Optimal Trajectory Generation for Aerial Towed Cable System Using APMonitor

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Outline

- Overview of UAVs
- Overview of Aerial Recovery
  - Basic concept and System dynamics
  - Flight test results
- Motivations of using APMonitor
- Preliminary results in APMonitor
  - Simulation (2D, 1-link cable)
  - OTG (2D, 1-link cable)
  - OTG (3D, 1-link cable)
  - OTG (3D, multi-link cable, no wind)
  - OTG (3D, multi-link cable, constant wind)
- Future work
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Overview of UAVs
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- Communication and Control

![Diagram of UAV communication and control system]

- Modem
- Autopilot
- Combox
- Virtual Cockpit
- VCListen.mex
- Matlab

UAV

Ground Station

RS232
Overview of UAVs

- Cool videos!
  - Fixed wing
    - [http://www.youtube.com/watch?feature=endscreen&v=Xlrqxhz1iGc&NR=1](http://www.youtube.com/watch?feature=endscreen&v=Xlrqxhz1iGc&NR=1)
  - Quadrotor
    - Aggressive Maneuvers
      - [http://www.youtube.com/watch?v=MvRTALJp8DM](http://www.youtube.com/watch?v=MvRTALJp8DM)
    - Builder
      - [http://www.youtube.com/watch?v=xvN9Ri1GmuY&feature=player_embedded](http://www.youtube.com/watch?v=xvN9Ri1GmuY&feature=player_embedded)
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Overview of Aerial Recovery

- Question:

  How can we retrieve Micro Air Vehicles (MAVs) in the air after they complete their missions?
Retrieval strategies
Basic concept

Mothership

Actuated drogue with small autopilot and homing beacon

$V$

$\ell$

$v_d$

$R$

$v$

MAV
System dynamics

- Cable-drogue dynamics using Newton 2nd law

\[
m_N \ddot{p}_N = T_N + \Omega_N
\]
\[
\Omega_N = G_N + D_N + L_N,
\]
\[
m_{j-1} \ddot{p}_{j-1} = T_{j-1} + \Omega_{j-1} - T_j
\]
\[
\Omega_{j-1} = G_{j-1} + D_{j-1} + L_{j-1}
\]
\[
j = 2, 3, \ldots, N,
\]
\[
T_j = \frac{EA}{\ell_0} \left( \|p_{j-1} - p_j\| - \ell_0 \right) \frac{p_{j-1} - p_j}{\|p_{j-1} - p_j\|},
\]
\[
j = 1, 2, \ldots, N,
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Flight test setup
Flight test results

- Drogue orbit with flat mothership orbit in wind

Flight Test

Simulation
Flight test results (cont’d)

Mothership Tracking Error

GPS Wind Est in VC

System Trajectory (80-150 s)
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Motivations of using APMonitor

- Replan the desired mothership trajectory each circle using the updated wind estimation
  - Replan every minute
- Constraints: mothership has its operational limits: airspeed, roll angle, pitch angle
  \[ 10 \text{ m/s} \leq V_a \leq 20 \text{ m/s} \quad -35^\circ \leq \phi \leq 35^\circ \quad -15^\circ \leq \gamma_a \leq 35^\circ \]
- Large amount of states in dynamic equations
  - 5-link cable = 30 states
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Simulation mode – 2-D 1-link model

- Simulation mode with no constraints
- Solution time: 0.624 sec.
Trajectory Generation (2-D 1-link model)

- “nlc” mode, solver: IPOPT
- CVs:
  - \( V_m \), Tension
- Solution time: 18.17 sec.

![System trajectory graph](image)
“nlc” mode, solver: IPOPT

CVs:
- Vm, Tension

Solution time: 14.3328 sec.
TG (3D, multi-link, no wind)

- “nlc” mode, solver: IPOPT
- CVs:
  - $V_m$
- Solution time: 141.6326 sec.
TG (3D, multi-link, wind)

- “nlc” mode, solver: IPOPT
- CVs:
  - CVs
- Wind (3,0,0) m/s
- Solution time: 163.6704 sec.
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Future work

- Decrease the solution time
  - different solver
  - different configuration of the problem

- Add more constraints
  - Tension, roll angle, pitch angle, and etc.

- Motion planning of orbit-insertion-removal
  - Fly into an orbit to perform the retrieval and leave out of the orbit

- Orbit regulation problem
  - Find an optimal orbit for the mothership to minimize the drogue altitude deviation
Thank You!
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Questions?