Advanced Technologies for Artificial Intelligence in Flight Applications

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Flight Intelligence

Human pilot controlled flying machines

Artificial intelligence controlled flying machines

- Safety
- Predictability
- Society acceptance

Same Performance

And same quality
Passenger comfort, noise, emission, …

Human Controlled Flight

Pilot is the authority
- Monitoring
- Communication
- Negotiation
- Decision making

How can we do better?

- Reasoning
- Training
- Memory
- Creativity
- Etc.

- Fatigue
- Distraction
- Stress
- Panic
- Etc.

Intelligent Pilot Assistance

Accidents happen

How to prevent?
Design onboard AI to assist the pilot

Technology requirements

- Reliable state estimation
- Maneuverability margin predictions
- Real-time pilot cueing
Margins From Piloting Perspective

Los-of-control Criteria

Reference: AIAA 2004-4811; Authors: Wilborn and Foster
The Predictive Architecture

Pilot → Reference Dynamics → Nominal Flight Control System → Aircraft

Adaptive Control Augmentation (Optional loop)

Adaptive Prediction

Estimated Dynamics

Pilot Cues

Pilot Aid

LoC Boundary Estimation

Control Deficiency
LOC Example Without Cueing

Pilot Cue (amber box) on left not displayed to pilot

Left wing damage with no pilot visual cue
LOC Example With Cueing

Left wing damage with pilot visual cue
Flying Robot’s Architecture

Pilot is out-of-the-loop → Artificial Intelligence is flying

Onboard Computing Power

- Dynamic Planner
- Trajectory generator
- Resilient Controller
- Real Time Estimator
- Sensors

Mission design
Offline planning

User interface

Advanced technologies for flying robots

Environment
Challenges of Robotic Flight

Environment Challenges
Degraded RF, SAT-COM, GNSS

Atmospheric Uncertainty
Winds and microbursts

Failures and Contingencies
Avoid endangering objects in environment.

Ground Operators

C3 and Surveillance Requirements

Detect, Operate-Near, Avoid-Endangering Other Aircraft

Other Aircraft

Detect, Operate-Near, Avoid-Endangering SGOs

Detect, Operate-Near, and Avoid-Endangering SGOs

Static Ground Objects (SGO)

Detect, Operate-Near, and Avoid-Endangering DGOs

Dynamic Ground Objects (DGO)

Hazard Footprint Awareness, Risk Minimization/Avoidance, Health Monitoring

Courtesy of C. Ippolito
How can we safely operate in high density urban environment?

- Estimator shall provide in real time:
  - Vehicle state and location in the environment
  - Obstacles locations and motion
  - Atmospheric disturbance
  - Detect and identify component failures

- Dynamic planner shall plan/replan in real time providing:
  - Man maid strictures and terrain avoidance
  - Static and dynamic ground obstacle avoidance
  - Cooperative dynamic air obstacle avoidance
  - Acceptable air and ground risk.

- Trajectory generator shall provide:
  - Feasible trajectories in real time
  - Power required to traverse the trajectory
  - Minimum endurance and maximum vehicle range
  - Acceptable time time of flight

- Resilient controller shall provide:
  - Stability of the vehicle
  - Acceptable tracking performance and flight envelop
  - Compensate for failures and disturbances
  - Flight within approved 4D volume in all phases
Use case 1: point-to-point

- Operator
- Cruise
- Pull-outs
- Park

Use case 2: Emergency (High-priority Flight)

- Emergency Landing
- Airspace conflict
- Approach Descent Landing
- Fire department

Use case: Point-to-Point Operation
Objective
Autonomously fly the UAV in the uncertain wind field using onboard sensors and estimation algorithms.

Challenges
• Real-time wind estimation
• Real-time re-planning to accommodate the wind
• Required power estimation for the new plan
• Decision making: continue or abort
• Find alternate landing site to abort
• Fly UAV though approved volume and change plan to land to alternate landing site taking into account wind and battery constraint.

• How reliable is the wind estimation?
• Is the mission still possible?
• Is the flight safe for the vehicle and environment?
• Are the predicted performance bounds acceptable?
Urban wind Field Specifics

- Wind characteristics
  - Turbulent air flow
  - Isolated roughness
  - Wake interference
  - Skimming flow
  - Hard to predict

- Local Measurement
  - Isolated roughness
  - No infrastructure
  - Too expensive

- Wind field modeling
  - Digital 3D mapping
  - Heavy computations
  - Large memory

- Not feasible onboard
- Expensive transmission
Wind Information

Can on-board sensors and compact CFD models provide sufficiently accurate and robust wind estimates?
Wind field is generated using CFD and city digital map
Is it still possible to safely fly this vehicle?
Failure Identification Test

Sample rate is 0.1 sec

Half throttle voltage is applied

Propeller came off
Resilient Control Application

- Motor 2 fails at t=8 sec
- Vehicle switches to safe mode
  - Find nearby emergence landing site
  - Land

Failure identification and intelligent control reconfiguration stabilizes the vehicle