Optimal Control and Line-of-Sight Guidance Formation Flight

Structured Abstract:
- **Purpose:** To design an integrated guidance and control design for a formation flight of four Unmanned Aerial Vehicles to follow a moving ground target.
- **Design/methodology/approach:** The guidance law is based on the line-of-sight. The control is optimal. The guidance law is integrated with the optimal control law and is applied to a linear dynamic model.
- **Findings:** The theoretical results are supported by the numerical simulations that illustrate a coordinated encirclement of a ground maneuvering target.
- **Research limitations:** A linear dynamic UAV model and a linear engine model were employed.
- **Practical implications:** This is expected to provide efficient coordination technique required in many civilian circular formation UAV applications; also the technique can be used to provide a safe environment required for the civil applications.
- **Social implications:** The research will facilitate the deployment of autonomous unmanned aircraft systems in various civilian applications such as border monitoring.
- **Originality/value:** The research addresses the challenges of coordination of multiple unmanned aerial vehicles in a circular formation using an integrated optimal control technique with line-of-sight guidance.

Abstract: This paper presents an integrated guidance and control design for a formation flight of multiple Unmanned Aerial Vehicles (UAVs). The guidance law is based on the line-of-sight (LOS) method which has ability to transfer UAVs to different formation patterns through a single parameter change. The guidance law is integrated with the optimal control law and is applied to a linear dynamic model. The problem is formulated as a linear quadratic regulator (LQR) control problem for a line-of-sight based circular coordination formation flight configuration of a leader and three follower UAVs. The mission is to have a coordinated encirclement around a ground maneuvering target. The design objective is to achieve a zero vertical spatial offset (i.e. same commanded altitude) and a 90 degree horizontal angular offset among four UAVs. In order to verify the performance of the proposed system, numerical simulation using a linear coupled six-degree-of-freedom (6-DOF) model is demonstrated for a circular multi-vehicle coordination flight of four UAVs.

Nomenclature

- $A, B, C, D$: matrices of the state-space representation
- $C_i$: aerodynamic force or moment coefficient
- $C_{ij}$: stability or control derivative of aerodynamic force or moment coefficient $i$, with respect to the state variable or input variable $j$
- $C, b, S$: mean aerodynamic chord (ft), wing span (ft), wing reference area (ft$^2$)
- $D_{13}$: distance between the follower UAV and the leader UAV (ft)
- $D, Y, L$: aerodynamic forces (drag, side force, lift) along the x, y, and z axes (lb)
- $g$: gravitational constant (32.17 ft/s$^2$)
- $I$: mass moment of inertia (slug.ft$^2$)
- $J$: quadratic cost function
- $K$: gain
- $L, M, N$: aerodynamic moments around the x, y, and z axes (lb.ft)
- $m$: aircraft mass (slug)
- $P$: solution to the Algebraic Riccati Equation
- $Q, R$: weighting matrices
- $T$: engine thrust (lb)

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