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0. INTRODUCTION

This report summarizes the results obtained during the period of the Grant. The topics are divided according to the publications generated from the research effort.

This first topic deals with a new procedure to carry out nonlinear transformations commonly encountered in practical surveillance systems, that eliminates the bias and provides a correct (rather than optimistic) covariance matrix.

The topics covered in Sections 2, 5 and 6 deal with discrete optimization (assignment) techniques applied to various multisensor-multitarget problems, including ballistic missile track initiation from a passive orbiting sensor.

Section 3 presents some new efficient factorization algorithms that improve the numerical accuracy for several advanced state estimation filters used in practice.

Section 4 deals with the evaluation of performability measures of complex manufacturing systems.

1. TRACKING WITH CONSISTENT CONVERTED MEASUREMENTS VS. THE EKF

(Don Lerro and Yaakov Bar-Shalom, to appear in IEEE T-AES, Oct. 1993; also in Proceedings 12th World Congress IFAC Sydney, Australia, July 1993)

In tracking applications target motion is usually best modeled in a simple fashion using Cartesian coordinates. However, in most systems the target position measurements are provided in terms of range and azimuth (bearing) with respect to the sensor location. This situation requires either converging the measurements to a Cartesian frame of reference and working directly on converted measurements or using an Extended Kalman Filter (EKF) in mixed coordinates. An accurate means of tracking with debiased consistent converted measurements is presented which accurately accounts for the sensor inaccuracies over all practical geometries and accuracies. This method is compared to the mixed coordinate EKF approach as well

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as the standard converted measurement approach which is an acceptable approximation only for moderate cross range errors. This new approach is shown to be more accurate in terms of position and velocity errors and provides consistent estimates (i.e. compatible with the filter calculated covariances) for all practical situations. The combination of parameters (range, range accuracy, and azimuth accuracy) for which debiasing is needed is presented in explicit form.

2. A MULTISENSOR-MULTITARGET DATA ASSOCIATION ALGORITHM FOR HETEROGENEOUS SENSORS

(Somnath Deb, Krishna R. Pattipati, and Yaakov Bar-Shalom, IEEE T-AES, April 1993)

The problem is dealt with here of associating data from three spatially distributed heterogeneous sensors, each with a set of detections at the same time. The sensors could be active (three-dimensional or two-dimensional radars), or passive (electro-optical sensors measuring the azimuth and elevation angles of the source). The source of a detection can be either a real target, in which case the measurement is the true observation variable of the target-plus-measurement noise, or a spurious one, i.e., a false alarm. In addition, the sensors may have nonunity detection probabilities. The problem is to associate the measurements from sensors to identify the real targets, and to obtain their position estimates. Mathematically, this (static) measurement-target association problem leads to a generalized 3-D assignment problem, which is known to be NP-hard.

3. EFFICIENT L-D FACTORIZATION ALGORITHMS FOR PDA, IMM, AND IMMPDA FILTERS
(Vijaya Raghavan, Krishna R. Pattipati, and Yaakov Bar-Shalom, IEEE Trans. AES. October 1993)

Over the past twenty years, square-root factorization methods for Kalman filtering have gained popularity due to increased numerical robustness and accuracy provided by these methods. However, square-root formulations have not been developed for the state-of-the-art tracking algorithms, such as the Probabilistic Data Association (PDA) - for tracking in clutter, Interacting Multiple Model (IMM) - for tracking maneuvering targets, and IMMPDA (for tracking maneuvering targets in clutter on track formation). The only exception is the recent square-root implementation of the PDAF by Kenefic. In this paper, we show that there is a substantially better implementation of the square-root PDAF than Kenefic's algorithm in terms of both numerical robustness and computational efficiency. The computational savings of our algorithm are obtained by using successive L-D rank-one corrections instead of the Modified Weighted Gram-Schmidt (MWG-S) technique for the overall covariance update. For the covariance prediction step, we present an alternate implementation of the square-root version when the process noise covariance is time-invariant, that requires successive L-D rank-one corrections obviating the need to use the computationally expensive MWG-S technique. On the average, the proposed algorithm for square-root PDAF requires half the number of computations required by Kenefic's algorithm. We extend the same approach to develop computationally efficient square-root algorithms for the IMM and IMMPDA filters.

4. PERFORMABILITY STUDIES OF AMSS WITH MULTIPLE PART TYPES

(N. Viswanadham, Krishna R. Pattipati, and V. Gopalakrishna, Proc. IEEE Robotics and Automation Conference, May 1993)

Automated Manufacturing Systems are computer controlled configurations of versatile workstations and automated guided vehicles or similar material handling devices. They are highly integrated in terms of both material and information flows. In such highly integrated systems, the consequences of failure could be catastrophic. We formulate the notion of performability, a measure of composite performance and dependability for AMS producing multiple part types. We show that the distribution of accumulated performance over a given interval of time, can be obtained by solving a set of forward or adjoint linear hyperbolic partial differential equations.

The performability analysis presented here allows us to compute such useful quantities as the probability of meeting a target mix production, probability that the manufacturing lead time of a part type is less than a given limit. We also conduct analysis using variance and cross covariance functions to evaluate the volume-variety tradeoff.

5. A NEW ALGORITHM FOR THE GENERALIZED MULTIDIMENSIONAL ASSIGNMENT PROBLEM

(Somnath Deb, Krishna R. Pattipati, Yaakov Bar-Shalom, and Haralampos Tsaknakis, Proc. IEEE International Conference on Systems, Man, and Cybernetics, Chicago, 1992)

In this paper we present a fast near-optimal assignment algorithm to solve the generalized multidimensional assignment problem. Such problems arise in surveillance and tracking systems estimating the states (target position and velocity) of an unknown number of

targets. The central problem in a multisensor-multitarget state estimation problem is that of data association -- the problem of determining from which target, if any, a particular measurement originated. The data-association problem for tracking can be formulated as a generalized S -dimensional (S -D) assignment problem. However, the problem is NP-hard for 3 or more sensor scans ($S \geq 3$). In this paper, we present an efficient and recursive generalized S -D assignment algorithm ($S \geq 3$) suitable for near-optimal track initiation of targets with ballistic trajectories in polynomial time. Complete algorithmic details and preliminary simulation results are presented in this paper.

6. A S -DIMENSIONAL ASSIGNMENT ALGORITHM FOR TRACK INITIATION

(Somnath Deb, Krishna R. Pattipati, and Yaakov Bar-Shalom, Proc. IEEE Systems Conference, Kobe, Japan, September 1992)

The central problem in the multisensor-multitarget state estimation problem is that of data association - the problem of determining from which target, if any, a particular measurement originated. Measurements originating from a particular target can then be fused to estimate the states of targets not directly measured by sensors. However, misassociations may lead to lost tracks and poor position estimates. The problem is further complicated in the track initiation stage when no a priori estimates of target states are available. Reliable track initiation requires that the measurement-to-measurement association be optimized over multiple scans. In this paper, we present a near-optimal polynomial time S -dimensional ($S \geq 3$) Assignment algorithm that is especially suited to the track initiation based on measurements from S sensors.