THE MIDDECK ACTIVE CONTROL EXPERIMENT (MACE):

IDENTIFICATION FOR ROBUST CONTROL

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Identification For Robust Control

Stages of Design

- Finite Element Method
- Structure and nominal parameters
- Uncertainty (bounds)
- Robust control design
- Robust stability
- Robust performance

"Expert" (arbitrary) bounds

no need any more!

Optimization
### Three Levels of Identification

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<tr>
<th>Algorithm</th>
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<tr>
<td>Model</td>
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<td>Product</td>
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<td>SISO</td>
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<td>MIMO (deterministic)</td>
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<td>Empirical Transfer Function Estimate</td>
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<td>Eigen Value Analysis</td>
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<td>Maximum Likelihood</td>
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<td>Prediction Error</td>
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<td>Extended Kalman-type filters (state and parameter estimation)</td>
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<td>State-space</td>
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<td>Model structure (number of modes, preliminary estimates)</td>
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<tr>
<td>Fitted estimates [but of &quot;indirect&quot; parameters $\gamma = \varphi(\alpha, \beta)$]</td>
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<td>High-precision estimates of &quot;direct&quot; parameters:</td>
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<td>- $\alpha$ (frequencies, damping ratios)</td>
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<td>- $\beta$ (mode shapes, masses)</td>
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<td>Realistic bounds</td>
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**Basic Elements of The Approach**

1. Non-linear problem of Riccati equation control for augmented covariance matrix:

   \[
   \begin{bmatrix}
   P_x & P_{x\alpha} \\
   \hline
   P_{\alpha x} & P_{\alpha}
   \end{bmatrix}
   \]

2. Equivalent linear problem
   (Received on the basis of non-traditional usage of RE analitical properties)

3. Converge numerical algorithm of optimization

4. Extended Kalman filter
   (Solution on the basis of decomposition with respect to frequencies)

5. Robust control problem
   - Cost averaging techniques (use the "Post-ID" bounds directly)
   - Petersen - Hollot's bounds (need modification)

   a). \[SA_0 + A_0^T S + (K + \beta \gamma \mathbf{N} \mathbf{W} \mathbf{N}^T) - S \left( BR^1 B^T - \beta \gamma^1 \mathbf{L} \mathbf{V} \mathbf{L}^T \right) S = 0\]
   \[\beta < 1, \quad \mathbf{VW} = P_{\alpha}\]

   b). Duality principle for design of dynamical feedback
What the Approach Provides

- **Realistic statistical model of uncertainty**
  (accuracy characteristics are received in the state-space model with "separated" noises in sensors and actuators)

- **Active ID**: Optimization of open- and close-loop inputs directly with respect to robust control performance

- **Taking into account constraints on excitation**
  (desirable ID accuracy can be achieved with much less excitation, extremely important for experiments in the space)

- **Possibility to identify time-varying parameters**
  (in case of moving rigid payloads)
Advantages of "Post-ID" Model of Uncertainty

- \( \alpha \) is Gaussian vector with covariance matrix \( P_\alpha \)

- Reveals "cost" of different errors
- Reveals covariances between parameters
- Prevents non-realistic "worst combination" of parameters
  (degrades conservatism of robust control)

"worst combination" (causes conservatism of robust control, for large \( N \) dramatically)
Advantages of Optimization

- Further degrading the conservatism

- Better coping with "difficulties" in the model, e.g. close modes (excitation in optimal directions amplifies the difference between modes)

- The best compromise between excitation and robust control performance

\[ J = J_R + pJ_E \] where \( p \) is a "price" of ID

All \( J \) are quadratic forms
Practical Realization

- Simulation of identification and robust control processes for MACE (important for confirming convergence of parameter estimates to "true" ones)

- Ground experiment

- Experiment in space

\[
\text{Optimal inputs } u = u^*(t) + L(t)y
\]

**Space**

- Experiment → Data (y)

**Ground**

- Data processing (EKF)

- Optimal parameter estimates; Model of MACE for robust pointing control