Autonomous Landing of A Quadrotor on a Moving Car

Work Summary

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Introduction

In the Cooperative Autonomous Systems Laboratory (CASY) unmanned small-sized aerial and terrestrial are being automatically conducted to accomplish certain missions. This review describes the method in which an autonomous landing of a quadrotor on a moving car is achieved.

Background

Several scenarios are active and proven for the time of writing of this paper. Among these are "*Track Waypoint"*, which guides a vehicle to visit certain spatial points defined prior to execution, and "*Follow Body*", which guides a vehicle to follow another vehicle. The Follow Body scenario is implemented by using waypoints – in each iteration of the control loop, the following vehicle is given a new waypoint it is required to visit. This waypoint is the current location of the target vehicle, and so a *pure pursuit* is actually being implemented. In both the above mentioned scenarios the vehicle is guided from waypoint to waypoint with a traditional guidance law such as proportional navigation.

Landing on a moving vehicle involves a pursuit, since the end location of the quadrotor is required to be the same as the car's location.

Implementation

The problem was divided to two – the pursuit problem in the horizontal plane and the altitude control, which must bring the quadrotor from its initial altitude to the same altitude as the car.

- Altitude control: At the moment of landing, the velocity of the quadrotor is desired to be as close as possible to zero, and with a horizontal component only, to minimize impact and friction. Since the vehicles used in the laboratory are rigid and unmanned, not much work was put in minimizing the velocity of impact, and the emphasis was put on achieving a vertical landing. An arc-shaped trajectory in the vertical plane, that will be a part of a circle whose center is somewhere behind the car and the car is constantly on the intersection of its perimeter and the horizon, will result in a vertical velocity at the point of touchdown. A theoretical circle, fixed to the car, is defined:

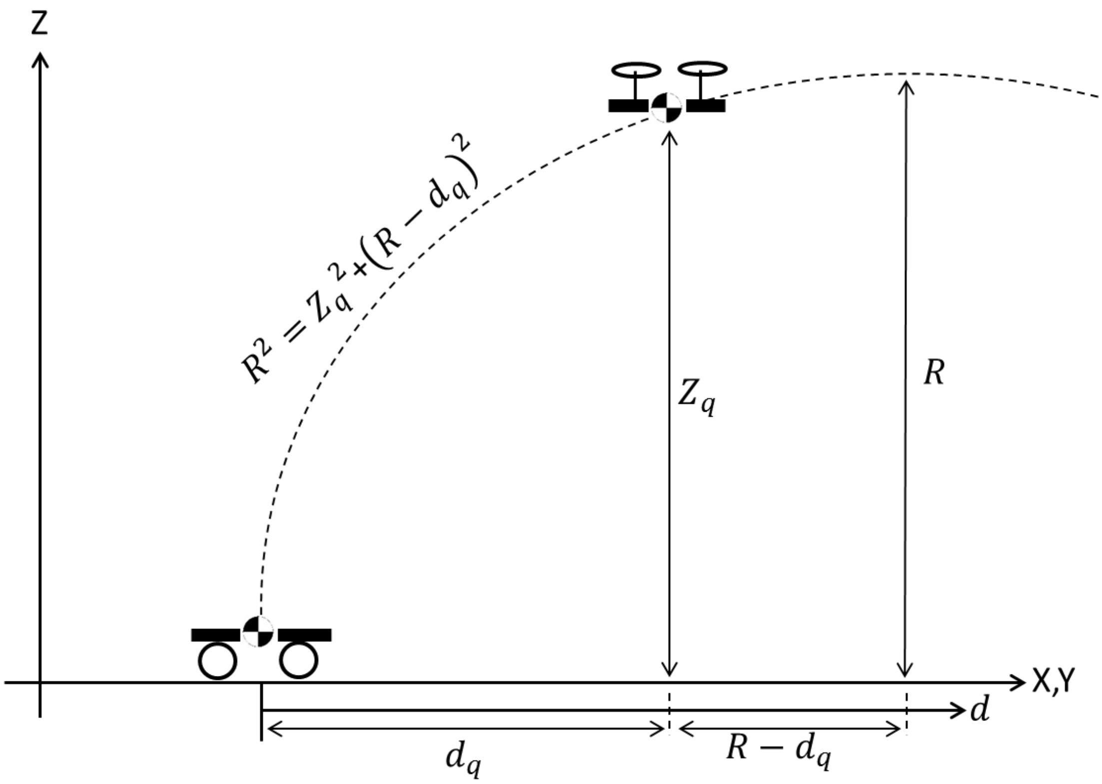
$$R^2 = {Z_q}^2 + \left(R - d_q\right)^2$$

Where R is the radius (constant), Z_q is the altitude of the quad relative to the car and $d_q = \sqrt{\left(x_c - x_q\right)^s + \left(y_c - y_q\right)^2}$ is the vertical distance. x_c and y_c are the planar coordinates of the car. From here a desired altitude is derived for the quadrotor as a function of the vertical distance:

$$Z_q = \sqrt{R^2 - \left(R - d_q\right)^2}$$

- Horizontal control: the Follow Body scenario was taken to make the quadrotor pursue the car and bring it to the same point in the horizontal plane.

As described in the introduction, the mechanism of the Follow Body scenario is defining to the quadrotor a new waypoint in each iteration. Let the waypoint be (x, y, z), then assigning $x = x_c,\ y = y_c,\ z = Z_q$, will point the quadrotor towards the car and will dictate it a decreasing altitude that will result in the desired arc-shaped trajectory in the vertical plane.



Additions

Some additional parameters had to be defined in order to make this scenario work in practice:

- *Land_Offset*: used to "lift" the whole theoretical circle above the car and the XY plane.
- *Length_Offset*: moves the desired landing point along the length axis of the car. It is required in order to prevent the quadrotor from landing directly on the reflectors that mark the car for the Tracking Tools software, which may result in loss of tracking of both the car and the quadrotor, and failure of the scenario.
- *Width_offset*: moves the desired landing point along the width axis of the car. It is set to zero at the moment and might be necessary in scenarios that include circular motion of the car.
- *delta_x/delta_y*: moves the desired landing point proportionally to the velocity of the car. This is necessary for handling with the car's trend of driving away from the quadrotor.

Further work

While sticking to the mechanism of using the existing Follow Body scenario for the implementation of the land on a car:

- Replace the constant R with a variable one depending on the velocity of the car. As the car moves faster, it is advantageous to have an even more horizontal landing. Increasing the radius of the theoretical circle will result in a straighter trajectory for the same change of altitude.
- Add a Low Pass Filter. There are currently vibrations in the altitude of the quadrotor, as the altitude control reacts to every little change of the distance. Adding a filter will allow it to respond to a trend rather than to every momentary change, and achieve a smoother trajectory and possibly higher portion of successful executions.

Change of mechanism:

- A horizontal landing can also be achieved by implementing a *trajectory shaping* guidance law in the vertical plane. These guidance laws allow to determine the angle of impact as a pursuer pursuits a target, and demanding a 90 degrees impact in the vertical plane will yield the desired result.

Follow-up:

- A complete aircraft-carrier-like scenario: take off from a moving car, execute a mission, and land back on the moving car.
- Landing of multiple aerial vehicles on the same car.
- Cooperative landing – the quadrotor descends while doing a certain trajectory, either shaped or just visiting waypoints, and the car's mission is to keep directly beneath until the quadrotor descends all the way down and a landing is achieved.