**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 survey addressed two topics: design requirements for UAV systems with a focus on CPT schemes, and contemporary research on CPT schemes using UAVs. The latter topic also considered a limited selection of CPT schemes using terrestrial vehicles, to provide additional control algorithms that might be exploited for CPT.

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 [1]. Tomic et al. explicitly identified the following design requirements [2]:

* Operability in unstructured indoor and outdoor environments
* Robust flight capabilities
* Autonomous, onboard decision making (this requires control algorithms with lower computational complexity [3])
* Modular and flexible sensing and control capabilities
* No dependence on external navigation aids

Specific to CPT schemes, Gimenez et al. ordered several common objectives in a hierarchy [4]:

1. Obstacle avoidance (also featured in [3] and [5])
2. Secondary objectives:
   1. Avoid collisions and excessive separation between agents
   2. Evenly distribute the payload weight between vehicles
3. Reduce oscillations caused by external disturbances such as wind (incompatible with fast and aggressive agent maneuvers [3])

Once the objectives are known, Gimenez et al. recommend that an appropriate control solution be chosen.

CPT schemes may be classified according to their design.[[1]](#footnote-1) An important design choice is the vehicle type: UAVs allow for maneuvers in three dimensions but may have shorter mission durations than terrestrial vehicles due to their limited onboard battery life. One must also consider whether the agents have a uniform or heterogeneous design (perhaps reflecting task specializations). After selecting the vehicle type and formation composition, a method for interacting with the payload can be chosen. Inspired by research on slung-load systems, suspension by cables enables more versatile maneuvering but is ineffective for exerting non-tensile forces. Rigid attachment to agent bodies allows direct inference of the payload’s location with respect to the agents but may not be suitable for all payload sizes and shapes, hence is used less frequently in load transportation. A suitable control architecture can then be designed to coordinate the agents’ behaviors:

* Centralized control algorithms require decisions to be made in one location and communicated to all agents;
* Decentralized control algorithms involve each agent making their own decisions without communicating with peers;
* Distributed control algorithms involve each agent making decisions with some communication with peers.

A contemporary trend in UAV-based CPT research has seen a shift from centralized control to decentralized control. Among CPT schemes using cable-suspension, all three types of control architectures have been implemented. Centralized architectures relying on PID controllers are proposed in Michael10, Gimenez18 and Pereira18, while a nonlinear PD controller is proposed in Lee14. Decentralized control underpins several recent proposals involving LQR (Gassner17, Shirani18), admittance control (Tognon18), a bio-inspired algorithm (Gabellieri18) and MPC (Tagliabue17). Fewer proposals have implemented a distributed control architecture; Cotsakis18 use a PD controller, while Klausen18 adopt a passivity-based approach. Among CPT schemes using rigid payload grasping, a centralized control architecture relying on LQR is presented in Tan18, while a distributed wrench controller is proposed in Wang18. A notable feature of the distributed control architecture in Lee18 is the online estimation of the payload’s mass and inertial properties.

A small number of contemporary CPT schemes involve terrestrial vehicles. Ebel and Eberhard18 propose a distributed architecture for collaborative pushing of an object by mobile robots, relying on PI controllers for agent propulsion and penalty forces for inter-agent collision avoidance. Babaie and Ehyaie17 study a decentralized sliding mode controller for a rigidly-grasped payload, while Verginis18 implement a distributed controller using receding horizon MPC.

1. Khamseh et al. 2018 – see November notes surveys.docx [↑](#footnote-ref-1)