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AESOP—A Computer-Aided Design Program for Linear Multivariable Control Systems

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SUMMARY

AESOP is an interactive computer program which solves quadratic optimal control and Kalman filter design problems for linear, time-invariant systems described in state-space form. The program can also be used to perform system analysis calculations such as transient and frequency responses, controllability, observability, etc. in support of the control and filter design computations.

INTRODUCTION

AESOP is a computer program designed to solve the linear quadratic Gaussian (LQG) control design problem. AESOP is an out growth of an earlier program (LSOCE) for control and filter design (reference 1). Computations performed, in addition to those for the time-invariant linear regulator and Kalman filter, include transient and frequency responses, transfer functions, eigenvalues, eigenvectors, covariance matrices, and other computations useful for linear system analysis. Calculations done by AESOP are defined in terms of numbered "functions". The user requests a function by typing in its assigned function number. The numbers can be entered singly (in an interactive mode) or as a string (in a batch mode) as the user's needs dictate. To aid the user, AESOP checks the validity of all requested function number sequences. On-line and off-line graphic output is provided, mainly for plotting of system responses.

SYSTEMS HANDLED BY AESOP

Systems for which design computations are to be performed are assumed to be in state variable form.

Figure 1 shows the structure AESOP assumes for the open-loop system. Inputs are control u, white noise disturbance w, white measurement noise v. System outputs are state x, output y, set-point output ysp, and noisy measurement z. The user defines the system by entering data for matrices A,B,C, etc., shown in the figure.

The structure of the Kalman filter designed using AESOP is shown in Figure 2. Here, control u and measurement z are filter inputs, and the output is state estimate $\hat{x}$. The user enters values for noise and disturbance PSD's and the program computes filter gain matrix KE.

Control design calculations can be performed for noisy or noise-free systems. Figure 3 shows the overall closed-loop system structure for linear quadratic regulator (LQR) control. The user inputs quadratic weighting matrices to define an LQR problem, whose solution is computed by AESOP as gain matrix KC. AESOP can analyze either the state or state-estimate feedback configuration. The user can also use AESOP to solve the non-zero set-point regulator problem (matrix KFF). Additional calculations performed by AESOP for the system of Figure 3 are described in the following section.

COMPUTATIONS PERFORMED BY AESOP

AESOP functions are divided into nine groups. The overall program structure is shown in Figure 4.

The functions in the group "Program Control" are used for changing default or reference parameter values such as time and frequency step sizes, indices for selecting input and output components, plotting options, etc.

The user requests functions in the "Matrix Input or Revision" group when entering or revising basic matrix data (e.g. the A,B,C, matrices) or when reading previously computed results for KE or KC. Also, one of the functions in this group is requested whenever LQR weights or noise PSD's are to be changed during a design iteration.

Matrix combinations which are used repeatedly throughout the program are computed by "Matrix Formation" functions. An example is the closed-loop LQR matrix, A-B*KC.

Functions for "Open-Loop System Analysis" calculate open-loop system information such as eigenvalues and eigenvectors, controllability, observability and residues.

The "Frequency Response" functions compute and plot frequency responses for the following configurations. For the open-loop system (Figure 1), frequency responses are computed for inputs u or w to outputs y or z. For state variable feedback (Figure 3), responses are computed for input w to outputs y or u.

For the LQR case (Figure 3), responses can be obtained for input w to outputs y,z or u. For this and for the state variable feedback case, cross plotting of closed vs open loop responses can be requested. Also, optimal controller frequency responses can be obtained, where z is the input and u is the output.

In the "Transient Response" group, open-loop system transient responses are computed for outputs x or y in response to either a step in a component of u or an initial condition on a selected state. Closed-loop step responses are obtained for the non-zero setpoint regulator configuration. Steps can be applied to setpoint yspd and responses plotted for selected components of x,y,ysp or u.

Functions in the "Transfer Functions" group compute zeroes of the open-loop system transfer functions relating u or w to y or z. Also, zeroes of the optimal controller transfer functions are computed here. Associated transfer function poles can be obtained either with the "open-loop analysis" functions or as by-products of LQR or Kalman filter design functions.

The group labeled "LQR, Kalman Filter and Covariances" primarily solve matrix Riccati equations related to the LQR or Kalman filter design problem. Also, state and estimation-error covariance matrices are computed to obtain covariances for x,y, and u for both open-loop, LQR and LQG systems. In addition, accuracy checks can be requested for matrix symmetry and positive definiteness, and for estimating residual equation errors.

The final "User-Supplied Subroutines" function group is included to allow user-supplied FORTRAN subroutines to be called within the AESOP program. Linkage to the main program is accomplished through the AESOP program's COMMON'S.

OPERATIONAL DETAILS

The AESOP program is written in ANSI-66 FORTRAN for running on an IBM 370/3033 time-shared system. The main program is dimensioned to handle up to 50th order systems, with the largest system run so far being 41st order. Object code requires about 200K bytes, with an additional 1.7M bytes required for matrix storage. A user's manual, in the form of a NASA report, is soon to be published. Source code may be obtained, after report publication from COSMIC (University of Georgia, Athens, GA).

REFERENCE

1. Geyser, Lucille, C.; and Lehtinen, Bruce: Digital Program For Solving the Linear Stochastic Optimal Control and Estimation Problem, NASA TN D-7820, March 1975.

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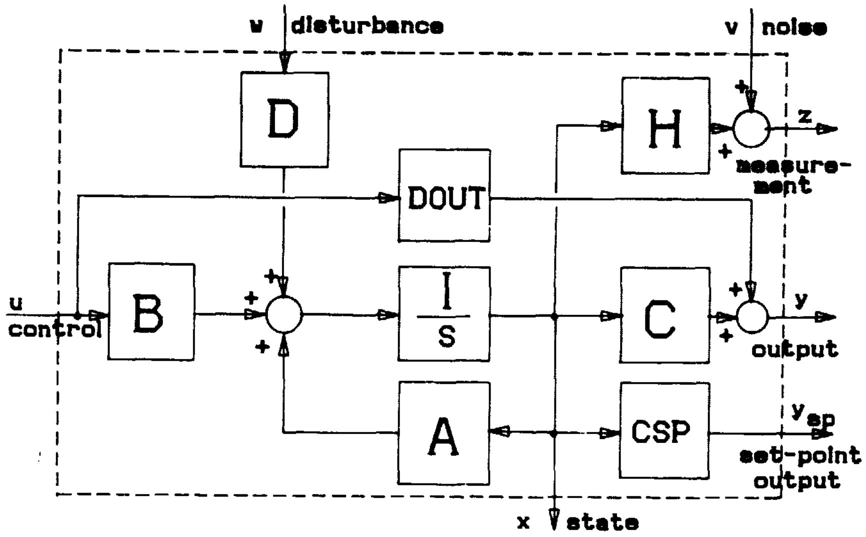

Figure 1. - Open loop system structure.

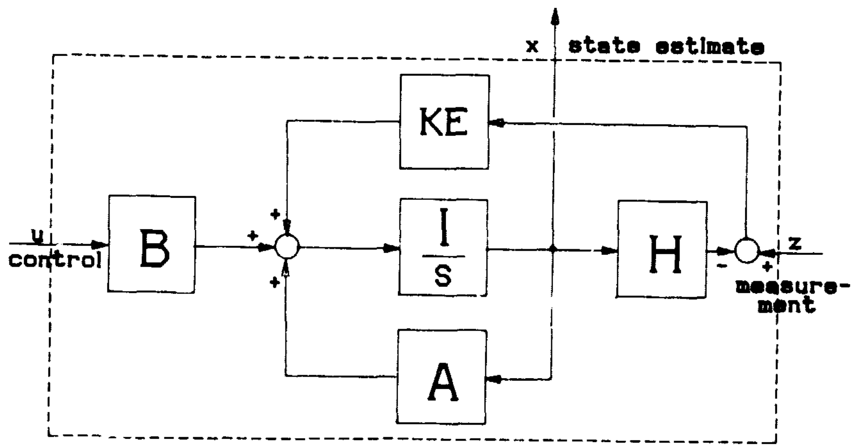

Figure 2. - Kalman filter structure.

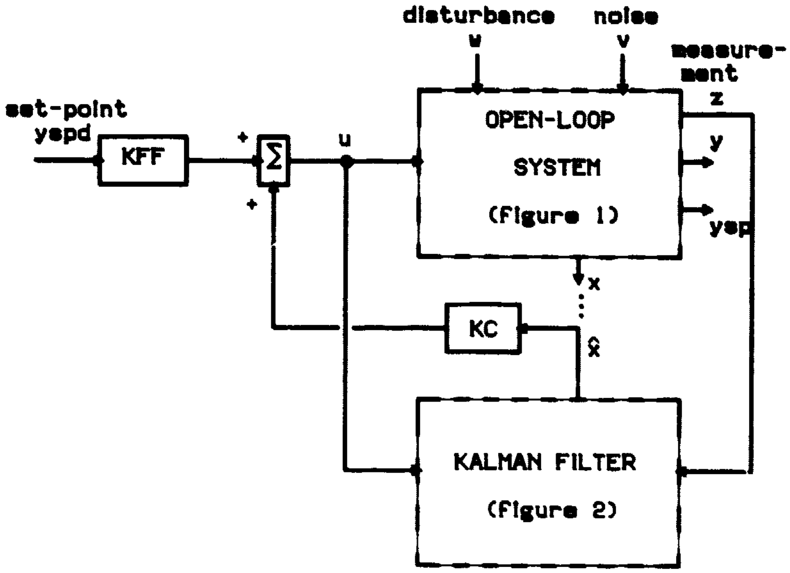

Figure 3. - Closed loop system with linear quadratic Gaussian control.

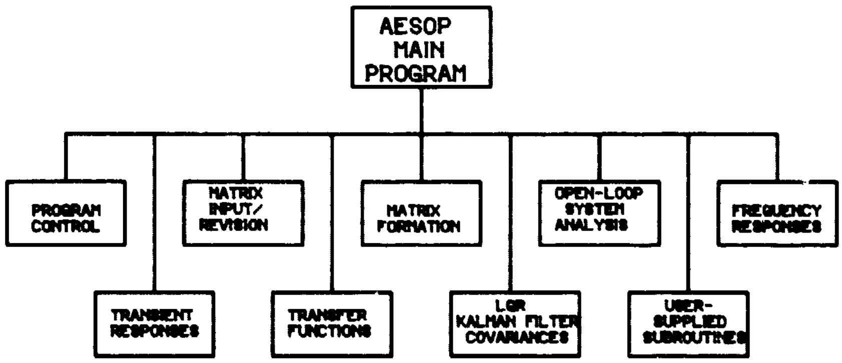

Figure 4. - AESOP program structure.