Control Synthesis and Design
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Workshop on Research and Curriculum Development
Opportunities 2013

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Background

• Safety, life cycle costs, environmental standards → evolution of control & diagnostic systems

• Cyber-physical system trends
  – Increased integration
  – Increased sophistication of embedded functionality
  – Fusion of heterogeneous information

• Aero-propulsion examples
  – Engine health management
  – Model predictive controls
Trends in Engine Controls and Health Management Systems

- 1970s Engine Health Management: Airborne Integrated Monitoring System
  - Automatic report generation
    - Engine takeoff, climb, cruise reports
    - Mechanical advisory reports (sensor failures, actuator faults)
• Present Diagnostics and Engine Health Management (EHM)
  • Mechanical system and gas path diagnostics and trending
  • Configuration and utilization tracking
  • Fleet fault analysis and alert watchlists
  • Removal planning and event tracking

**Fault Isolation using Gas Path Analysis**

**Mechanical Systems Diagnostics**

Trending to detect slow deterioration and discrete events


10/2/2013

EAR Export Classification: ECCN EAR99
Trends in Engine Controls and Health Management Systems

- Future: Transforming **Condition Data** into **Maintenance Information**
  - Wireless sensors and MEMS
  - Onboard gas path analysis
  - Information fusion

- Time Critical Data
- On-Board Data Generation
- Bulk Data
- Supply Chain
- Aircraft Scheduling
- Web-Served Decision Support Tools
- Life Mgmt
- Trending Prognostics
- Watch List
- Alerts
- Secure Data Transfer
- Config
- Fleet Manager
- Observations
- Line Maintainer
- Optimized Maintenance
- Shop

Wireless sensors and MEMS
- Onboard gas path analysis
- Information fusion

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Trends in Engine Controls and Health Management Systems

- 1970s Engine Controls
  - SISO “Loop Select” control law architectures
  - Limited number of controlled variables

- Present: MIMO model predictive control laws
  - Management of interacting subsystems and constraints
  - Scalable to large number of control variables and constraints
    - Compressor stability and material temperature management

- Future trends and drivers for increasing complexity
  - Onboard optimization of engine operation (fuel efficiency)
  - Design optimization (variable geometry to improve efficiency)
  - System integration (using propulsion system to aid damaged aircraft)
  - Emissions and noise standards
    - Example: Emissions regulations driving more complex fuel systems to prevent fuel leakage at start and shutoff

- *Similar trends exist for building HVAC systems, aircraft power and thermal management systems.*
Technical Challenges in Control and Health Management of Thermal Fluid systems

• Emergent behavior
  – Unanticipated system behavior arising from complexity and subsystem interactions.
  – Not feasible to predict via simulation
  – Synthesis / V&V methods required that prevent/bound/predict unsafe emergent behavior

• Dimensionality of design space
  – Systems engineering methodologies required to improve engineering efficiency and enable rapid design space exploration to achieve optimal and robust control system design targeting safety, life cycle cost and performance objectives.

• Modeling and analysis of off-nominal conditions and uncertainty propagation for robust design
  – Fuel system examples: Inertial/gravity effects, air entrainment and two phase flow, observer-based fuel leak isolation

• Cyber Security
  – Particularly important for systems incorporating wireless technologies, information fusion, and distributed architectures.
Research Program Objectives and Value Measures

- **Controls, Diagnostics, and Health Management**
  - Objectives: Increase system availability, safety and performance through system engineering methodologies
    - Robust system optimization -> robust system performance
    - Formal methods for V&V of complex control systems -> bounded and understood system behavior
    - Information fusion, physics-based modeling and estimation -> earlier failure isolation, failure prediction -> Increased system availability and reduced unsafe events
  - Value Measures
    - Increased operational reliability and safety
    - Lower maintenance and operating costs
    - Lower product cost

**Model Predictive Control**

- Minimal overshoot during accels
- Increases system life

**Fault Detection, Isolation, Prediction**

- Discrete Event
- Gradual Deterioration
- Measurement ΔΔ

Reduce maintenance cost, increase availability

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Research Topics

• **Requirements Analysis**
  – Formalization of requirements for non-linear, time-delayed dynamic systems and development of contracts that support correct-by-construction formulation of control system architectures and algorithms.

• **Architecture Selection**
  – Robust multi-estimator architecture design for sensor and actuator fault detection, isolation and accommodation (FDIA).
    • Examples include detection and isolation of control component failures in gas turbine engines (e.g. sensor failures, valve failures).
    • Optimize mix of sensors and analytic redundancy (models) to maximize reliability and safety and simultaneously achieve competitive system life cycle cost.

• **Model Based Development**
  – Fast model predictive control for complex (many control variables, nonlinear dynamics) aero-space systems.
  – Creation of libraries for modeling and design of control systems that include functional modules with different levels of abstraction that support requirements validation and reuse across multiple system domains.

• **Design Flows**
  – Supervisory control system synthesis and validation methodologies. Development of synthesis methodologies that enable application of formal methods for V&V. Demonstrate advantages over simulation-based validation. Applications of interest include building climate control systems and aircraft thermal management systems.
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