Two-State Control Structure for 2 DOF Aerial Manipulator on 6 DOF Hexarotor

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INTRODUCTION

Unmaned Aerial Vehicles (UAVs) are nowadays some of the most interesting methods for data collection. Their ability to fly to and through different geographical settings without the need of human control makes them ideal for sensing and photographing purposes. Nevertheless, there is much to be done on the **actuating functions** of UAVs.
Thus:

- A regular 3 DOF **hexarotor** was built modified to provide 6 DOF through **tilted motors**. Through these 6 DOF, manipulator needs of freedom and the complexity of its control are greatly reduced.
- A 2 DOF **aerial manipulator** was created.
- The main capabilities of the aerial manipulator are to **point** and **lock** the end-effector.

TWO-STATE CONTROL

The control structure was divided into two states for fulfilling the manipulator's main purpose:

Free State

The manipulator may receive any coordenates within its physical reach and position the end-effector through triangulating the desired coordinates using a mesh of reach endpoints.

Locked State

The manipulator may receive any displacement angle from the UAV's IMU and compensate it's motion.

DESCRIPTION

The control of a robotic arm attached to the bottom of a tilted motor hexarotor with 6 DOF was developed witht the intention of fulfilling distinct tasks relating aerial manipulation, including pointing and locking onto a target. For such purposes, a two-state control structure was developed. "Free" state allows the arm to reach any point within it's physical capabilities; "Locked" state alows the end-effector to remain still despite changes in the UAV's orientation.

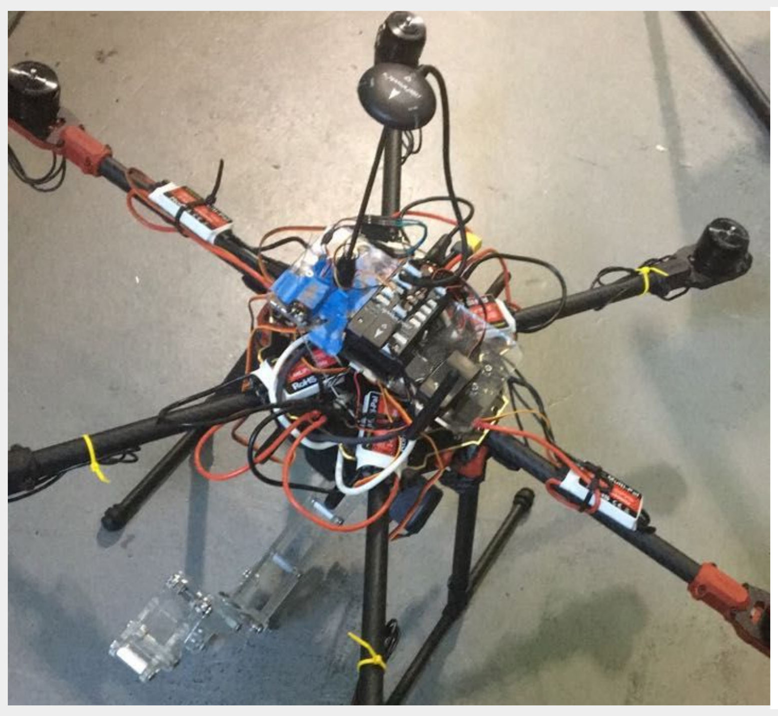

Figure 1. Picture of Hexarotor with prototype Aerial Manipulator

Figure 2. CAD Design of Aerial Manipulator rendering.

FREE STATE METHOD

The Free State uses a numerical method of **triangulation** based on the bisection method. For this, you first need a **mesh of endpoints** located on the limits of the reach. The method consists on the following loop:

1. Creat a triangle through the following vertex criteria:
   a. Current end-effector position
   b. Closest endpoint to desired position
   c. Closes endpoint to AB midpoint on desired position's direction.
2. Find triangle's centroid.
3. Replace vertext furthest from new position with centroid.

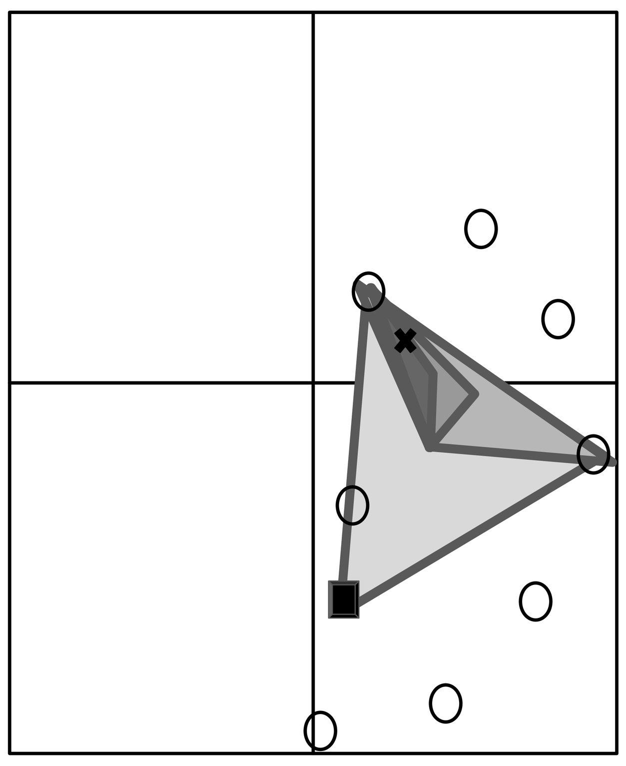

Figure 3. Representation of triangulation method. Square is start point, circles represent de mesh and X is desired position

LOCKED STATE METHOD

The main objective of the Locked State is to be able to compensate for the UAV's **unplanned displacements** while using the end-effector for a task that requires stability. To achieve this, the angle between the Y and Z axis displacements is calculated. Then, the **servo angles** needed to counteract such displacement are mathematically computed and sent to each motor.

RESULTS

Free State

The method was ran with 4 distinct max-iteration quantities, 10.000 times each. The following table shows the success and error rates of those experiments:

Method Iterations	Success Rate	Average Error
4	83.78 %	10.53 %
12	94.23 %	5.72 %
36	94.94 %	3.96 %
360	97.47 %	4.78%

Figure 4. Table representing the data obtanied through 10.000 repetitions of the numeric method.

Locked State

The manipulator was able to react to displacements from 20 to 65 mm 92.76 % of the time responding to an IMU simulation.

CONCLUSIONS

Tilting the motors of a UAV to achieve 6 DOF greatly simplifies the design and control of an **aerial manipulator**. With just 2 DOF on one and by syncronizing a drones IMU with the manipulator's position control, it is possible to **point and lock** the end-effector through relatively simple mathematical computations.

The impact this milestone has on UAV's present and future is the possibility to use drones for various actuating next. Nevertheless, while a 2 DOF manipulator may work for a 6 DOF hexarotor and point-lock operations, more DOF are needed for more complex tasks. What comes next is to scalate these methods to higher DOF systems while maintaining or increasing the method's simplicity and effectivity.
There is obviosly still much to be done for Unmanned Aerial Vehicles.

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