THE MIDDECK ACTIVE CONTROL EXPERIMENT (MACE):

IDENTIFICATION FOR ROBUST CONTROL

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Identification For Robust Control

Stages of Design

Finite Element Method

Model
- Structure and nominal parameters
- Uncertainty (bounds)

Robust control design

Robust stability

Robust performance

Inputs

ID

"Expert" (arbitrary) bounds

no need any more!

Optimization
### Three Levels of Identification

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Model Product</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empirical Transfer Function Estimate</td>
<td>SISO (deterministic)</td>
<td>Model structure (number of modes, preliminary estimates)</td>
</tr>
<tr>
<td>Eigen Value Analysis</td>
<td>MIMO</td>
<td>Fitted estimates [but of &quot;indirect&quot; parameters $\gamma = \varphi(\alpha, \beta)$]</td>
</tr>
<tr>
<td>Least Square</td>
<td>TF</td>
<td>High-precision estimates of &quot;direct&quot; parameters: - $\alpha$ (frequencies, damping ratios) - $\beta$ (mode shapes, masses)</td>
</tr>
<tr>
<td>Maximum Likelihood</td>
<td>ARMAX $A(q)y(t) = B(q)u(t) + e(t)$ at $t = 0, ..., K$</td>
<td>Realistic bounds</td>
</tr>
<tr>
<td>Prediction Error</td>
<td>State-space $\dot{x} = A(\alpha)x + B(\beta)u + \xi$ $y = C(\beta)x + D(\beta)u + \eta$, $t \in (0, T)$</td>
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<tr>
<td>Methods</td>
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<td></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). \( SA_0 + A_0^T S + (K + \beta \gamma NWN^T) - S(BR^1 B^T - \beta \gamma^{-1} LVL^T) S = 0 \)
\( \beta < 1, \; VW = P_\alpha \)

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)
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

\[ u = u^*(t) + L(t)y \]

Space

- Experiment
- Data (y)

Ground

- Data processing (EKF)

Optimal parameter estimates; Model of MACE for robust pointing control