Pulsar navigation using Doppler Effect

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Abstract

Autonomous technology in space navigation is an important key to solar system exploration and beyond. Today space navigation technology requires constant communication between spacecraft and ground-based stations with typical error about 5 kilometres per astronomical unit [1]. Pulsars are fast rotating neutron stars. Having high precision (in order of μs) in their spin periods, which have been observed to range from seconds to milliseconds, they can be used as galactic transmitters for Space navigation purposes (i.e.ref [1,2,3,4])—or reference for Time travel. Because the measured pulsar's spin period changes with the relative motion between the spacecraft and the pulsar, with complete timing solutions astronomers can determine spacecraft's velocity. Considering only the Doppler effect on the pulse period, a complete velocity solution can be determined using three or more pulsars. Proof-of-concept simulations have been done with C programming. The results indicate that the simulation error strongly depends on the sky-distribution of the three pulsars, that the maximum deviation occurs when they are in the same position

Keywords: space navigation, pulsar.

Introduction

Most spacecraft missions widely depend on Earth communication. The popular method is sending the signal to the detector in the spacecraft then it will sent the same signal back, so we can measure the arrival time and the spacecraft position can be measure. This system does not require active complicated hardware on the spacecraft. The achieved position uncertainty increases with the spacecraft distance from Earth. For example, the Viking mission accuracy reaches about 50 km error at Mars [1]. Therefore, it is necessary for future mission to have high precision autonomous navigation in space mission.

There are various autonomous methods previously considered, for example, by measuring angles between solar system bodies and astronomical objects[2]. However, they have relatively large error compared to ground-based [2]. Pulsars have long been considered as perfect triangulation elements. This is possible not only because of pulsar's unique properties, but also our near-perfect understanding of physics (e.g.http://www.sciencemag.org/)

Another choice is based on pulsar timing information [3] which The position of spacecraft can be evaluated by comparing pulse arrival times measured on board the spacecraft with the predicted arrival times at an inertial reference location [4].From the simulation this method can have position accuracies around 5 km [2]. However, our work will evaluate the velocity of spacecraft by comparing pulse period between on board measured and prediction.

Materials and Methods

In this work, the celestial coordinate(RA,δ). The Doppler effect show the change in pulsar's rotation period(Pm), depending on the relative velocity in direction of pulsar's m, which has intrinsic rotational period (P0m). With 3 or more velocity vector determined, we can find the absolute velocity.

Dec

$$\tan(\delta) = \frac{v_j \sin(\delta_i) - v_i \sin(\delta_j)}{v_j \cos(\delta_i)\cos(RA_i - RA) - v_i \cos(\delta_j)\cos(RA_j - RA)}$$

Velocity

$$v_m = v(sin(\delta_m)sin(\delta) + cos(\delta_m)\cos(\delta)\cos(RA_m - RA))$$

Period

$$p_m = p_{0m}(1 - \frac{v_m}{c})$$

RA

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

$$\beta_{mn} = \cos(RA_n)\tan(\delta_m) - \cos(RA_m)\tan(\delta_n)$$

$$\gamma_{mn} = \sin(RA_n)\tan(\delta_m) - \sin(RA_m)\tan(\delta_n)$$

$$C = \frac{\alpha_{ij}}{\alpha_{ik}}$$

$$\alpha_{mn} = (\frac{v_m}{\sin(\delta_m)} - \frac{v_n}{\sin(\delta_n)})$$

All equations will be used to write the simulation with C programing. The flowchart is shown in figure 1.

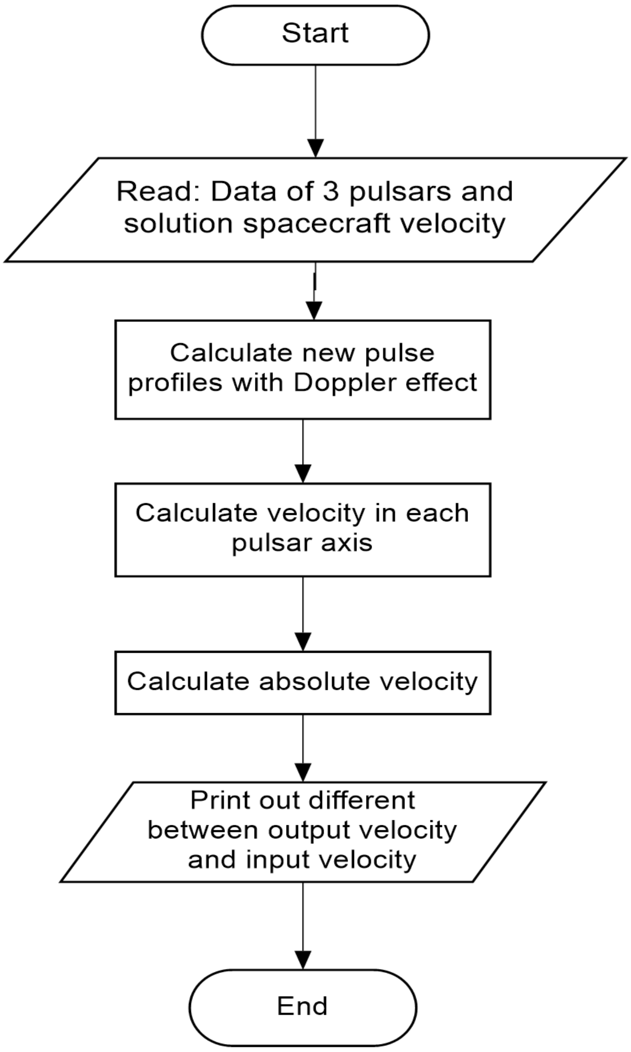

Figure 1 : Simulation flowchart

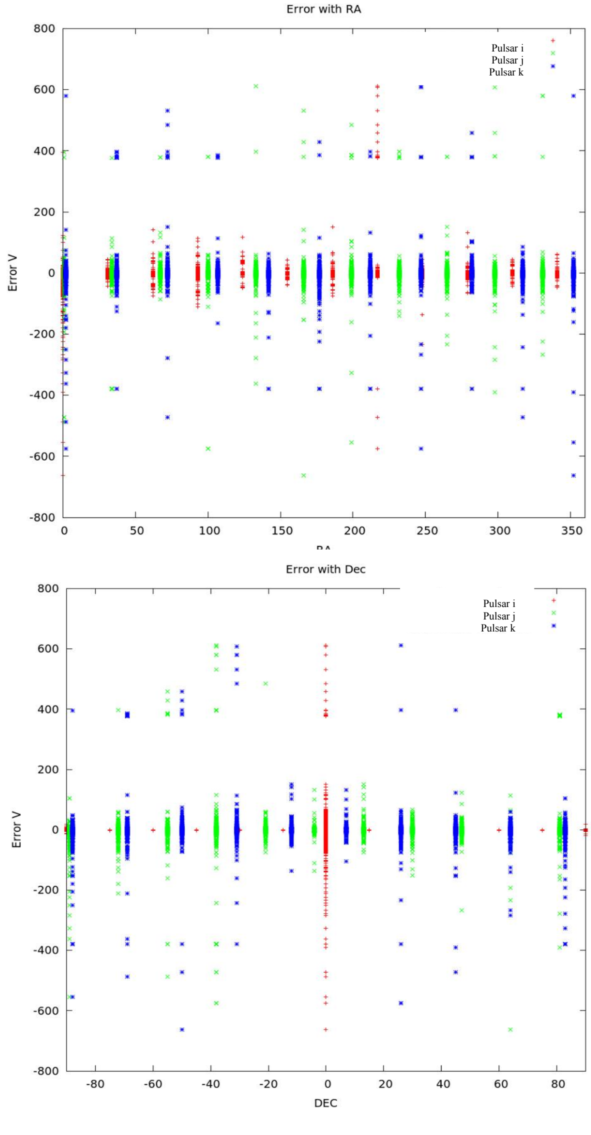

Figure 2: Relation between Error and Dec or RA

Results and Discussion

At δi = - 90°, Rai = 0°, δj = - 22°, Raj = 66°, δk = -33°, Rak = 140° and RA = 30°, δ = 45°, They indicate that on av average the pulsar position error is in order of 10^{-16}(negligible the relativistic effect). However, the error is correlate with the pulsars position. This effect may come from the limit that the 3 pulsars must be separated enough for the detector to see the delay for each signal

Conclusions

We note that Doppler's effect is one of many physical parameters in a more realistic timing model, e.g. Roemer, Shapiro and Einstein delays

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