**Structure**

* General system requirements for UAV systems: dAndrea, Tomic
* Requirements for CPT schemes: Gimenez
* CPT system classifications
  + Vehicle type: UAVs v. Ground Vehicles
  + Interaction with payload: cable-suspension, rigid grasp, pushing (ground vehicles only)
  + Control architecture: centralized, decentralized, distributed
  + Controller class
* Current efforts in CPT with UAVs:
  + Cable-suspension
    - centralized control: PID - Michael10, Gimenez18, Pereira18, PD nonlinear ctrl - Lee14
    - decentralized control: LQR - Gassner17, LQR + PD – Shirani18, Admittance ctrl - Tognon18, Bio-inspired algorithm – Gabellieri18, Estimation + MPC - Tagliabue17
    - distributed control: PD – Cotsakis18, Passivity-based controller – Klausen18
  + Rigid grasp
    - Centralized control: LQR + RPTC – Tan18
    - Distributed control: w Online estimation of payload mass and inertia – Lee18, distributed wrench controller – Wang18
* CPT with ground vehicles
  + Pushing: distributed control, PI for agent propulsion and penalty-force for collision avoidance – Ebel and Eberhard18
  + Rigid Grasp:
    - Decentralized control: Sliding mode controller – Babaie and Ehyaie17
    - Distributed control: Receding horizon MPC – Verginis et al. 2018

The literature identified several important requirements for UAV systems. In analyzing the feasibility of UAV delivery systems, d’Andrea emphasized a need for robustness in a range of environments and minimal reliance on external infrastructure [9]. Tomic et al. explicitly identified the following design requirements [10]:

* Operability in unstructured indoor and outdoor environments
* Robust flight capabilities
* Autonomous operation, onboard decision making (this requires control algorithms with lower computational complexity [7])
* Modular and flexible sensor and planning capabilities
* Independence from external navigation aids

Specific to CPT schemes, Gimenez et al. ordered several common objectives in a hierarchy [11]:

1. Avoid obstacles (also featured in [12] and [7])
2. Secondary objectives:
   1. Maintain safe distances between vehicles to avoid collisions or undesirable separation
   2. Properly distribute the load weight between vehicles
3. Follow a predetermined trajectory to reduce oscillations caused by external factors such as wind. (This is incompatible with fast and aggressive agent maneuvers [7])

Once the objectives are known, Gimenez et al recommend that an appropriate control strategy be chosen. Many classes of control algorithms have been successfully applied to CPT, including PID techniques [4].[[1]](#footnote-1)

Regarding control architectures, earlier CPT schemes focused on centralized control, while recent proposals have shown a trend towards decentralized control. For example, Michael et al. implemented a ‘leader-follower’ system in which one agent’s trajectory is tracked by the other [4]. Gassner et al. have combined this formation with a novel mutual localization method to eliminate explicit communication between agents [8]. Other scenarios may require some communication between agents, justifying a distributed control architecture [13].

The control strategy may be dictated by the choice of payload configuration. Two common attachment methods exist for CPT schemes with UAVs: grasping the payload rigidly and suspending the payload by cables. Rigid grasping is explored in [5], [13] and [14]. This configuration enables agents to infer the payload’s location with respect to themselves but may not be suitable for all payload sizes and shapes. Cable suspension is more common, as it builds on existing research about single-UAV slung-load systems [3] [4] [6] [8] [15]. Despite having a more complex control problem, cable suspension allows for more versatile control of the payload’s attitude.

1. Please refer to Appendix 1 for a list of papers discussing CPT schemes and their respective algorithms. [↑](#footnote-ref-1)