Fully autonomous object transportation using multiple robots with cables

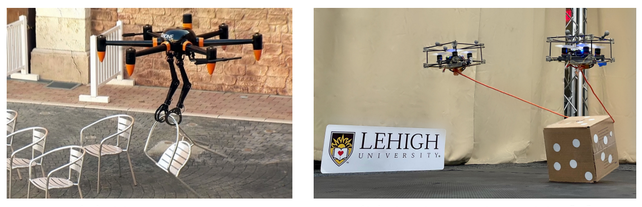
David Saldaña

LEHIGH UNIVERSITY AIRLab Autonomous and Intelligent Robotics Laboratory

I-DISC INSTITUTE FOR DATA, INTELLIGENT SYSTEMS, AND COMPUTATION

Motivation

Cables are versatile and lightweight and have the potential to replace heavy mechanisms that are being used in the robotics literature.



(a) Heavy arms (b) Lightweight cable [2]

Figure: Aerial robot manipulators

1. Aerial manipulation with cables is lightweight and versatile, but **current methods in the robotics literature still require human intervention.**

Research challenges

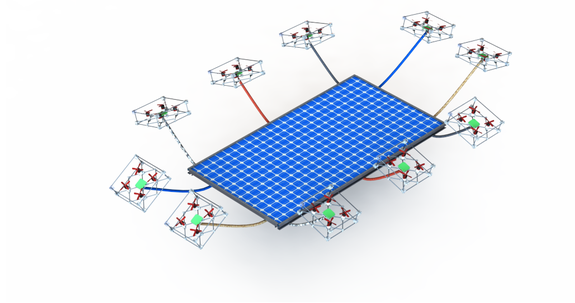
1. Estimating the cable's shape is **computationally intensive** and difficult for real-time applications.
2. The planning methods in the literature are not suitable for cables and their constraints.
3. Developing cooperative control strategies that deal with **unknown variables** such as friction.

Methods

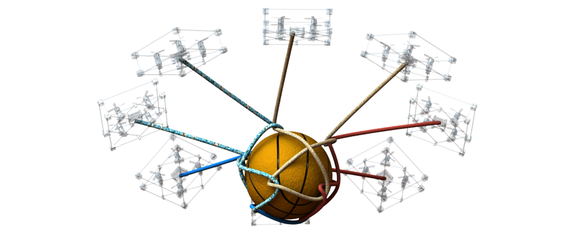
1. The proposed resarch consists of a set of actions that include different actions to change the shape of the hitch.
2. The trajectories should be excecuted in parallel, enabling hitches to be formed in constant time even with a large number of robots.
3. The team of aerial robots with cables is used to form and morph the hitch in midair.

Applications

(a) Transporting tools



(b) Holding heavy objects



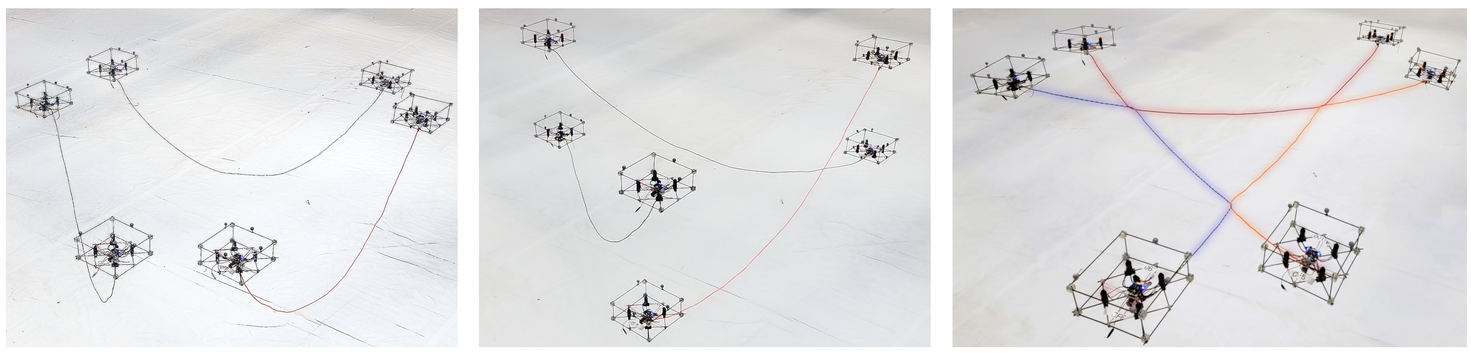
(c) Wrapping and packing

(d) Assisting constructors

Figure: Multiple robots can be connected to an object using adjustable cables, enabling versatile movement for various applications.

Forming a hitch

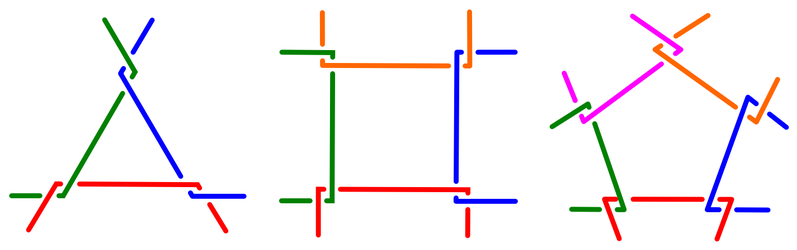
This work proposes using aerial robots with cables to form and morph hitches in midair. The hitches are modeled as convex polygons, making them adaptable to a wide variety of objects.



(a) Step 1: Free catenary robots [1] (b) Step 2: Interlacing cables (c) Step 3: Triangular hitch

Figure: Action 1: Six quadrotors forming a triangular polygonal hitch.

Methodology



(a) Triangular hitch (b) Square hitch (c) Pentagon hitch

Figure: Polygonal hitches: The hitch is defined by a polygon, making it versatile and adaptable to a wide variety of objects.

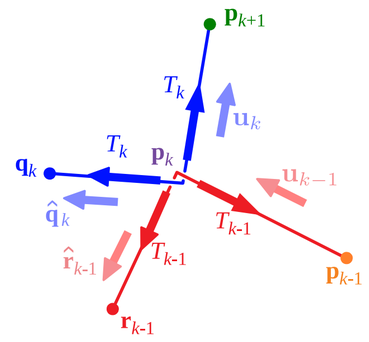
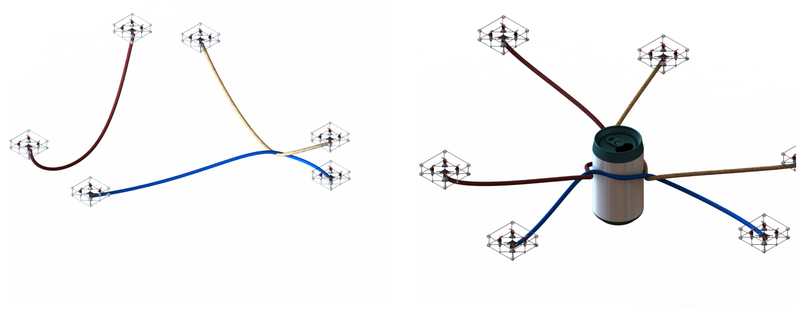
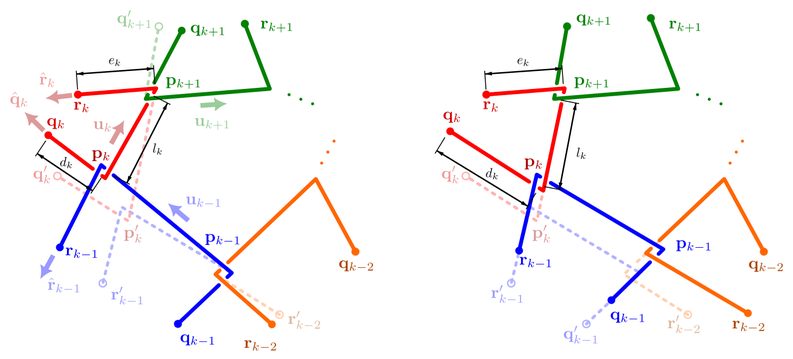


Figure: A vertex is formed by interlacing two cables, forming an x-like shape with four tensions. We consider a special case where all the cables have the same tension $T > 0$, *i.e.*, $T_1 = ... = T_n = T$.



(a) Interlacing a cable (b) Control the hitch shape

Figure: Action 1: Stages of forming a hitch with aerial robots.

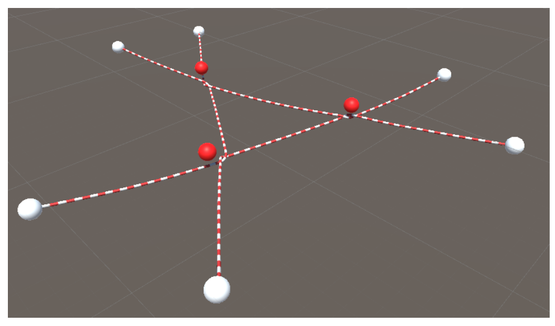


(a) Action 2: Moving vertex (b) Action 3: Moving edge

Figure: Multiple cables form a section of a polygonal-hitch. The dashed lines represent the actions of moving a vertex, edge, and adjusting cables.

Simulation

1. We performed experiments with the Obi Rope Unity package version 6.3, which is based on an advanced particle physics engine.
2. We are able to quickly implement and test different types of maneuvers that involve cables.



Experiments with actual robots

1. We show action 1 with four cables, and it can be scaled effectively.
2. With the quasi-static approach, robots performed demonstrations of Actions 2, 3, and 4.

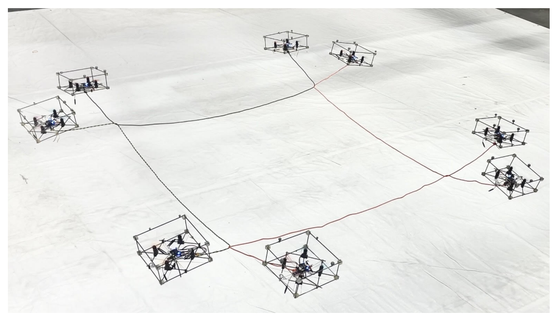


Figure: Actual robot forming a square hitch.

Conclusions

1. Aerial manipulation using hitches formed and morphed in midair using a team of aerial robots with cables is a novel and effective way to secure objects without human intervention.
2. The proposed algorithm and set of actions enable hitches to be formed systematically and efficiently. The hitch is modeled as a versatile convex polygon adaptable to a range of object shapes and sizes.
3. The scalability and reliability of the method demonstrated through simulation and actual experiments make it a promising approach for aerial manipulation in the future.

References

[1] D S. D'Antonio, G. A. Cardona, and D. Saldaña, "The catenary robot: Design and control of a cable propelled by two quadrotors," *IEEE Robotics and Automation Letters*, vol. 6, no. 2, pp. 3857–3863, 2021.

[2] G. A. Cardona, D S. D'Antonio, C.-I. Vasile, and D. Saldaña, "Non-prehensile manipulation of cuboid objects using a catenary robot," in *2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 5270–5275, 2021.

[3] D S. D'Antonio and D. Saldaña, "Folding knots using a team of aerial robots," in *2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 3372–3377, 2022.

[4] D S. D'Antonio, S. Bhattacharya, and D. Saldaña, "Forming and controlling hitches in midair using aerial robots," in *2023 IEEE International Conference on Robotics and Automation (ICRA)*, 2023.

Video

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