Online Parameter Estimation with Maneuver Visuals

Dynamic System

Mathematical Model ??

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Modeling & Identification
FMCD, NAL
Content

- Modeling & Identification
- Online Estimation Process
- Maneuvers, Measurements, Methods, Models
- Recursive Parameter Estimation
- Implementation
- Maneuver Visualization
- Conclusions
Identification Algorithms

Mathematical models
- Define math models based on 6DOF equations and aircraft aerodynamics

Identification methods
- Extract unknown model parameters

Model validation
- Various criteria, Model predictive capability

Manoeuvres Selection
- Designing inputs to excite the modes

Measurement pre-processing
- Filtering, time sync, segmentation, Kinematic consistency, ....
Conventional vs Online

Conventional:
1. Design maneuver
2. Plan Flight testing
3. Aircraft take off
4. Execute maneuver
5. Aircraft lands
6. Analyse data
7. Results
   - Acceptable
     - stop
   - stop

Online:
1. Plan Flight testing
2. Aircraft take off
3. Execute maneuver
4. Analyse data
5. Results
   - Acceptable
     - Design maneuver
     - Aircraft lands
     - stop
   - stop
Online Estimation at Telemetry Station

- **Receiver**
- **Data Acquisition/Mater console**
- **Test Director**
- **Consoles for real time monitoring**

Communication with Test director
Data Flow
Applications of Online Estimation

- Envelope Expansion
- Immediate Manoeuvre Repetition
- Cut Down Extra Test Points
- Reconfigurable Control Laws
- Sensor/Actuator Failure Detection
- Damage of Lifting Surfaces
- Stability and Control Derivatives
- Speed Up Aircraft Certification
- Aircraft Icing
Measurements

- Time synchronization
- Sampling rates
- Signal to noise ratio
- Sensor calibrations
- Data drop outs

Typical set of Measurements

<table>
<thead>
<tr>
<th>Control Surfaces</th>
<th>elevator, aileron &amp; rudder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerations</td>
<td>all three axes</td>
</tr>
<tr>
<td>Angular rates</td>
<td>roll, pitch and yaw rates</td>
</tr>
<tr>
<td>Flow angles</td>
<td>AOA and sideslip</td>
</tr>
<tr>
<td>Attitude angles</td>
<td>pitch and bank angle</td>
</tr>
<tr>
<td>Airspeed data</td>
<td>airspeed and Mach</td>
</tr>
<tr>
<td>Thrust data</td>
<td>engine thrust</td>
</tr>
<tr>
<td>Others</td>
<td>pressure altitude, static pressure, total pressure and outside air temperature</td>
</tr>
</tbody>
</table>
Manoeuvre Design

**Flight Maneuvers**

**Parameter Estimation**
- Short Period Pitch Stick
- Phugoid maneuver
- Bank to Bank roll
- Dutch Roll
- SHSS maneuver

**Performance**
- Acceleration - Deceleration
- Roller Coaster (Pull up/Push over)
- Wind up Turn
- SHSS maneuver

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**Important Aspects**

If the information is not in the data, it cannot be modeled.

**Control Inputs**
Choose adequate form of input to excite the aircraft motion.

**Excitation Level**
- Sufficient excitation of different aircraft modes

**Flight Maneuvers**

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Methods

**Offline estimation after the flight test sortie**
- Equation error
- Output error
- Filter error
- Neural Networks

**Online /Real time estimation along with data acquisition**
- Recursive Estimation (EKF/DFT/RLS)

**Near Real time estimation using flight data saved for short duration during the sortie**
- Equation error
- Output error
- Filter error

**Equation Error**
- Simple,
- one-shot, account for process noise,
- require good quality data

**Output Error**
- Non linear optimization
- Iterative, Accounts measurement noise
- Most routinely used

**Filter Error**
- State and parameter estimation
- Accounts both process and measurement noise
- complex

**Recursive**
- Parameter and state estimate at every sample
- Suitable for online estimation

**Neural network**
- Highly non linear models
- Black box modeling
Mathematical models

- Point Mass
  - Linear equations of motion
  - Short period dynamics
  - Small perturbations
  - Useful for control design
  - useful for quick checkout

- Linear Lateral/Directional Eqs.

- Linear Longitudinal Eqs.

- Rigid Body Dynamics
  - Full 6DOF nonlinear Eqs.
  - Long/Lateral motion
  - Useful for complete nonlinear simulation

L1-21
Longitudinal/Lateral Models

Short period dynamics:

\[
\dot{\alpha} = Z_o + Z_\alpha \alpha + Z_q q + Z_\delta \delta_e \\
\dot{q} = M_o + M_\alpha \alpha + M_q q + M_\delta \delta_e 
\]

Dutch Roll Model:

\[
\dot{\beta} = L_o + L_\beta \beta + L_p p + L_r r + L_\delta_a \delta_a + L_\delta_r \delta_r \\
\dot{\gamma} = N_o + N_\beta \beta + N_p p + N_r r + N_\delta_a \delta_a + N_\delta_r \delta_r 
\]
Implementation in MATLAB®

- Maneuver visualization using MATLAB® built in commands
- Recursive estimation involves matrix operations - easy to implement using MATLAB®
- Visuals can be saved as video files
- Easy to implement at telemetry station
Recursive Parameter Estimation

- Provides parameter estimate with every time step
- Signals measured are fed sample by sample to get the estimation results.
- Results can be displayed in real-time mode.
Maneuver Animation

Visualization of flight data for
- 3-Dimensional flight simulation
- Quality evaluation by replaying manoeuvre
- Flight state analysis.
- Analysis of accidents/incidents

Real time / Frame by Frame animation using Position and attitude information.

Video production
Animation of Windup turn Maneuver
Real-time Estimation & Maneuver Visualization
PITCHING MOTION IN REAL TIME
Concluding Remarks

- Results generated have shown that, combined with optimized inputs, online identification can yield accurate math models in real time.
- Maneuver visualization though animation provides better understanding of the flight states, leading to improved maneuver design and data analysis.

Future Work

- Future work will focus on real-time identification of global math models that can meet the FAA specified requirements under “Acceptance Test Guide”.

THANK YOU