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UTILIZATION OF LANDMARK DATA IN ATTITUDE/ORBIT DETERMINATION

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Picture data are taken both by geostationary and medium altitude satellites primarily for meteorological purposes. Abundant availability of picture data suggests that, both for navigation and picture registration for earth resources and meteorological purposes, the possibility of using landmarks is attractive. (Techniques of pattern recognition for identifying known landmarks are being developed currently at Goddard and by other contracting companies and universities, therefore, my talk will not address itself to this aspect.) One may find usage of landmarks in:

- Reduction of tracking requirements,
- Autonomous navigation,
- Potential improvement in attitude accuracy, and
- Improvement in geographic analysis of picture data.

One has the following options in using picture data from satellite fixed camera to determine:

1. Position given attitude,
2. Attitude given position,
3. Both attitude and position given:

   (α) enough landmarks

   (β) realistic attitude and orbit dynamic models

The problem is to express landmark coordinates in terms of satellite position, attitude, and camera scan angle.

This presentation will describe a mathematical model for determination of satellite position, velocity, and attitude using landmark coordinates as observables. This model, although developed with respect to earth-stabilized missions, Tiros-N and Nimbus-G in particular, is applicable to any earth-stabilized satellite in general.

As is usual in any mathematical discussion of flight mechanics, one has to use several coordinate systems simultaneously. The coordinate systems used here are:

1. (x^I, y^I, z^I) - Inertial, earth-centered
2. (x^R, y^R, z^R) - Rotating, earth-centered
3. (x^B, y^B, z^B) - Satellite body fixed
4. (x^A, y^A, z^A) - Instantaneous auxiliary orbital, earth-centered
5. (x^0, y^0, z^0) - Instantaneous orbital, earth-centered,

where

$$\hat{x}^A = -x^0; \hat{y}^A = -\hat{z}^0; \hat{z}^A = -\hat{y}^0$$

$$\vec{r}^A = F\vec{r}_0; F = \begin{bmatrix} -1 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & -1 & 0 \end{bmatrix}$$

If $\hat{n}$ is a unit vector along the line of sight of the landmark, then,

$$\hat{n}^B = G(\alpha, \beta, \gamma)\,\hat{n}^0 \tag{1}$$

where $G(\alpha, \beta, \gamma)$ is the attitude matrix associated with 2-1-3 rotation.

If ξ, η, and ζ are the angles made by the line of sight with the positive direction of the axes, then

$$\hat{n}^B = (\cos\xi, \cos\eta, \cos\zeta) \tag{2}$$

Let

$$\hat{n}^A = (n_x^A, n_y^A, n_z^A) \tag{3}$$

Then

$$\hat{n}^0 = G^T\hat{n}^B \tag{4}$$

$$\hat{n}^A = FG^T\hat{n}^B \tag{5}$$

If (x_L^A, y_L^A, z_L^A) are the coordinates of a landmark sighted, then

$$\frac{x_L^A}{n_x^A} = \frac{y_L^A - (R_S + h)}{n_y^A} = \frac{z_L^A}{n_Z^A} \tag{6}$$

where $(0, R_s + h, 0)$ are the coordinates of the spacecraft.

Since

$$(n_L^A)^2 + (y_L^A)^2 + (z_L^A)^2 = R_L^2 \tag{7}$$

we have

$$x_L^A = \frac{n_x^A}{n_z^A} z_L^A \qquad (8)$$

$$y_L^A = \frac{n_y^A}{n_Z^A} z_L^A + (R_s + h) \qquad (9)$$

$$\frac{z_L^A}{R_L} = \frac{-B - \sqrt{B^2 - 4AC}}{2A} \qquad (10)$$

where

$$A = \left[\left(\frac{n_x^A}{n_z^A} \right)^2 + \left(\frac{n_y^A}{n_z^A} \right)^2 + 1 \right] \qquad (11)$$

$$B = \left[2 \frac{R_s + h}{R_L} \frac{n_y^A}{n_z^A} \right] \qquad (12)$$

$$C = \left[\left(\frac{R_s + h}{R_L} \right)^2 - 1 \right] \qquad (13)$$

Finally

$$\vec{r}_L^{\,T} = E^T (\phi, \theta, \psi) \vec{r}_L^{\,A} \qquad (14)$$

$$\vec{r}_L^{\,R} = RE^T \vec{r}_L^{\,A} \qquad (15)$$

where

E is the 3-1-3 rotation matrix

R is the transformation matrix from the inertial to the earth-fixed system

ϕ is the longitude of the ascending node, and

ψ $= \omega + \nu - \frac{\pi}{2}$

where

ω is the angle of perigee

ν is the true anomaly

In the light of relations (3) and (6), one can also consider the camera angles as observables.

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