THE MIDDECK ACTIVE CONTROL EXPERIMENT (MACE):

IDENTIFICATION FOR ROBUST CONTROL

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Identification For Robust Control

Stages of Design

Inputs → ID → Finite Element Method → Model

Model:
- Structure and nominal parameters
- Uncertainty (bounds)

→ Robust control design
→ Robust stability
→ Robust performance

"Expert" (arbitrary) bounds

no need any more!

Optimization

Space Engineering Research Center
## Three Levels of Identification

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

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

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

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). \( S A_0^T + A_0^T S + (K + \beta \gamma N W N^T ) - S (B R^T B^T - \beta \gamma^T L V L^T ) S = 0 \)
   \( \beta < 1, \; V W = P_{\alpha} \)

   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

\[ J = J_R + pJ_E \text{ where } p \text{ is a "price" of ID} \]

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

\[
\begin{align*}
\text{Optimal inputs} & : u = u^*(t) + L(t)y \\
\end{align*}
\]

\[\text{Experiment} \rightarrow \text{Data (y)}\]

\[\text{Data processing (EKF)} \rightarrow \text{Optimal parameter estimates; Model of MACE for robust pointing control}\]