PRECISION TRACKING SYSTEMS OF THE IMMEDIATE FUTURE: A DISCUSSION 10

David E. Smith

Geodynamics Branch
Trajectory Analysis and Geodynamics Division
Goddard Space Flight Center
Greenbelt, Maryland

INTRODUCTION

This paper discusses briefly the present status and future expectations of four satellite tracking systems, satellite-to-satellite tracking, lasers, very long baseline interferometry (VLBI) and geoceiver. None of these techniques are being fully exploited at the present time but all can be expected to provide measurements in the next few years of a quality that will contribute extensively to studies of Earth and ocean dynamics.

SATELLITE-TO-SATELLITE TRACKING

This technique has been discussed extensively during the last few years as a possible means of maintaining current orbits on active spacecraft and also as a precision tool for studying the perturbations in satellite motion for Earth physics. In its simplest terms satellite-to-satellite tracking is an electronic tape measure connecting a master satellite, usually depicted in a high stable orbit, with a relatively low altitude, strongly perturbed spacecraft. The big advantage for Earth physics of satellite-to-satellite tracking compared to normal tracking is that extensive coverage both geographically and in time is possible with nearly all proposed systems. Indeed, it has been argued that this technique is probably the only way many of the objectives described in the Williamstown Report on Solid-Earth and Ocean Physics (ref. 1) can be achieved.

Although satellite-to-satellite tracking is not yet a reality the technique has essentially been explored and applied to problems of the lunar gravitational field. The way lunar satellites are tracked from the Earth is essentially the same method and, furthermore, it has been successfully spplied to the mascon problem where the perturbations, of too high a frequency for adequate representation by spherical harmonics, were shown by Muller and Sjogren (ref. 2) to be correllated with topographical features.

The type of spaceborne tracking system that will be used for the Earth physics investigations is expected to be similar to the Goddard Range and Range-Rate System (GRARR) which operates at S-band. The present accuracy of the range-rate measurements based on an averaging time of 10 seconds is about 0.3 mm/sec compared with the 0.03 mm/sec which will be actually required for Earth physics investigations. Improvement of the system to the required level is not expected to be a major problem.

LASER TRACKING

Of the four systems being discussed the laser technique has probably been in operation longer than any of the others. However, only a limited amount of operational experience has been gained with this system, and most of that has been gained during the last year. In concept, the laser is probably the simplest of all measuring devices since, like radar, it sends a pulse of energy towards the spacecraft which is reflected and received back down near the transmitter. The real measurement is the roundtrip travel time which is then turned into a range.

Systems of this kind have been operating in a network configuration only recently and then with only a few stations and with systems not fully tested. Furthermore, the best way of analyzing these data for Earth physics purposes has not yet been determined and, in this respect, puts this system in essentially the same position as the others.

In the United States it is Goddard Space Flight Center and the Smithsonian Astrophysical Observatory who have been the main organizations responsible for the development of laser tracking of artificial satellites and for investigating and fostering the application of these systems to Earth physics. The present systems probably have an accuracy of about 50 cm but this is a rather arbitrary figure because there is no absolute scale by which their quality can be judged and for this reason a laser system tends to be judged by the rms range noise about some reference, such as an orbit. In some respects, however, this is not an undesirable parameter, provided it is not confused with accuracy, because the noise is an indication of the stability, albeit short-term, of the system, and for many investigations this may be even more important than accuracy.

The quality of the laser in the next few years is expected to improve to about the 5 to 10 cm level. This is not a great deal better than is currently being claimed for the present lunar laser ranging system and is, in fact, a little worse than is expected of future lunar systems. The major disadvantage of the laser over competitive techniques is that it is a fair weather instrument. The operation of the systems during both day and night has been routine for several years but little can be done to overcome clouds or heavy fog, except perhaps, by choosing a more favorable site location. This question of site selection is one that can be expected to be of considerable importance for all the precise tracking systems of the future because their quality will make them sensitive to the very small changes in station position associated with such movements as creep, subsidence, tidal loading and fault slips. The question of weather is just one more factor in an area which can be expected to become increasingly complex.

Finally, a problem that is unique to the laser, and for which very little information is presently available, is the restrictions that may be placed on the operation of the system near highly congested air-traffic lanes. At present, safety regulations require that an observer keep watch for aircraft and that the system cease operation, when necessary. However, the locating of stations on the west coast by GSFC is necessitating the addition of radars to the systems that will detect aircraft at much greater distances and the impact of this may be to reduce the overall effectiveness and efficiency of the system. These questions will only be answerable after a period of operation under these conditions.

VERY LONG BASELINE INTERFEROMETRY (VLBI)

It is only recently that the technique of very long baseline interferometry has been applied to the problems of geodesy, notably, baseline determination. However, VLBI has been successfully demonstrated as a radio astronomical tool as far back as 1967 with many measurements of angular resolutions smaller than a thousandth of a second of arc (ref. 3).

Of the techniques being discussed here this is the only one which has the ability to make measurements in an inertial frame of reference and this is an important advantage. With this capability VLBI can be used to monitor the motion of the Earth in space and on its axis in addition to the ability to measure chord lengths. However, the prime consideration here is for the interferometer to be used to track a spacecraft. Recently VLBI experiments conducted jointly by SAO and GSFC on an ATS spacecraft from sites at Rosman and Mojave have detected fringe rates that correspond to changes in the velocity of the spacecraft as small as 1 mm/sec and with a resolution of the order 0.1 mm/sec. These velocity measurements can greatly enhance the position determination capability of synchronous spacecraft, thereby enabling the recovery of low degree and order geopotential coefficients to be significantly improved.

One of the major problem areas of VLBI is in the atmospheric distortion of the ray paths to the source. For very short baseline systems, such as Minitrack, the ray paths are almost identical for both antennas and consequently the atmosphere is not of major importance. However, as the baseline increases to inter-continental distances the ray paths through the ionosphere can differ by several meters even at C-band frequencies. Atmospheric modeling can be applied to the measurements but to achieve accuracies of 10 cm will require models accurate to a few percent and this may not be practical.

GEOCEIVER

The Geoceiver is a continuously integrated doppler system, similar in design to the TRANET doppler stations but considerably smaller and simpler yet designed to produce position determinations of equal quality.

The Department of Defense is apparently obtaining over thirty of these systems and the first few production models are already being tested.

One method of using the Geoceiver system is in a small dense network of, say 7 or 8 stations on a continent with baselines of about 1000 km. Studies of the potentialities of such a network (ref. 4) indicate a position determination of the spacecraft to be about 10 cm. Now the Geoceiver is not, inherently, a ranging system but when used in groups the biases for each of the systems can be recovered enabling spacecraft position to be determined with considerable precision. However, individually, the stations cannot be used as ranging systems and this is probably the biggest disadvantage of Geoceiver.

The production models of Geoceiver are reportedly exceeding the specifications (ref. 5) and under test the rms of the deduced range residuals are about 5 cm. These tests suggest that a geometric determination of the spacecraft position with respect to the ground stations is probably of the same order and that the absolute accuracy of the spacecraft position while being tracked is largely due to the errors in the locations of the ground stations and unmodelable atmospheric effects. Furthermore, it seems highly probable that with sufficient data the station positions relative to each other could be improved upon to the level of a few tens of centimeters and in a geocentric system to at least one meter.

The possible application of these systems to the calibration of a spaceborne altimeter are obvious but with our present gravitational models it would be impossible to extend the same quality of calibration to areas over which the spacecraft was not being continuously tracked by several of these systems.

DISCUSSION

During the next few years the four systems that have been discussed can be expected to approach the quality required for the Earth physics investigations of the kind described in the Williamstown report (ref. 1). However, it is very doubtful at the present time if the software availale for handling these data and our knowledge and ability to model the effects of the atmosphere are anywhere near adequate. Consequently, even if these systems provide measurements of 10 cm precision, it is doubtful that we shall be able to make proper use of the data unless considerable effort is expended on improving orbital perturbation theories, numerical integration systems, atmospheric and gravitational modeling, etc.

Table 1 is an attempt to summarize the present capabilities of the four systems that have been described, together with an estimate of their precision in two or three years time. Some of the advantages and disadvantages of each of these systems are also given but it should not be inferred that the systems should be competitive, but rather complementary. When working at the 10 cm level it will be dangerous to take for granted the results of any one system for very many years until it has been fully proved. The confirmation of geophysical measurements by at least two systems employing different techniques and data handling methods should be a major aim of this new work for many years to come.

References

1. "The Terrestrial Environment: Solid-Earth and Ocean Physics" NASA CR-1579, April 1970.

2. Muller, P. M. and W L. Sjogren, "Mascons: lunar mass concentrations", Science, Vol. 161, p. 680, 1968.

3. Cohen, M. H., D. L. Jauncey, K. I. Kellerman and B. G. Clark, "Radio interferometry at one-thousandth second of arc", Science, Vol. 162, p. 88, 1968.

4. Brown, D. C., "Near term prospects for positional accuracies of 0.1 to 1.0 meters from satellite geodesy", D.B.A. Systems, Inc., Final report on contract number F19628-69-C-0264 for AFCRL, Report Number 70-0501, August 1970.

5. Private communication with Duane C. Brown, D.B.A. Systems, Melbourne, Florida, Sept. 1971.

	PRESENT PRECISION 1971	FUTURE PRECISION 1973	ADVANTAGES	DISADVANTAGES
SATELLITE-TO-SATELLITE TRACKING	0.3 mm/sec	0.05 mm/sec	near continuous coverage	2 active spacecraft
LASERS	35 cm	5 - 10 cm	one station operation, mobile	fair weather instrument, aircraft
VLBI	0.1 mm/sec	0.01 mm/sec(?)	inertial reference frame	large antennas, fixed locations
GEOCEIVER (network)	10 cm	5 cm	cheap, easy to use	large numbers of stations

Fig. 1 Comparison of Systems