Task and Motion Planning for Collective Robot Construction

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To improve construction efficiency and enable structure fabrication in hazardous terrestrial and underwater environments, we envision a team of autonomous mobile manipulators (AMMs) capable of assembling and re-arranging construction materials. In order to accomplish this goal, a large number of overlapping tasks and geometric constraints must be imposed on the AMM end-effectors to allow for cooperative manipulation. We propose a cooperative path planning algorithm: Intersection of Manifolds RRT* (IMaRRT*), which enables complex cooperative manipulation by exploring an intersection of manifolds and solving for a large system of nonlinear constraints. We also discuss the existing challenges for determining the task order to assemble the structure, executing the planned path due to AMM and object dynamics, and incorporating environmental uncertainties.

I. Cooperative Planning on Manifolds

When using a team of autonomous mobile manipulators (AMMs) to transport rigid pieces of a structure cooperatively, a motion planner must generate AMM configurations that simultaneously satisfy all the implied constraints due to object geometry. This may lead to a large set of overlapping constraints. We provide a solution to solve an extensive system of nonlinear equations representing multiple overlapping constraints by integrating a nonlinear variant of the Kaczmarz method [1] into a path planner, where constraints are defined as manifolds. This formulation leads to a cooperative path planning algorithm for multiple AMMs based on rapidly-exploring random tree* (RRT*), which we refer to as the intersection of manifold RRT* (IMaRRT*) (presented in our prior conference submission [2]).

II. Challenges and Future Work

Our primary motivation lies in collective robot construction underwater, where each of the AMMs has a high degree-of-freedom robotic arm attached to the underwater vehicle. The resulting high-dimensionality AMMs must operate in an environment where disturbances (e.g., ocean currents and waves) lead to non-trivial dynamics. Individual dynamic models for an underwater vehicle and a robotic arm are well defined and experimentally validated. However, modeling a combined dynamics model for an AMM where the attached manipulator has comparable mass to the vehicle itself is a persistent challenge. Moreover, for cooperative transportation, object dynamics add a layer of complexity. We acknowledge that though we have generated feasible paths for cooperative transportation, we have not accounted for object and AMM dynamics. In the future, we are inclined to develop a cooperative trajectory planner that can successfully operate under dynamic constraints.

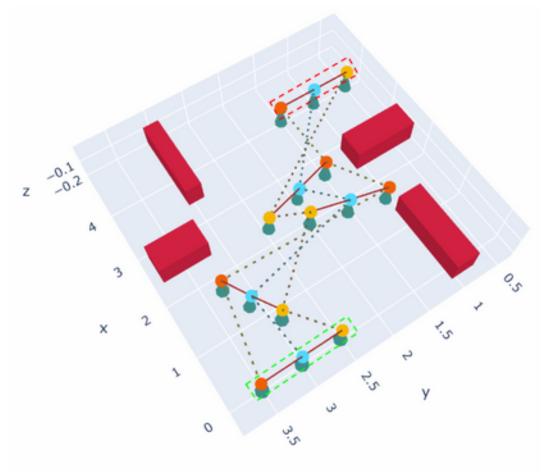

Fig. 1: IMaRRT* path for three mobile manipulators carrying a straight structure in an obstable-rich environment. Yellow, blue, and orange points represent the end-effector positions, the green cone represents end-effector orientation, and the solid red line connecting the end-effectors is the illustration of a straight structure [2].

For delegating tasks, a task planner should generate a robust plan that can assign robots to smaller teams and dictate immediate short-term goals. The planner should also account for different capabilities of robots (e.g., a screwing/fitting robot) and make teams capable of completing the assigned tasks. We expect such a planner would generate a large set of possible plans. These plans will have a different combination of effort and execution efficiency. A potential challenge is to select the best suitable task planner by trading off between collective AMM efforts and the time required to assemble a structure. To assemble a structure underwater, we require extending our current work to integrate an efficient task planner and a cooperative trajectory planner.

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