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Statistical inversion method for binary asteroids orbit determination

I. Kovalenko, D. Hestroffer, A. Doressoundiram, N. Emelyanov, R. Stoica
ikovalenko@imcce.fr (IMCCE - LESIA, Paris Observatory)

Introduction

We focus on the study of binary asteroids, which are common in the Solar system from its inner to its outer regions. These objects provide fundamental physical parameters such as mass and density, and hence clues on the early Solar System, or other processes that are affecting asteroid over time. The present method of orbit computation for resolved binaries is based on Markov Chain Monte-Carlo statistical inversion technique. Particularly, we use the Metropolis-Hastings algorithm with Thiele-Innes equation for sampling the orbital elements and system mass through the sampling of observations. The method requires a minimum of four observations, made at the same tangent plane; it is of particular interest for orbit determination over short arcs or with sparse data. The observations are sampled within their observational errors with an assumed distribution. The sampling yields the whole region of possible orbits, including the one that is most probable.

Orbit determination

The astrometric observations are related to the theoretical positions through the observational equation:

\[ \varphi = \psi(X) + \varepsilon \]

where

\[ p(X|\varphi) = \frac{p(\varphi|X)p(X)}{p(\varphi)} \]

- Observations: \( \varphi = (\rho_1, \theta_1; \ldots; \rho_N, \theta_N) \)
- Sky-plane position: \( \psi(X) \)
- Orbital elements + system's mass: \( X = (a, e, i, \Omega, \omega, M, m_{\text{sys}}) \)
- Observational errors: \( \varepsilon = (\varepsilon_{a1}, \varepsilon_{\delta1}; \ldots; \varepsilon_{aN}, \varepsilon_{\deltaN}) \)

Markov Chain Monte-Carlo method

The Metropolis–Hastings algorithm will be used for sampling the parameters \( X \).

For each iteration:

- Select a random set of 4 observations
- S = (\( \rho_1, \theta_1; \rho_2, \theta_2; \rho_3, \theta_3; \rho_4, \theta_4 \))

The algorithm is run for a large number of iterations until the entire possible orbital-element space is mapped.

Acceptance criteria

\[ a = \frac{p(X'|\varphi)|f'|}{p(X|\varphi)|f|} \]

If \( a \geq 1 \)

\( X^{t+1} = X' \)

If \( a < 1 \)

\[ \begin{align*}
X^{t+1} &= X', \text{ with probability } a \\
X^{t+1} &= X^t, \text{ with probability } 1 - a
\end{align*} \]

This process is repeated until the stationary a posteriori density is reached.

References

1) R. Palacios 1958 AJ 63, 395
2) D. Oszkiewicz et al. 2013, 5F2A 237

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