Pulsar navigation using Doppler's effect

Jompoj Wongphecauxsorn

e-mail:Jompoj.bjstp@gmail.com

Dr.Phrudth Jaroenjittichai

National Astronomical Research Institute of Thailand

Dr.Siramas Komonjinda

Chiang Mai University

Abstract

Autonomous technology to navigate in space is key to exploring the solar system. However, nowadays space navigation is required to contact with The Earth. In order to find the new method which not require Earth-contact. Doppler's effect has been used with pulsar's pulse period to evaluate the velocity. The equation has been examined by creating a C/C++ program withch turn spacecraft velocity in axis x, y, z and three's pulsar's position to velocity in each pulsar direction which relate to pulse profile which is included Doppler's effect. After that, the information will use to calculate the spacecraft velocity in x, y, z axis. The error of this method can be estimate from variance in input velocity in x, y, z direction and output velocity in x, y, z direction.

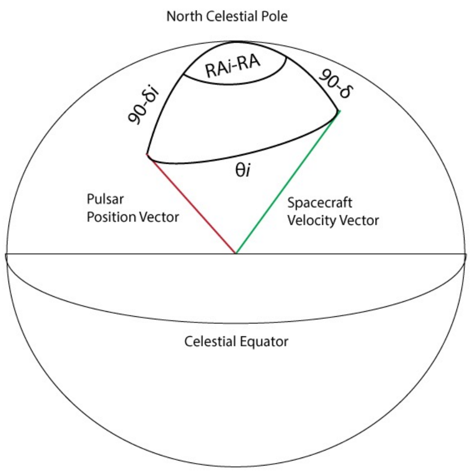

Figure 1.1 Navigation sphere

Key words : Pulsar,Navigation,Simulation

Introduction

Most of spacecraft mission which are widely used are depend on ground-based communication. In addition, Ground-based tracking system is not require active hardware on spacecraft itself with low-cost maintenance. However, the position evaluation error are increases with the range from the earth. For example, in Viking mission the accuracies of position estimation error is about 50 km at Mars [1]. Although, this method has been used successfully in many mission. Nonetheless, It might be necessary for future mission for autonomous navigation in space mission or space navigation with highly precision. The new autonomous spacecraft navigation method could be discussed.

There are varies of autonomous method were previously considered. For example, spacecraft's position can be determined by measuring angles between solar system bodies and astronomical object but the uncertainty in this method is in term of thousand kilo meters [2]. As a conclusion they have relatively large result compared to ground-based.

The new choice in autonomous spacecraft navigation is based on pulsar timing information [3] which specific with X-ray pulsars navigation which require small X-ray detector with low uncertainty. Because of the radio pulsar are require large antenna due to the angular resolution limits. Moreover, Pulsar have stable periodic profile [1] and distributed in all direction in space. The position of spacecraft can be evaluated by comparing pulse arrival times measured onboard the spacecraft with predicted arrival times at an inertial reference location [4] .From the simulation this method can have position accuracies around 5 km [2]. On the other hand, this work will evaluate the velocity of spacecraft by comparing pulse period between onboard measured and prediction the diagram has been shown in Figure1.1.

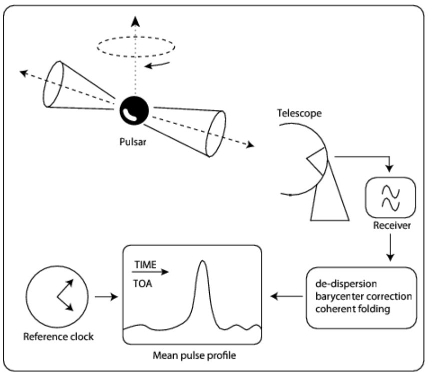

Figure 2.1 Show Diagram of X-ray pulsar navigation [2]

In this work, the celestial coordinate that described by Declination and Right Ascension has been used. Declination is the length between the star and Celestial equator. Right Ascension is the length between Vernal equinox (γ) and intersection between the star and Celestial equator which has been describe in Figure 2.2 [5].

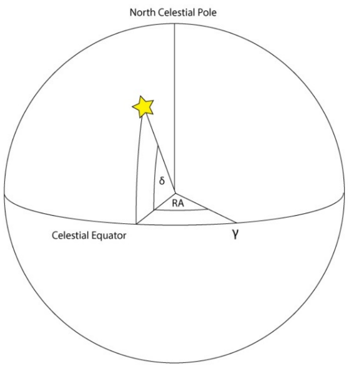

Figure 2.2 described the definition of RA and DEC

After the position in this work has been defined.The Doppler's effect has been used as navigation tool. From the change of period the velocity in each axis can be evaluated from the equation [6] .Now the absolute velocity can be determined.

Method

If we assume that every pulsars is far from the Earth. We can expect that every pulsar is on the celestial sphere with the incident of spacecraft velocity vector, pulsar positional vector and celestial pole. This situation can be written as a spherical triangle in figure 3.1

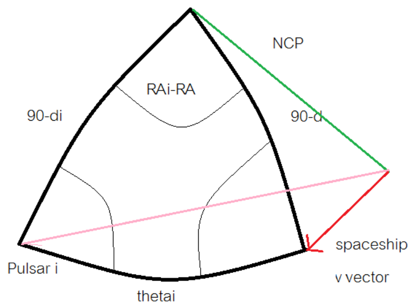

Figure 3.1

Now we can calculate RA with this equation ! From equation i , This equation can be written as

$$v = \frac{v_i}{(\sin D_i \sin D + \cos D_i \cos D \cos(RA_i - RA))}$$

Owning to, v value was constant to equation j and k .so

$$\frac{v_i}{(\sin D_i \sin D + \cos D_i \cos D \cos(RA_i - RA))} = \frac{v_j}{(\sin D_j \sin D + \cos D_j \cos D \cos(RA_j - RA))}$$

Since D is only variable left in this equation. Thus,

$$(\sin D_i \sin D + \cos D_i \cos D \cos(RA_i - RA)) x v_j = (\sin D_j \sin D + \cos D_j \cos D \cos(RA_j - RA)) x v_i$$

The equation above can be expressions as

$$\sin D x (\sin D_i x v_j - \sin D_j x v_i) = \cos D x (\cos D_i x \cos(RA_i - RA) x v_j - (\cos D_j x \cos(RA_j - RA) x v_i)$$

So, using the property that tan(a)=sin(a)/cos(a)

$$\tan D = \frac{(\sin D_i x v_j - \sin D_j x v_i)}{(\cos D_i x \cos(RA_i - RA) x v_j - (\cos D_j x \cos(RA_j - RA) x v_i)}$$

When we know D and RA we can calculate velocity from equations i or j or k.

Conclusion

A spacecraft with velocity (v), declination (D) , right ascension (Ra) from three know pulse period pulsars i,j,k with D_i , D_j , D_k and RA_i, RA_j , RA_k can be evaluate with three equation .First,

$$tan(RA) = \frac{(C\beta ik - \beta ij)}{(\gamma_{ij} - C\gamma_{ik})}$$

When β_{mn} = $cosRA_n tanD_m - cosRA_m tanD_n$ and γ_{mn} = $sinRA_n tanD_m - sinRA_m tanD_n$

and $C = \frac{\alpha_{ij}}{\alpha_{ik}} = \frac{(cos(RA)x\beta_{ij} + sin(RA)x\gamma_{ij})}{(cos(RA)x\,\beta_{ik} + sin(RA)x\,\gamma_{ik})}$

Second,

$$tan\,D = \frac{(sin\,D_i xv_j - sin\,D_j xv_i)}{(cos D_i xcos(RA_i - RA)xv_j - (cos D_j xcos(RA_j - RA)xv_i)}$$

Last,

$$V_i = Vx\,(sin\,D_i\,sin\,D + cos\,D_i\,cos\,D\,cos\,(RA_i - RA)) \qquad (i)$$

$$V_j = Vx(sin\,D_j\,sin\,D + cos\,D_j\,cos\,D\,cos\,(RA_j - RA)) \qquad (j)$$

$$V_k = Vx\,(sin\,D_k\,sin\,D + cos\,D_k\,cos\,D\,cos\,(RA_k - RA)) \qquad (k)$$

Result and Discussion

At Deci=-90,RAi=0,DECj=-22,RAj=66,DECk=-33,RAk=140 and RA=30 ,DEC= 45 the result from simulation has been shown in figure 3.1. The code of this experiment has been shown in appendix 1.

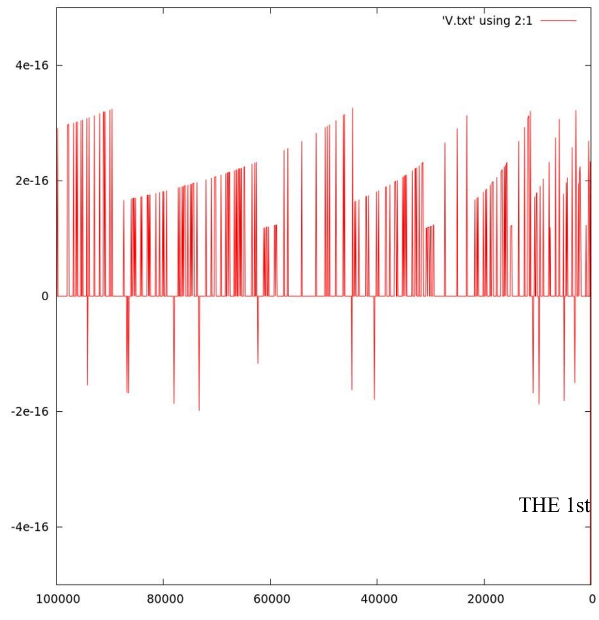

Figure 4.1 Show the relation between (Vin-Vout)/Vin and Vin

At this orientation the error are low. However, there are no relation between two axis the error may come from computational roundoff errors.

Every variable except has been varies the relation between each variable has been show in figure 3.2 and 3.3.

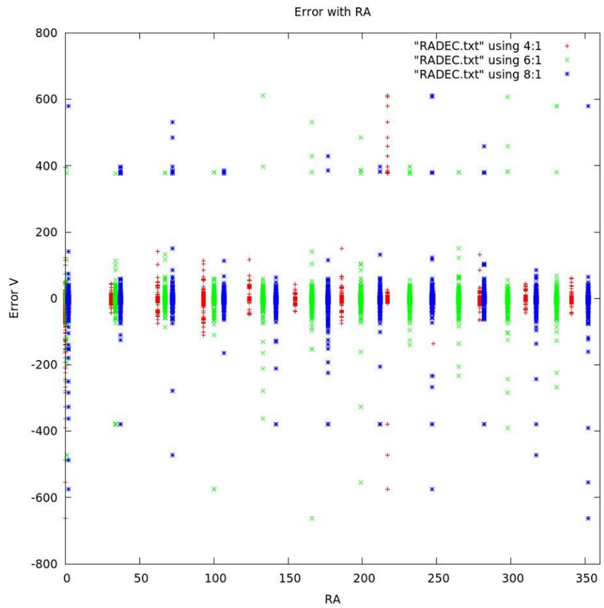

Figure 3.2 The relation between error V and Dec I,Dec j,Dec

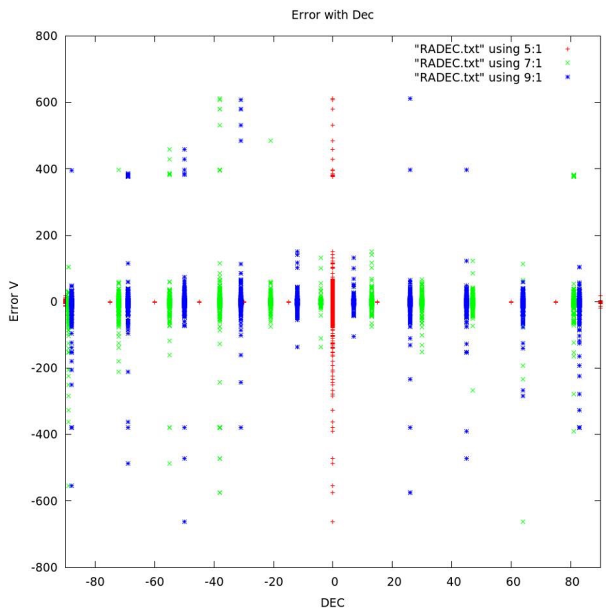

Figure 3.3 The relation between error V and RAi,RAj,RAk

From figure 3.2 and 3.3 there are no relation between errors of v and pulsar's position. However, the velocity uncertainty are depends on the position of each pulsar and no explanation for this error.

Suggestion and Future work

The relation between pulsar position and error of V should be explained. In addition, the relativistic effect and other effect should be concerned to develop more accuracies simulation. Currently we are exploding for the explanation for errors. The future simulation should improve to be more realistic. The gamma-rays pulsar navigation should be concern as navigation tools due to their short wavelength.

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