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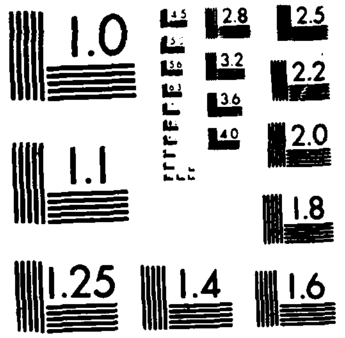

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Annual Technical Report

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"Advanced Guidance Algorithms for Homing Missiles

With Bearings-Only Measurements"

by

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Summary

Homing missile guidance is formulated as an optimal stochastic control problem where the special nonlinear structure of the missile-target engagement is exploited. Since this stochastic control problem assumes a nested information pattern, the filter structure can be developed independently of the guidance scheme. However, the guidance scheme is dependent on and affects predicted filter performance. Significant progress is being made on both the estimation problem and the guidance problem.

Investigation of nonlinear estimators, especially tailored to the homing missile problem, has produced not only a good deal of insight but very responsive and mechanizable schemes. Although these schemes are applicable to active sensors, our emphasis has been on the more difficult passive sensor case where only angles are available. Recently developed schemes based on (1) coordinate transformations and (2) an assumed probability density function peform well, but the modified-gain extended Kalman filter seems to be the most promising. Furthermore, this filter has been used as the basis of a stochastic adaptive flight control scheme. In order to improve this class of stochastic control schemes, new results have been obtained in control synthesis for structured plant uncertainty.

Two important current efforts in missile guidance with bearings-only information are in the development of guidance schemes that enhance an information measure by trajectory modulation and in target acceleration detection. Currently, a mechanizable guidance law based upon linear-quadratic-Gaussian theory is being tested which modulates the path initially to enhance the information measure but which meets terminal miss constraints. Finally, based upon deterministic detection filter design by spectral methods, a detection scheme is under investigation for rapidly detecting target motion and is being compared with current designs.

Research Objectives and Status

A special class of stochastic control systems is being developed for the guidance system of a homing missile by exploiting the special nonlinear structure of the missile-target engagement. Improvements are required in the current guidance law, proportional navigation, because the guidance system degrades under initial intercept geometries that produce large nonlinearities about the homing triangle or due to active target motion which also induces large nonlinearities. Our guidance law investigations have emphasized measurements from passive sensors for which only bearing information is available. This bearings-only guidance problem is most challenging because the stochastic controller has a dual role which is to enhance the filter performance so as to achieve minimal expected terminal cost. However, this problem is somewhat simplified since the separation theorem in the sense of Witsenhausen is satisfied. The separation theorem states that the filter structure, given the classical information pattern, is independent of the controller structure although the controller is highly dependent on the predicted filter performance.

Motivated by the separation theorem, high-performance estimators have been developed which are tailored to the special nonlinearities of the missile-target engagement. One new estimator, called the modified-gain extended Kalman filter (MGEKF), is applicable to two important engineering problems: bearings-only estimation [1] and state and parameter estimation [2]. Although we consider the MGEKF a breakthourgh in guidance filter development, the coordinate-transformation-based filter [3] has also shown considerable promise. Since the conditional mean estimator is infinite dimensional, the finite dimensional MGEKF is proposed as the estimation processor for the homing guidance dual controller. Furthermore, the MGEKF is also proposed as the state and parameter estimator for an explicit adaptive control law which is applicable to flight control and autopilot design. In particular, the MGEKF has been applied to the problem of on-line state estimation and the identification of aircraft stability derivatives [4]. An adaptive control loop using this estimator is given in [5] where the essential parameter required is moment coefficient due to elevator defection. The adaptive gain is inversely proportional to this parameter which seems well estimated by the MGEKF even in modestly-high clear air turbulence. However, more elaborate controllers will be required for bank-to-turn missiles. A multivariable synthesis scheme is suggested in [6] in which the LQG controller can be made insensitive to a class of parameter variations. It is seen in [4,5] that the moment coefficients are estimated well but the force coefficients are not. In particular, their estimation response is quite sluggish due to the effect of high-frequency noise associated with the model of the clear air turbulence. An adaptive system is being designed so that the controller is only sensitive to the moment coefficients. This approach to autopilot design is being considered for application to a bank-to-turn missile.

Both homing missile guidance and adaptive control schemes are currently designed based upon the certainty equivalence principle. That is, a controller and estimator are placed in cascade where both are designed independently of one another. These ad hoc controller structures are not adequate in general, and improvements are sought through the dual control concept. The dual controller structure which has never been realized by even the simplist stochastic control example needs much study. We began our efforts by noting that the essence of the dual control problem is captured in a deterministic setting where the nonlinear observer performance is enhanced by trajectory modulation. In particular, a measure associated with the Fisher information matrix is maximized in order to obtain an information-enhanced homing path [7,8]. In a recent study [9,10 (pages 2 to 9)] not only is the EKF performance improved by trajectory modulation over the proportional navigation path, but the performance of the MGEKF along these information-enhanced paths relative to that of the EKF is impressive.

Based on these results an ad hoc guidance rule which seems to possess the dual control property is proposed. It is seen that the trace of the information matrix weighted by the range to go when combined with the current control performance index reduces to a quadratic form. This form differs from current forms in that the performance index due to the information measure is <u>not</u> convex. Some preliminary results are given in [10 (pages 22 to 26)]. It is noted that this simple guidance rule produces trajectories similar to those generated in [7,8].

The essential difficulty in dealing with dual control problems is that the structure of the controller is not well understood. For this reason, ad hoc schemes pervade the literature, but no rational scheme is ever suggested. For this reason, we have begun looking into asymptotic approaches to this class of problems as sugested in [10 (pages 29 and 30)]. For small measurement and process noise variances, the optimal control law, obtained from the Hamilton-Jacobi-Bellman PDE of a particular nonlinear problem, is determined in terms of an asymptotic expansion in the state estimate and state error variance. This problem is chosen because the estimation process is conditionally Gaussian and the deterministic problem (or zeroth-order solution of the Hamilton-Jacobi-Bellman equation) is integrable. Since it is hypothesized that dual control problems are not integrable, the expansion about the zeroth-order solution should give valuable insight into the structure of the dual control problem. The objective is to apply these ideas to both the homing guidance and the adaptive control problems.

There is a real need to determine the effects of guidance system errors on missile guidance. To do this, a measure of performance is used which is associated with the optimal return function of the LQG problem and has the property of a Lyapunov function. Since the guidance laws considered to date are based upon the certainty equivalence principle, the control is a function of the filter or observer output. The Lyapunov function [10 (pages 10 to 21)] is a function of three terms, one associated with the LQ problem, one associated with the observer, and one associated with the error in the control law due to the inaccuracy of the state estimate from the observer. Some initial results are given in [10].

Finally, the very important problem of target maneuver detection is considered. Our approach is to develop target motion sensitive filters (actually observers). The theory has been developed for time invariant linear dynamic systems [11,12]. The objective is to design the detection gain so that the target motion can be associated directly with the measurement residuals. Our present effort is briefly described in [10 (page 31)].

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