Optimized Rendezvous of a Quadrotor

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Introduction

Quadrotors have a wide set of applications. They range from delivery vehicles to aerial photography vehicles to surveillance vehicles. One particular application that is of interest to us is the use of quadrotors at construction sites. On these construction sites, there will be various instances when the quadrotor must dock to other mechanisms. These may include docking to a charging station, docking to a payload mechanism etc. Through this research, we present an effective path planning algorithm that maximizes the probability of quadrotor docking to a passive gripper mechanism.

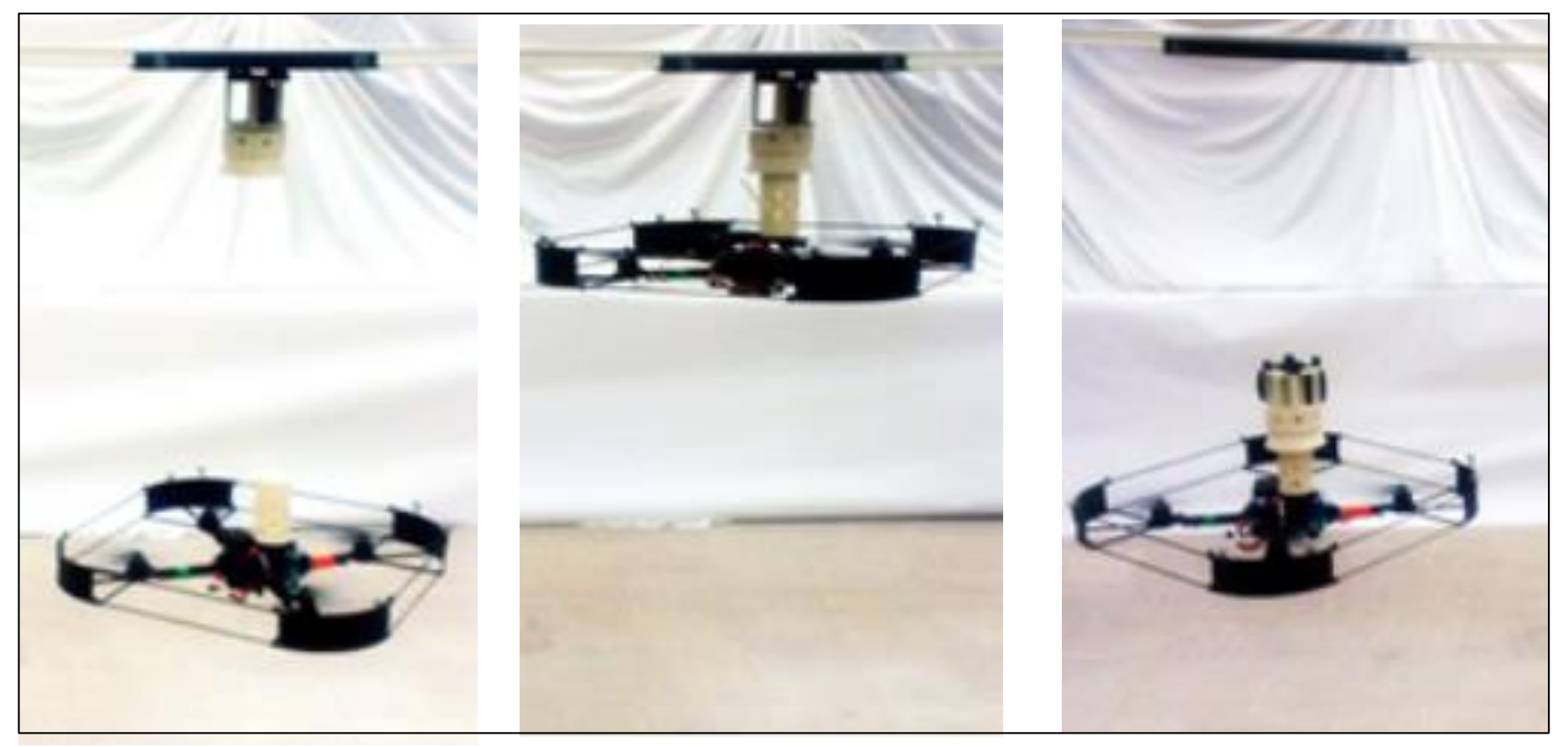


Figure 1: A Pelican quadrotor rendezvousing with a docking mechanism hosting a payload.

Problem Statement

Assumptions

- Perfect position sensing is assumed.
- Disturbances due to wind are present.
- There is uncertainty in attaining a desired velocity vector.

Problem

- Need a path planner that can ensure quadrotor rendezvousing capabilities from any location.

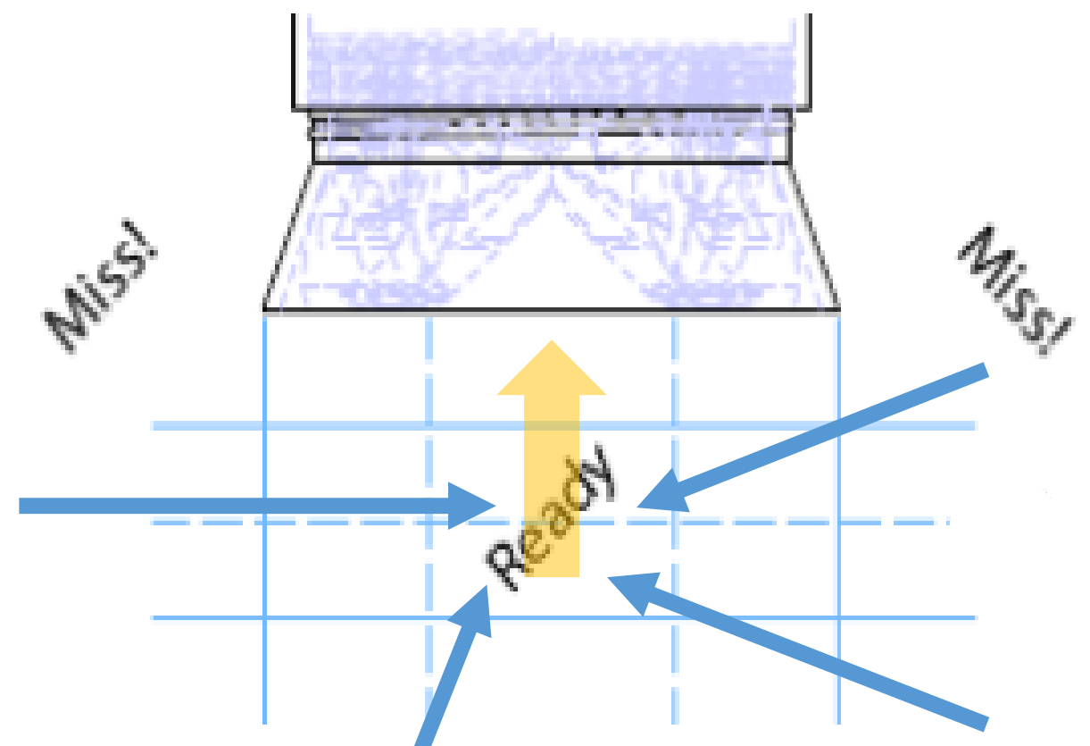


Figure 2: Current rendezvousing method forces the quadrotor to be in a pre-specified "Ready" location in order to dock.

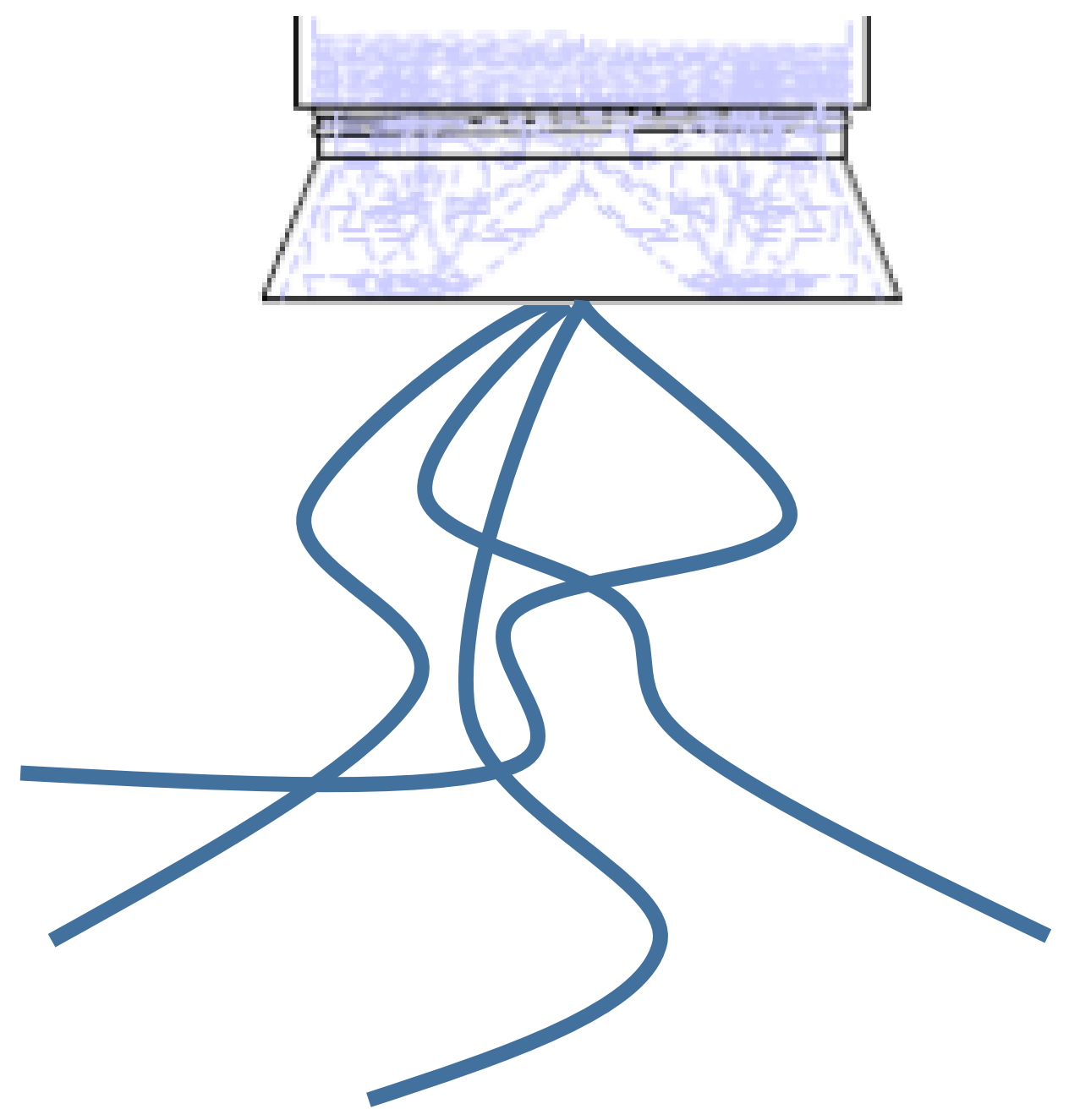


Figure 3: Through this research, it is ensured that the quadrotor can have docking capabilities from any location.

Methods

The uncertainty in R^3 is modeled using a set of possible velocity vectors within a cone shown below. The desired velocity is centered within the cone.

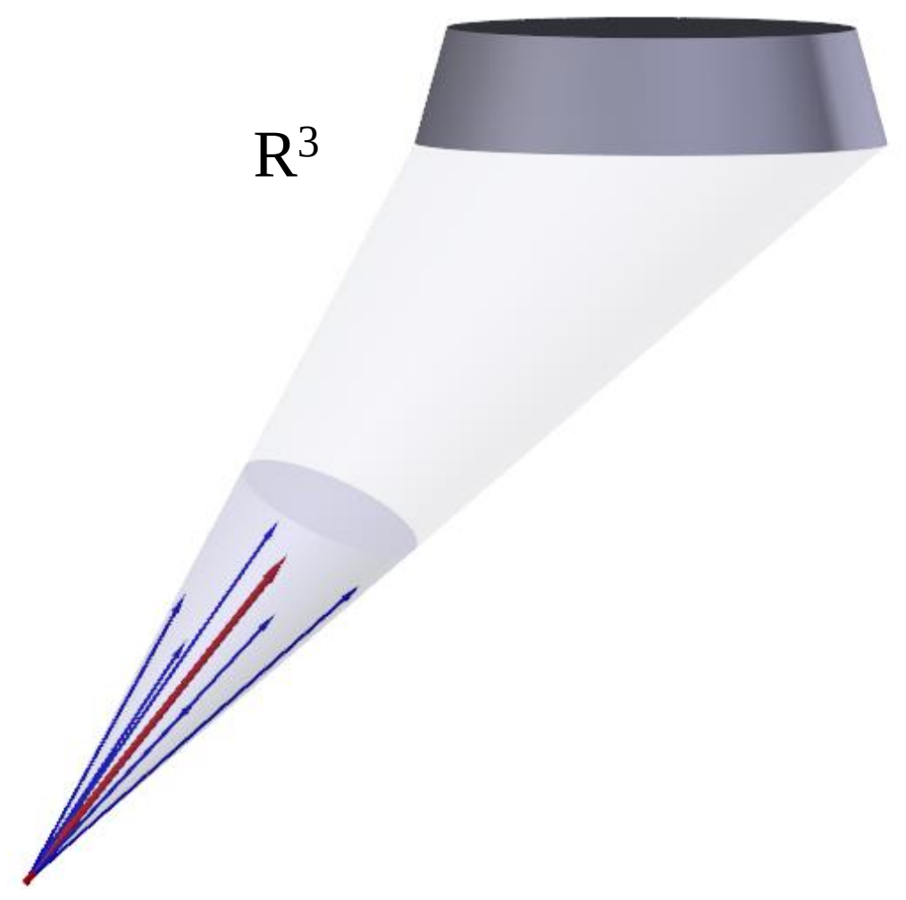


Figure 4. The Uncertainty cone

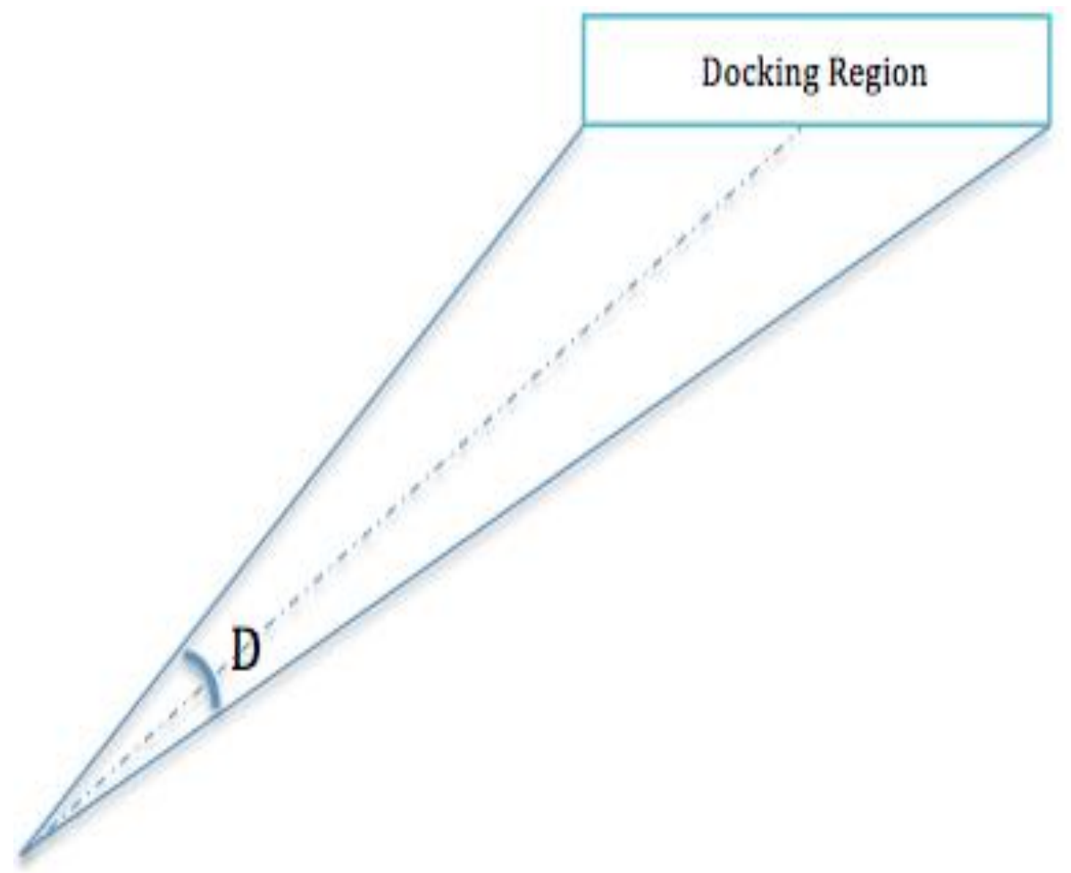


Figure 5. The Difference Angle

Based on the uncertainty cone, an angle is defined dictated by the geometry of the docking region. This angle bounds the allowable uncertainty for a commanded velocity. Any velocity within this angle is guaranteed to reach the docking region. Therefore, the goal is to maximize this angle which we call the "Difference angle" shown in Figure 5.

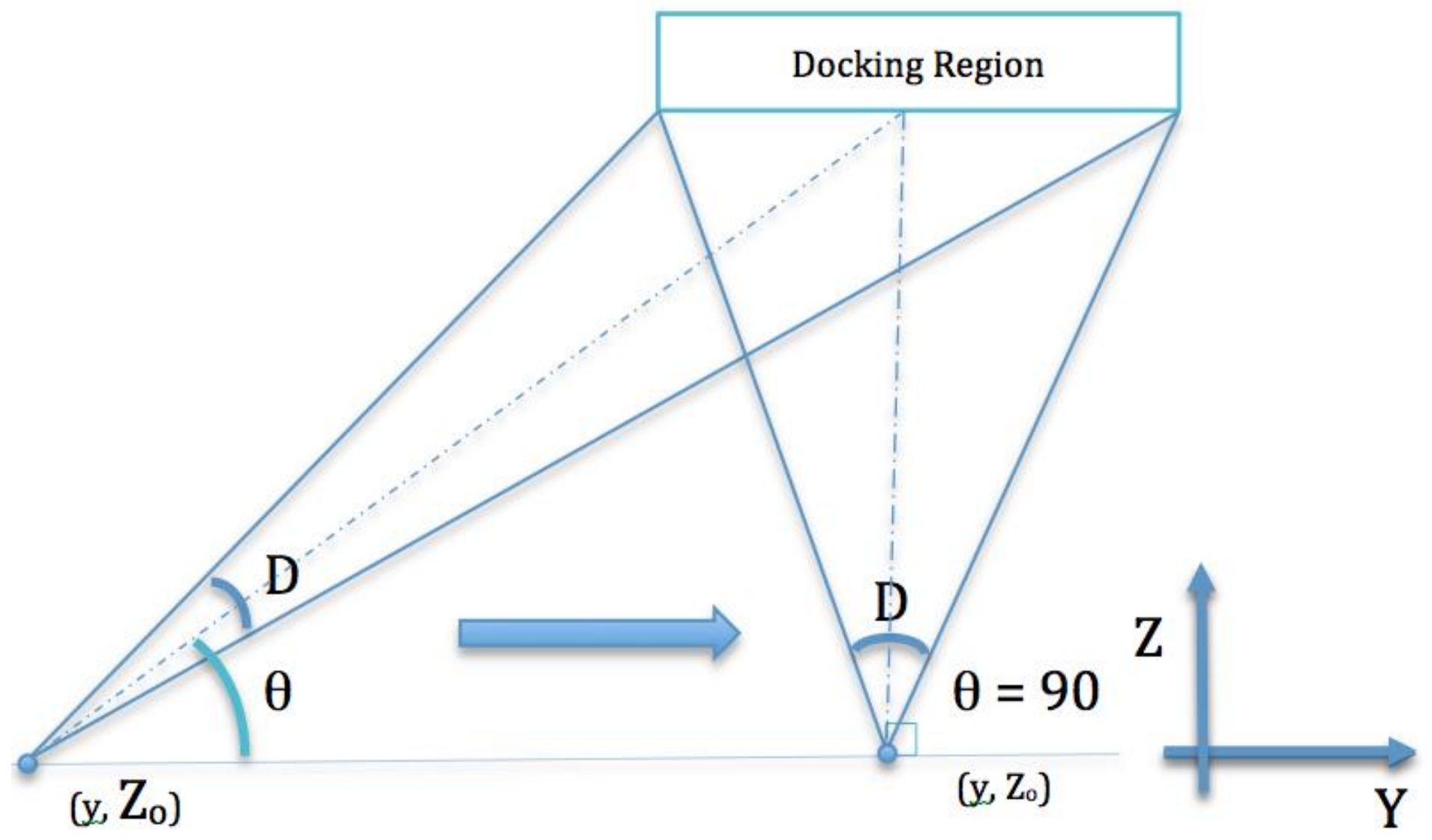


Figure 6: Difference angle is maximized as θ goes to 90° .

In Figure 6, it can be seen that as θ goes to 90° for any value of Z_o, we increase the difference angle D, which increases the probability of docking.

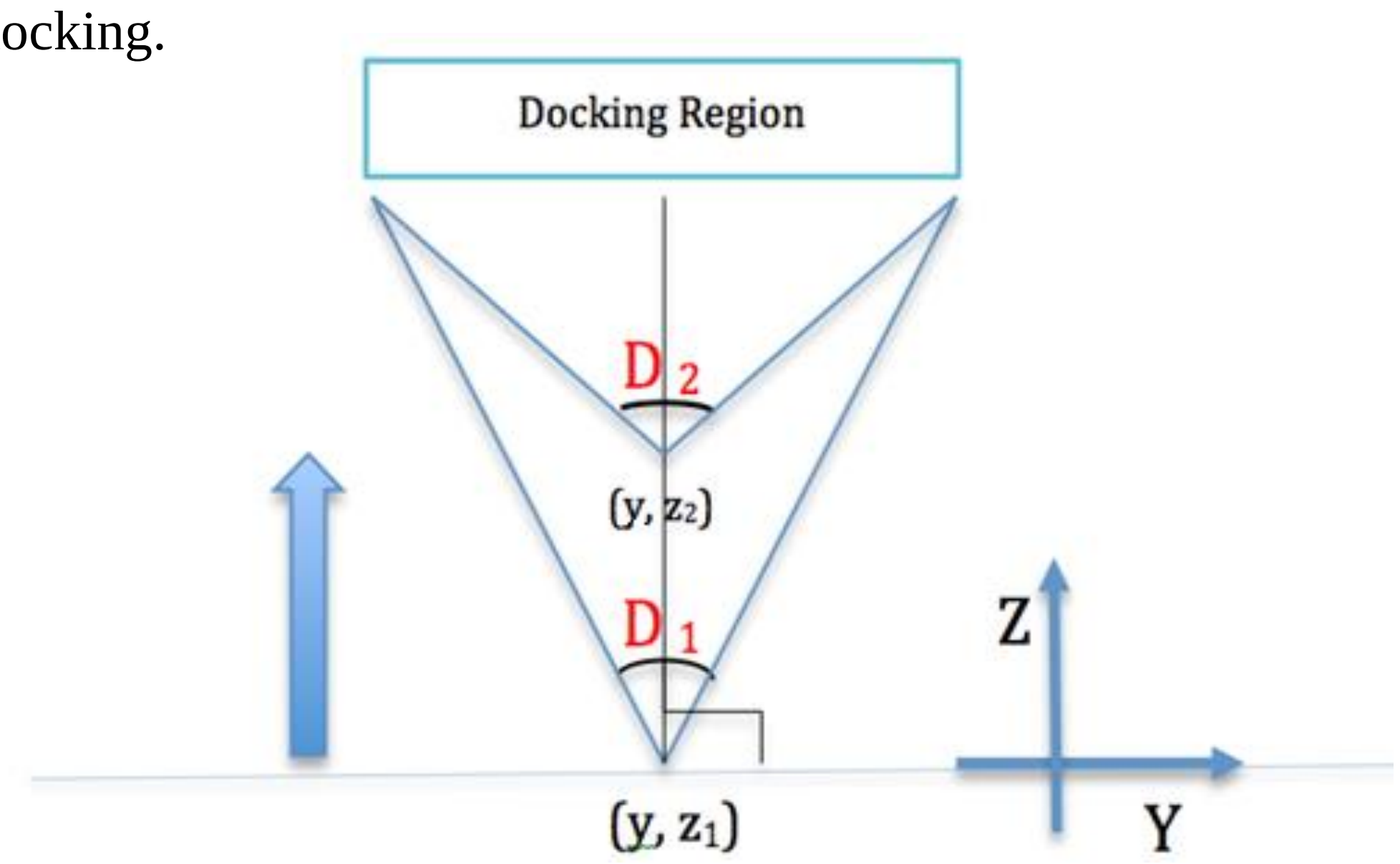


Figure 7: Difference angle is maximized as we go up towards the docking region when θ = 90° .

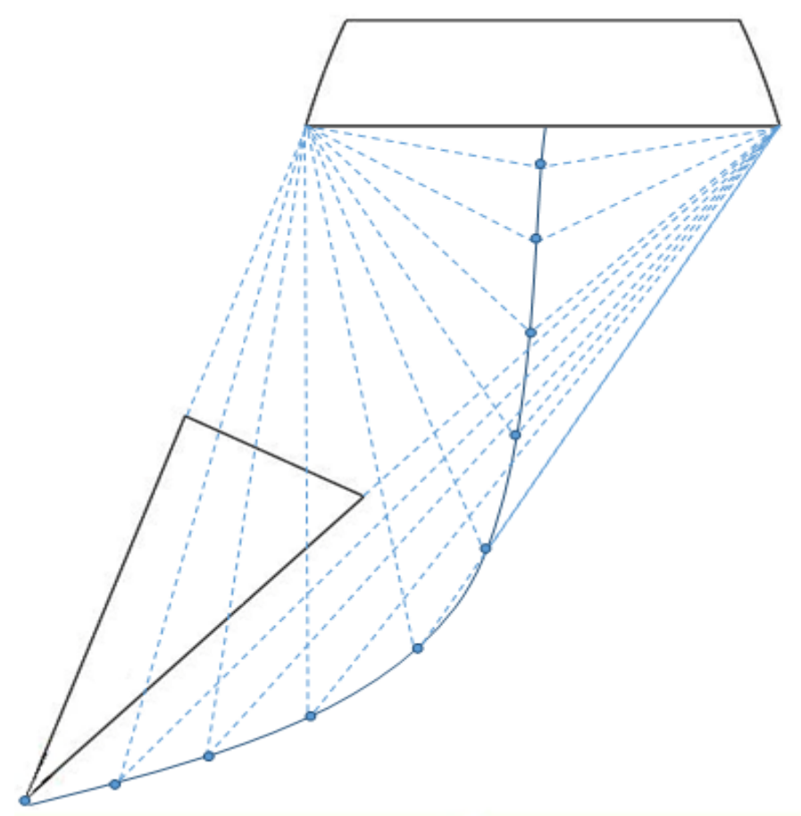
In Figure 7, As we move up along the z-axis with constant θ = 90°, we again increase the Difference angle, D, which increases the probability of docking

Gradient Descent Optimization

- The Difference angle, D, is then optimized using the Gradient Descent algorithm.
- The "next position" is a function of gradient of 'D' and the current position.

$$q_{i+1} = q_i + \alpha \nabla D$$

Methods



- Optimizing the Difference angle leads to a "curved trajectory as shown in Figure 8.
- This curved trajectory increases the probability of a quadrotor rendezvousing with its docking mechanism.

Figure 8: A visualization of the trajectory generated by maximizing the Difference angle.

The Difference angle increases robustness, but in order to decrease the time to dock, we employ a new objective function assuming a constant velocity. We call this the "Proposed method".

$$J = A\left(\frac{1}{D}\right) + B\|x_m - x_q\|$$

- 'A' penalizes the "Difference angle"
- 'B' penalizes the "time to dock"
- x_m denotes the position of the docking mechanism.
- x_q denotes the current position of the quadrotor
- Setting B = 0 gives a pure "Difference angle" trajectory.
- Setting A = 0 gives a "straight line" trajectory.

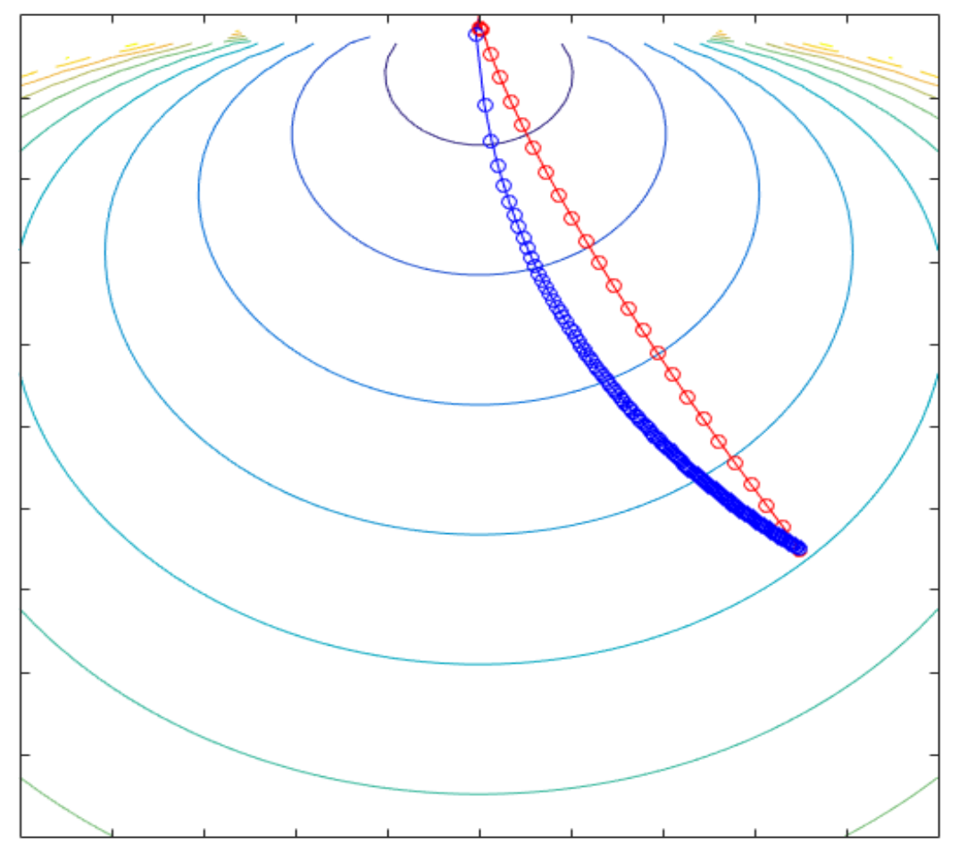


Figure 9: Difference angle trajectory (Blue) compared to the Proposed method trajectory (Red) with weights A = 0, B = 50

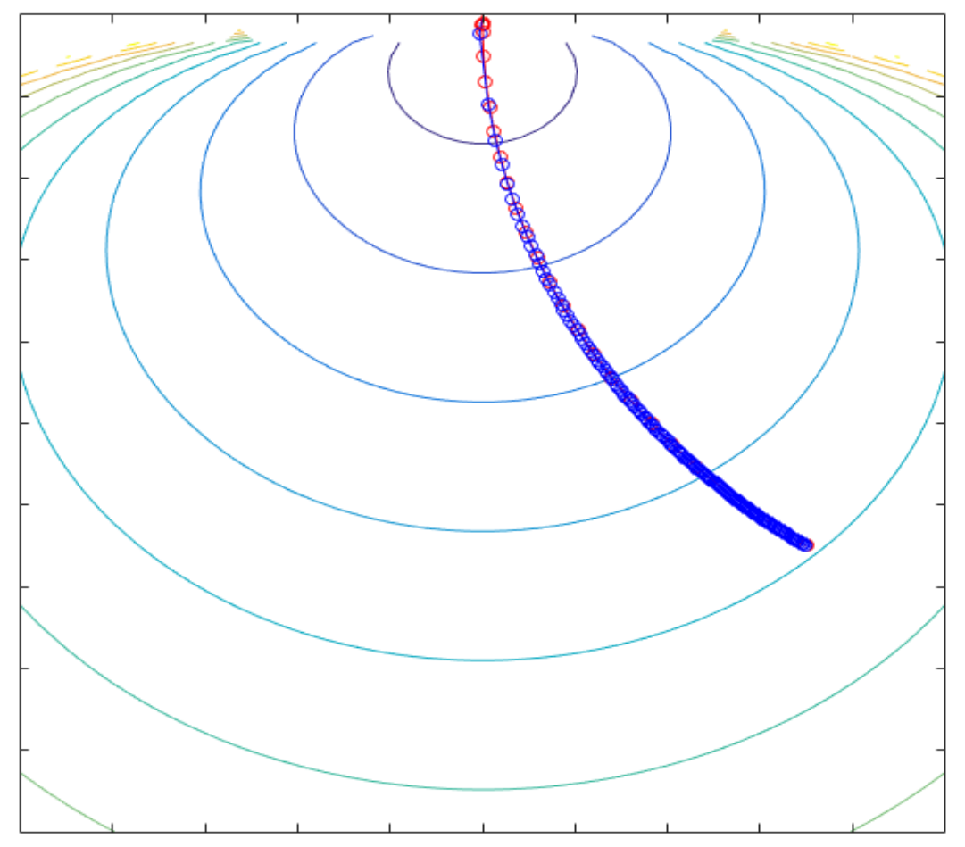
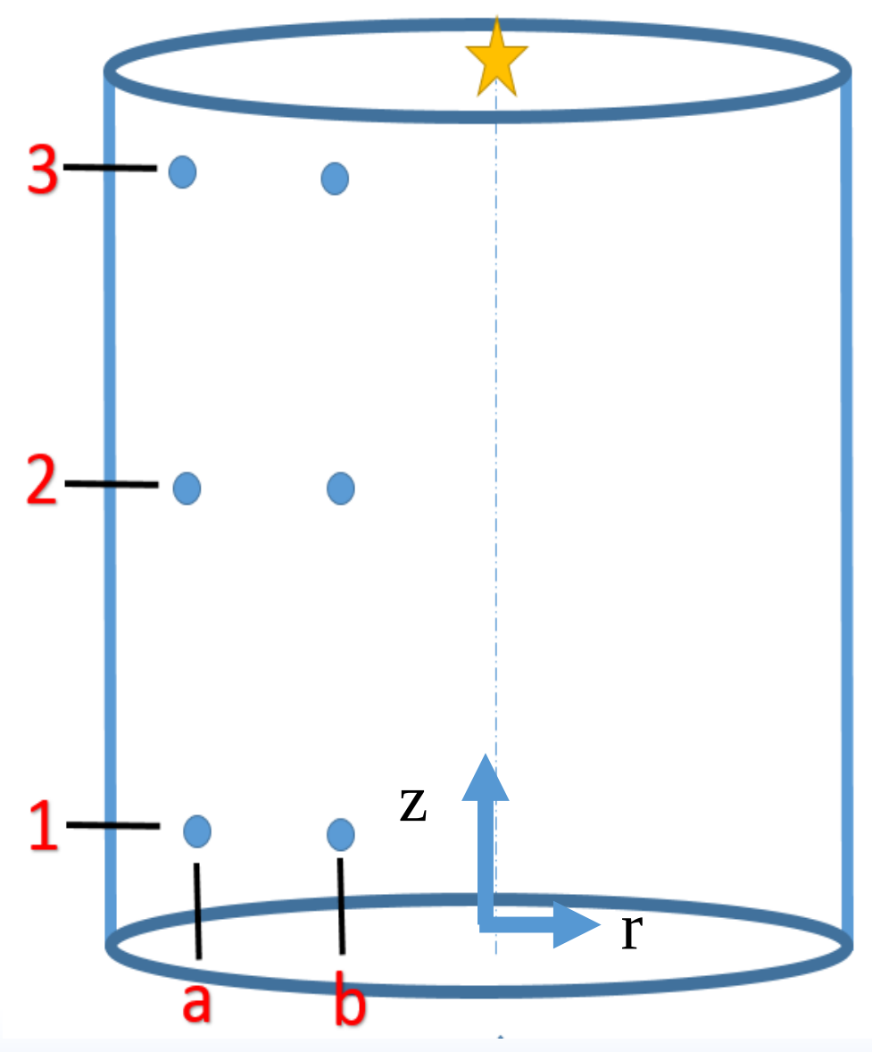


Figure 10: Difference angle trajectory (Blue) compared to the Proposed method trajectory (Red) with weights A = 50, B = 0

Monte Carlo Simulations

A set of Monte Carlo simulations were conducted to validate the "Proposed method". The Proposed method was compared against the "Difference angle method" and the "Straight line method". The configuration of the simulation was set as following:

- Proportional Derivative (PD) controller with constant gains
- Disturbance with mean of 0 and variance of 0.01
- Docking region limit of 0.043
- A and B set at 2 and 50 respectively for the "Proposed method"
- A and B set at 0 and 50 for "straight line method"
- A and B set at 1 and 0 for the "Difference angle method"



Position Initial Conditions (r, z)

- a_1 = (0.95,0.15)
- a_2 = (0.95.1.00)
- a_3 = (0.95.1.85)
- b_1 = (0.50.0.15)
- b_2 = (0.50.1.00)
- b_3 = (0.50,1.85)

Figure 11: Visual of position initial conditions

Results

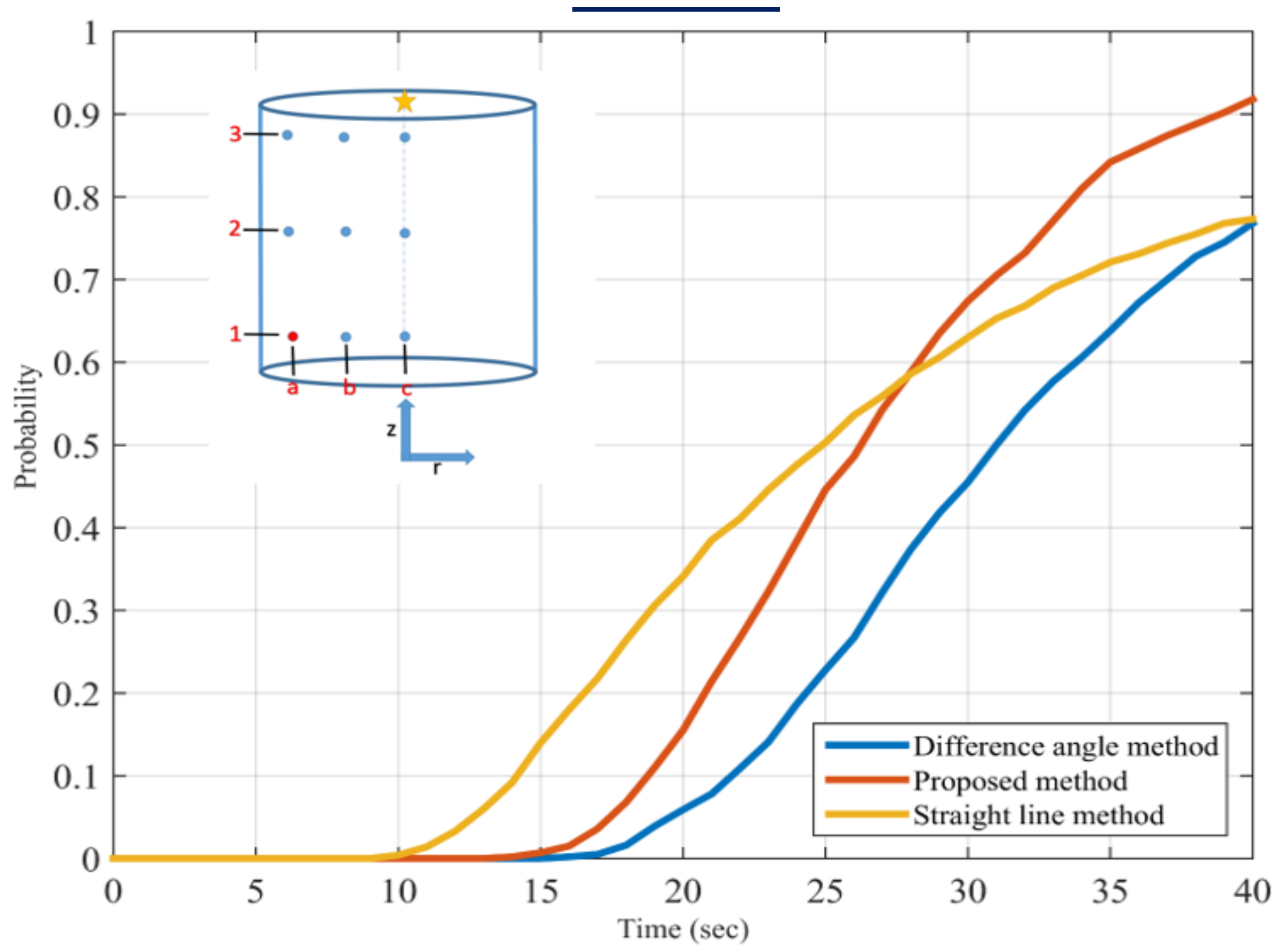


Figure 12: Cumulative Distribution of successful dockings from location a_1

The "Difference angle" method increases robustness and the "straight line" method, being the shortest path to the docking region decreases time to dock. Since, the "Proposed method" is a combination of the two methods, it increases robustness while minimizing time. The results shown in Figure 12 and Figure 13 were consistent from all the other previously mentioned position initial conditions.

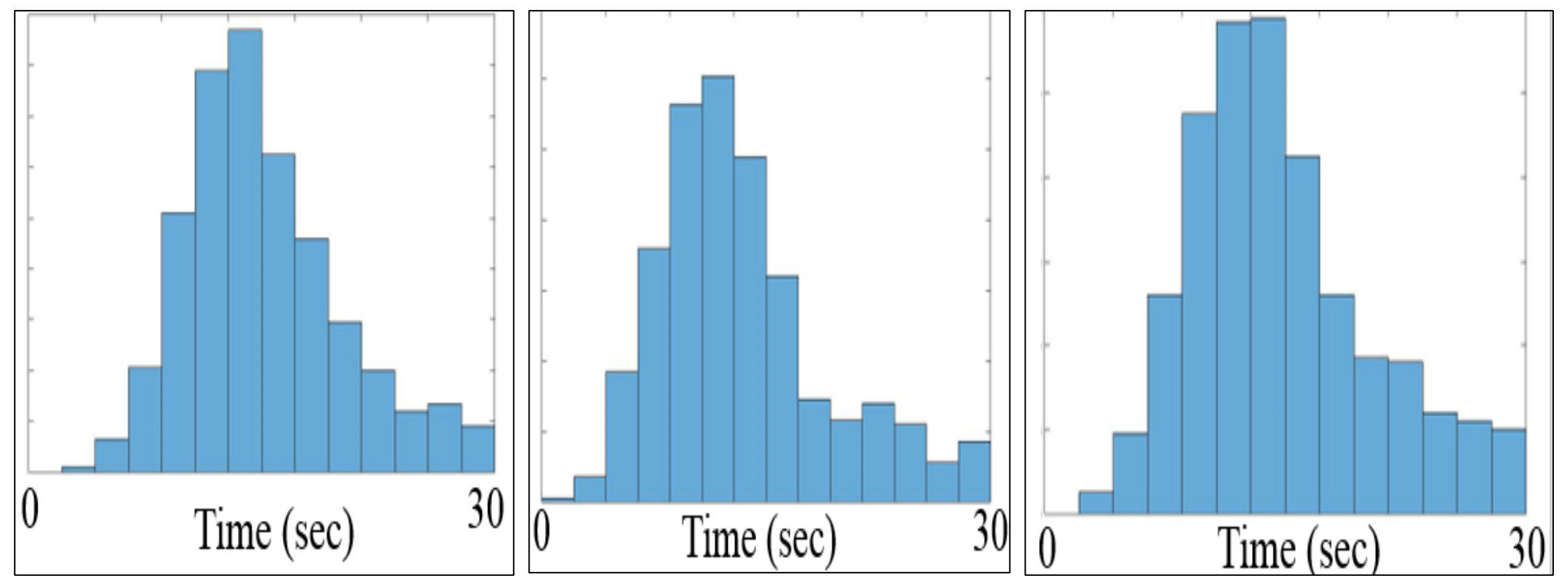


Figure 13: Histograms showing time taken by the number of successful dockings from location a_1. The leftmost showing results from the "Difference angle method" followed by the "Proposed method" and "Straight line" method.

Conclusions

- Using the idea of idea of an "Uncertainty cone", a Difference angle dictated by the geometry of the docking mechanism can be computed.
- By maximizing the "Difference angle", the probability of quadrotor rendezvousing with its docking mechanism can be increased.
- The performance can be further improved by adding a time-minimizing part to the objective function.

References

J. DeGol, D. Hanley, N. Aghasadeghi, and T. Bretl. "A Passive Gripper Mechanism for Aerial Manipulation with a Quadrotor." in Intelligent Robots and Systems (IROS), 2015 IEEE/RSJ International Conference.

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