6-D manipulation with aerial towed-cable systems

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***Abstract*—We propose a new approach for the reliable 6-dimensional quasi-static manipulation of an aerial towed-cable system. The novelty of this approach lies in the combination of results deriving from the static analysis of cable-driven manipulators with the application of a cost-based motion-planning algorithm to solve manipulation queries. Using this approach, we can ensure that the produced paths are feasible and do not approach dangerous configurations that could provoque the malfunction of the system. The approach has been simulated on the *FlyCrane*, consisting of a platform attached to three flying robots using six fixed-length cables. The obtained results show the success and the suitability of the approach.**

I. INTRODUCTION

Most of the applications where aerial towed-cable systems have been applied use them as crane devices, only monitoring the position of the carried load [1, 8]. Instead, little work has been done on trying to govern the load in both position and orientation on the mentioned systems. Up to our knowledge, the only existing approach able to perform such 6-dimensional manipulation queries is given in [4]. It requires a given discrete set of intermediate load poses for which the IKP and the static equilibrium are solved. However, requiring a given set of load poses may be too restrictive, especially in constrained workspaces, because it can prevent the system from obtaining feasible motions, while there may exist solutions for different intermediate load poses.

In contrast, we provide an approach for 6-dimensional quasi-static manipulation with an aerial towed-cable system that only requires a start and a goal configurations and provides a feasible path to achieve the desired manipulation task. The novelty of the proposed approach lies in the combination of static properties derived from cable-driven manipulators with a cost-based motion-planning algorithm that will ensure the reliability of the computed manipulation paths.

II. OVERVIEW OF THE APPROACH

We will assume an aerial towed-cable system consisting of a platform attached to three flying robots by means of six cables linked by pairs to each robot as in Fig. 1. This structure will be called the *FlyCrane* system. It is worth noting that three is the minimal number of flying robots required to properly operate the six degrees of freedom of the platform.

Due to their similarities, a towed-cable system can be analyzed as a cable-driven manipulator. Actually, while cable-driven manipulators have to adjust the lengths of their cables to reach a precise pose of the platform, towed-cable systems have fixed-length cables and are actuated by displacing their anchor points. In general, actuating six degrees of freedom requires a minimum of seven cables, unless some convenient forces reduce this number. In our case, gravity acts as an implicit cable, and thus six cables will suffice for the 6-dimensional manipulation of the load.

However, the six degrees of freedom of the load cannot be governed in the whole configuration space. The pose of the load is locally determined only when all cables are in tension. Therefore, it is important to prevent the cables from being slack or too tight. Besides, it must be ensured that the flying robots can counteract the forces exerted on them. So, two types of constraints must be fulfilled along a quasi-static manipulation path:

- *Wrench-feasibility* constraints: guaranteeing that the system is able to statically counteract a set of wrenches applied on the platform while ensuring that the cable tensions always lie within a pre-defined, positive acceptance range. These constraints are derived from the static analysis of cable-driven manipulators [3, 2].
- *Thrust* constraints: guaranteeing that the thrust of the flying robots can equilibrate the forces applied on them, namely the forces exerted by the cables and the force of gravity.

In general, for a given manipulation query, there may exist a high number of solution paths that satisfy both constraints. In order to privilege the most appropriate ones, we introduce a quality measure on the configuration space, which indicates how far from not satisfying the aforementioned constraints is a configuration. This will define a cost function over the configuration space of the system.

To perform the 6-dimensional quasi-static manipulation of a load, we have to use a motion-planning method. Any general path planner, such as the Rapidly-exploring Random Tree (RRT) algorithm [6], is able to compute collision-free paths satisfying the previous feasibility constraints. But it may not produce good-quality paths. Instead, we can take advantage of the previously defined cost function and use a cost-based path planner, such as the Transition-based RRT (T-RRT) [5], in order to obtain *good-quality* paths. Although T-RRT has been successfully applied to various types of problems in robotics [5], to the best of our knowledge this is the first time it is applied to aerial manipulation problems.

Fig. 1. The *Puzzle* problem: the *FlyCrane* has to get a 3D puzzle piece through a hole.

III. RESULTS

We have evaluated the approach on some 6-dimensional quasi-static manipulation problems, and we have compared the obtained paths to those produced by RRT, which does not take the cost function into account, on the same manipulation queries. Figure 2 shows three screenshots illustrating the resolution of the *Puzzle* problem.

The results of the evaluation show that, rather than simply computing collision-free manipulation paths, the approach produces reliable 6-dimensional quasi-static manipulation paths. While RRT may produce paths that occasionally reach dangerous situations, our approach favors paths whose configurations are far from violating the given constraints, thus resulting in safer paths.

More details on the proposed approach can be found in [7].

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