MONITORING EARTH ROTATION AND POLAR MOTION USING SPACE VLBI: A FEASIBILITY STUDY

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ABSTRACT. Space Very Long Baseline Interferometry is an extension of the ground based VLBI to the space. With the launching of two Space VLBI satellites in the future, Space VLBI observations will be available for astrometric, geodetic and geodynamic applications. This new technique holds potential for various important applications including monitoring Earth rotation. The aim of this feasibility study has been to investigate the possibility of precise estimation of Earth rotation parameters from the Space VLBI observations. A simplified mathematical model is derived in terms of estimable parameters. Sensitivity analysis has been carried out to study the sensitivity of this system to the geodetic parameters of interest. Some of the dominant systematic effects have been investigated. Simulation studies have been carried out to study the influence of these systematic effects and a priori information on the estimation of the Earth rotation parameters. The results indicate that the Space VLBI technique may be used to complement other existing techniques for monitoring Earth rotation, only if the orbital systematic effects can be modeled to a high degree of accuracy (or the satellites can be tracked, with high accuracy, independently), and precise a priori information on station coordinates from other sources is used.

1. INTRODUCTION

The radio-interferometric technique of Very Long Baseline Interferometry (VLBI) is presently the most accurate geodetic technique for monitoring Earth rotation and polar motion. Space VLBI is an extension of the ground based VLBI to the space, which overcomes the obvious limitation on the length of the baselines imposed by the physical dimension of the Earth. The Space VLBI observables, with their unique characteristics, hold potential for some important geodetic and geodynamic applications, including monitoring Earth rotation. With the launching of two Space VLBI missions in this decade, Space VLBI observations will be available to geodesists, which should be exploited for interconnection of reference frames and estimation of the Earth Rotation Parameters (ERP's). The aim of this feasibility study has been has been to investigate the possibility of precise estimation of ERP's from the Space VLBI observations. A

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simplified mathematical model is derived in terms of estimable parameters, and sensitivity analysis and simulation studies have been carried out to investigate the sensitivity of this system to the estimation of the ERP's.

2. REFERENCE FRAMES INTERCONNECTION AND THE SPACE VLBI SYSTEM

Space VLBI, as the name suggests, is a simple extension of the present ground based VLBI in to the space, with either one or both of the VLBI antennas observing the signal from an extra-galactic radio source having been mounted on an Earth-orbiting satellite. Due to the extension of the VLBI baseline beyond the physical dimension of the Earth possible through Space VLBI, this technique overcomes some of the limitations of the ground based VLBI, thus making it an important tool for potential applications in various fields including geodesy, geodynamics, geophysics and astrometry. The basic principle behind Space VLBI has been explained by Adam[1990] (see Fig. 1). As this unique system has all the three reference systems of geodesy and geodynamics inherent to it: the Conventional Inertial System (CIS), Conventional Terrestrial System (CTS), and the dynamic CIS defined through the satellite orbit [see Mueller, 1988], the Space VLBI observations have the potential of providing a direct tie between these systems (see Fig. 2), in addition to their potential applications in the field of gravity field determination from satellite observations. Two Space VLBI missions have been planned for launching in the near future - RADIO ASTRONomical satellite (RADIOASTRON) of Russia and VLBI Space Observatory Program (VSOP) of Japan. Two more proposals are under consideration - QUAsar SATellite (QUASAT) and International VLBI Satellite (IVS) of the European Space Agency (ESA) [see Kulkarni, 1992].

3. MATHEMATICAL MODEL FOR ESTIMATING ERP'S FROM SPACE VLBI

A simplified mathematical model for the Space VLBI ground-to-space time delay has been derived by Adam[1990]. Estimability analysis has been carried out to investigate the estimability of geodetic parameters from these observations, the results of which can be found in [Kulkarni, 1992]. An estimable set of parameters has been established and mathematical model reformulated in terms of this modified set of parameters (see Fig. 3).

4. SENSITIVITY ANALYSIS

Sensitivity analysis to investigate the sensitivity of ERP determination from Space VLBI observations to different parameters, including the number of observing stations, radio sources, observation epochs, observation interval, etc. has been carried out, from which an optimum set of observing parameters has been has been estimated to be: 15 ground stations observing simultaneously with the satellite antenna over a total observation period of about 45 hours to a total of 9 radio sources with observation interval of 90 seconds, over 1800 observation epochs. The effect of assigning different levels of a priori errors

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to the parameters on the expected root mean square error (rms) of ERP estimation has also been analyzed, the results of which can be seen in Fig. 4. From this error analysis it has been concluded that the expected rms of ERP estimation from Space VLBI observations is likely to be of the order of 0.7 mas for polar motion and 0.05 ms for variations in the rotation rate, which is marginal compared to the present level of estimated rms from other existing techniques.

5. INFLUENCE OF SYSTEMATIC EFFECTS AND A PRIORI INFORMATION

In the estimability and sensitivity analysis discussed above, effect of systematic errors has not been included. In order to analyze the influence of some of the dominant systematic effects on the Space VLBI satellite orbit, observations, and ERP estimation, models have been derived/modified and numerical investigations have been carried out. The systematic effects considered include solar radiation pressure, atmospheric refraction, clock offsets, drifts and jumps, and relativistic effects. From a comparison of the estimated magnitudes of the errors introduced by these systematic effects, it has been concluded that the dominant systematic effect is the mismodeling of the solar radiation pressure on the satellite, which is likely to degrade the accuracy of ERP estimation significantly. The rms of ERP's determined using accurate a priori information is estimated from the simulation studies to be of the order of 0.5 mas. The results of the numerical tests carried out to study the influence of step size on ERP estimation, presented in Fig. 5 indicate that a step size of 12 hours may be sufficient for precise estimation of ERP's. The influence of systematic effects and a priori information is shown in Fig. 6. Different cases with different levels of errors assigned to the a priori information used in ERP estimation, with and without considering the effect of systematic errors, have been investigated. From these results it may be concluded that with erroneous a priori information, the expected precision and accuracy of ERP estimation deteriorates rapidly.

6. CONCLUSIONS

From this feasibility study to investigate the possibility of using Space VLBI observations for monitoring Earth rotation, it can be concluded that the expected accuracy of ERP determination from Space VLBI is likely to be marginally close to the present level of accuracy from existing techniques, provided that orbital errors are modeled to a high degree of accuracy, and accurate a priori information on station coordinates from external source is used. Thus, Space VLBI technique may have the potential for being used as complementary to the existing geodetic systems for ERP determination, only if the satellite orbit can be tracked to a high degree of accuracy, and accurate a priori information on station positions is available. It may also be possible to carry out precise estimation of the ERP's from the Space VLBI observations at a step size of 12 hours, under these conditions.

7. ACKNOWLEDGEMENTS

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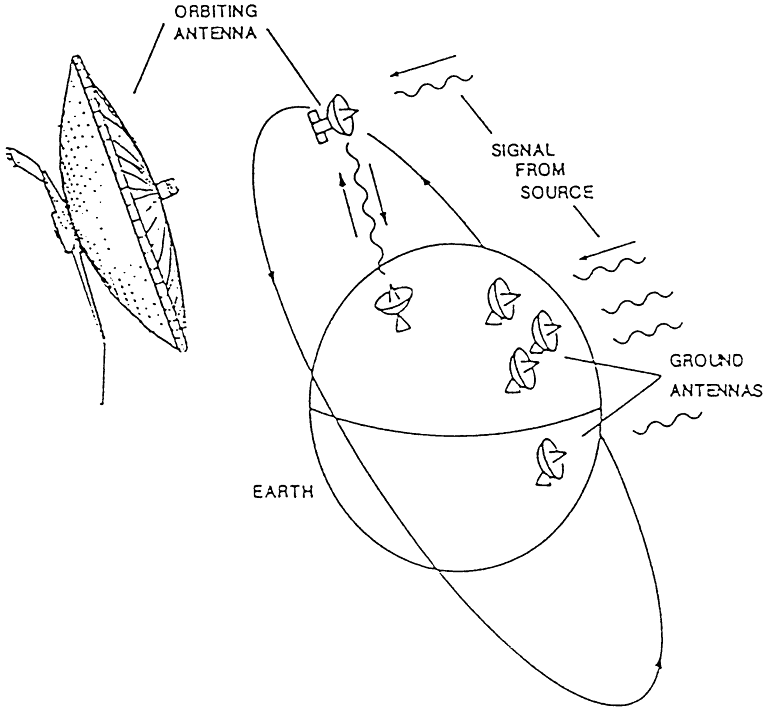

Fig. 1 The Principle of Space VLBI

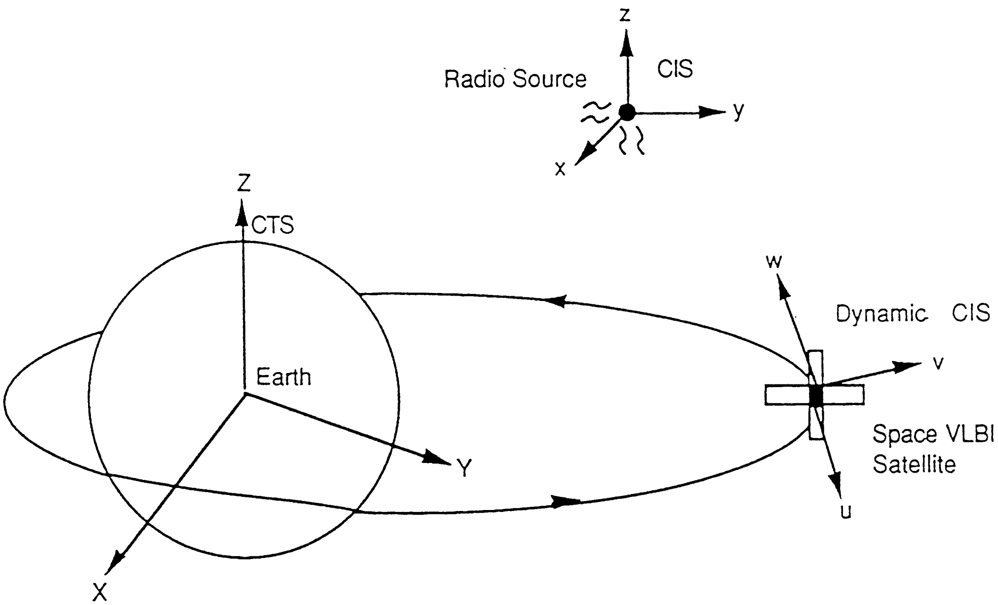

Fig. 2 The Reference Frames in the Space VLBI System

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Reformulation of Mathematical Model in Terms of Estimable Sets of Parameters to Remove the Datum Defect

$$d^I_{jkl} = -\left\{ \begin{bmatrix} X_j \\ Y_j \\ Z_j \end{bmatrix}^T R_2\ (-(x_{po}+\Delta x_p))\ R_1\ (-(y_{po}+\Delta y_p))\ R_3\ (\theta_{ko}+\Delta\theta_k) - \right.$$

$$\left.\left(\begin{bmatrix} X^I_{ko} \\ Y^I_{ko} \\ Z^I_{ko} \end{bmatrix}^T + \begin{bmatrix} \Delta X^I_k \\ \Delta Y^I_k \\ \Delta Z^I_k \end{bmatrix}^T \right) \right\} \begin{bmatrix} \cos\delta_l & \cos\ (\alpha_{lo} + \Delta\alpha_l) \\ \cos\delta_l & \sin\ (\alpha_{lo} + \Delta\alpha_l) \\ \sin\delta_l & \end{bmatrix} + c\left[\Delta C^I_{0rj} + \Delta C^I_{1rj}\ (t_k - t_0)\right]$$

Estimable Parameters:

Station Coordinates: X_j, Y_j, Z_j

Clock Parameters: ΔC_0, ΔC_1

Declination of the Source: δ

Change in RA of the Source: $\Delta\alpha$

Changes in Orbital Elements: Δa, Δe, Δi, $\Delta\omega$, $\Delta\Omega$, ΔM

Changes in the ERP's: ΔX_p, ΔY_p, Δ(UT1-UTC)

**Note: $\Delta\Omega$ and Δ(UT1-UTC) are not separable.*

Fig. 3 Mathematical Model and Estimable Set of Parameters

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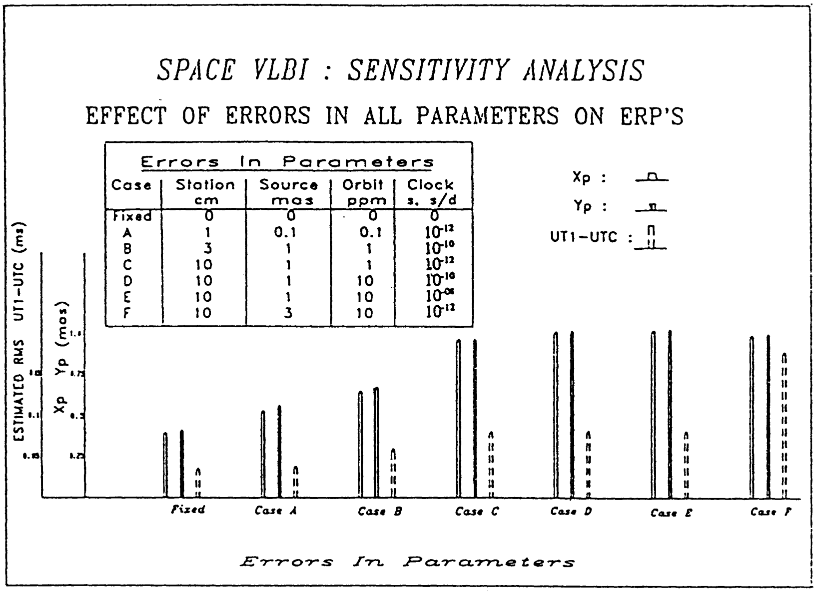

Fig. 4 Effect of Errors in All Parameters

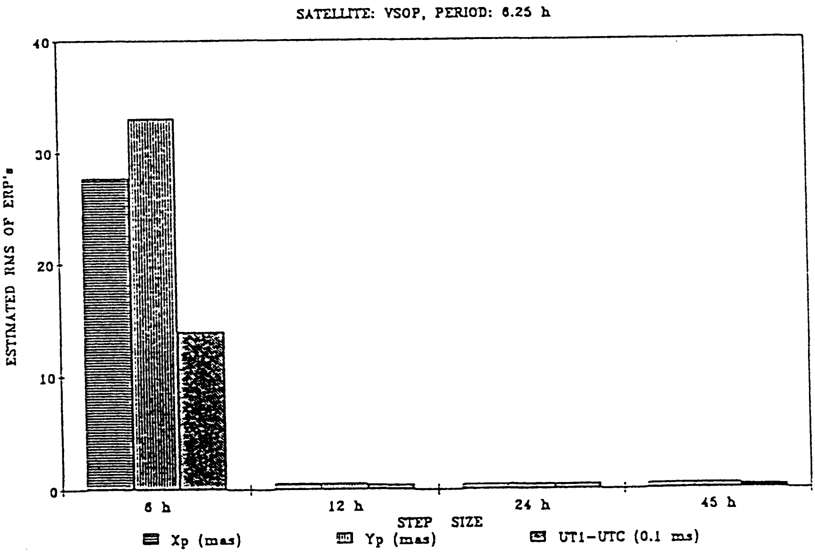

Fig. 5 Effect of Step Size on ERP Estimation

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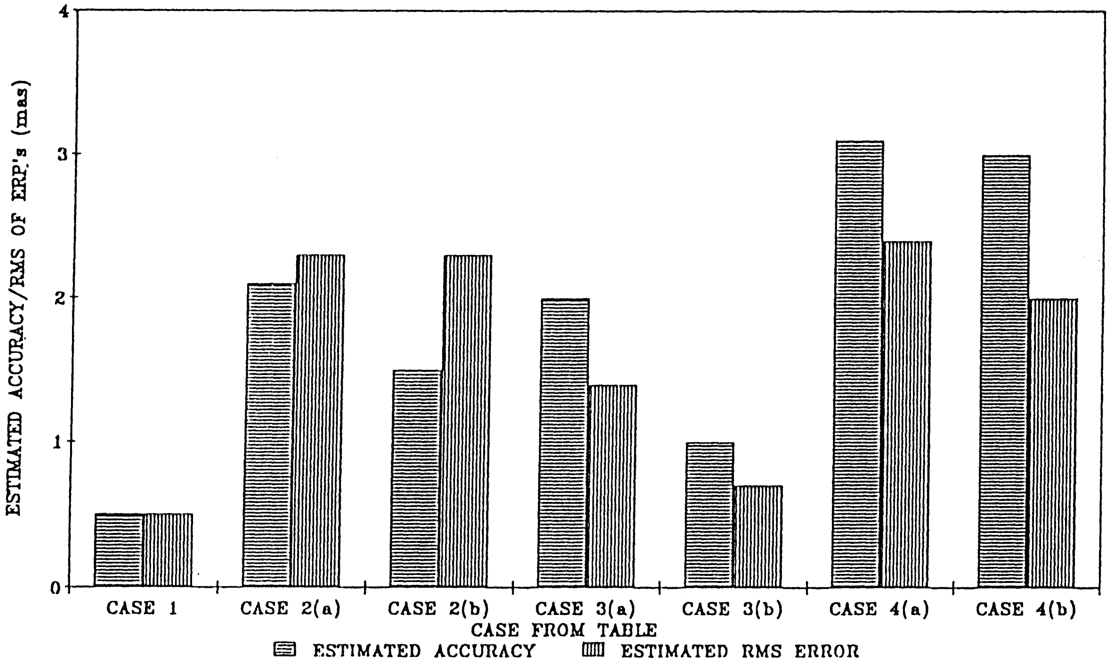

CASE	1	2(a)	2(b)	3(a)	3(b)	4(a)	4(b)
Sys. Effects	Yes	Yes	No	Yes	No	Yes	No
A priori Info.: (i) Stations	IERS	Shift 10 m	as in 2(a)	IERS	as in 3(a)	Shift 10 m	as in 4(a)
(ii) ERP's	IERS	IERS	as in 2(a)	Shift 0.5"	as in 3(a)	Shift 0.5"	as in 4(a)

Fig. 6 Influence of Systematic Effects and a priori Information

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