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Orbit determination using incremental phase and TDOA of X-ray pulsar

Key words: Orbit determination algorithm, Single X-ray pulsar detector, Phase increment, Two-body motion equations, Weighted least squares method

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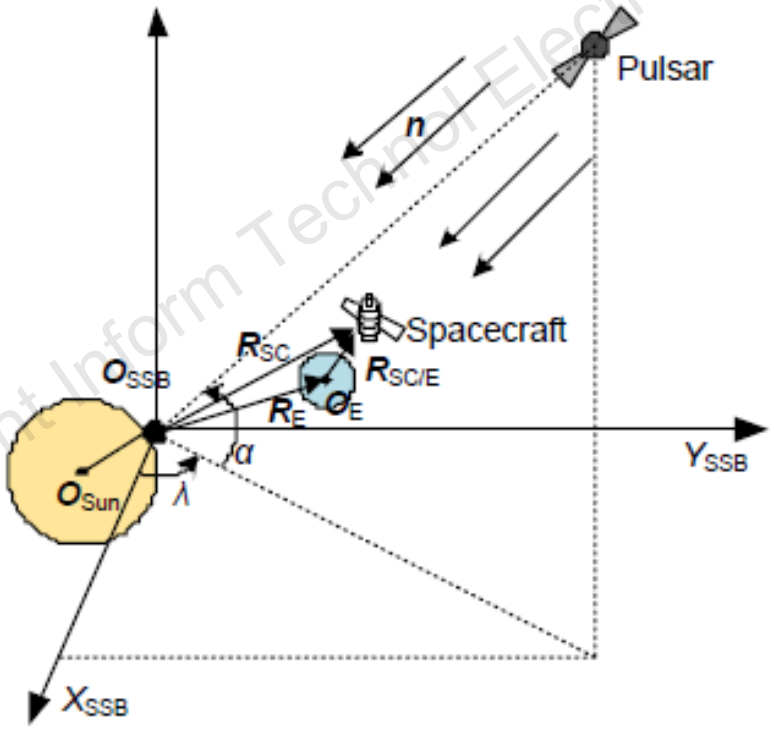
Introduction

- The conventional X-ray pulsar navigation system is complexity due to its additional subsystem, and it can reach only several hundred meters accuracy on the initial orbit determination.

- A method using only one detector, which observes three pulsars in turn, is presented in this work.

- To improve the precision, the weighted least squares algorithm (WLS) is constructed to be integrated with the TDOA and the increment phase, which can provide more information than the traditional XNAV.

The geometric model of time increment observation



Initial orbit determination based on WLS

The observation function

$$\begin{cases} y_1 = Z_1 = \dot{\boldsymbol{H}}_1 \boldsymbol{\Phi}(t_1, t_k)\boldsymbol{x}_k + \varepsilon_1, \\ y_2 = Z_2 = \dot{\boldsymbol{H}}_2 \boldsymbol{\Phi}(t_2, t_k)\boldsymbol{x}_k + \varepsilon_2, \\ y_3 = \hat{T}_{21} = \dot{\boldsymbol{H}}_2 (\boldsymbol{\Phi}(t_2, t_k) - \boldsymbol{\Phi}(t_1, t_k))\boldsymbol{x}_k + \varepsilon_3, \\ \vdots \\ y_i = Z_j = \dot{\boldsymbol{H}}_j \boldsymbol{\Phi}(t_j, t_k)\boldsymbol{x}_k + \varepsilon_i. \end{cases}$$

The best estimation of state vector is

$$\hat{\boldsymbol{x}} = (\boldsymbol{H}^{\mathrm{T}} \boldsymbol{w} \boldsymbol{H})^{-1} \boldsymbol{H}^{\mathrm{T}} \boldsymbol{w} \boldsymbol{y}, \text{ where } \boldsymbol{w} = \mathrm{diag}(\varepsilon_1^{-2}, \varepsilon_2^{-2}, \ldots, \varepsilon_i^{-2}).$$

Simulation result: the GPS BIIA-10 orbit determination

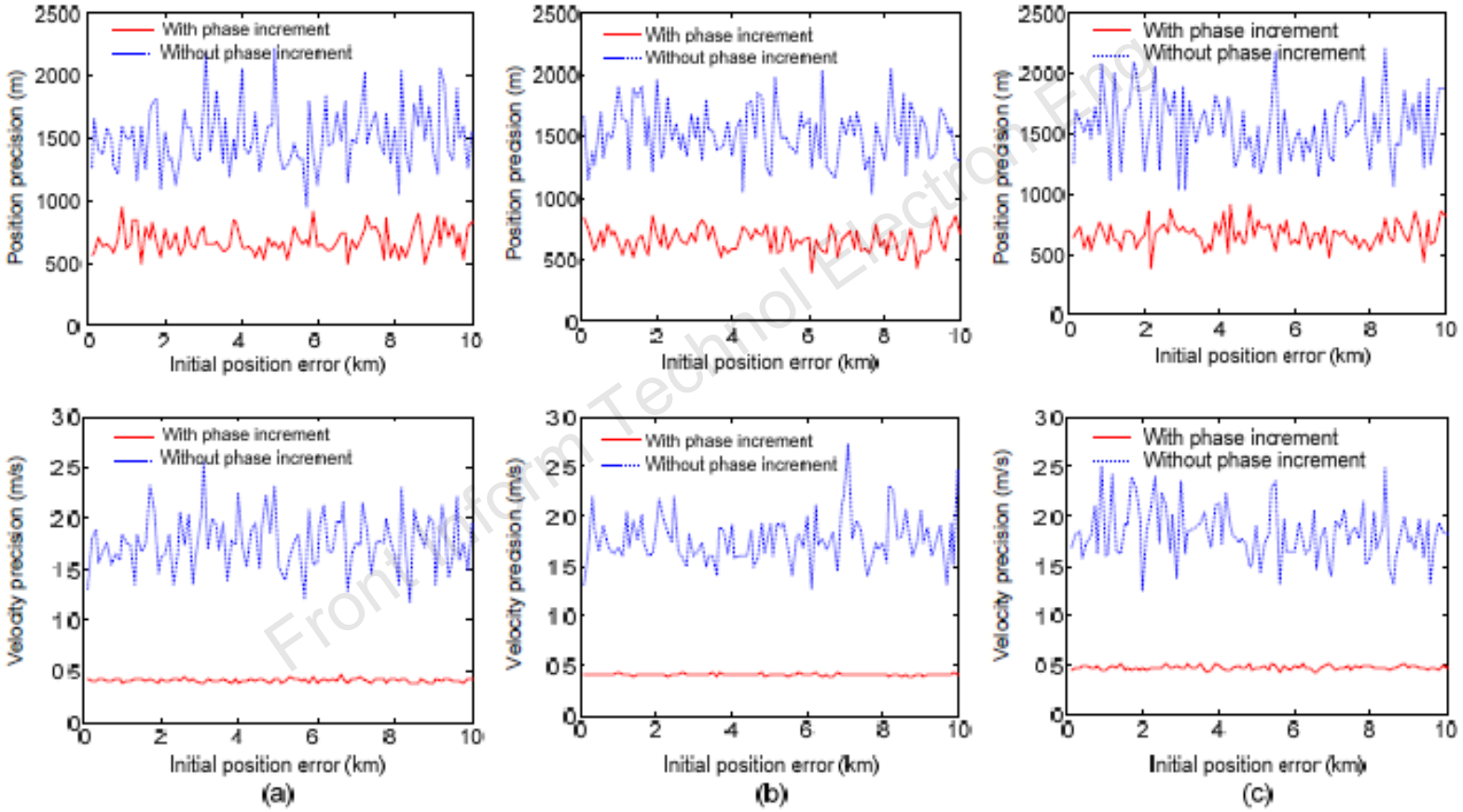


Fig. 3 Position and velocity precision in the simulation of the GPS BIIA-10 initial orbit determination: (a) δv=0.5 m/s; (b) δv=2.0 m/s; (c) δv=5.0 m/s

Simulation result: the Sat orbit determination

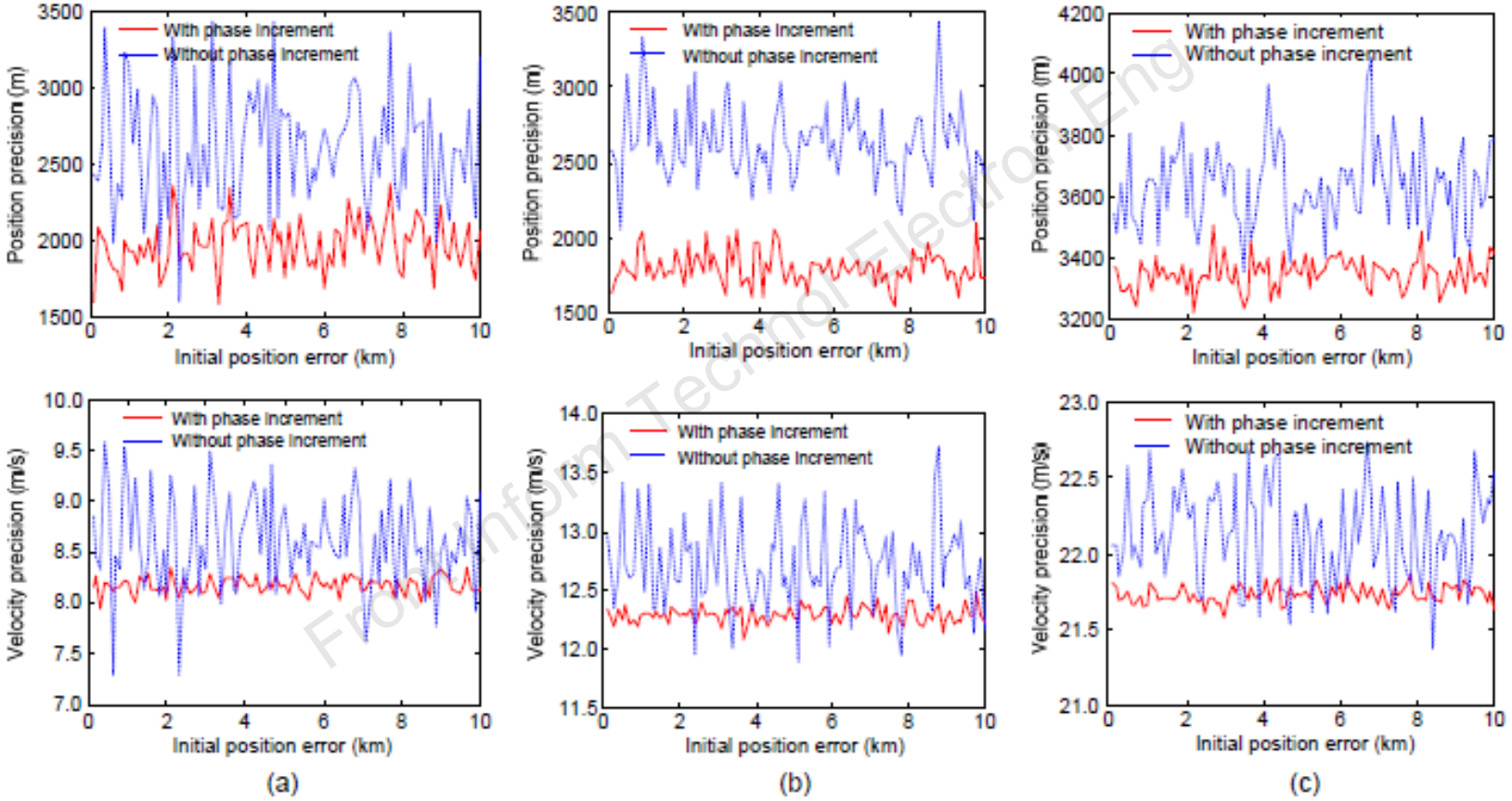


Fig. 4 Position and velocity precision in the simulation of the Sat initial orbit determination: (a) δv=0.5 m/s; (b) δv=2.0 m/s; (c) δv=5.0 m/s

Simulation result: the MEGSAT-1 orbit determination

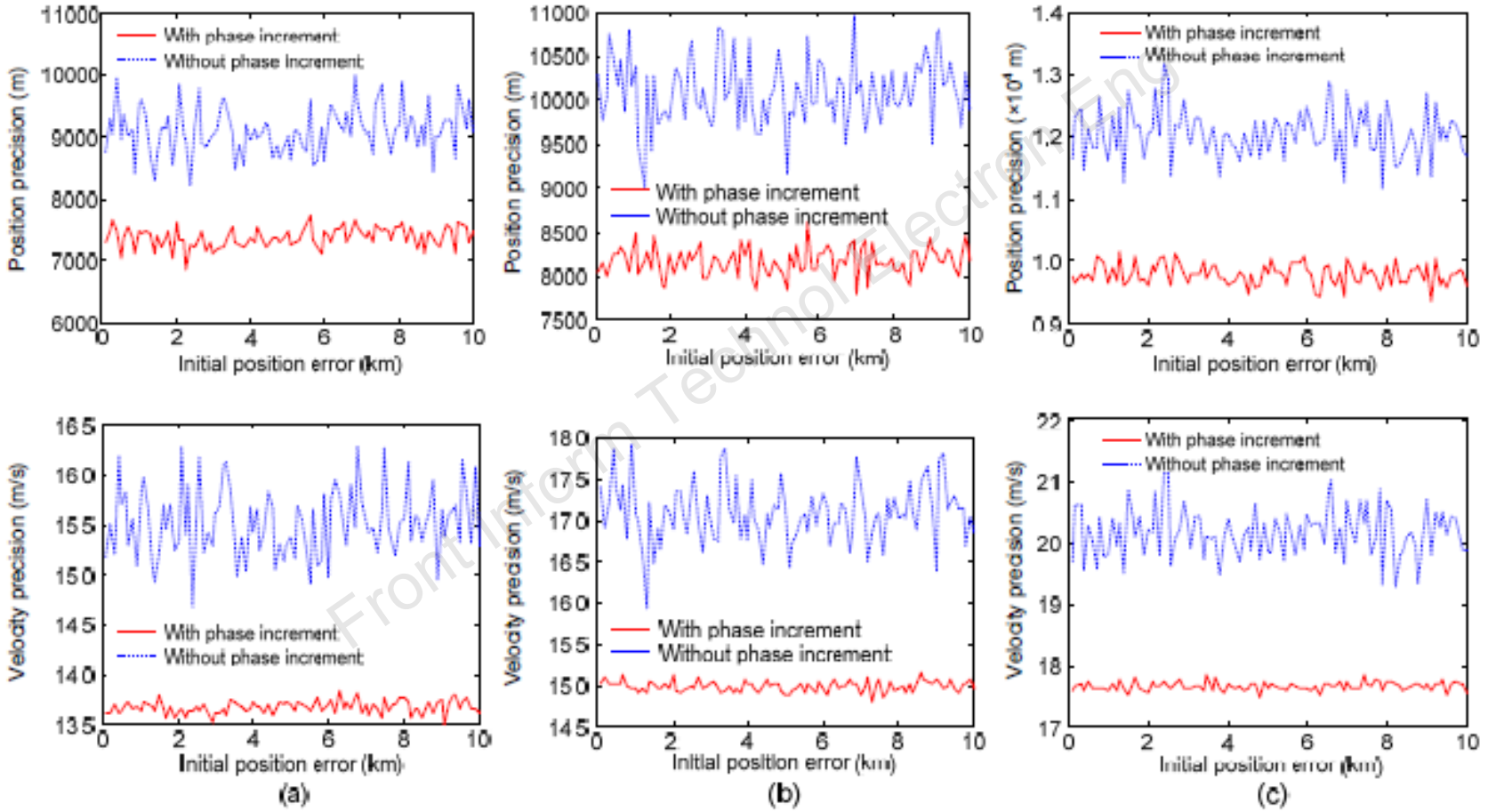


Fig. 5 Position and velocity precision in the simulation of the MEGSAT initial orbit determination: (a) δv=0.5 m/s; (b) δv=2.0 m/s; (c) δv=5.0 m/s

Conclusions

- The method combined with the phase increment observation and TDOA proposed in this paper gives better performance than that without the phase increment.
- The new method meets the rough initial determination requirement and provides a potential strategy for the following higher precision orbit determination.