ANALYSIS OF THE HEADING SENSITIVITY IN THE
LITTON INERTIAL SURVEY SYSTEM *

Abstract

The straight line concept which has developed as a practical design restriction in inertial surveys with the Litton System is not only cumbersome in the planning stage but also often affects the economy of the survey adversely. A more flexible use of the system is therefore desirable.

The analysis of test data taken along a well-controlled L-shaped traverse near Ottawa indicates that software modifications can eliminate a large part of the errors due to heading sensitivity. The paper discusses the design of an appropriate smoother and ways to find its model structure and its weighting from a series of test runs. Results show that the maximum standard deviation along an L-shaped traverse of 100 km length is about half a metre. Further improvements are envisaged by changes in the survey procedures and a more effective use of the filter output. Optimal smoothing is not possible at present and would require a redesign of the filter output.

1. Description of the Problem

At the First Inertial Symposium in Ottawa Harris (1977), in his assessment of the Litton system, gave the following description of the problem treated in this paper:


The IPS provides excellent results if each leg is a straight-line traverse. ... If a traverse leg deviates from this operational concept, the results are severely degraded for that leg. Where a straight-line survey might yield an accuracy of 20 to 30 centimeters, if the same distance is made into an L-shaped traverse the error may become several meters. There may be some residual effects in the next leg due to the Kalman filter. ... One can visualize the restrictions that are imposed on a survey by this operational concept. The choice often comes down to economics versus accuracy, where one accepts survey degradation rather than field a large force of conventional survey teams to provide the supplementary control required for an ideal IPS survey. This straight-line traverse operational constraint is a major problem which must be resolved if the inertial systems are truly to become complete geodetic survey systems.

A graphical demonstration of this problem is given in figures 1 and 2 which show the errors in geodetic latitude and longitude along an L-shaped traverse for a set of 9 forward and backward runs. The error pattern changes in a nonlinear fashion at station number 4 which is the turning point of the traverse. Similar results have been obtained by other investigators, see e.g. Todd (1979) and von Luetzow (1980). The usual explanation is that internal system temperature gradients and perhaps imperfect magnetic shielding are the causes of the trouble, i.e. that the errors are hardware related. There is little published proof for this at the moment but even if it is the case, the errors are remarkably systematic which means, they are not completely unpredictable. Fig. 1 shows this very clearly. The errors in $\phi$ are very systematic and of about the same size but opposite sign in the forward and backward runs. Differences between forward and backward runs are not so obvious in the $\lambda$-coordinate (Fig. 2) but the residual errors are also quite systematic. They could therefore be modelled either in the filtering or in the smoothing procedure.

While a change of the Kalman filter in the Litton system cannot be done by the user, a change of the smoothing routine is possible. The question is therefore whether a smoother can be designed which gives random instead of systematic errors and which at the same time reduces the variance of the residual errors. An answer to this question can be obtained by using the filtered (raw) data coming from the system and modelling them parametrically by a least-squares adjustment using the known control points. Figures 3 and 4 show the result of such a computation for the same data set as before using a 7 parameter model. The change with respect to figure 1 and 2 is dramatic. The maximum standard errors drop sharply from 2.3 m to 0.3 m and the residual errors are approaching a random behaviour. Since this result is dependent on the amount of control point information available, it cannot be achieved in a run which has only the minimum coordinate update information at the end of the traverse. But it indicates that a simple parametric model can take care of most of the systematic error in the data. It can therefore be expected that a redesign of the smoother will give improved results. This redesign is the main topic of the following sections.

2. Smoothing — Optimal and Empirical

In the ideal case, the data coming from an Inertial Measuring Unit (IMU) have been obtained by optimal Kalman filtering during the zero velocity updates. At the end of the mission the filtered results can be improved by optimal smoothing, i.e. by minimizing the trace of the final covariance matrix. It should be noted that no new measurements are necessary for this process. Smoothing uses the complete information