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OFFICE OF NAVAL RESEARCH/E21-H28
SEMI-ANNUAL REPORT
Period: 1/1/94 - 6/30/94

The research during this time period has focused on achieving more accurate realizations of the SME filter that than based on the Extended Kalman Filter (EKF). Simulation studies have shown that the linearization carried out in the EKF implementation can result in degraded performance in certain situations. To correct this, we are working on a much more accurate approximation based on the idea of sampling distribution functions. A brief description of the approach is given below.

It is well known that the minimum-variance estimate of a random signal x(k) having finite second moment is equal to the conditional mean. Furthermore, when the signal state model and the measurement model are linear and the probability distributions are Gaussian, the conditional mean can be computed from a unique linear combination of the measurement data. Unfortunately, when the signal or measurement model is nonlinear, the solution to the estimation problem has proven to be much more elusive. The traditional approach has been to adapt the linear theory to nonlinear signal and measurement models through the use of the Taylor Series approximation. While this approximation simplifies the nonlinear estimation problem to the point that an implementation is realizable, it has two fundamental drawbacks:

(1) the poor approximation of the expectation E[f(x(k))] by f(E[x(k)])

(2) a dependence on the Jacobian which is all too often numerically unstable.

To see the effect of the former, suppose that f is a convex function. Then from Jensen's inequality, f(E[x(k)]) is known to provide a lower bound of E[f(x(k))]. Thus, the residual used in such nonlinear filters as the EKF is always larger than the true residual and the estimates are then necessarily biased.

This points out the two most significant shortcomings of the traditional approach and emphasizes the need for more refined algorithms. In the current work, a solution to the nonlinear estimation problem is proposed that avoids the use of the Taylor series approximation. The filter construction is based on the use of distribution sampling, the Law of the Unconscious Statistician, and an averaging operation to approximate expectation. This approach appears to be well suited to the SME filter formulation of the multiple target tracking problem. Once the new nonlinear implementation is developed, simulation studies will be carried out on performance, including comparisons with the standard EKF implementation that has been used up to the present time.

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OFFICE OF NAVAL RESEARCH/E21-H28
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The work during this time period has continued to focus on a new implementation of the SME filter based on distribution sampling. A paper on this is being prepared for presentation to the 1995 SPIE Conference on Signal and Data Processing of Small Targets.

A second part of the research has focused on tracking maneuvering targets. There are a number of algorithms currently available for tracking highly maneuverable targets using position measurements. A comparison of some of these algorithms using benchmark trajectories is given in a session [1] of the 1994 American Control Conference. Dramatic increases in tracking performance (lower loss of lock rates, larger interdwell intervals, and more accurate state estimates) can be expected to result from novel uses of additional non-traditional sensor information. In particular, an imaging sensor provides such information which can be used to increase tracking performance. The most extensive research along this line has been by Sworder, Hutchins, and others in a number of papers including [2]. One disadvantage to the approach developed in these papers is that they depend on "measurements" of the target's three-dimensional orientation. Cooperative targets may provide the tracker with the three Euler angles needed but non-cooperative targets will never provide such information. One must resort to pattern recognition techniques that require an extensive database of target images at various orientations. In [2], for instance, the Generalized Hough Transform is used for image encoding and matching. For each possible target (F-16, MIG-25, etc.) such a database needs to be constructed.

In this work, we eliminate the need for a database or knowledge of the target type. The target mode is determined using image features (mostly moment-based) which are easy to calculate. The scalar, linear difference equation, with unknown system parameter a(k), which models the evolution of the feature is filtered using an EKF that estimates the state (feature) and the unknown parameter simultaneously. The parameter estimates are monitored to detect abrupt changes in the feature dynamics. A composite hypothesis testing problem is formulated and test statistics derived that determine the current target mode. Knowledge of the target mode allows us to reconfigure the tracking filter in order to decrease the loss of lock rate, increase the interdwell interval, or estimate the system states more accurately. The algorithm developed is tested on the benchmark trajectories [1] and is shown to detect maneuvering periods extremely well with little delay. A paper on this work is being prepared for presentation to the 1995 SPIE Conference on Signal and Data Processing of Small Targets.

References:

1. W. D. Blair (Chair), G. A. Watson (Co-chair), Benchmark Problem for Tracking Maneuvering Targets, Session TP05, Proceedings of the 1994 American Control Conference, Baltimore, MD, June, 1994, 2071-2097.

2. D. D. Sworder, P. F. Singer, D. Doria, and R. G. Hutchins, "Image Enhanced Estimation Methods", IEEE Proceedings, Vol. 81, No. 6, June 1993, 797-812.

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