

6.3. Space Discretization - Avoidance Grid

Operation Space: The *Operation Space* is a space where UAS can effectively surveillance its surroundings, and it has the capability to act.

A Motivation for Discretization: The UAS surroundings needs to be represented in an *avoidance-friendly manner*, following principles matters:

1. *Discrete representation* - the space around UAS should be segmented into finite and exclusive portions which are considered as one point of the grid. This enables fast situation assessment.
2. *Threat proximity* - any form of threat gets more important with decreasing distance to UAS.
3. *LiDAR swipe density* - one LiDAR swipe scans many points; the grid needs to be customized to swipe characteristics.

The *Main Sensor* is *LiDAR* (problems ??-??). The *effective occupancy computation* needs to be done for all problems; the inspiration is taken from [1]. The *effective occupancy computation* is done in *LiDAR* scan portioned into *polar coordinates grid*. The *operation space* is abstracted as a *grid* where *space portions* are representing the points in the grid.

Note. Each member of the grid is a cell, represented as a point with properties, like threat level, visibility.

The *Discrete Situation Evaluation* is executed for a *UAS* local coordinate frame in fixed *time*. The goal is to enable *fast discrete situation assessment*.

LiDAR Swipe: The *point* scanned by *LiDAR*, where the *UAS position* is center of the *local coordinate frame*, and *UAS heading* is defining the *main axes* is given as:

$$point = [distance, horizontal^\circ, vertical^\circ]. \quad (6.1)$$

Note. For polar/Euclidean transformations and local/global coordinate frames refer to background theory (app. ??).

The *right side* of UAS $horizontal^\circ \in] - \pi, 0[$, the *left-side* of UAS $horizontal^\circ \in [0, \pi]$, the *down-side* of UAS $vertical^\circ \in] - \pi, 0[$, the *top side* of UAS $vertical^\circ \in [0, \pi]$

LiDAR Swipe Portioning: The *polar coordinate space* can be portioned into distinctive cells. Each cell then represents one point in the grid.

The *reason* for this swipe portioning is *LiDAR* scanning density¹, which is extremely dense. The *threat* state in the cell can be assessed with linear complexity.

The *polar* \rightarrow *euclidean* coordinate frame transformation is not amenable for *LiDAR* swipe. The *threat* assessment based on *LiDAR swipe* in *planar space portions* has minimal complexity, and it is cost effective. [2].

¹Example rotary LiDAR Velodyne VL-16 specs: https://www.cadden.fr/wp-content/uploads/2017/02/Velodyne_VLP-16-Puck.pdf

Cell: To discretize operational space into a grid of points there is a need to define cell space, which bounds the portion of the *local planar coordinate frame*. The point (eq. 6.1) is defined by distance, horizontal^o offset angle, and vertical^o offset angle. The cell is a closed compact set of such points. The boundary can be defined like follow:

Definition 1. Cell

The cell bounds a portion of space in UAS local polar coordinate frame, defined by boundary ranges:

1. Distance Range - *starts and ends: $distance_{start} < distance_{end}$ in \mathbb{R}^+ .*
2. Horizontal Range - *starts and ends: $horizontal_{start}^o < horizontal_{end}^o \in] - \pi, \pi]$.*
3. Vertical Range - *starts and ends: by $vertical_{start}^o < vertical_{end}^o \in] - \pi, \pi]$.*

The space portion belonging to the cell is given by function as:

$$cell.spacePortion = \dots \left\{ \begin{array}{l} point \in \mathbb{R}^3 \text{ where :} \\ \left(\begin{array}{l} cell.distance_{start} < point.distance \leq cell.distance_{end}, \\ cell.horizontal_{start}^o < point.horizontal^o \leq cell.horizontal_{end}^o, \\ cell.vertical_{start}^o < point.vertical^o \leq cell.vertical_{end}^o \end{array} \right) \end{array} \right\} \quad (6.2)$$

To evaluate a static obstacle threat, it is necessary to know how many LiDAR hits landed in the cell space portion. For one LiDAR Scan the hits set is given a set of all points which lands into cell space portion:

$$cell.LiDARHits = \{point \in LidarScan : point \in cell.spacePortion\} \quad (6.3)$$

Note. The cell space portion volume is increasing with the distance. This satisfies the requirement for threat-distance importance.

Effective Operation Space: The goal is to determine which of the operation space is going to be considered in our avoidance grid. The effective operation space determination according to [3] is influenced by the following factors:

1. *Sensors ranges* - there is no reason to assess the situation over effective *sensor range*.
2. *Information sources impact* - there is no real impact on *effective space boundary*, the information search and intersection algorithms are only of the importance.
3. *UAS maneuverability* - the space where UAS can maneuver, bounded by space-time (reach set boundary).
4. *Computation power* - the situation evaluation and threat assessment capabilities of the onboard computer.
5. *Airworthiness requirements* - the *regulations* can impose some minimal requirements on *effective operation space boundary*.

Let show an example of an *effective operation space* for the UAS (fig. 6.1). The *full LiDAR Swipe* (cyan and red lines) of UAS (blue plane) has a *shape* of the conical cylinder.

Note. Under *ideal circumstances*, the *LiDAR swipe* would have a *ball shape*, but in real cases the *UAS body portion* where *LiDAR* is mounted is unused.

The *frontal portion* (red line) is a set of cells where *UAS* can make maneuvers. According to the *previous conditions*, there is no reason to consider a space portion out of this area.

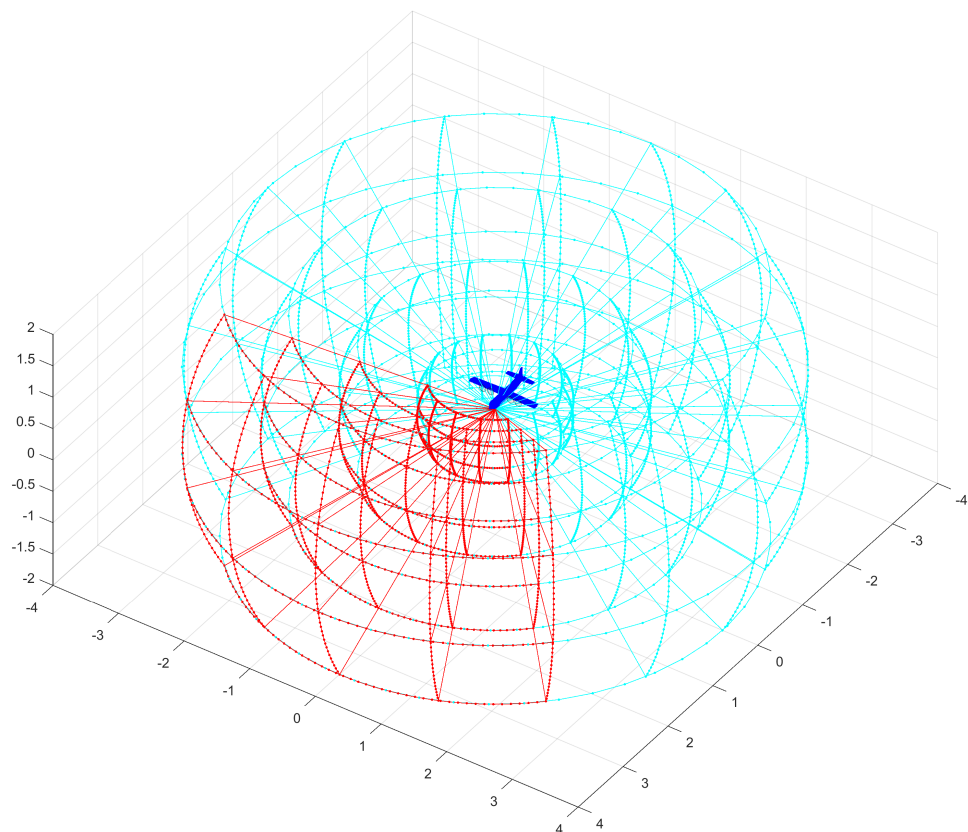


Figure 6.1: Example: The *LiDAR* reading portioning - cells.

Avoidance Grid Definition: The *effective operation space* is going to be portioned into cells.

Note. The avoidance grid is a set of cells from the full LiDAR swipe, that are reachable in limited number of movements by given control (sec. ??).

Definition 2. Avoidance Grid

The effective space portion (fig. 6.1 red lines) given by a portion of space in UAS local polar coordinate frame, bounded by:

1. Distance Range - in range $distance_{start} < distance_{end}$ in \mathbb{R}^+ .
2. Horizontal Range - in range by $horizontal_{start}^\circ < horizontal_{end}^\circ \in]-\pi, \pi]$.
3. Vertical Range - in range $vertical_{start}^\circ < vertical_{end}^\circ \in]-\pi, \pi]$.

The goal is to separate the effective operation space into cells (def. 1). The idea is to split distance range into multiple distinctive distance ranges with count $layerCount \in \mathbb{N}^+$. The ranges for distance layers are given as follow:

$$\begin{aligned} layer_{start}^i &= (i-1) \times \frac{distance_{end} - distance_{start}}{layerCount} \\ layer_{end}^i &= i \times \frac{distance_{end} - distance_{start}}{layerCount} \end{aligned} ; \quad i \in 1 \dots layerCount \quad (6.4)$$

The same separation Layer horizontal/vertical separations defined by $horizontalCount \in \mathbb{N}^+$ / $verticalCount \in \mathbb{N}^+$:

$$\begin{aligned} horizontal_{start}^j &= (j-1) \times \frac{horizontal_{end}^\circ - horizontal_{start}^\circ}{horizontalCount} \\ horizontal_{end}^j &= j \times \frac{horizontal_{end}^\circ - horizontal_{start}^\circ}{horizontalCount} \end{aligned} ; \quad j \in 1 \dots horizontalCount \quad (6.5)$$

$$\begin{aligned} vertical_{start}^k &= (k-1) \times \frac{vertical_{end}^\circ - vertical_{start}^\circ}{verticalCount} \\ vertical_{end}^k &= k \times \frac{vertical_{end}^\circ - vertical_{start}^\circ}{verticalCount} \end{aligned} ; \quad k \in 1 \dots verticalCount \quad (6.6)$$

Then $cell_{i,j,k}$ space portion by (def. 1) has the following ranges:

1. Cell Distance Range (eq. 6.4) depending on layer index i .
2. Cell Horizontal Angle Range (eq. 6.5) depending on horizontal angle index j .
3. Cell Vertical Angle Range (eq. 6.6) depending on vertical index k .

Note. The example of Avoidance Grid Cells is given in (fig. 6.1 red boundary).

The Avoidance Grid is the set of cells:

$$AvoidanceGrid = \left\{ \begin{array}{l} i \in 1 \dots layerCount \\ cell_{i,j,k} : j \in 1 \dots horizontalCount \\ k \in 1 \dots verticalCount \end{array} \right\} \quad (6.7)$$

Note. For any distinctive cells $cell_{i,j,k}$, $cell_{m,n,o}$ their space portion intersection is empty set:

$$\forall cell_{i,j,k}, cell_{m,n,o} : cell_{i,j,k} \cap cell_{m,n,o} = \emptyset, i \neq m \vee j \neq n \vee k \neq o \quad (6.8)$$

Grid Sizing Approach: The sizing approach used in this work is outlined in (app. ??).

Cell in Avoidance Grid Properties: For each cell in the Avoidance Grid there are properties to be checked:

1. *Is there visibility to the cell?* - how good is an observation of the cell by Sensor Field.
2. *Is there threat present?* - how sure the data fusion is that there is eminent threat in the cell.
3. *Is the cell reachable?* - if there is any trajectory which can get UAS to that cell without too much threat along the way.

The answers to these questions are given later in *data fusion procedure* outline (tab. ??).

Bibliography

- [1] Florian Homm, Nico Kaempchen, Jeff Ota, and Darius Burschka. Efficient occupancy grid computation on the gpu with lidar and radar for road boundary detection. In *Intelligent Vehicles Symposium (IV), 2010 IEEE*, pages 1006–1013. IEEE, 2010.
- [2] Sandeep Gupta, Holger Weinacker, and Barbara Koch. Comparative analysis of clustering-based approaches for 3-d single tree detection using airborne fullwave lidar data. *Remote Sensing*, 2(4):968–989, 2010.
- [3] Osmar R Zaiane and Chi-Hoon Lee. Clustering spatial data when facing physical constraints. In *Data Mining, 2002. ICDM 2003. Proceedings. 2002 IEEE International Conference on*, pages 737–740. IEEE, 2002.