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A New Method for Determining Which Stars Are Near a Star Sensor Field-of-View

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ABSTRACT

A new method is described for determining which stars in a navigation star catalog are near a star sensor field-of-view (FOV). This method assumes that an estimate of spacecraft inertial attitude is known. Vector component ranges for the star sensor FOV are computed, so that stars whose vector components lie within these ranges are near the star sensor FOV. This method requires no presorting of the navigation star catalog, and is more efficient than traditional methods.

1.0 INTRODUCTION

Many spacecraft maintain inertial attitude knowledge by sighting navigation stars with star sensors. The process of determining exactly which navigation stars are in a star sensor field-of-view (FOV), given an estimate of spacecraft attitude, is computer intensive. Consequently, spacecraft first determine which navigation stars are *near* the star sensor FOV, and then determine which nearby stars are *in* the star sensor FOV. This paper presents a new method of determining which navigation stars are near a star sensor FOV that is more efficient than previous methods.

2.0 BACKGROUND

There are two classes of methods for determining which navigation stars are near a star sensor FOV: those methods that *do not* require presorting the navigation star catalog and those methods that *do* require presorting the navigation star catalog.

The primary no-presorting method is the scalar-product method. This method is used on the Space Shuttle. It takes advantage of the simple scalar-product relation

$$\theta = \cos^{-1}(\mathbf{b} \cdot \mathbf{s})$$

where **b** is a unit star sensor boresight vector in inertial coordinates, **s** is a unit navigation star position vector in inertial coordinates, and θ is the angle between **b** and **s**. If θ is less than the angular radius of the star sensor FOV, then **s** is near the star sensor FOV. Obviously, the scalar-product method is simple, but it is also computer intensive.

There are numerous presorting methods that determine which navigation stars are near a star sensor FOV. Although these methods are normally less computer intensive than the scalar-product method, they do introduce some additional problems. For example, some algorithms require that the navigation star catalog be presorted into predefined zones on the celestial sphere. These algorithms are complicated and require additional computer data storage to index the navigation stars.

It is desirable to have a method for determining which navigation stars are near a star sensor FOV that is simple, fast, and requires no presorting of the navigation star catalog. The method described below satisfies these requirements: it is a no-presorting method that is faster than the scalar-product method.

3.0 METHOD

Let us assume that we have a star sensor with a known FOV and an associated navigation star catalog. In addition, let **x**, **y**, and **z** be the principal axes of the inertial coordinate system in which the coordinates of the navigation stars are cataloged. Then we may define orthogonal bands on the celestial sphere that are normal to the **x**, **y**, and **z** axes; and whose unique intersection Σ bounds a circular cap on the celestial sphere that is circumscribed about the star sensor FOV. This concept is illustrated in Figure 1 below.

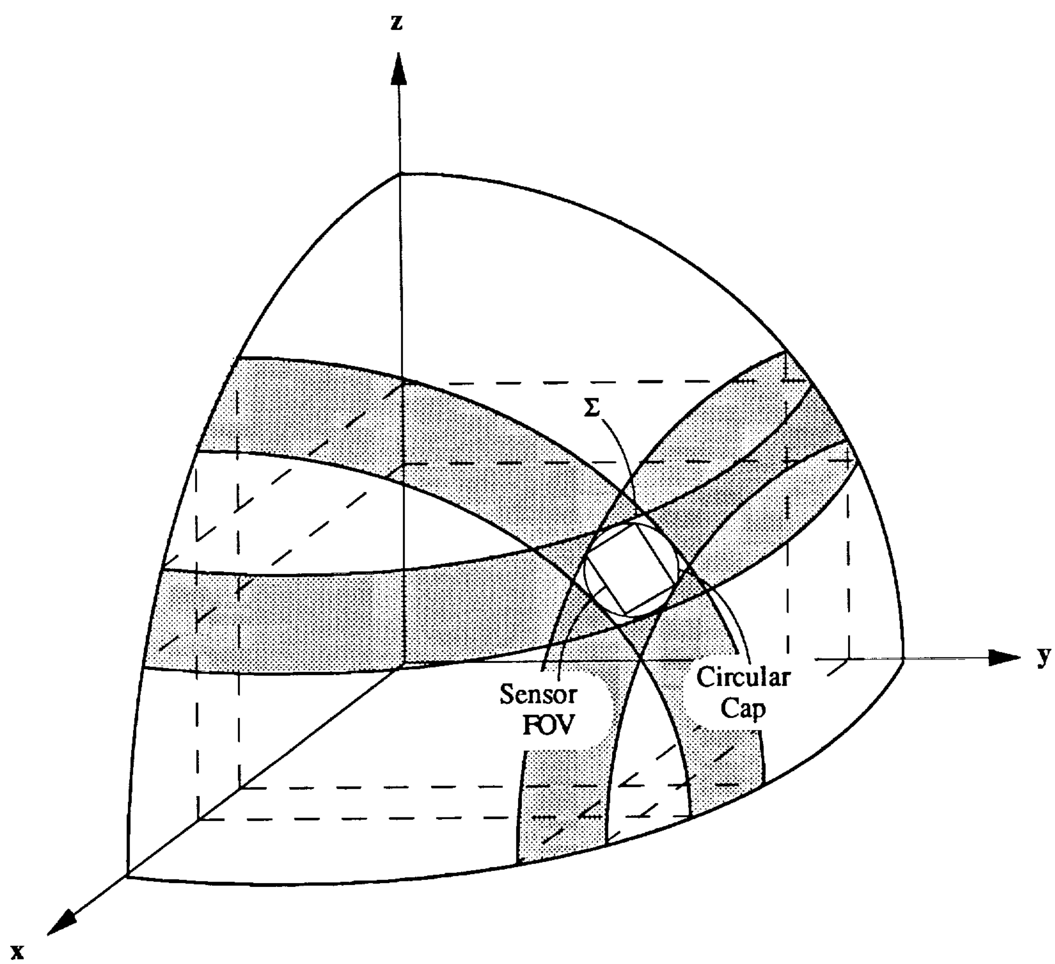

Figure 1 - Intersection of orthogonal bands containing star sensor FOV.

To determine which navigation stars are near the star sensor FOV, we need simply determine which navigation stars are in Σ. Since the orthogonal bands illustrated above are normal to the **x**, **y**, and **z** axes, Σ may be defined by its projections onto **x**, **y**, and **z**. Let the intervals $[x_{min}, x_{max}]$, $[y_{min}, y_{max}]$, and $[z_{min}, z_{max}]$ be the projections of Σ onto **x**, **y**, and **z** respectively. Then to determine which navigation stars are in Σ, and thus near the star sensor FOV, we need simply search the navigation star catalog for stars whose inertial coordinates are contained in $[x_{min}, x_{max}]$, $[y_{min}, y_{max}]$, and $[z_{min}, z_{max}]$.

4.0 ALGORITHM

To compute the coordinate interval $[x_{min}, x_{max}]$, let $\mathbf{b} = (b_x, b_y, b_z)$ be the star sensor boresight vector in inertial coordinates, α_x be the angle between the boresight vector and the x-axis, and β be the diagonal radius of the star sensor FOV. These parameters are illustrated in Figure 2 below.

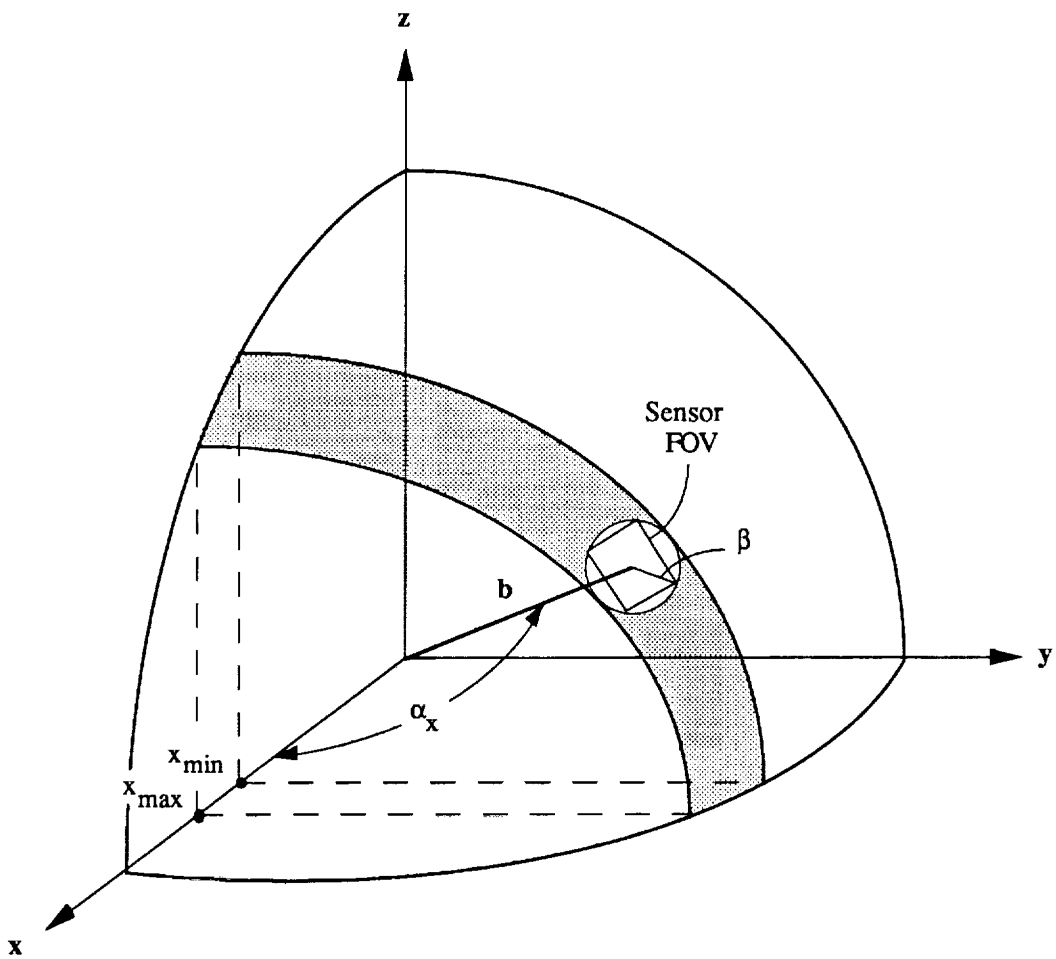

Figure 2 - Star sensor FOV within coordinate interval $[x_{min}, x_{max}]$.

The angle between the boresight vector and the x-axis, α_x, is given by

$$\alpha_x = \cos^{-1}(b_x), \qquad \text{where } 0 \le \alpha_x \le \pi.$$

The coordinate interval $[x_{min}, x_{max}]$ may be computed as follows:

```
if  (αx - β) < 0   then
    xmax  =  1
    xmin  =  cos(αx + β)
elseif  (αx + β) > π   then
    xmax  =  cos(αx - β)
    xmin  =  -1
else
    xmax  =  cos(αx - β)
    xmin  =  cos(αx + β)
endif
```

The intervals $[y_{min}, y_{max}]$ and $[z_{min}, z_{max}]$ can be computed in a completely analogous manner.

Once the coordinate intervals $[x_{min}, x_{max}]$, $[y_{min}, y_{max}]$, and $[z_{min}, z_{max}]$ have been computed, we must search through the navigation star catalog for stars whose inertial coordinates are contained in these intervals, and thus in Σ and near the star sensor FOV. The following is an example of how this process may be implemented.

```
loop Star Catalog
    if  sx  >  xmin  then
        if  sx  <  xmax  then
            if  sy  >  ymin  then
                if  sy  <  ymax  then
                    if  sz  >  zmin  then
                        if  sz  <  zmax  then
                            Star is near star sensor FOV
                        endif
                    endif
                endif
            endif
        endif
    endif
end loop
```

The algorithm above may be improved by ordering the "if" statements so that the least-probable "if" statements appear first.

5.0 TEST RESULTS

The results of a comparison between the scalar-product method and the new method described above are given in Table 1 and Table 2 below. The tests were run on a Macintosh IIx using Absoft MacFortran/020, Version 2.4. A constant star sensor FOV diagonal radius of 8 degrees was assumed. Table 1 summarizes data generated using a math coprocessor, and Table 2 summarizes data generated without using a math coprocessor.

Table 1. Comparison of the scalar-product method and the new method using a math coprocessor.

Number of Trials	Number of Stars	Scalar-Product Method (sec)	New Method (sec)	Ratio of Times (S-P : New)
1000	100	4.72	1.93	2.4 : 1
1000	1000	46.85	16.33	2.9 : 1
1000	5000	234.18	80.05	2.9 : 1

Table 2. Comparison of the scalar-product method and the new method without using a math coprocessor.

Number of Trials	Number of Stars	Scalar-Product Method (sec)	New Method (sec)	Ratio of Times (S-P : New)
1000	100	27.33	14.37	1.9 : 1
1000	1000	273.17	26.17	10.4 : 1
1000	5000	1365.85	78.73	17.3 : 1

The test results indicate the new method is superior to the scalar-product method. Improvement was shown over the scalar-product method, both with and without a math coprocessor.

6.0 CONCLUSIONS

A new method for quickly identifying which stars in a navigation star catalog are near a star sensor FOV has just been described. This method is faster than the traditional scalar-product method, yet retains the advantage of requiring no presorting of the navigation star catalog.

If a faster algorithm is desired, the navigation star catalog may be presorted by unit vector components. This will increase computational speed, but it is more complicated and will require additional computer data storage to index the stars.

The method is presented as an application for onboard spacecraft attitude determination, but it may also apply to other areas such as astronomy.

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