Collective Aerial Additive Manufacturing

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Collective Robotic Construction (CRC) enables a team of robots undertaking parallel building operations to construct a structure greater in size than the individual robot builders (K. H. Petersen et al., 2019), requiring scalability in both robot coordination and building design approaches. To date, CRC has primarily focused on the assembly of discrete volumetric elements (K. Petersen et al., 2011; Seo et al., 2013) and filament winding/weaving (Augugliaro et al., 2013; Duque Estrada et al., 2020; Stuart-Smith, 2016) with little research undertaken into CRC mission planning for additive manufacturing (AM) or its relation to digital twin building designs. AM CRC research has been demonstrated with mobile ground vehicles that remain on grade (Napp & Nagpal, 2014; Sustarevas et al., 2019; Zhang et al., 2018), or constrained to move on top of previously built material (Jokic et al., n.d.). In both cases, circulation is restricted by building operations that increase congestion. Aerial robots can circulate to and from building tasks without being constrained to sharing the congested space of the building site. To date, aerial robots have not been utilized for AM CRC, while assembly-based CRC (Augugliaro et al., 2014; Lindsey, Q., Mellinger, D., Kumar, 2011) has been demonstrated using pre-determined flight paths. Research challenges remain for securing a scalable, adaptive approach to AM aerial mission planning that is capable of responding to dynamic conditions such as impact from activities or air turbulence of individual robots, changing building, environmental and weather conditions, or in response to the state and robustness of individual robots.

Although AM allows for greater insitu adaptation of building compared to assembly-based modular designs, not all geometrical designs are viable for incremental manufacture. Inclined geometries can be unstable during the building process unless a scaffolding strategy is employed. However, scaffolding approaches scale poorly as increases in building surface area or structural span can require exponential increases in scaffolding volume. To support greater geometrical freedom, adaptive building and design approaches that can mitigate mid-build instability are needed.

An approach to Collective Aerial Additive Manufacturing (CAAM) is presented that involves real-time adaptive multi-agent flight, mission planning and task coordination, together with adaptive building design and construction sequencing. A series of experiments were undertaken to evaluate a real-time adaptive approach to aerial robot high-level flight control. Custom-built DJI F450 quadcopters with PX4 flight controllers, an onboard computer and custom ROS software stack were calibrated to fly continuously through small incremental vector-based steering behaviors in lieu of a sequence of predetermined waypoints. Proof of concept is achieved by a team of aerial robots producing a light-trace flight choreography of an AM geometry captured by time-lapse photography. Simulation modelling further explores the capacity of the method to support building design and robot behavior adjustments in relation to real-time anticipatory structural and geometric analysis of a 3D digital twin in-the-loop, monitoring both final and interim states of a building process. CAAM demonstrates an adaptive approach to the design and construction of structurally efficient freeform geometries, extending CRC into AM for scalable robot populations and variable geometrical conditions.


