Space Efficient Geofence Volume Sizing

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ENGINEERING HONORS PROGRAM
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Abstract

We investigated and analyzed methods to construct space-efficient airspace geofence volumes around Unmanned Aircraft Systems (UAS) for two specific cases: longitudinal climbing/descending flight paths, and cooperatively controlled swarms for which a provable containment boundary can be defined. Airspace geofencing defines polygon or polyhedron boundaries that partition the airspace into available fly zones (keep-in boundaries) and no-fly zones (keep-out boundaries) to assure aircraft separation and obstacle/terrain avoidance. Geofencing is a key enabler for safe Unmanned Aircraft System (UAS) Traffic Management (UTM). Constructing spatially efficient geofences around climb/descent paths becomes increasingly important in densely populated airspace to maximize usable airspace for other UAS. For the case of swarm flight/containment control, a single geofence volume can be used to wrap the entire team for air traffic control treatment as a "flight-of-n" vehicles, assuming the controller and connected network are robust. In both cases of climb/descent and swarm flight/containment control, the geofencing problem is to construct spatially efficient airspace volumes wrapping the UAS or swarm throughout its flight trajectory.

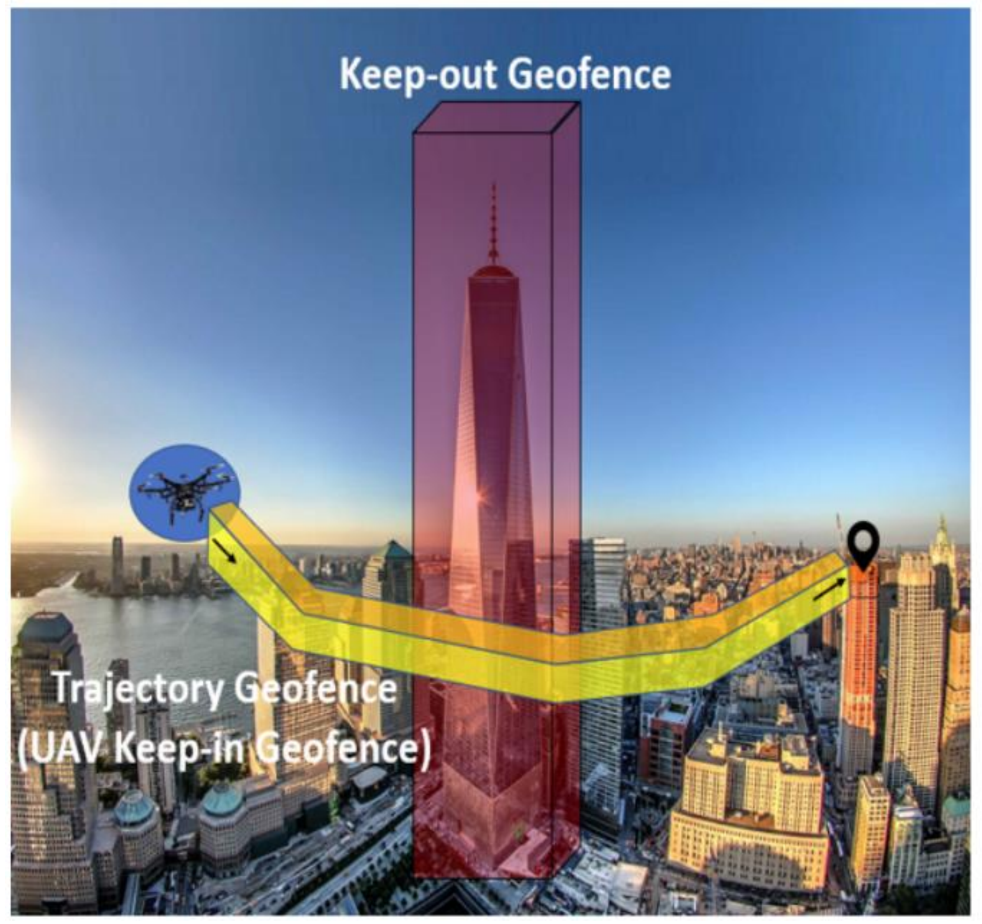

Fig. 1 Visualization of a red keep-out geofence creating a safety barrier around a building and a yellow keep in geofence creating a safety barrier around the path of a drone [1]

Motivation

Much of this research was done to improve on previous work [1]. This previous work used Multi-Staircase Geofence Volumes for climb/descent geofences. These geofences are inherently space inefficient when compared to a parallelepiped (a 3D parallelogram). The purpose of this research was to see how much more efficient these parallelepipeds were.

In addition, multiple drones will need to operate in the same geofence when flying in formation or as a swarm. There are several ways to generate a geofence around multiple drones. One such method is a convex hull. We analyze that method against a simple bounding box geofence

Methods

Parallelepiped and Multi-Staircase Geofences

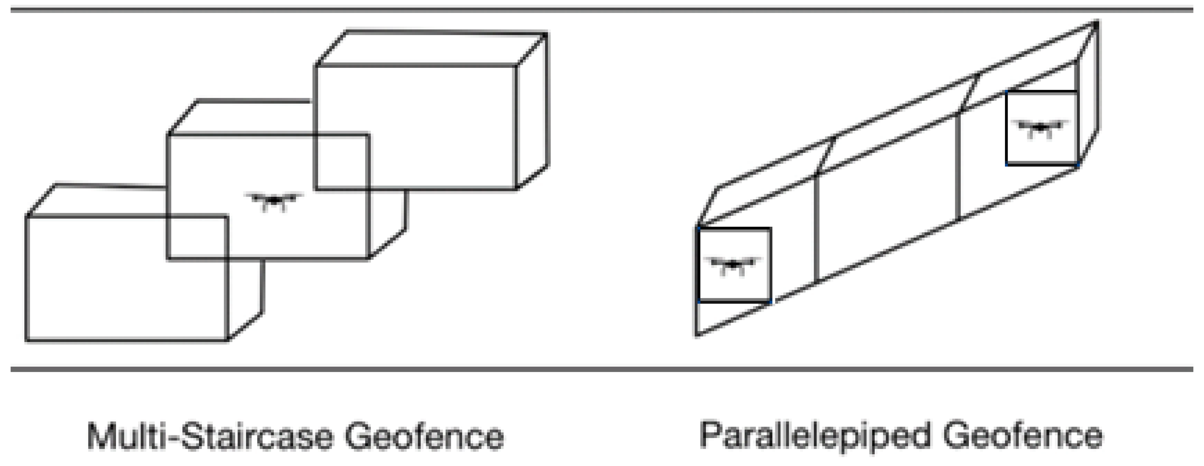

Fig. 2 Visualization of a multi-staircase geofence (left) and a parallelepiped geofence (right)

- Create the MSG and Parallelepiped
  - Rise/descent angle (γ)
  - Safety Buffer (δ)
    - Distance reserved around the drone to ensure safety
  - Number of blocks
  - Distance traveled
- Compare the MSG and Parallelepiped
  - Average amount of volume used during entire climb/descent

Convex Hull Geofence

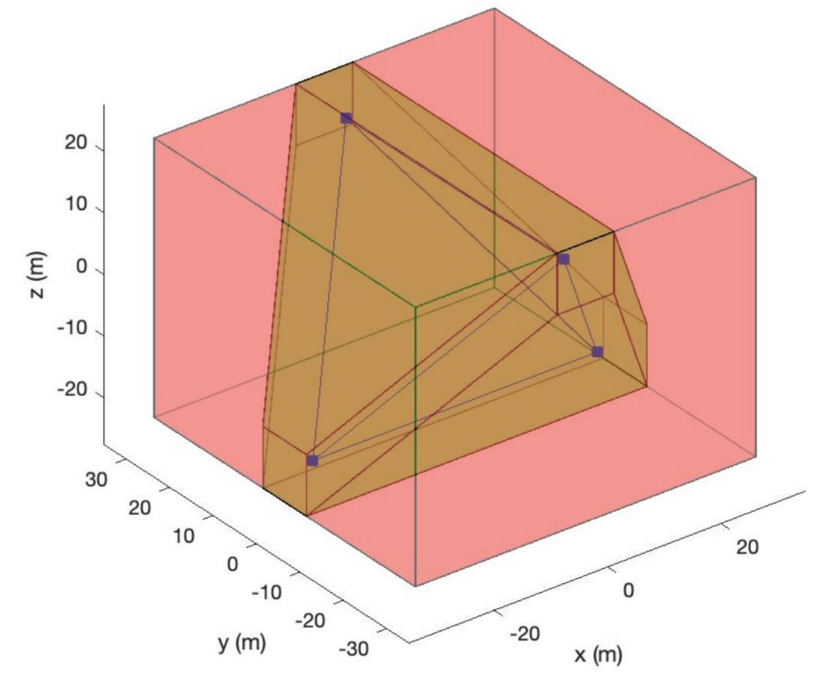

Fig. 3 Visualization of a convex hull geofence (green) surrounding a set of drones in a tetrahedron shape (blue) inside a larger bounding geofence (red)

- Create the Convex Hull Geofence
  - Place drones in a regular tetrahedron shape
  - Create small bounding boxes around individual drones based on their safety buffers (δ)
  - Convex hull the boxes
- Compare the MSG and Parallelepiped
  - Average amount of volume used during entire climb/descent

Results

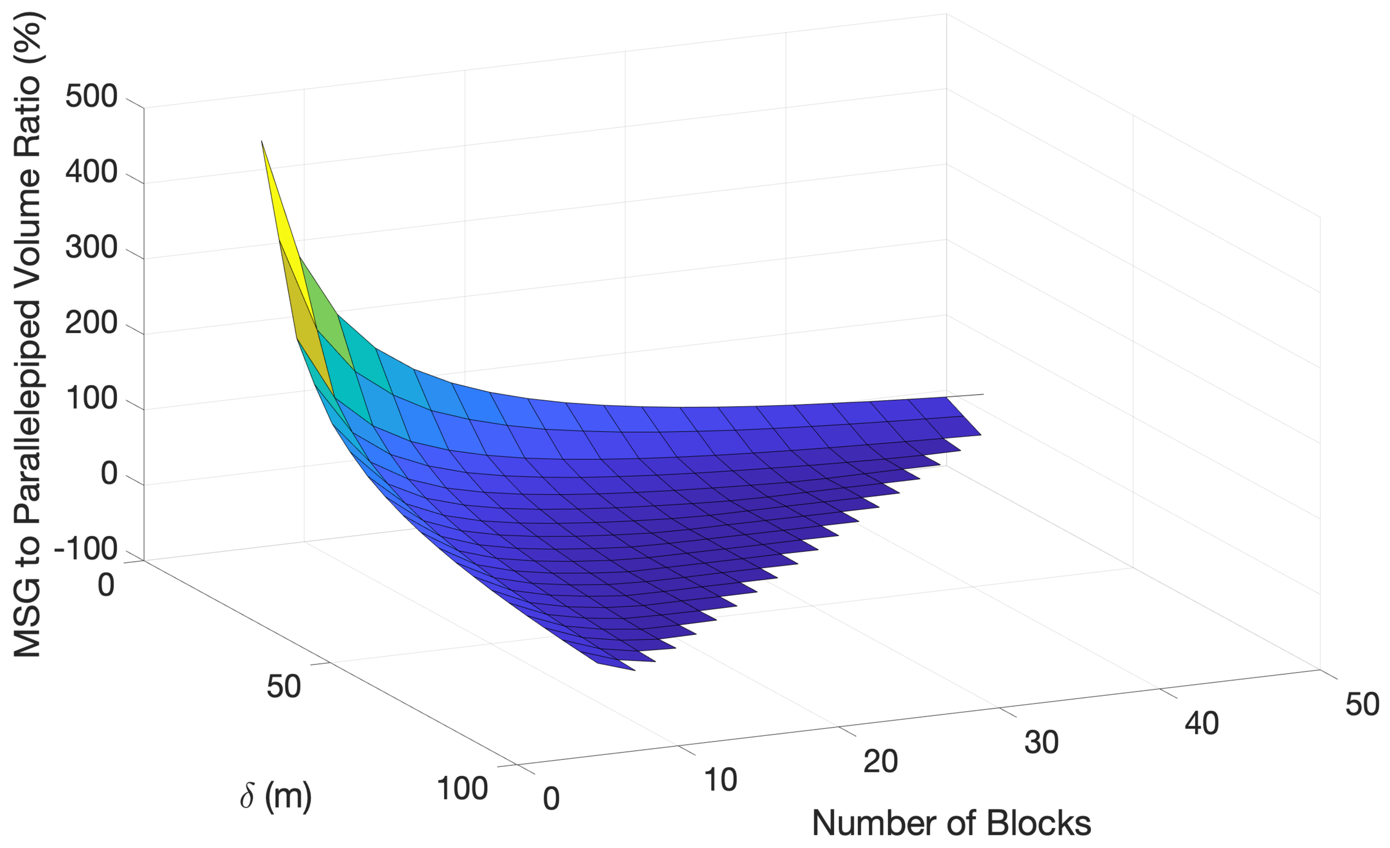

Fig. 4 Comparison of MSG and parallelepiped geofence volumes as a function of number of geofence blocks and safety buffer distances.

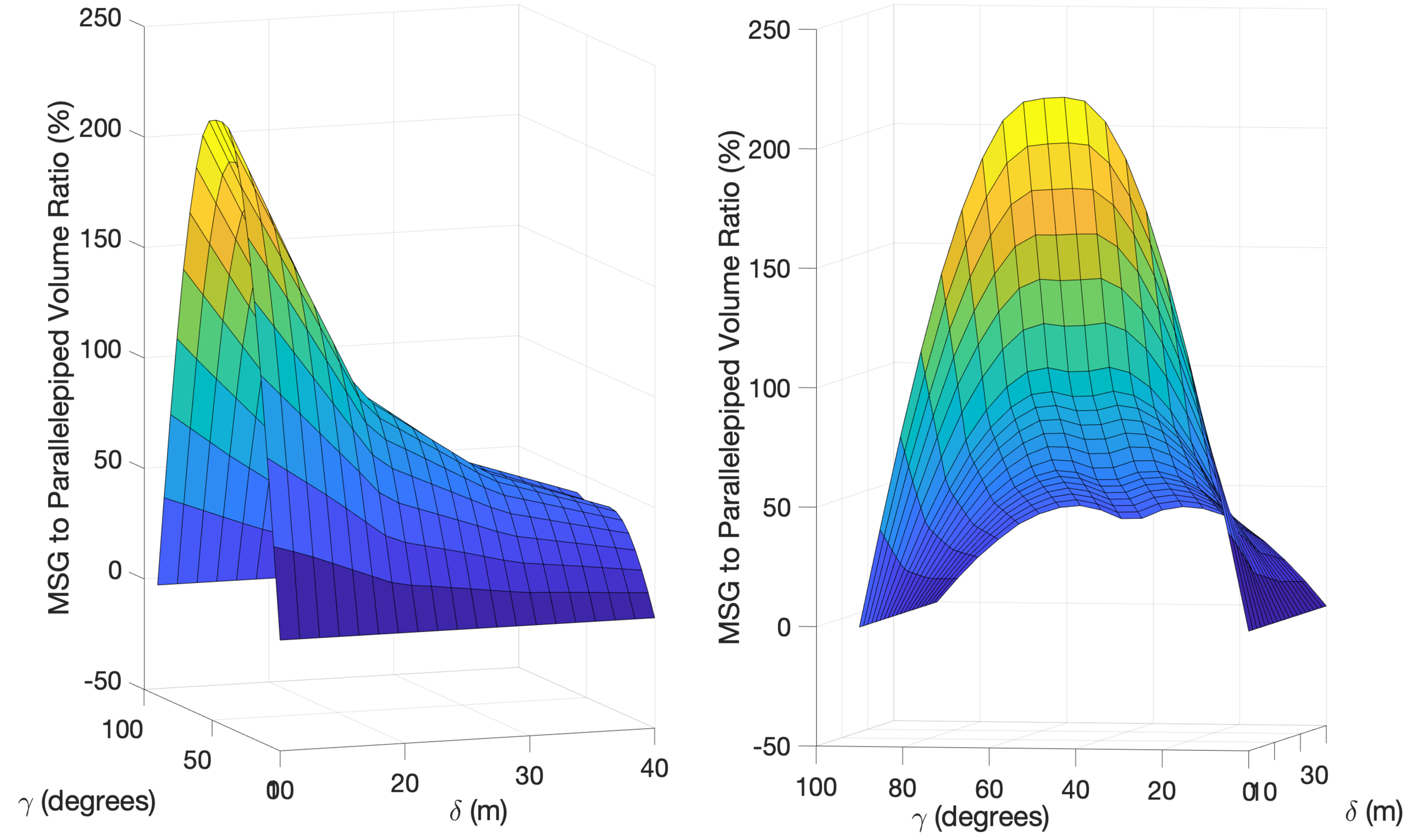

Fig. 5 Comparison of MSG and parallelepiped geofence volumes as a function of flight path angle and safety buffer size.

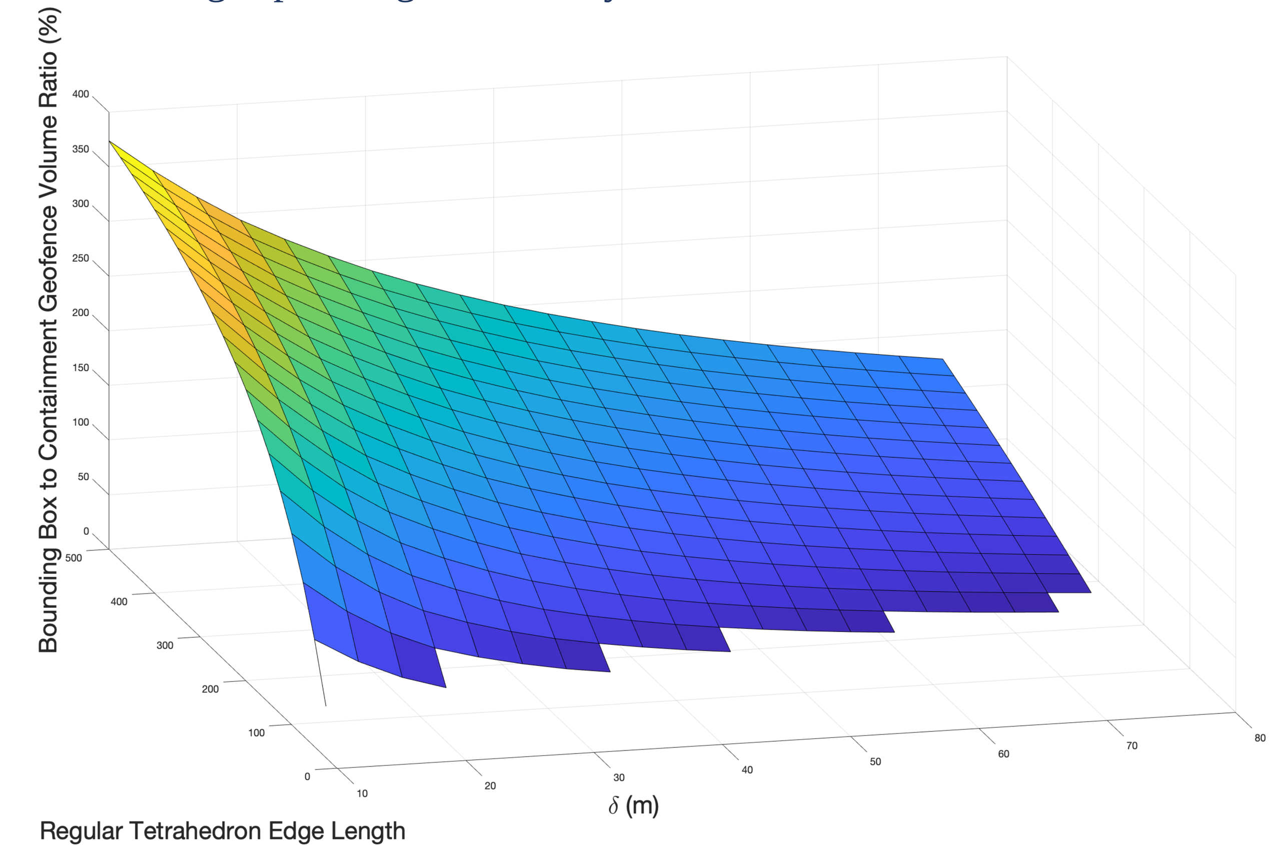

Fig. 6 Comparison of containment and bounding box cooperative UAS team geofencing designs as a function of distances between UAS and safety buffer sizing.

Conclusions

Parallelepiped and Multi-Staircase Geofence

- Parallelepiped geofence was consistently more space efficient than the multi-staircase geofence
- This efficiency was reduced under certain circumstances
  - Large numbers of blocks
  - Large safety distances (δ)
  - Very large rise/descent angles (γ)
  - Very small rise/descent angles (γ)

Convex Hull Geofence

- Convex hull geofence was consistently more space efficient than the bounding box geofence
- This efficiency was reduced under certain circumstances
  - Large safety distances (δ)
  - Small distances between drones

Complexity

This research focused on the space efficiency of these different methods for generating geofence volumes. What it does not consider is the computational complexity of either generating these volumes or deconflicting them. Both of these are huge considerations when creating an Unmanned Traffic Management (UTM) system. It is anticipated that the parallelepiped geofence and the convex hull geofence will both be more complex and computationally costly than the geofences they were compared to. Further work will need to be done to compare the computational complexity of these different geofence methods and determine whether their space efficiency benefits outweigh their computational cost.

Acknowledgements

I would like to thank my honors capstone advisor, Professor Atkins, for the opportunity to pursue this research as well as the knowledge and advice to lead it to fruition. I would also like to thank PhD candidate Joseph Kim for all wonderful help he gave me throughout this research as well as his constant upbeat attitude. In addition, thank you Mrs. Armstrong-Ceron for her years of help and advice in the honors program.

Finally, I would like to thank Collins Aerospace whose grant made this research possible.

References

[1] Kim J, Atkins E. Airspace Geofencing and Flight Planning for Low-Altitude, Urban, Small Unmanned Aircraft Systems. Applied Sciences. 2022; 12(2):576. https://doi.org/10.3390/app12020576