THE MIDDECK ACTIVE CONTROL EXPERIMENT (MACE):

IDENTIFICATION FOR ROBUST CONTROL

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Identification For Robust Control

Stages of Design

Robust stability → Robust control design → Robust performance

Model

Structure and nominal parameters

Uncertainty (bounds)

"Expert" (arbitrary) bounds

Optimization

Finite Element Method

ID

Inputs

no need anymore!
### Three Levels of Identification

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>1</th>
<th>2</th>
<th>3</th>
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</thead>
<tbody>
<tr>
<td>- Empirical Transfer Function Estimate</td>
<td>- Least Square</td>
<td>- Extended Kalman-type filters (state and parameter estimation)</td>
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<tr>
<td>- Eigen Value Analysis</td>
<td>- Maximum Likelihood</td>
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<tr>
<td>- ......................</td>
<td>- Prediction Error</td>
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<tr>
<td>- ......................Methods</td>
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<tr>
<td>Model</td>
<td>SISO</td>
<td>TF</td>
<td>State-space</td>
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<tr>
<td>- MIMO (deterministic)</td>
<td>ARMAX</td>
<td>$\dot{x} = A(\alpha)x + B(\beta)u + \xi$</td>
<td>$x = A(\alpha)x + B(\beta)u + \xi$</td>
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<tr>
<td></td>
<td>$A(q)y(t) = B(q)u(t) + e(t)$</td>
<td>$y = C(\beta)x + D(\beta)u + \eta$, $t \in (0,T)$</td>
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<tr>
<td>Product</td>
<td>Model structure (number of modes, preliminary estimates)</td>
<td>Fitted estimates [but of &quot;indirect&quot; parameters $\gamma = \varphi(\alpha, \beta)$]</td>
<td>High-precision estimates of &quot;direct&quot; parameters:</td>
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<td></td>
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<td></td>
<td>- $\alpha$ (frequencies, damping ratios)</td>
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<td></td>
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<td></td>
<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 analytical 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). \[SA_0 + A_0^T S + (K + \beta \gamma N WN^T) - S (BR^T B^T - \beta \gamma \Lambda V L^T ) S = 0\]
\[
\beta < 1, \quad VW = P_{\alpha}
\]

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

- Realistic statistical model of uncertainty
  \textit{(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
  \textit{(desirable ID accuracy can be achieved with much less excitation, 
  extremely important for experiments in the space)}

- Possibility to identify time-varying parameters
  \textit{(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

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

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

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

Data processing (EKF)

Optimal parameter estimates; Model of MACE for robust pointing control