Aircraft Approach and Landing Trajectory Optimization for a 6-DoF Aircraft with a Runway Alignment Constraint

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Trajectory generation for aircraft landing

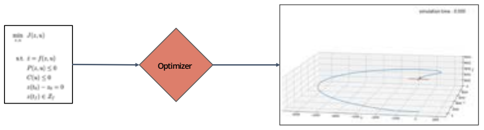
- Safe and optimal trajectory generation is crucial for the autonomy of aerospace vehicles

- Technical challenges in trajectory generation
  - The trajectory must satisfy many operational constraints
  - The algorithm should be reliable and fast enough

Numerical optimization-based trajectory generation

- This provides a systematic framework to specify mission objectives while enforcing constraints

- Contributions of this work:
  1) Formulate the optimization problem for aircraft landing considering operational constraints
  2) Develop an efficient solution method to solve the problem
  3) Validate the method through various numerical simulations



6 DoF fixed-wing aircraft dynamics

- A 6-DoF model that consists of translational and rotational dynamics with aerodynamic effects

$$
\begin{aligned}
\dot{p}(t) &= B_B^\top v(t) + w_{wind} \\
m(\dot{v}(t) + \Omega(t) \times v(t)) &= F_e(t) + F_a(t) + F_g(t) \\
\dot{\Phi}(t) &= R^E(t)\Omega(t) \\
J\dot{\Omega}(t) + \Omega(t) \times J\Omega(t) &= M_e(t) + M_a(t)
\end{aligned}
$$

p : position, v : velocity,

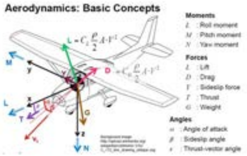
Φ : Euler angles, Ω : angular velocity

F : forces, M : momentums

- State : position, velocity, Euler angles, angular velocity
- Input : aileron, elevator, rudder, thrust commands

- The dynamics is compactly written as

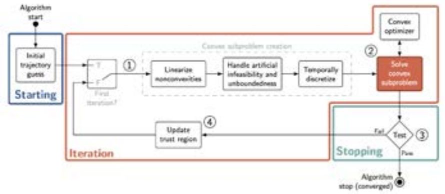
$$
\begin{aligned}
&\dot{x}(t) = f(x(t), u(t)), \\
&x : \text{state}, u : \text{input} \\
&x = [p, v, \Phi, \omega], \\
&u = [\delta_A, \delta_E, \delta_R, \delta_T]
\end{aligned}
$$



Sequential convex programming

- Algorithm for nonconvex optimization problems

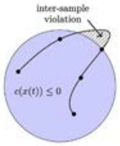
- In every iteration, it repeats:
  1. convexification,
  2. handling infeasibility and unboundedness resulted from convexification,
  3. Solve convex subproblem.



Two key features in the developed SCP

- Continuous-time constraint satisfaction
  - prohibits the inter-sample constraint violation

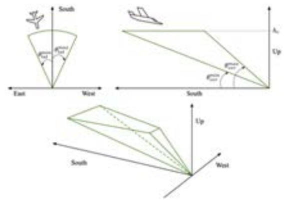
- Extrapolation update
  - expedites the convergence of the problem



Runway alignment constraint

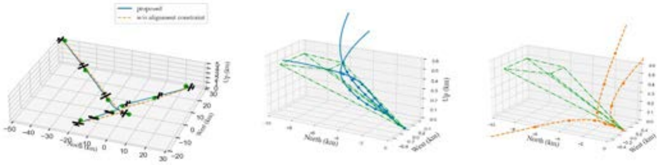
- A key feature to ensure the trajectory is operational

- Enforces aircraft alignment with the runway only during the final approach

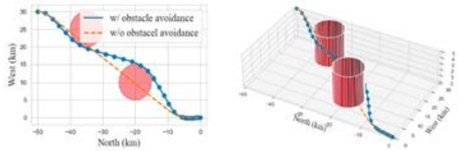


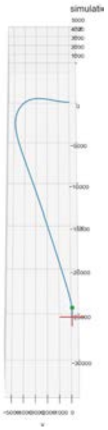
Simulation results

- Trajectories with 3 different initial conditions

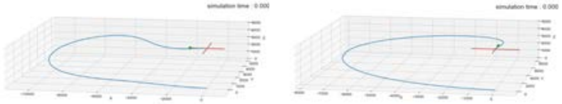


- Obstacle avoidance



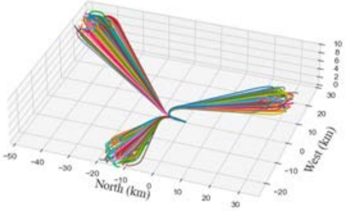


- Other trajectories



- Monte-carlo study with 300 different initial conditions

Success	290 / 300 (96.67%)
Fail by divergence	0 (0%)
Fail by max iteration	10 (3.33 %)
Mean iteration count	23.59
Mean computational time	10.85 (s)



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