Final Report

Grant AFOSR-88-0202

Stochastic Adaptive Control and Estimation Enhancement

Y. Bar-Shalom

February 1991

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Univ. of Conn. ESE Dept. — 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Air Force Office of Scientific Research
6c. ADDRESS (City, State and ZIP Code) Box U-157 Storrs, CT 06269-3157	7b. ADDRESS (City, State and ZIP Code) Directorate of Mathematical & Information Sciences, Bolling AFB DC 20332-6448 Attn: PKZ P. Bell
8a. NAME OF FUNDING/SPONSORING ORGANIZATION AFOSR — 8b. OFFICE SYMBOL (If applicable) NM	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFOSR Grant 88-0202
8c. ADDRESS (City, State and ZIP Code) Bld 410 Bolling AFB DC 20332-6448	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO. 61102F; PROJECT NO. 2304; TASK NO. A1; WORK UNIT NO

11. TITLE (Include Security Classification)
Stochastic Adaptive Control and Estimation Enhancement

12. PERSONAL AUTHOR(S)
Y. Bar-Shalom

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
Final	FROM 8/1/88 TO 6/30/90	1991/2/11	6

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The investigations summarized in this report deal with (a) adaptive dual control of systems with unknown parameters, (b) estimation and control of hybrid stochastic systems, (c) distributed estimation in systems with measurements of uncertain origin and (d) solution of continuous-time hybrid stochastic differential equations, (e) use of point process theory for target mode estimation.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Col. J. Crowley	22b. TELEPHONE NUMBER (Include Area Code) (202) 767-5025 — 22c. OFFICE SYMBOL NM

DD FORM 1473, 83 APR — EDITION OF 1 JAN 73 IS OBSOLETE. — UNCLASSIFIED

The main results obtained and published during the period covered by this report, August 1988 - July 1990, are described below together with references given to the corresponding publication.

1. The Interacting Multiple Model Algorithm for Systems with Markovian Switching Coefficients, (Henk A. Blom and Yaakov Bar-Shalom, IEEE Transactions on Automatic Control Vol. 33, No. 8, August 1988)

   An important problem in filtering for linear systems with Markovian switching coefficients (dynamic multiple model systems) is the one of management of hypotheses, which is necessary to limit the computational requirements. A novel approach to hypotheses merging has been developed for this problem. The novelty lies in the timing of hypotheses merging. When applied to the problem of filtering for a linear system with Markovian coefficients this yields an elegant way to derive the interacting multiple model (IMM) algorithm. Evaluation of the IMM algorithm makes it clear that it performs very well at a relatively low computational load. These results imply a significant change in the state of the art of approximate Bayesian filtering for systems with Markovian coefficients.

2. Failure Detection Via Recursive Estimation for a Class of Semi-Markov Switching Systems, (L. Campo, P. Mookerjee and Y. Bar-Shalom, Proceedings 1988 IEEE CDC, Austin, Texas)

   An area of current interest is the estimation of the state of discrete-time stochastic systems with parameters which may switch among a finite set of values. The parameter switching process of interest is modeled by a class of semi-Markov chains. This class of processes is useful in that it pertains to many areas of interests such as the failure detection problem, the target tracking problem, socio-economic problems and in the problem of approximating nonlinear systems by a set of linearized models. It is shown in this paper how the transition probabilities, which govern the model switching at each time step, can be inferred via the evaluation of the conditional distribution of the sojourn time. Following this, a recursive state estimation algorithm for dynamic systems with noisy observations and changing structures, which uses the conditional sojourn time distribution, is derived and and applied to a failure detection problem.

3. Distributed Adaptive Estimation with Probabilistic Data Association, (K.C. Chang and Y. Bar-Shalom, Automatica, Vol. 25, No. 3, pp. 359-369, 1989)

The probabilistic data association filter (PDAF) estimates the state of a target in a cluttered environment. This suboptimal Bayesian approach assumes that the exact target and measurement models are known. However, in most practical applications, there are difficulties in obtaining an exact mathematical model of the physical process. In this paper, the problem of estimating target states with uncertain measurement origins and uncertain system models in a distributed manner is considered. First, a scheme is described for local processing, then the fusion algorithm which combines the local processed results into a global one is derived. The algorithm can be applied for tracking a maneuvering target in a cluttered and low detection environment with a distributed sensor network.

4. An Adaptive Dual Controller for a MIMO-ARMA System, (P. Mookerjee and Y. Bar-Shalom, IEEE Transactions on Automatic Control, Vol. 34, No. 7, July 1989)

An explicit adaptive dual controller has been derived for a multiinput multioutput ARMA system. The plant has constant but unknown parameters. The cautious controller with a one-step horizon and a new dual controller with a two-step horizon are examined. In many instances, the myopic cautious controller is seen to turn off and converges very slowly. The dual controller modifies the cautious control design by numerator and denominator correction terms which depend upon the sensitivity functions of the expected future cost and avoids the turn-off and slow convergence. Monte-Carlo comparisons based on parametric and nonparametric statistical analysis indicate the superiority of the dual controller over the cautious controller.

5. Time-Reversion of a Hybrid State Stochastic Difference System, (Henk A.P. Blom and Yaakov Bar-Shalom, Proc. 1989 IEEE Intn'l. Conf. on Control & Applications, Jerusalem, Israel, April 1989, and in IEEE Trans. Info. Theory, IT-36, July, 1990)

This paper develops the reversion in time of a stochastic difference equation in a hybrid space, with a Markovian solution. The reversion is obtained by a martingale approach, which previously led to reverse time forms for stochastic equations with Gauss-Markov or diffusion solutions. The reverse time equations follow from a particular non-canonical martingale decomposition, while the reverse time equations for Gauss-Markov and diffusion solutions followed from the canonical martingale decomposition. The need for the non-canonical decomposition stems from the hybrid state space situation. The non-Gaussian discrete time situation leads to reverse time equations that incorporate a Bayesian estimation step.

6. A New Controller for Discrete-Time Stochastic Systems with Markovian Jump Parameters, (L. Campo and Y. Bar-Shalom, 11th IFAC World Congress, Tallinn, USSR, Aug. 1990

A realistic stochastic control problem for hybrid systems with Markovian jump parameters may have the switching parameters in both the state and measurement equations. Furthermore, both the system state and the jump states may not be perfectly observed. Prior to this work the only existing implementable controller for this problem was based upon a heuristic multiple model partitioning (MMP) and hypothesis pruning. In this paper a stochastic control algorithm for stochastic systems with Markovian jump parameters was developed. The control algorithm is derived through the use of stochastic dynamic progamming and is designed to be used for realistic stochastic control problems, i.e., with noisy state obeservations. The state estimation and model identification is done via the recently developed Interacting Multiple Model algorithm. Simulation results show that a substantial reduction in cost can be obtained by this new control algorithm over the MMP scheme.

7. From Piecewise Deterministic To Piecewise Diffusion Markov Processes, (Henk A.P. Blom, Proc. IEEE CDC 1988)

Piecewise Deterministic (PD) Markov processes form a remarkable class of hybrid state processes because, in contrast to most other hybrid state processes, they include a jump reflecting boundary and exclude diffusion. As such, they cover a wide variety of impulsively or singularly controlled non-diffusion processes. Because PD processes are defined in a pathwise way, they provide a framework to study the control of non-diffusion processes along same lines as that of diffusions. An important generalization is to include diffusion in PD processes, but, as pointed out by Davis, combining diffusion with a jump reflecting boundary seems not possible within the present definition of PD processes. This paper presents PD processes as pathwise unique solutions of an Itô stochastic differential equation (SDE), driven by a Poisson random measure. Since such an SDE permits the inclusion of diffusion, this approach leads to a large variety of piecewise diffusion Markov processes, represented by pathwise unique SDE solutions.

8. Control of Discrete-Time Hybrid Stochastic Systems (L. Campo and Y. Bar-Shalom, Proc. 1990 ACC, May 1990; to appear in IEEE Trans. Auto. Control, 1991)

A realistic stochastic control problem for hybrid systems with Markovian jump parameters can have the switching parameters in both the state and measurement equations. Furthermore, both the system state and the jump states are, in general, not perfectly observed. Currently there are only two existing controllers for this problem. One is based upon a heuristic multiple model partitioning (MMP) and hypothesis pruning. The other utilizes the entire future *tree of models*, and is called the Full-Tree (FT) controller. The performance of the latter is superior to the former and their complexities are similar. In this paper we present a new stochastic control algorithm for stochastic systems with Markovian jump parameters. This control algorithm is derived through the use of stochastic dynamic programming and is designed to be used for realistic stochastic control problems, i.e., with noisy state observations. This new scheme, which is based upon the interaction of r (the number of models) model-conditioned Riccati equations, has a natural parallelism and is straightforward to implement. The state estimation and model identification is done via the recently developed Interacting Multiple Model algorithm. Simulation results show that a substantial reduction in cost can be obtained by this new control algorithm over the MMP scheme. Furthermore, the performance of the new algorithm is shown to be practically the same as that of the FT scheme even though the new scheme, which has a fixed amount of computations at each step of the recursion, is much simpler to implement than both the MMP and FT algorithms.

9. Discrete Time Point Process Filter for Image Based Target Mode Estimation (C. Yang and Y. Bar-Shalom, Proc. 1990 IEEE CDC; to appear in IEEE Trans. Auto. Control, 1991)

The performance of tracking and prediction systems of a maneuvering target can be improved by using additional (and unconventional) measurements of its apparent modes, typically provided by an imaging sensor. A model for the image-based observation channel for target mode estimation in discrete time is presented in this paper. A multidimensional point process filter is obtained by making use of the discrete time point process theory and its utilization is illustrated through simulation examples.

10. A New Approximation for the Partially Observed Jump Linear Quadratic Problem (C. Yang and M. Mariton, to appear in Int'l. Journal of Systems Science, 1991).

We consider the Jump Linear Quadratic Problem where linear state dynamics are made contingent upon the Markovian transition of a regime variable. It is desired to regulate the state while minimizing a quadratic performance index. In the case of partial observations the exact solution has proved to be elusive and, in this paper, we present a new approximation based on the optimal solution of an averaged version of the original problem.