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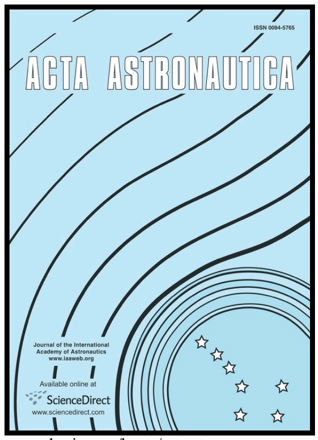

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Abstract

Doppler frequency in pulsar navigation is an effect caused by spacecraft and pulsar motion , which would worsen the pulsar navigation accuracy. To describe this influence, we establish the Doppler frequency measurement model based on pulsar timing. With this model, we describe the relationship between the phase estimation performance and the observation time when Doppler frequency exists. To reduce the pulsar navigation error due to the Doppler frequency, we designed the phase tracking loop for the pulsar navigation. The pulsar frequency can be modified before the phase estimation. As a result, the impact of the Doppler frequency could be lessened, and the observation interval lengths can be lengthened to improve the phase estimation performance.

Index Terms –X-ray pulsar navigation; Phase estimation; Doppler frequency; Tracking loop

1. INTRODUCTION

Pulsars are celestial bodies that emit extremely stable periodic X-ray signals [1], which can provide navigation information for spacecraft anywhere in the solar system. The X-ray pulsar navigation (XPNAV) uses observations of pulsars to calculate the position and velocity of spacecraft.

In order to achieve measurement, XPNAV may create binned pulse profile and compare this profile with a template [5]. One of the problems of this method, which is seldom discussed, is the observed frequency must be known. Therefore estimated position and velocity based on previous calculate result has to be used. Huang in [6] suggest navigation using binary pulsars, which makes the Doppler frequency more complex for introducing the binary motion.

To deal with this, Golshan and Sheikh designed the PLL technique to solve the frequency estimation in [9]. But the PLL model is separated from the phase estimation model, and provides no information for phase estimation. Huang provided the detailed Doppler frequency model and shown the fact that the longer observation length would bring worse phase estimation result by simulation result [10]. But Huang suggested shorten the observation time to bypass the problem rather than give the solution to it. Anderson and Pines in [22] presented an encouraging result achieved by using phase tracking loop to remove the dynamics. Still again, the information feedback did not provide to phase estimate and made the tracking loop unlocked after a relative short time.

The purpose of this paper is to generalize the model of observed pulse deform caused by Doppler frequency of X-ray pulsars in dynamic situation, and discuss the degeneration of phase estimation precision due to such transform. The tracking loop is designed to solve problem by taking the period feedback as a modifier to period which is needed in phase estimation to decline the effect of Doppler frequency in phase estimation. The epoch folding method as the phase estimator is applied in this paper for the reason to describe the effect of Doppler frequency on phase estimation more clearly rather than computation-efficient, but the result would stand in maximum likelihood method. The photon-level numerical simulation is designed to investigate the validity of the algorithms, and positive results are obtained.

2. DOPPLER FREQUENCY MODEL OF PULSAR NAVIGATION

Before the further discussion of the relationship of the Doppler frequency and the navigation, the Doppler frequency model has to be introduced as the fundamental. Pulsar navigation and pulsar timing is a pair of opponent operation. The latter uses the known observation position to estimate the parameter of pulsar, and the former utilizes the foregone pulsar parameter to estimate the position. Both operations call for an establishment of the relationship between the time of emission (TOE) and the time of arrival (TOA). Therefore, pulsar timing could become the groundwork of the pulsar navigation.

Two of the reference systems would be used in following. First reference system used is the barycentric celestial reference system (BCRS), whose coordinate time is the barycentric coordinate time (TCB) t_{BCRS} [11-13]. The binary-barycentric celestial reference system (BBCRS) is the reference systems with the origin of binary barycenter (BB) at the position epoch to describe motion of a binary pulsar system t_{BBCRS} [14]. The coordinate time of BCRS is equal to the proper time of an observer at BB if no gravitational field exists [15].

There are parameters also be used in Doppler frequency model. The vector $\boldsymbol{R}$ is points from the spacecraft to the pulsar, $\boldsymbol{R}_0$ points from the solar system barycenter (SSB) to the initial position of the binary barycenter (BB) at the position epoch E_{POS}, $\boldsymbol{l}$ is BB's displacement relative to its initial position, and $\boldsymbol{r}$ and $\boldsymbol{b}$ are respectively the spacecraft's and pulsar's position vector in the solar and binary system. Their relationship is illustrated as Fig. 1. The time variables τ_{S} stands for the spacecraft's proper time and τ_{P} is the pulsar's proper time. $\boldsymbol{v}$ denotes the spacecraft velocity vector in BCRS.