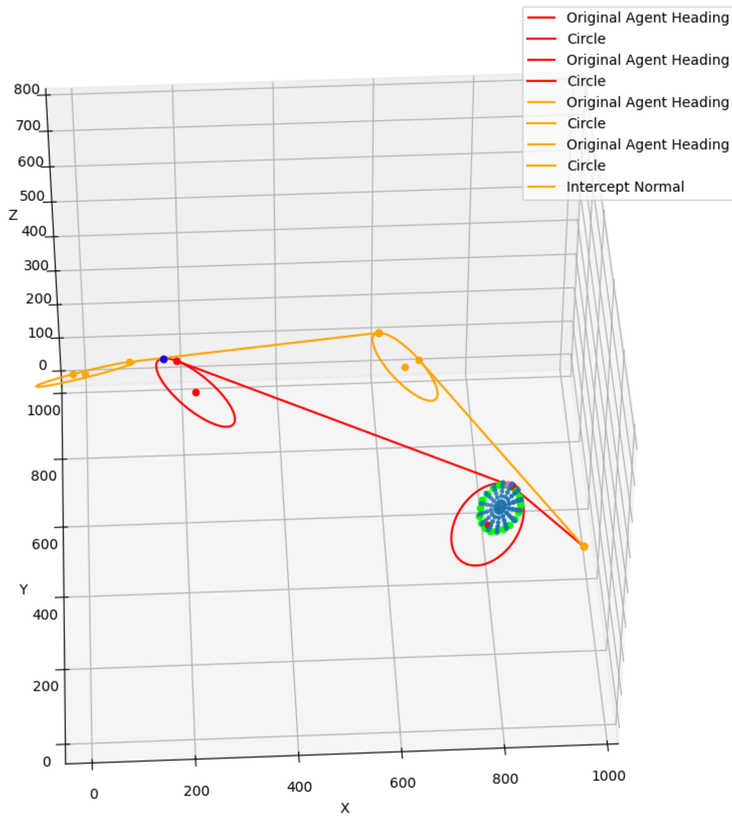
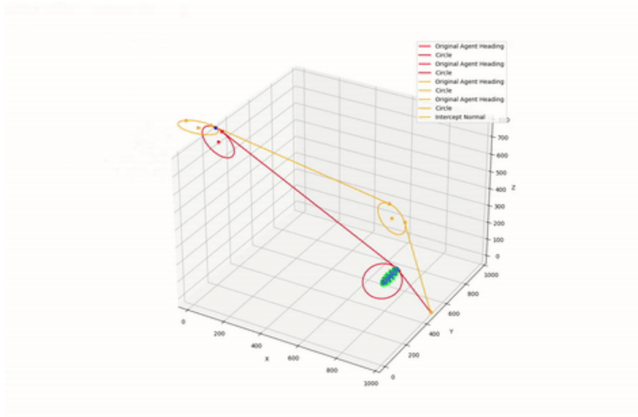
**Finding Feasible Region for Interception Slow Flying Intruders.**




This project's aim was to find a decentralized method for intercepting fixed wing drones using a swarm of much slower multi-rotor drones, called Dubins Feasibility Intercept Plane (DFIP) method. The basis of the method relies on a reachability analysis subject to time constraints, referenced from here on as feasibility. This method can be shown to predict the feasible region of transit of an intruder through an arbitrary plane. This allows for the command of a swarm of drones to the region to all but guarantee interception of the intruder




Nearly 1,000 lines of code were written to make the simulated system work. In the area of autonomous aircraft there is a concept of the shortest possible path to a given location called a waypoint. The waypoint often has an associated heading (direction of travel) associated with it. It was proven in 1957 by L. Dubins that the shortest path for an aircraft is to take a turn of minimum radius and then fly straight and conclude by taking a turn of minimum radius to end at the waypoint with the desired heading. The method developed in the project takes the basis of 2 papers and the proof by Dubins and extends them to a new and novel area. These Dubins paths were extended to 3D applications and given a straight forward geometric method for their construction by Sungsu Park in 2020. This project extends his framework from requiring 4 waypoints to only requiring 3. It is also extended to the relaxed Dubins path. The relaxed Dubins is the path from a waypoint with a particular heading to another waypoint with no constraint on heading. The next paper of consequence was a recent paper by Yan et. al, in which they apply relaxed Dubins paths to a reachability analysis for intercepting missiles. This project takes the concept of Dubins paths describing the feasibility region and shows that particular constraints can produce feasibility regions of interest.

As mentioned above, the DFIP relies on time constraints and Dubins path optimality to generate the feasible region. It is reasoned that there is a set of trajectories from the current position of the intruder to the target, and the intruder will take one of these paths. Finding each of these trajectories is intractable and predicting which one the intruder will take is likewise untenable. The solution presented is that we need only consider paths that end at the target in a certain region around the fastest possible time to reach the target. This family of trajectories is also impossible to calculate individually, however finding the region through which they will pass through a particular plane is possible. This is done by first finding the fastest possible relaxed Dubins path. Next a time allowance called $\boldsymbol{\Delta}t$ is introduced. The method for choosing a $\boldsymbol{\Delta}t$ is not discussed, however choosing an arbitrary value is shown to be effective. We then find the region that all paths of time length $t + \boldsymbol{\Delta}t$ must pass through a defined interception plane. This is done by sampling lines in the plane and then sampling points along the line as intermediate waypoints on the way to the target. A deterministic optimization is used to find paths of length $t + \boldsymbol{\Delta}t$ along the line. These points are recorded and then compiled. This yields the points seen in green in the figures. This is repeated at each measurement of the intruder.

It is important to note that the intruder cannot take a path shorter than $t$ in length, and it is necessary that at some time the intruder will take less than $t + \Delta t$ to reach the target. This ensures that despite the actual time length of the intruder's path, it will eventually take a path from its current location to the target in the time given. This means that the region guarantees to contain the intruder's position as it passes through the plane.

The region described is an ovoid, and cannot be readily described by a closed form function. However, in order to control drones to the region, it is approximated as an ellipse and then a gaussian is developed from it to inform the drone's control.

With those guarantees, it can be seen that if you can command a swarm of drones to occupy the region and you couple it with a final stretch interception control, you can all but guarantee interception. This is of vital importance when it comes to asymmetric warfare. When a military with large resources can send drones worth $100,000 dollars to do millions in damage, and take missiles worth 10 to 20 times the worth of the drone to intercept them, it becomes untenable to defend against these attacks. With a framework like DFIP a much more underfunded military can utilize drones that cost ~$500 to intercept incoming intruders. This allows for more feasible defense of critical infrastructure and targets.

References

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