitions and for the acquisition guidance in order to guarantee the image quality.

Figure (1) Control momentum gyro

Agile Earth Observing Satellites (AEOS) are placed on sun synchronous, low altitude, circular orbits around the Earth.

In this paper an algorithm which allows an efficient management of the operations concerning optical acquisitions of agile satellites, can be adapted to satellites with different characteristics, is described. The algorithm can be subdivided into three parts, closely linked: algorithm for geometric analysis, algorithm for satellite attitude dynamics and algorithm for temporal analysis. The algorithm for geometric analysis consists of the geometric classification of each Area of Interest (AOI, area of the Earth's surface for which the data acquisition is required) and in the subsequent partitioning of these Area of Interests in properly designed stripes, called Acquisition Requests (ARs). The characteristic directions of the Acquisition Requests are called loxodromic lines and represent the scan directions for the acquisition activities. The algorithm for satellite attitude dynamics in this algorithm we will identify two mathematical functions calculating the attitude and angular rates of the satellite and the feasibility of the slew maneuvers. Function 1 consists of two parts: determining the attitude of the satellite when pointing towards the target, and the angular rates of the satellite that is necessary to scan the AOI. Afterwards we will present the calculations for Function 2 that checks the feasibility of the slew maneuver The third algorithm Temporal Analysis, which is considered once the Geometric Analysis is completed, consists of the calculation of the time windows, called Data Take Opportunities (DTOs), in which the acquisitions are feasible (for each Acquisition Request). By using flight dynamics of many of satellites that can create by STK

2- GEOMETRIC ANALYSIS

According to the shape of the AOI we define the mode of shooting which will be used in geometric analysis, in fact we have three main types of modes:

- Spot imaging mod, which the AOI consist of one strip as in Figure 2

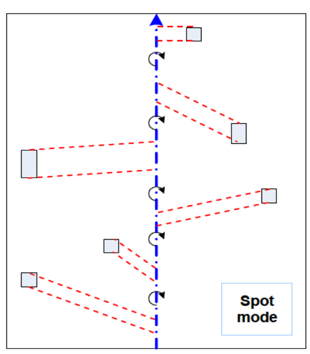

Figure (2) spot imaging mode

-Area imaging mod, which the AOI subdivided into many strips developing in the same direction w.r.t. the north -south direction as in Figure 3.

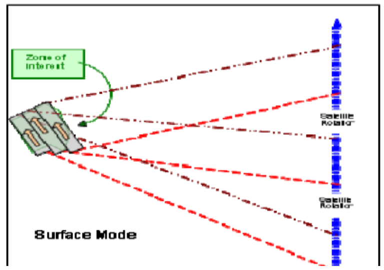

Figure (3) area imaging mode

- Corridor imaging mode, which multiple segments which do not form a closed area, which has to be subdivided into strips developing, in general, in different directions as in Figure 4

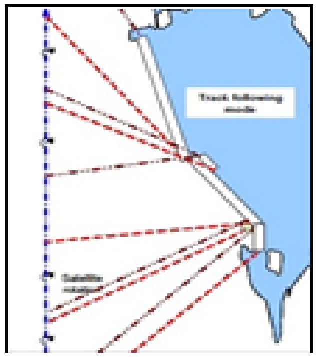

Figure (4) Corridor imaging mode

Once the geographical coordinates of an Area of Interest are identified (by the User), the Geometric Analysis consists of the choice of the shape which has to be associated with this area and in its partitioning in rectangular strips. In the proposed algorithm each Area of Interest can be represented, by one of the three following types of geometry:

- Polygonal area, which has to be subdivided into strips developing in the same direction.
- Polylinear geometry (multiple segments which do not form a closed area), which has to be subdivided into strips developing, in general, in different directions.
- Spot, which requires the consideration of a single strip.

Cutting up of the AOI is carried out as the following steps:

a- Find the center of the polygon.

b- Define the two axes of the polygon where X axis along the loxodromic line, Y axis right hand perpendicular characteristic directions, referred to as loxodromic directions (or loxodromes). These directions represent the lines along which the satellite will has to perform the scanning of the region. These loxodromes are identified by an angle Λ , measured from the North axis (N), clockwise ($0 \leq \Lambda < 360°$). As an example, Figure 5 shows the basic elements of the Geometric Analysis for a polygonal Area of Interest, where a bi-dimensional reference frame, called Loxo-Frame, with origin in the center of an Acquisition Request (AR), X-axis along its loxodromic line (Λ) and Y-axis right-handed perpendicular, is introduced.

The determination of the loxodromic directions is carried out according to the geometry of the Area of Interest, to the ground track pattern of the satellite and to the features of the satellite (agility and scan velocity). While the closed areas and the spots are characterized by a single loxodrome, the polylinear geometries require the introduction of a set of loxodromes.

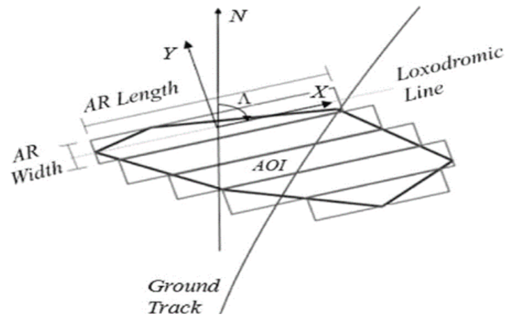

Figure (5) Geometric cutting up

2.1. POLYGONAL AREA

For polygonal area of interest, the partitioning is based on the determination of an optimal angle (Λ, identifying the inclination of the Acquisition Requests) which is able, at the same time, of minimizing the number of strips and of maximizing the time interval to retrieve data from the Area of Interest (Data Take Opportunities). To gain this result, two functions, both variable from 0 (best case) to 1 (worst case), which consider the above-mentioned goals, have been implemented in the following flow chart which illustrate the sequence of algorithm.

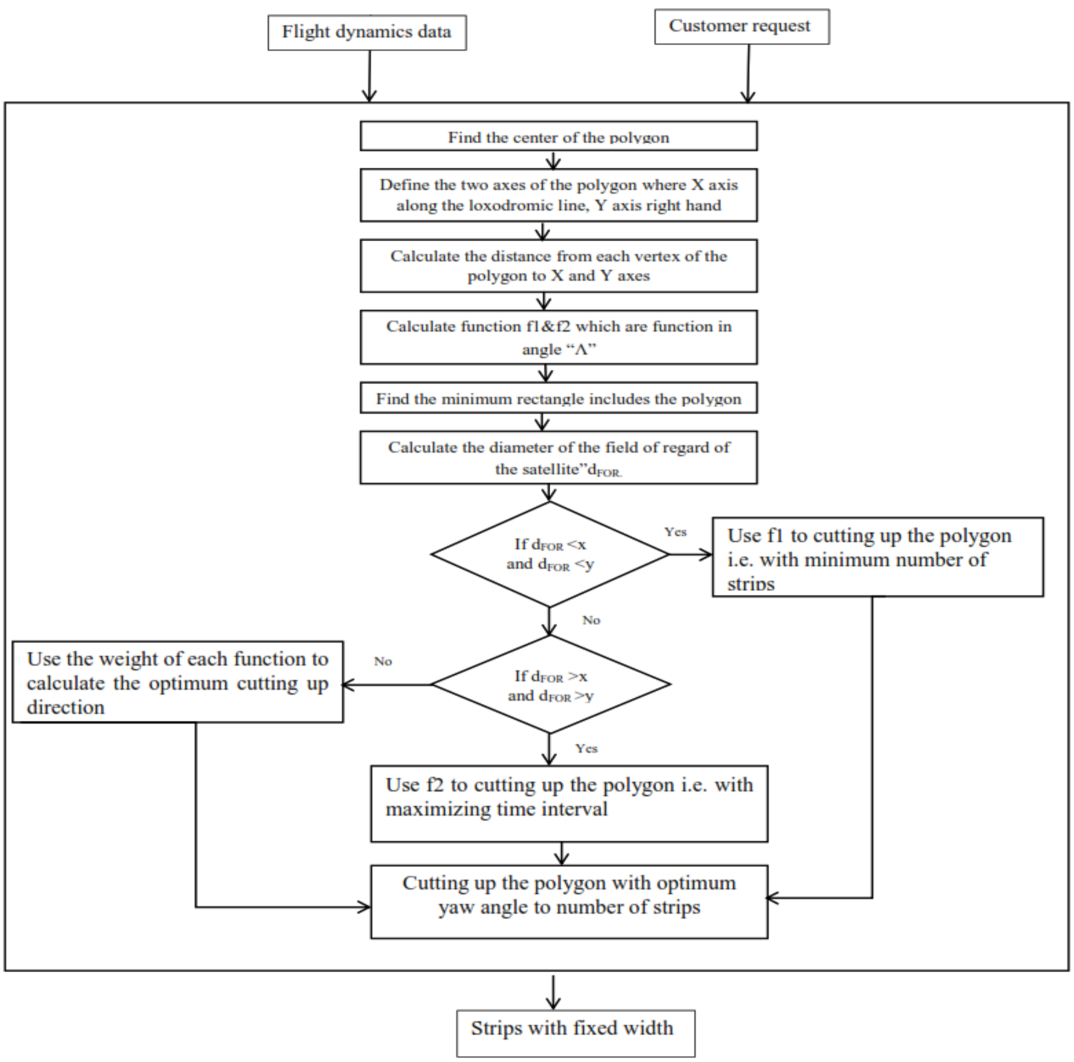

Figure (6) Flow chart for cutting up process

Where

$$f1 = \frac{D(\Lambda) - D(\Lambda_{MIN})}{D(\Lambda_{MAX}) - D(\Lambda_{MIN})} \quad (1)$$

$$f2 = \left| e^{-[\tan(\Lambda t) - \tan(\Lambda_{GT})]^2} - 1 \right| \quad (2)$$

3-FEASIBILITY STUDY OF THE REQUEST

3.1- **Lighting conditions in the target**:

After cutting up the request to one or more strip, we check of the target illumination and calculate the sun elevation angle to the target.

We choose the center point of the strip to check the sun elevation angle as follow:

$$h_s = \sin^{-1}(\sin(\delta_s)\sin(\phi) + \cos(\delta_s)\cos(\phi)\cos(\omega)) \quad (3)$$

Where:

δs is the declination angle of the sun.

ϕ is the latitude angle of the center point of the strip.

ω is the hour angle.

The declination angle of the sun can calculated by the following equation:

$$\sin(\delta_s) = 0.3995 \times \cos\big(0.98563 \times (N - 173)\big) - 22.05 \quad (4)$$

Where N is the number of day in the year.

For optical earth observation satellites the minimum sun elevation angle accepted to perform acquisition is 10 degree.

3.2 limits of visibility:

The maximum viewing angle is determined according to the design of the satellite which is a function of several parameters as attitude control, agility of the satellite and orbital parameters, so we must calculate the angle of visibility between satellite to the target to check if the satellite can access the target or not as follow

$$\tan(\eta) = \frac{\sin(\eta_{max})\sin(\chi)}{1 - \sin(\eta_{max})\cos(\chi)} \quad (5)$$

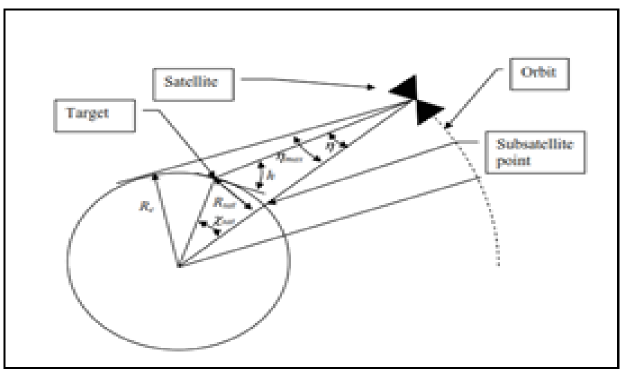

Figure (7) Satellite position geometry

Where

- η_{max} is the maximum semi vertex angle for the satellite height, deg.

$$\sin(\eta_{max}) = \frac{Re}{r} \quad (6)$$

- χ is the central angle between target and sub satellite point.

$$\cos(\chi) = \sin(\phi_T)\sin(\phi) + \cos(\phi_T)\cos(\phi)\cos|\lambda_T - \lambda| \quad (7)$$

Where ϕ_T and λ_T are latitude and longitude of the target respectively.

ϕ and λare latitude and longitude of the satellite respectively.

This check should tack place for every point on the track of the satellite, if the calculated viewing angle is less than the maximum designed one so the satellite can access the target, if not we check the next point.

3.3 **Satellite Attitude Dynamics**

We will divide this section into two parts first one about coordinate system that will be used, the second one about attitude deamination of the satellite during imaging the target.

3.3.1 **Coordinate system**

Due to the different of the coordinate system used to identify the polygon(which use earth fixed coordinate system) and coordinate system used to identify satellite position (which use orbital coordinate system), so we should transform from fixed coordinate system to orbital coordinate system as follow:

$$P_{interial\ -orbital} = \begin{bmatrix} R_{12} & R_{22} & R_{32} \\ -R_{13} & -R_{23} & R_{33} \\ -R_{11} & -R_{21} & -R_{31} \end{bmatrix} \quad (8)$$

Where

$R_{11} = \cos(\Omega)\cos(u) - \sin(u)\sin(\Omega)\cos(i)$

$R_{12} = -\sin(u)\cos(\Omega) - \cos(u)\sin(\Omega)\cos(i)$

$R_{13} = \sin(\Omega)\sin(i)$

$R_{21} = \sin(\Omega)\cos(u) + \cos(\Omega)\sin(u)\cos(i)$

$R_{22} = -\sin(\Omega)\sin(u) + \cos(\Omega)\cos(u)\cos(i)$

$R_{23} - \cos(\Omega)\sin(i)$

$R_{31} = \sin(i)\sin(u)$

$R_{32} = \sin(i)\cos(u)$

$R_{33} = \cos(i)$

Transformation matrix from earth-centered earth fix frame to earth – centered inertial frame:

$$P_{Fix-nterial} = \begin{bmatrix} \cos(S_G) & -\sin(S_G) & 0 \\ \sin(S_G) & \cos(S_G) & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (9)$$

Where:

S_G is Greenwich Sidereal Time.

$$S_G = S_G(0^h) + \omega_e t \quad (10)$$

$S_G(0^h)$ is right ascension of the Greenwich meridian at 0^h UTC.

ω_e is sidereal angular velocity of the earth=360.9856^o per day.

Finally the transformation matrix from fixed coordinate system to orbital coordinate system is:

$$P_{Fix-orbital} = P_{Fix-nterial} \times P_{nterial\ -orbital} \quad (11)$$

3.3.2 **Attitude determination:**

We define the attitude of the satellite at the imaging mode by determining roll, pitch and yaw angles which roll angle is defined by the rotation of the satellite around the x axis ,pitch angle defined the rotation of the satellite around y axis and yaw angle is defined the rotation of the satellite around z axis.

We can get the coordinate of SSP value (Lat,Long)referring to reference frame WGS-84(World Geodetic system 1984),the geodetic coordinates are converted to Cartesian coordinates (X,Y,Z)by equations (Xiaoning and Wei2003):

$$x = N \times \cos(lat)\cos(long) \quad (12)$$

$$y = N \times \cos(lat)\sin(long) \quad (13)$$

$$z = N(1 - e^2)\sin(lat) \quad (14)$$

Where

N is the curvature radius in prim vertical.

$$N = \frac{a}{\sqrt{1 - e^2 \sin^2 lat}} \quad (15)$$

e is the eccentricity.

$$e = \sqrt{a^2 - \frac{b^2}{a}} \quad (16)$$

a is the semi major axis.

b is the semi minor axis.

by the same way we convert the target location from geodetic coordinates to Cartesian coordinates(X_{Target},Y_{Target},Z_{Target}).

Then calculate the range between target and satellite as follow:

$$X_{Rang} = X_{Targe} - x \quad (17)$$

$$Y_{Rang} = Y_{Targe} - y \quad (18)$$

$$Z_{Rang} = Z_{Targe} - z \quad (19)$$

$$Rang = \begin{bmatrix} X_{Rang} \\ Y_{Rang} \\ Z_{Rang} \end{bmatrix} \quad (20)$$

Finally to obtain Roll and Pitch angle:

$$Rang_{InOrbitalPlan} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = Rang \times P_{Fix-orbital} \quad (21)$$

$$Roll\ angle = \tan^{-1}\left(\frac{Y}{Z}\right) \quad (22)$$

$$Pitch\ angle = \tan^{-1}\left(\frac{X}{YZ}\right) \quad (23)$$

RESULTS AND DISCUSSION:

We use Pleiades 1A satellite with its TLE file to measure and make verification the imaging of multi strip algorithm:

PLEIADES 1A

1. 38012U 11076F 17103.85755185 .00000014 00000-0 12788-4 0 9990
2. 38012 98.2019 179.8786 0001512 85.7485 274.3876 14.58549044283483

And we select area of interest which have the following coordinates:

Latitude	Longitude
30	28
30	30
28	30
28	28

The result strips due to cutting up process are:

Latitude:

1. 30.0027 27.9033 27.9065 30.0059 30.0027

2.	27.9065	27.9096	30.0091	30.0059	27.9065
3.	27.9096	27.9127	30.0122	30.0091	27.9096
4.	27.9127	27.9158	30.0154	30.0122	27.9127
5.	27.9158	27.9189	30.0186	30.0154	27.9158
6.	27.9189	27.9220	30.0218	30.0186	27.9189
7.	27.9220	27.9251	30.0250	30.0218	27.9220
8.	27.9251	27.9283	30.0281	30.0250	27.9251
9.	27.9283	27.9314	30.0313	30.0281	27.9283

Longitude:

1.	30.0948	30.0312	29.8270	29.8864	30.0948
2.	29.8270	29.6227	29.6779	29.8864	29.8270
3.	29.6227	29.4185	29.4695	29.6779	29.6227
4.	29.4185	29.2142	29.2611	29.4695	29.4185
5.	29.2142	29.0100	29.0526	29.2611	29.2142
6.	29.0100	28.8057	28.8441	29.0526	29.0100
7.	28.8057	28.6014	28.6356	28.8441	28.8057
8.	28.6014	28.3971	28.4271	28.6356	28.6014
9.	28.3971	28.1928	28.2186	28.4271	28.3971

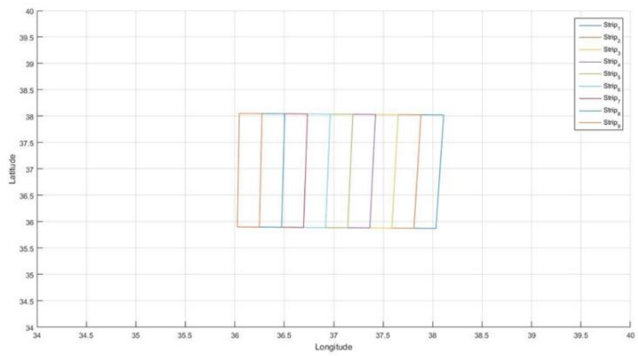

Figure (8) Acquisition area coming from cutting up process

We check the incident angle for each strip which is combined with pitch and roll angle.

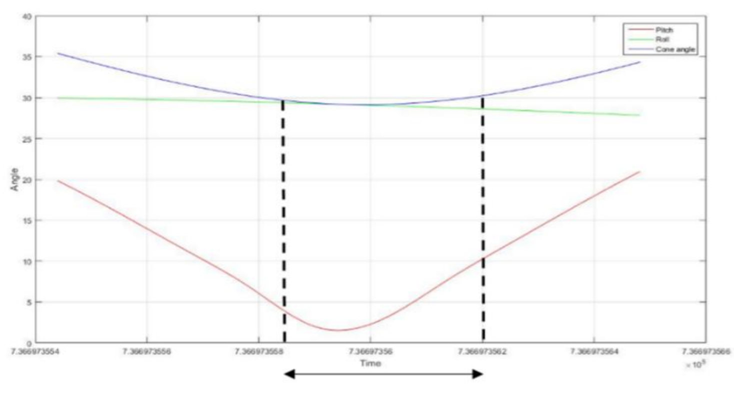

Figure (9) changing in roll, pitch and cone angle

CONCLUSIONS:

The planning and scheduling for agile satellite is very complicated process because it contains a lot of variables and restrictions and the output plane should be efficient enough to satisfying the customer needs and plan targets, so the proposed algorithm in this paper solve some of the planning problems like the cutting up the area of interest into optimum strips which face the objective of the plan, then calculate the optimum feasible time window which the satellite can scan this area with its allowable maneuverability .by applying this algorithm by Matlab program and compare the results with STK program the results was accurate enough .

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