Boundary points from 900 - 930

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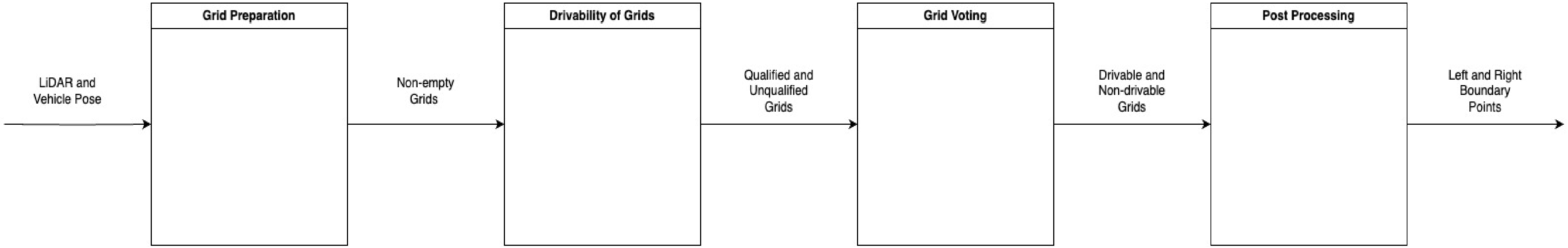
Goal: Convert 3D lidar points into the calculation of the road edge. The BIG PICTURE of the process is shown below



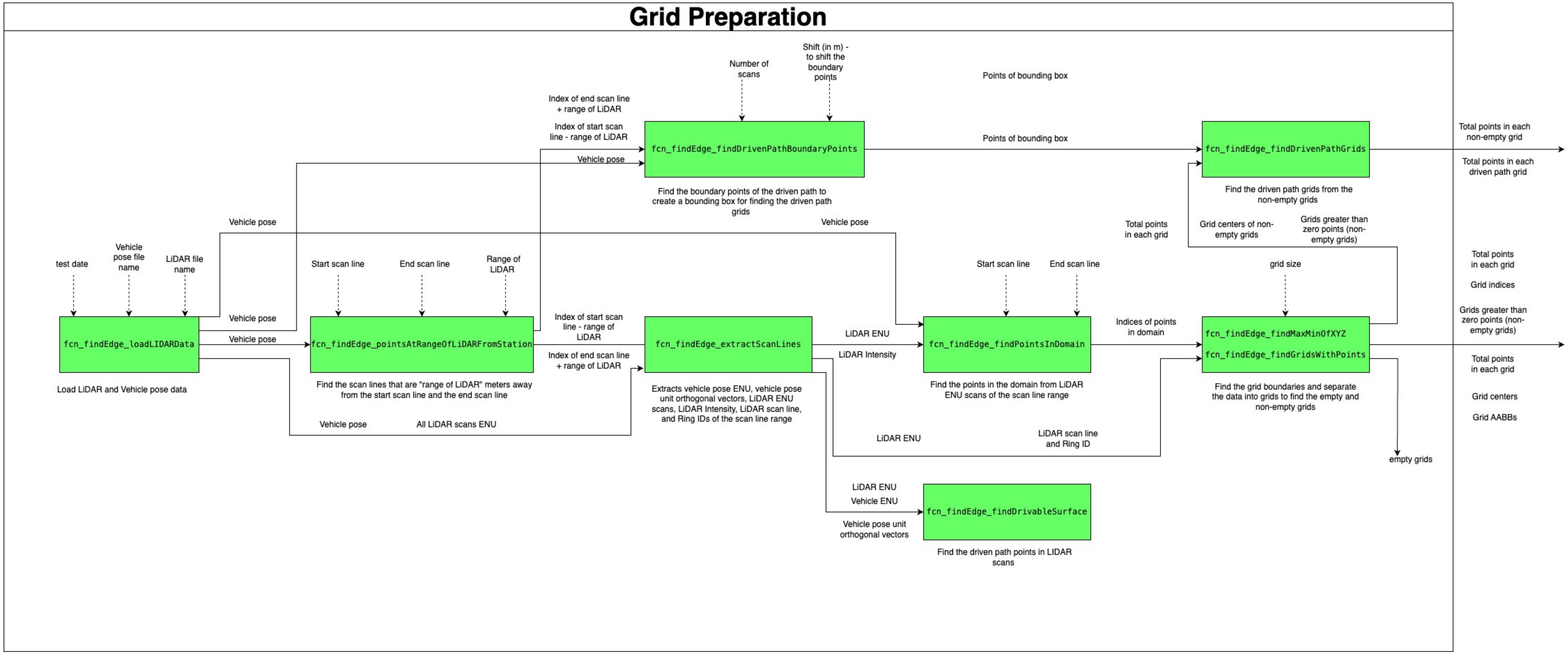
Right Boundary Points = Road Edge

- Road edge: The edge of the pavement and the vegetation next to the road.

Overview

Grid Preparation
Drivability of Grids
Grid Voting
Post Processing

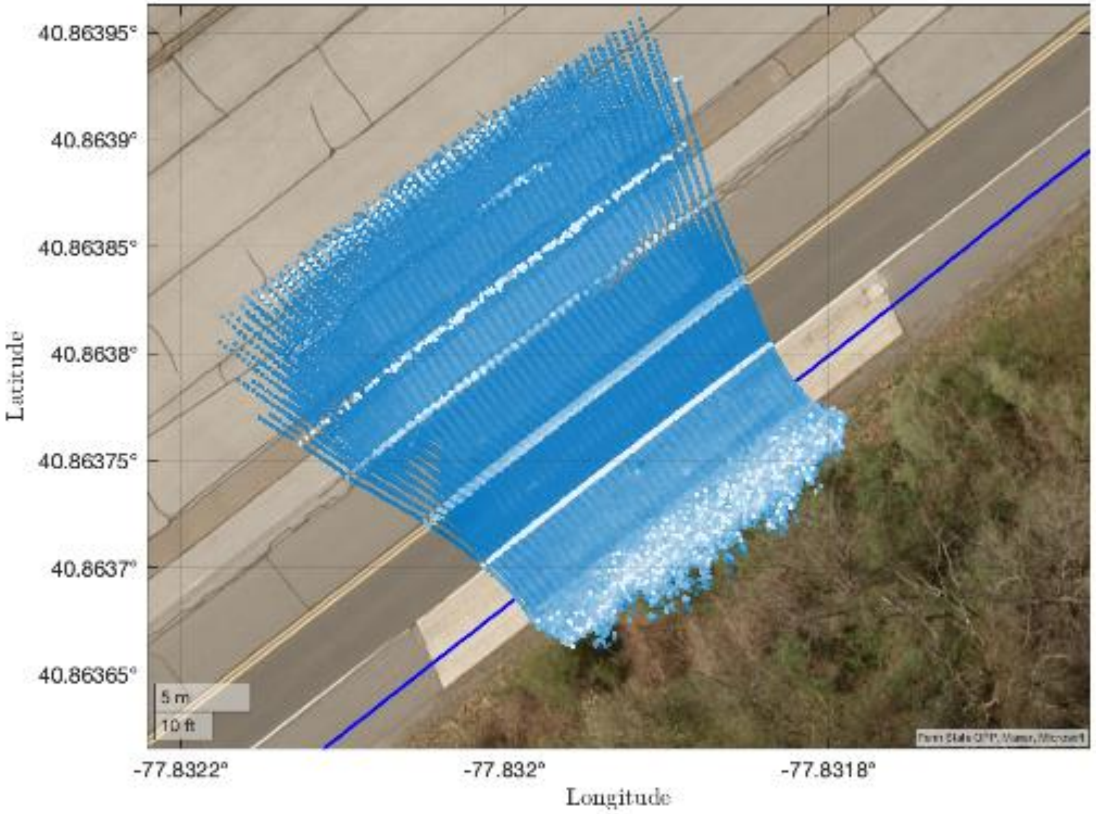
Grid Preparation



Load LiDAR and Vehicle Pose Data

LIDAR_file_stri...	'Velodyne_LiDAR...
LiDAR_Scan_E...	*2463x1 cell*
test_date_string	'2024_06_28'
vehicle_pose_s...	'VehiclePose_ENU...
VehiclePose	*2463x6 double*

LiDAR scan lines [900 - 930] are plotted on a geo plot. The RHS plot is the zoomed-in plot of the LHS



fcn_findEdge_loadLIDARData

The scan lines that are "range of LiDAR" meters away from the start scan line and the end scan line are computed

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The index of the scan line that is 100 meters before the start scan line is 745.
The index of the scan line that is 100 meters after the end scan line is 1111.
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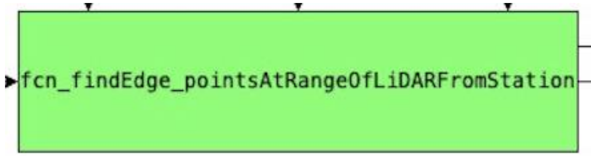
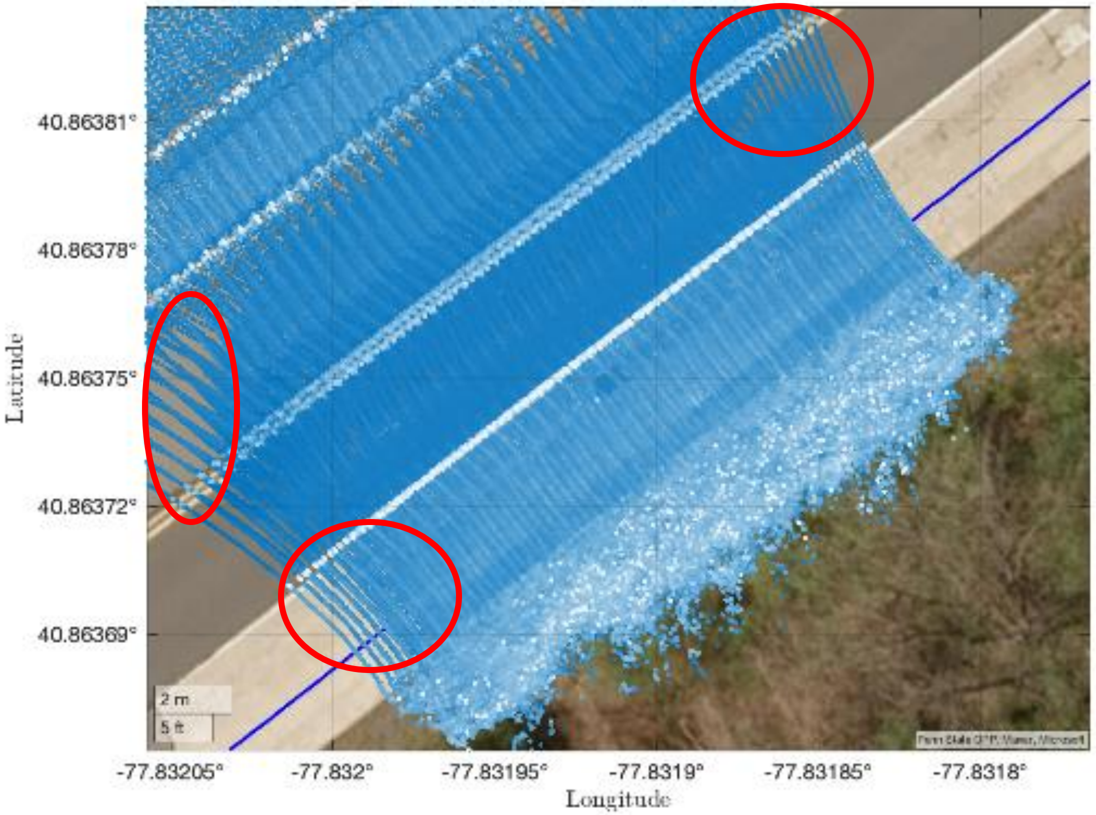
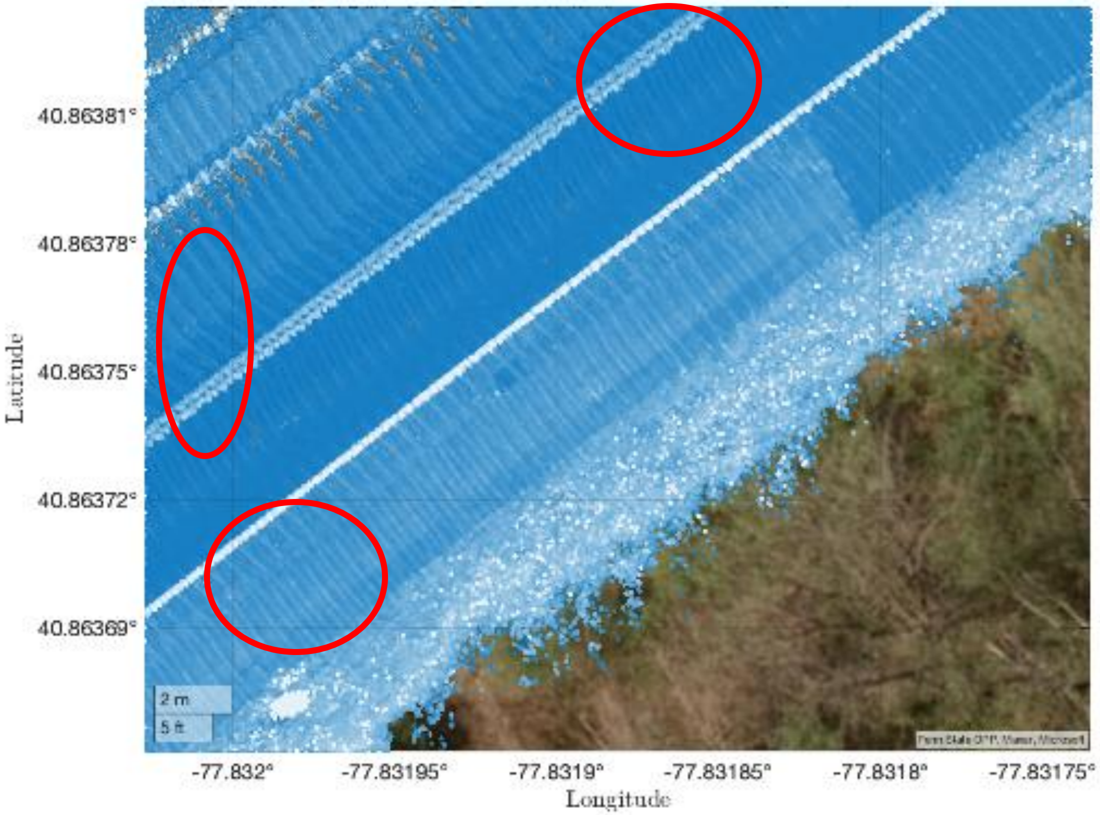
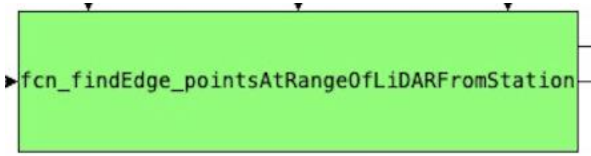


The gaps in the LiDAR scans (900-930) (LHS) indicate that insufficient data was captured. To address this, the indices of the scan lines that are 100 meters (the range of LiDAR) before the start scan line (900) and 100 meters after the end scan line (930) were determined by computing the distances of the scan lines from each station.



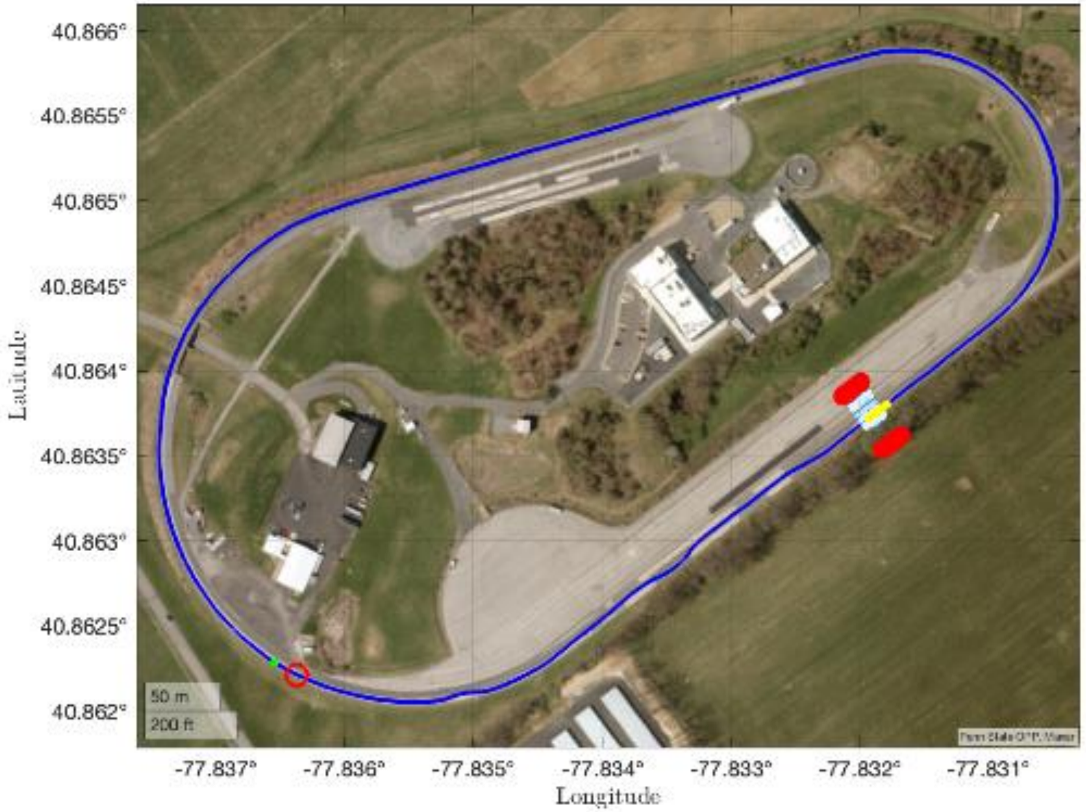


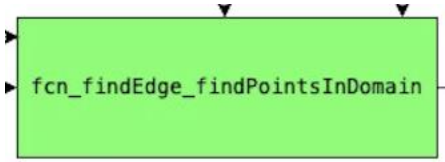


Extract the vehicle pose ENU, vehicle pose unit orthogonal vectors, LiDAR ENU scans, LiDAR Intensity, LiDAR scan line, and Ring IDs of the scan line range ([745 1111])

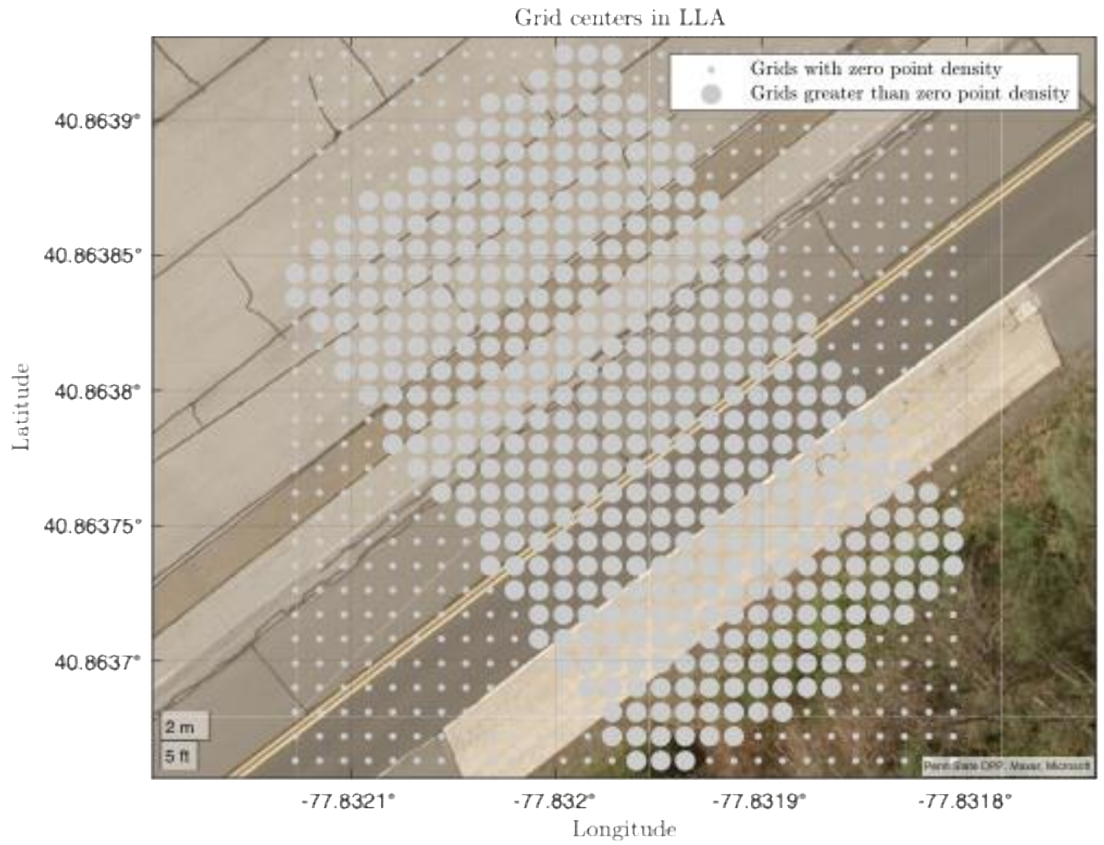
LIDAR_ENU	4413965x3 double
LIDAR_scanLin...	4413965x2 double
LIDAR_intensity	4413965x1 double
VehiclePose_E...	4413965x3 double
VehiclePose_U...	4413965x3 double

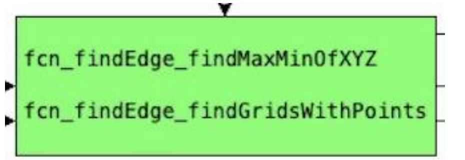
The points in the domain are selected by extending the orthogonal vector of the change in the XY position of the vehicle by 22 m (six times lane width). All the points within these boundaries (red points) are considered to be in the domain.



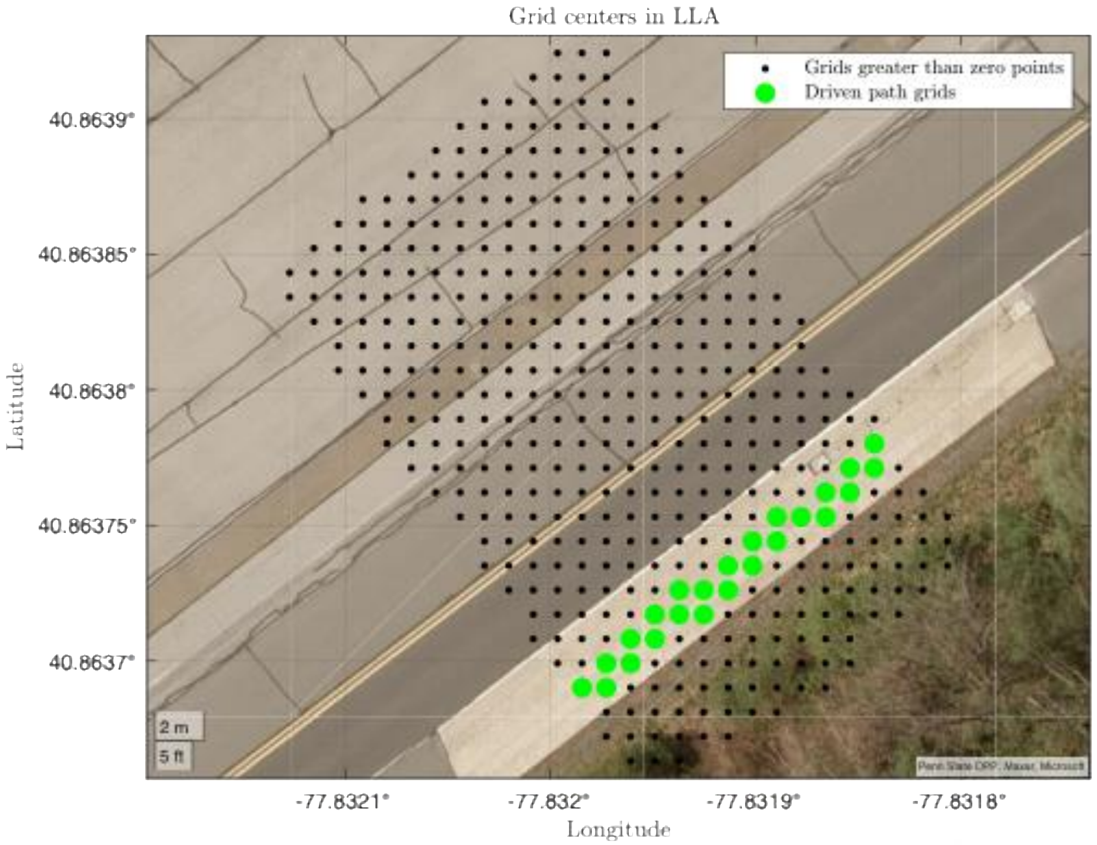


LiDAR data is segmented into grids to classify them into those with zero points and those with more than zero points (non-empty grids). The grids with zero points (empty grids) are then dropped from the further analysis.





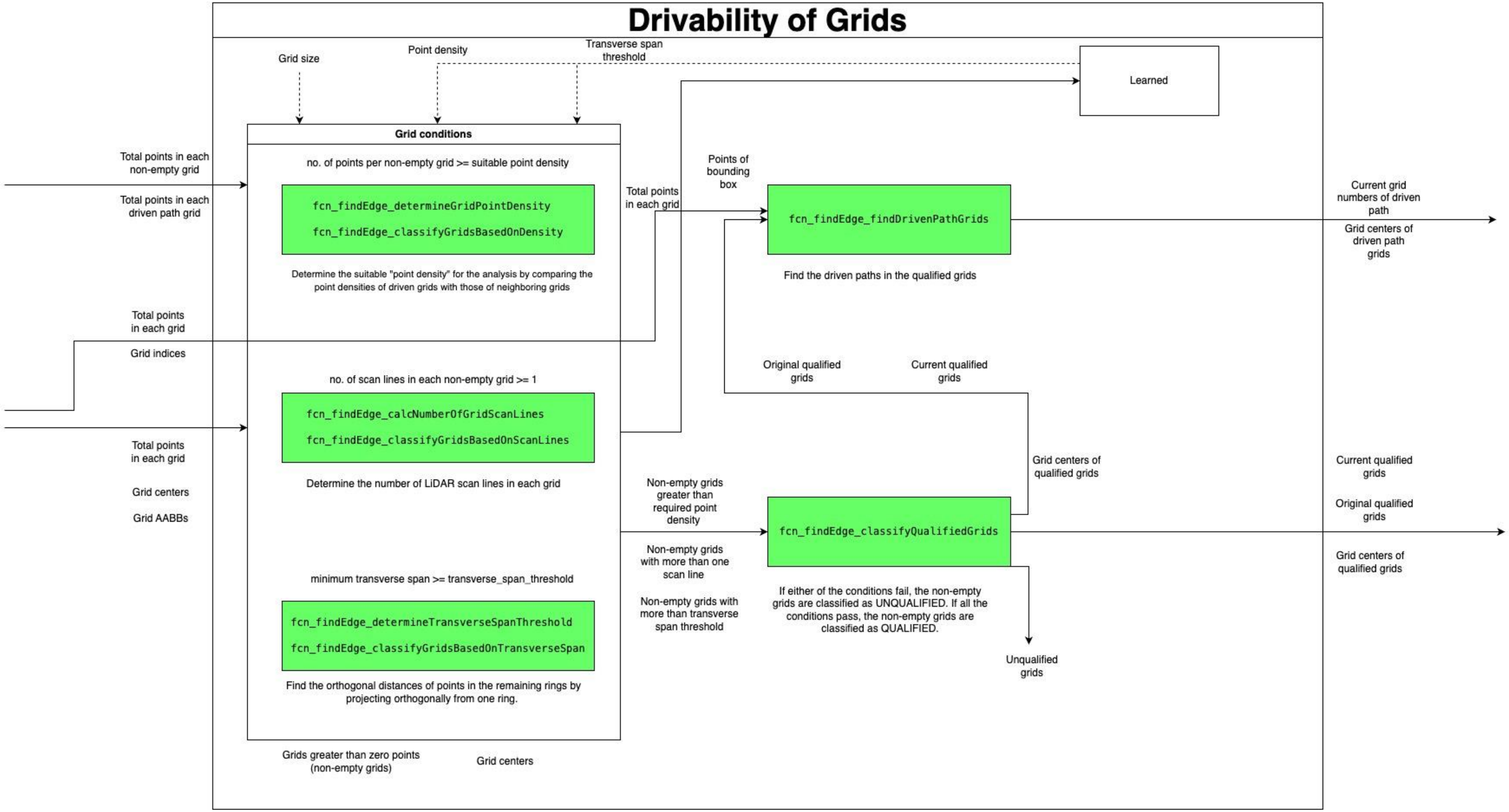
The boundary points (LHS) of the driven path are computed to create a bounding box for finding the driven path grids. The RHS plot has the driven path grids



fcn_findEdge_findDrivenPathBoundaryPoints

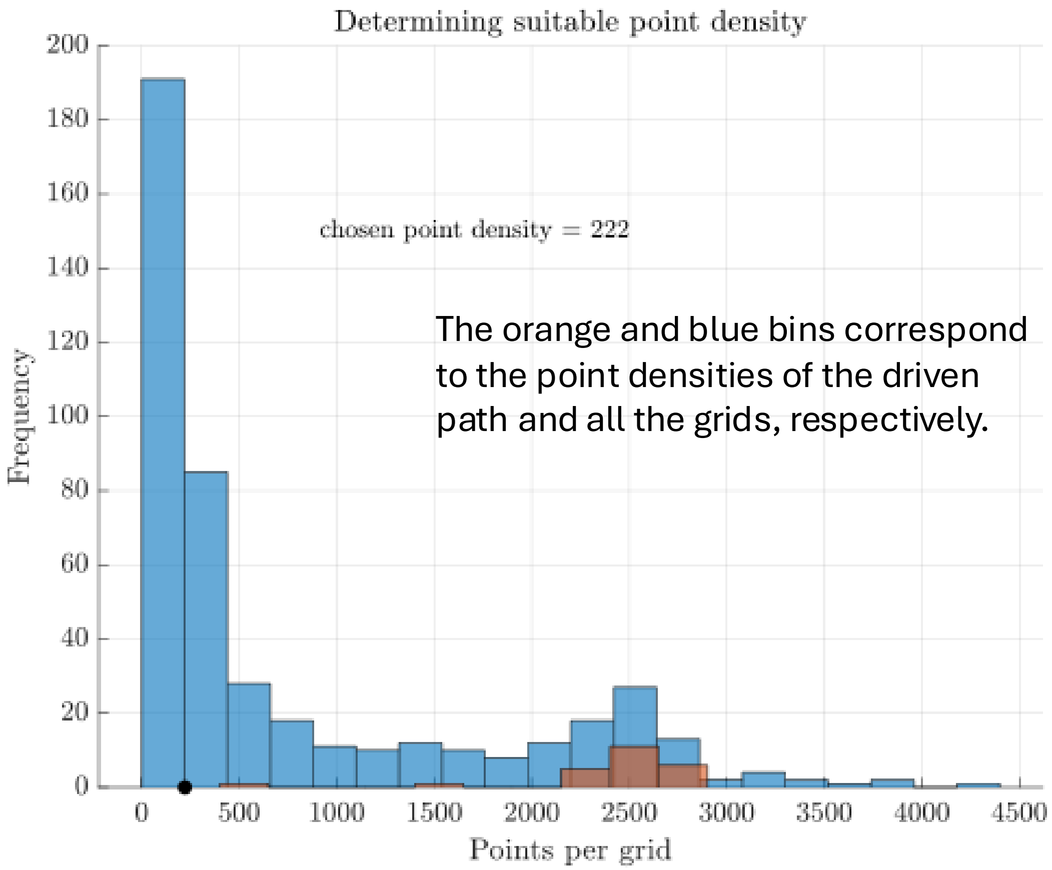
fcn_findEdge_findDrivenPathGrids

Drivability of Grids

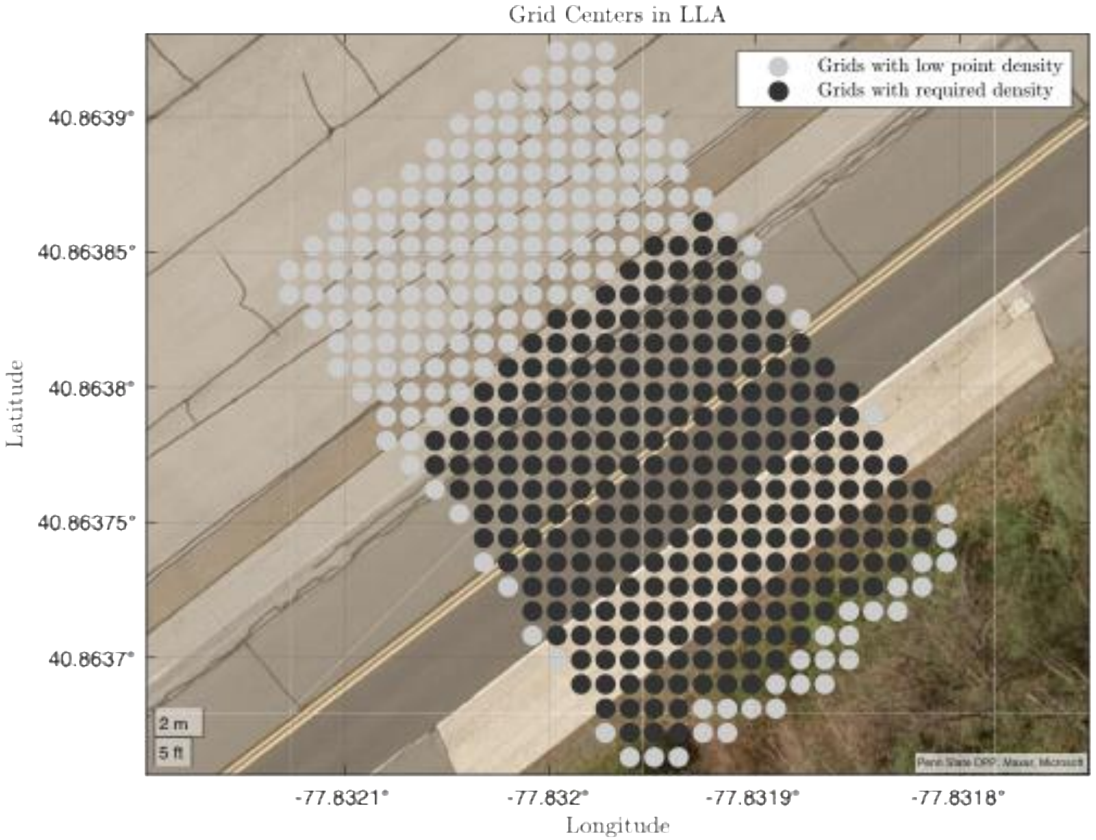


Grid Condition: Determine the point density (points per grid) by comparing the driven path densities with those of neighboring grids. This comparison has been done for multiple datasets with different grid sizes. In the current analysis, the grid size is chosen as 1 m. The RHS plot depicts the grids with the required point density and those with insufficient point density.

```
fcn_findEdge_determineGridPointDensity
fcn_findEdge_classifyGridsBasedOnDensity
```



The orange and blue bins correspond to the point densities of the driven path and all the grids, respectively.



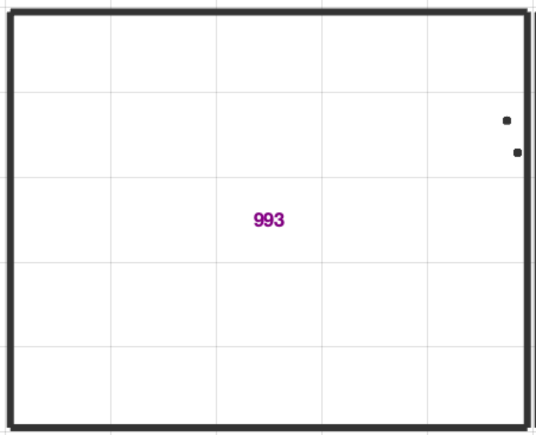
For plane fitting in the next steps, it was determined that each grid should contain at least 20 points when the grid size is 0.3 m (0.3 × 0.3). Therefore, this criterion has been extrapolated for other grid sizes as well.

The point density is calculated as:

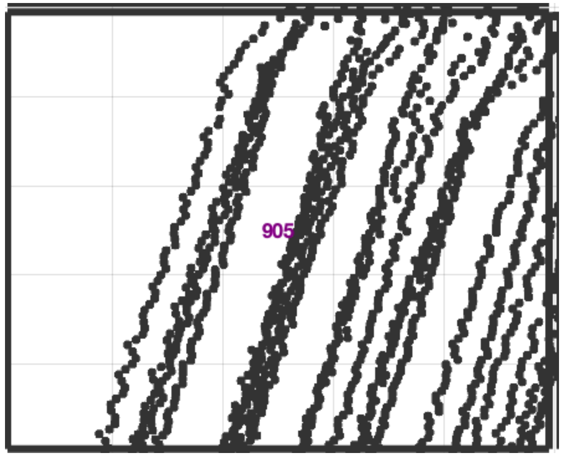
$$point\ density = floor(20 * \frac{grid\ size^{2}}{0.3^{2}})$$

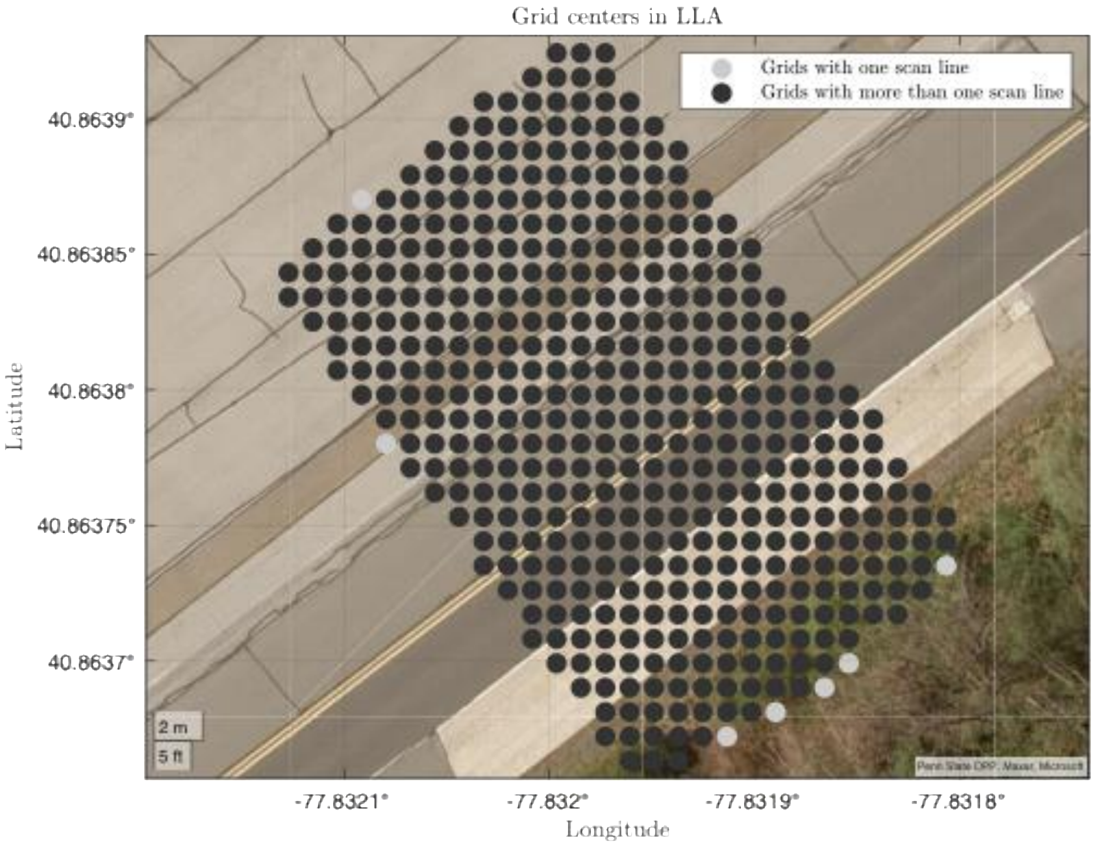
Grid Condition: Determine the number of scan lines in non-empty grids. Grids containing only one scan line cannot be used to fit a plane, as the angle deviation in these grids is high and they are automatically classified as uncertain grids (neither drivable nor non-drivable). To reduce the number of uncertain grids, these grids are identified and dropped from further analysis. Fitting a plane and angle deviation are discussed in the following slides.

Grids with one scan line



Grids with more than one scan line

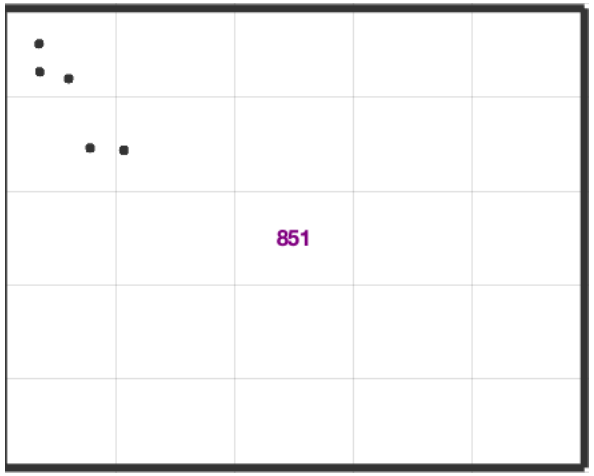




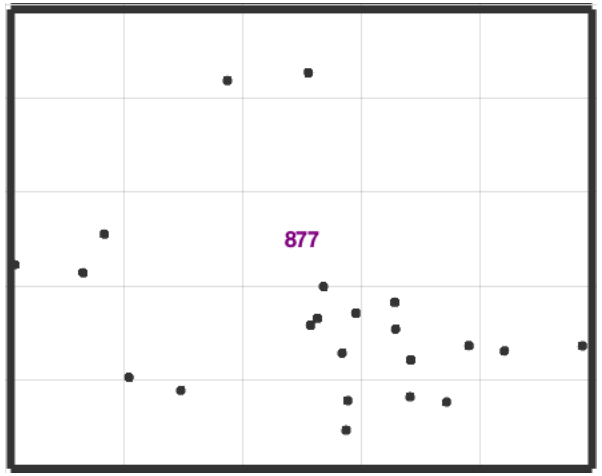

```
fcn_findEdge_calcNumberOfGridScanLines
fcn_findEdge_classifyGridsBasedOnScanLines
```

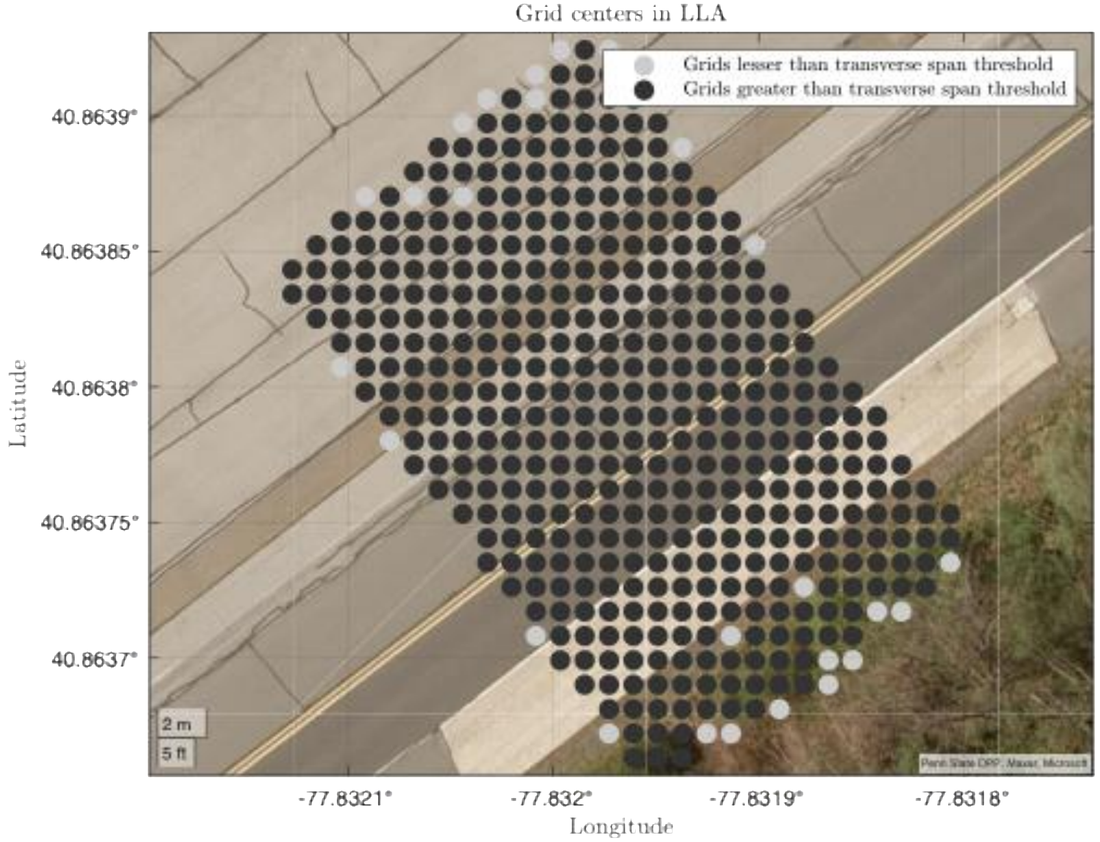
Grid Condition: Sometimes, grids containing more than one scan line may still be classified as uncertain (as discussed in later slides) due to the overlapping of scan lines within the grid. It has been found that the maximum span distance of each grid should be at least 0.15 meters, based on an analysis of various locations and grid sizes.

Maximum span distance of this grid < 0.15m



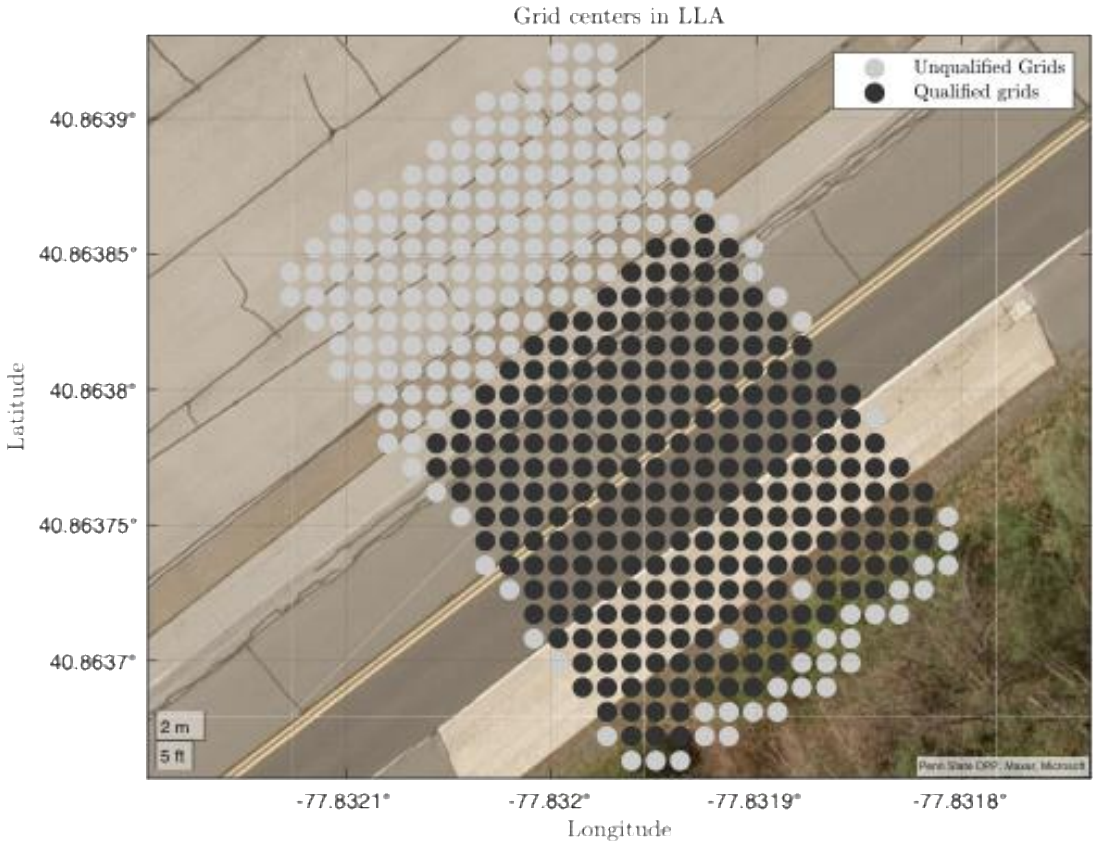
Maximum span distance of this grid > 0.15m

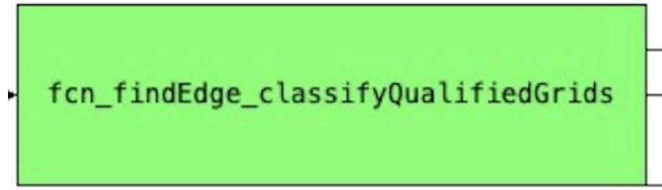




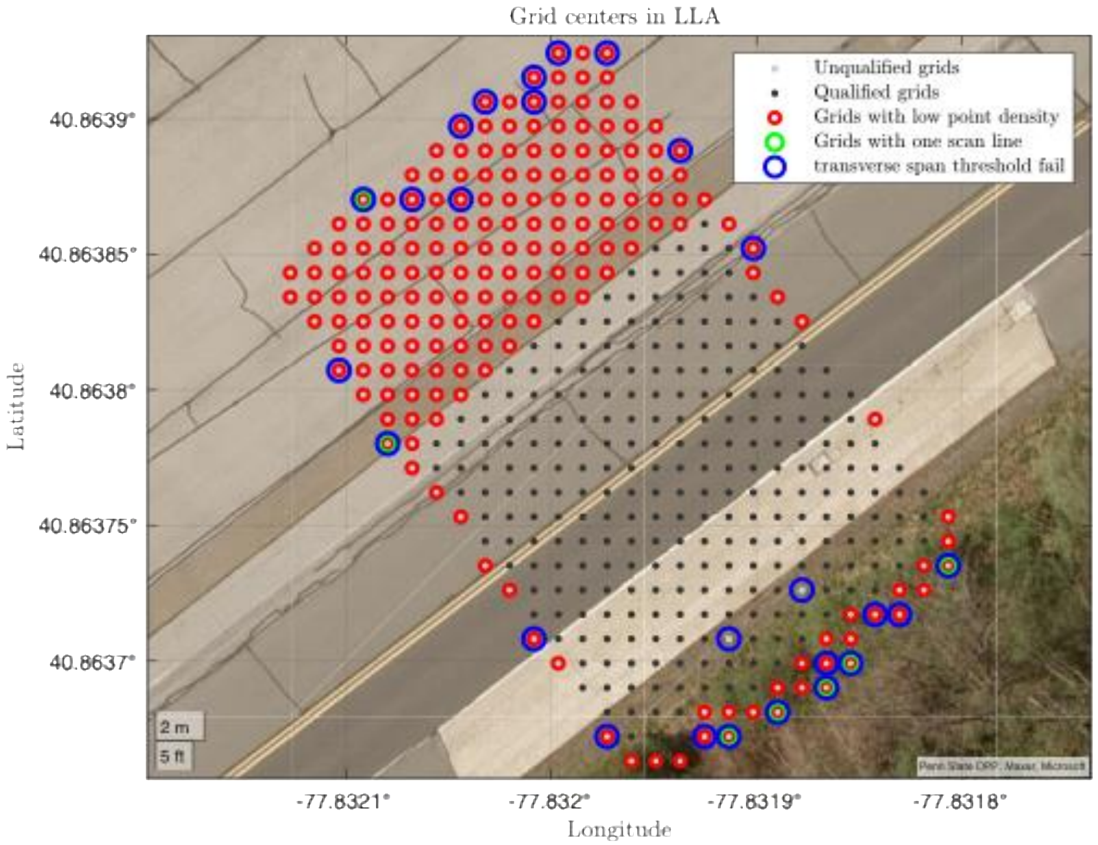

```
fcn_findEdge_determineTransverseSpanThreshold
fcn_findEdge_classifyGridsBasedOnTransverseSpan
```

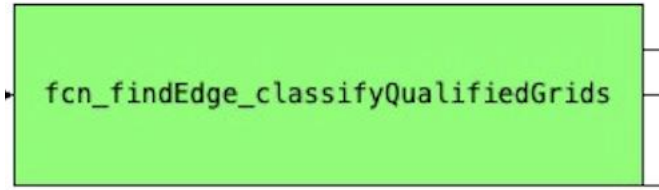
Grids that contain sufficient point density, have more than one scan line, and meet the maximum span distance are classified as qualified grids. The remaining grids are classified as unqualified and are dropped from further analysis.



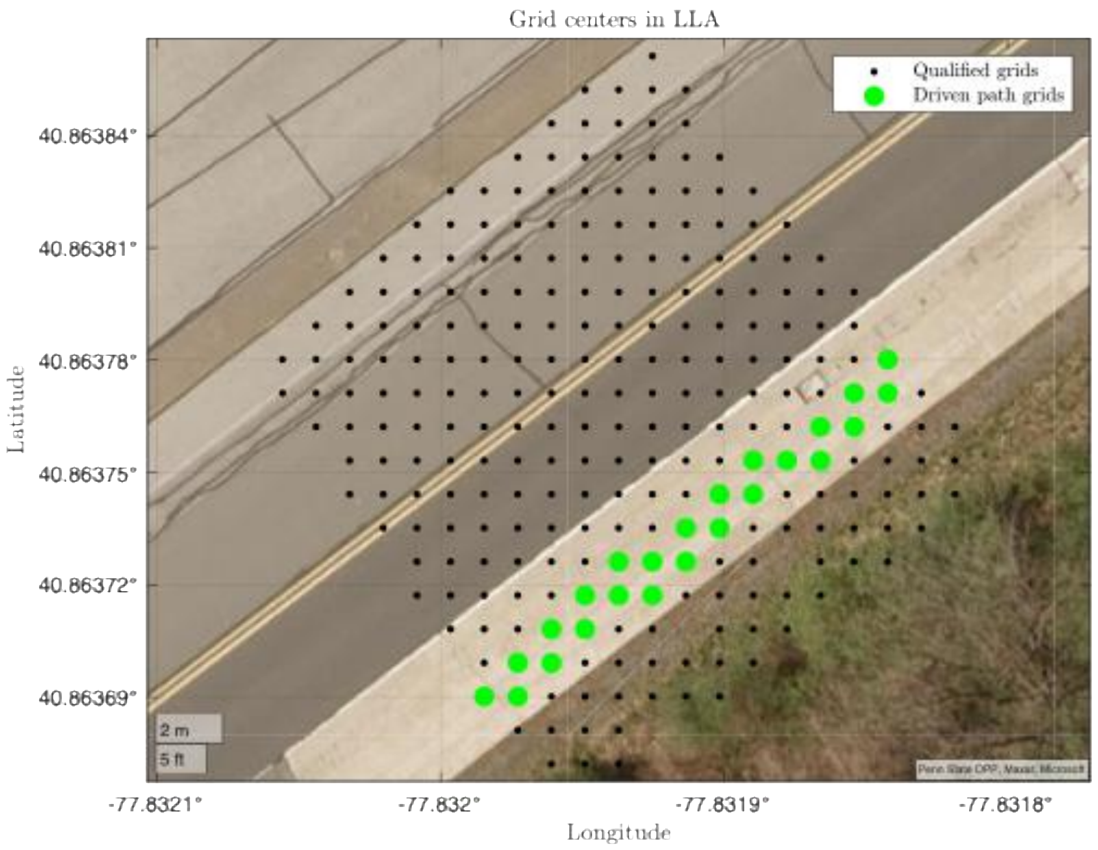


The failed conditions of unqualified grids are highlighted with different color circles.

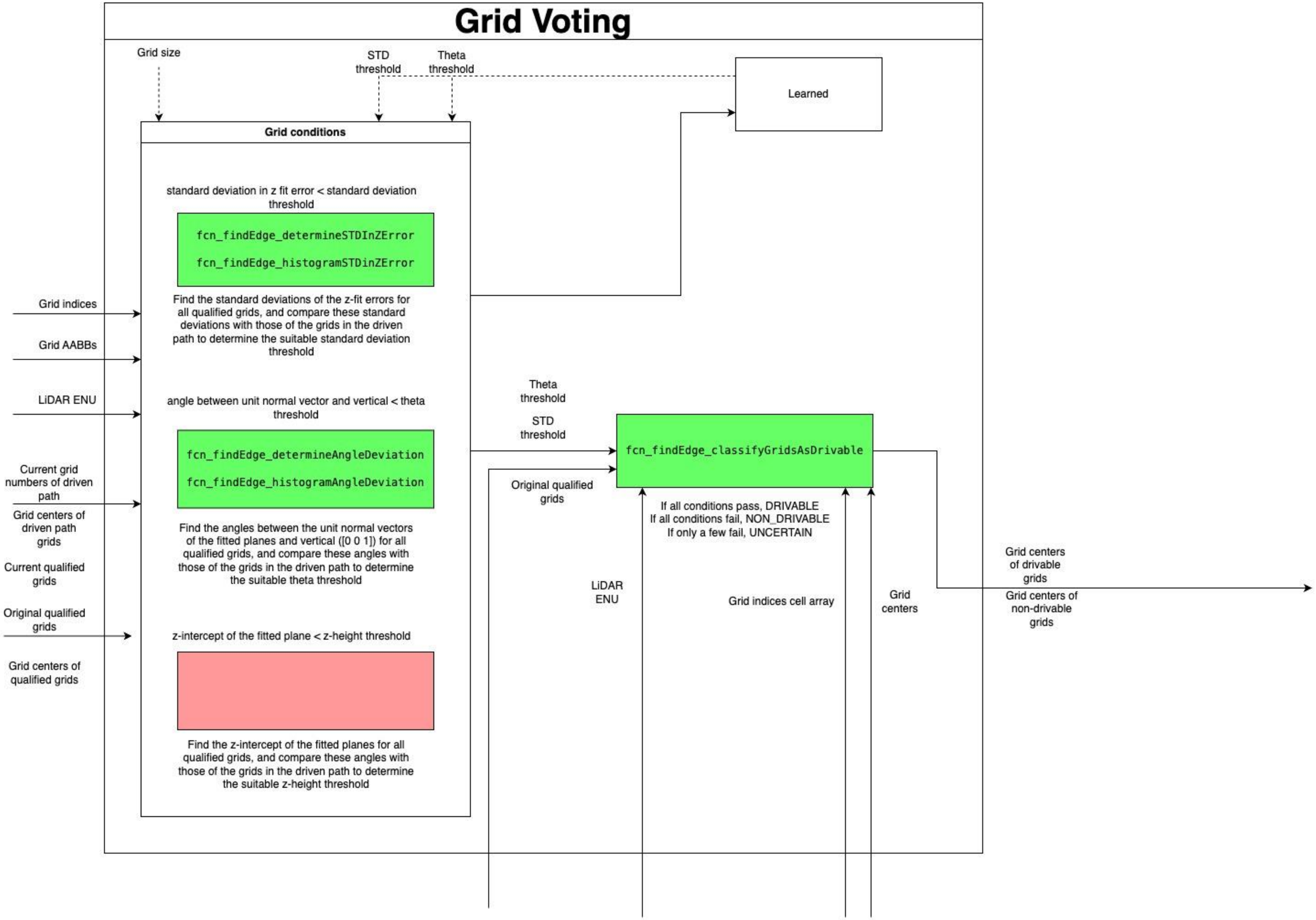




Recalculate the driven path grids from the qualified grids for further analysis.

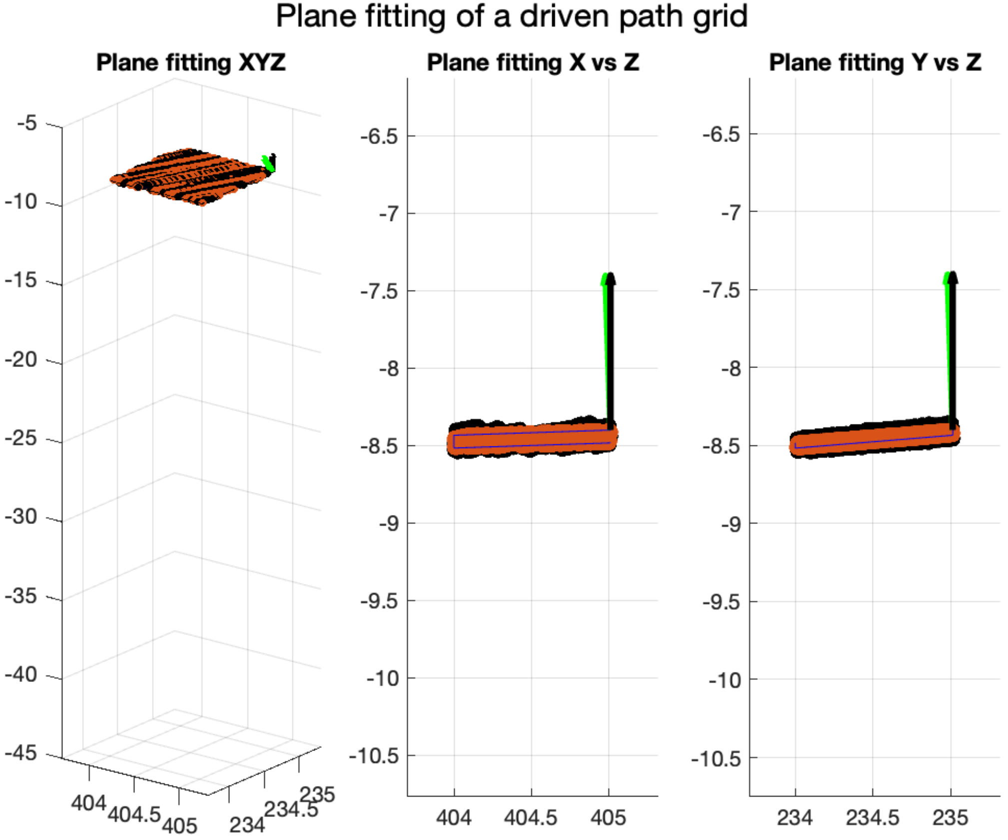


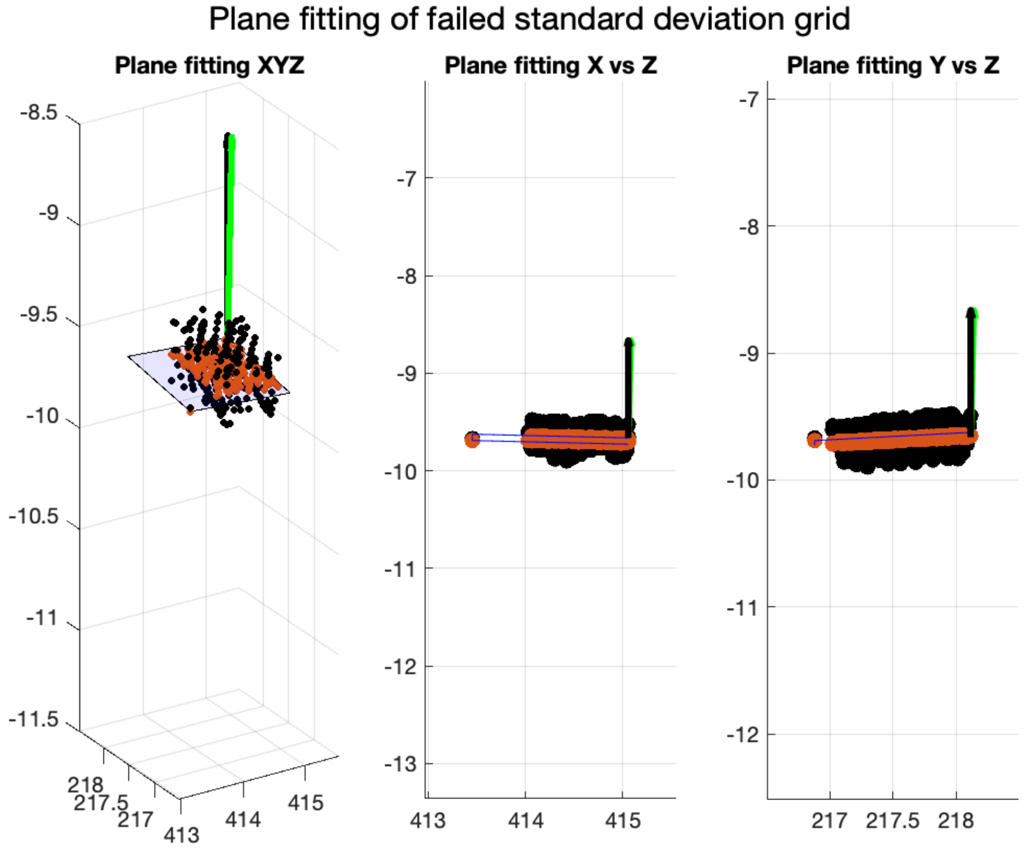
Grid Voting



Grid Voting
Grid size
STD threshold
Theta threshold
Learned
Grid conditions
standard deviation in z fit error < standard deviation threshold
fcn_findEdge_determineSTDInZError
fcn_findEdge_histogramSTDinZError
Find the standard deviations of the z-fit errors for all qualified grids, and compare these standard deviations with those of the grids in the driven path to determine the suitable standard deviation threshold
angle between unit normal vector and vertical < theta threshold
fcn_findEdge_determineAngleDeviation
fcn_findEdge_histogramAngleDeviation
Find the angles between the unit normal vectors of the fitted planes and vertical ([0 0 1]) for all qualified grids, and compare these angles with those of the grids in the driven path to determine the suitable theta threshold
z-intercept of the fitted plane < z-height threshold
Find the z-intercept of the fitted planes for all qualified grids, and compare these angles with those of the grids in the driven path to determine the suitable z-height threshold
Grid indices
Grid AABBs
LiDAR ENU
Current grid numbers of driven path
Grid centers of driven path grids
Current qualified grids
Original qualified grids
Grid centers of qualified grids
Theta threshold
STD threshold
fcn_findEdge_classifyGridsAsDrivable
Original qualified grids
If all conditions pass, DRIVABLE
If all conditions fail, NON_DRIVABLE
If only a few fail, UNCERTAIN
LiDAR ENU
Grid indices cell array
Grid centers
Grid centers of drivable grids
Grid centers of non-drivable grids

Plane fitting of a driven path grid (standard deviation in z-error = 0.02 m and angle deviation = 5.03 degrees) and a grid with a standard deviation of 0.12 m, with an angle deviation (the angle between the green and unit vector of [0 0 1])) of 3.2 degrees.

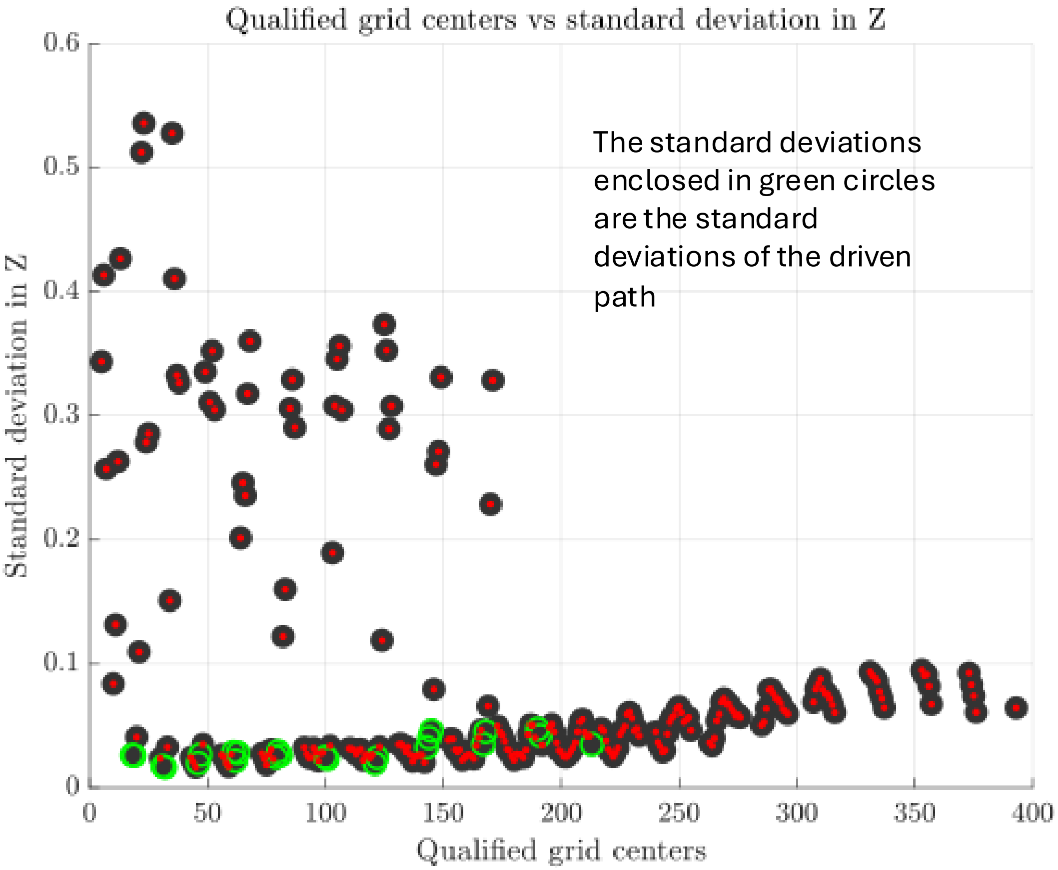


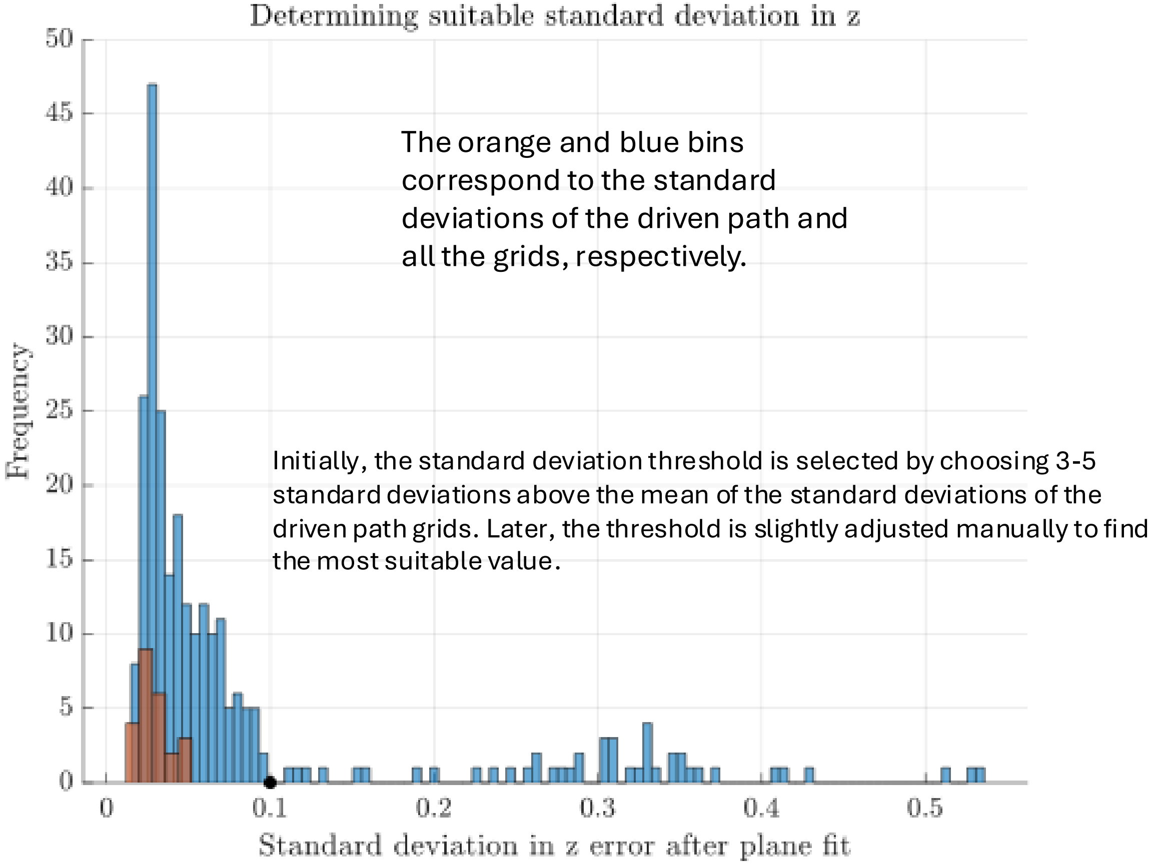



```
fcn_findEdge_determineSTDInZError

fcn_findEdge_histogramSTDinZError
```

Grid Condition: Find the standard deviations of the z-errors for all qualified grids by fitting a plane and compare these standard deviations with those of the grids in the driven path to determine a suitable standard deviation threshold. This comparison has been done for multiple datasets with the same grid size.

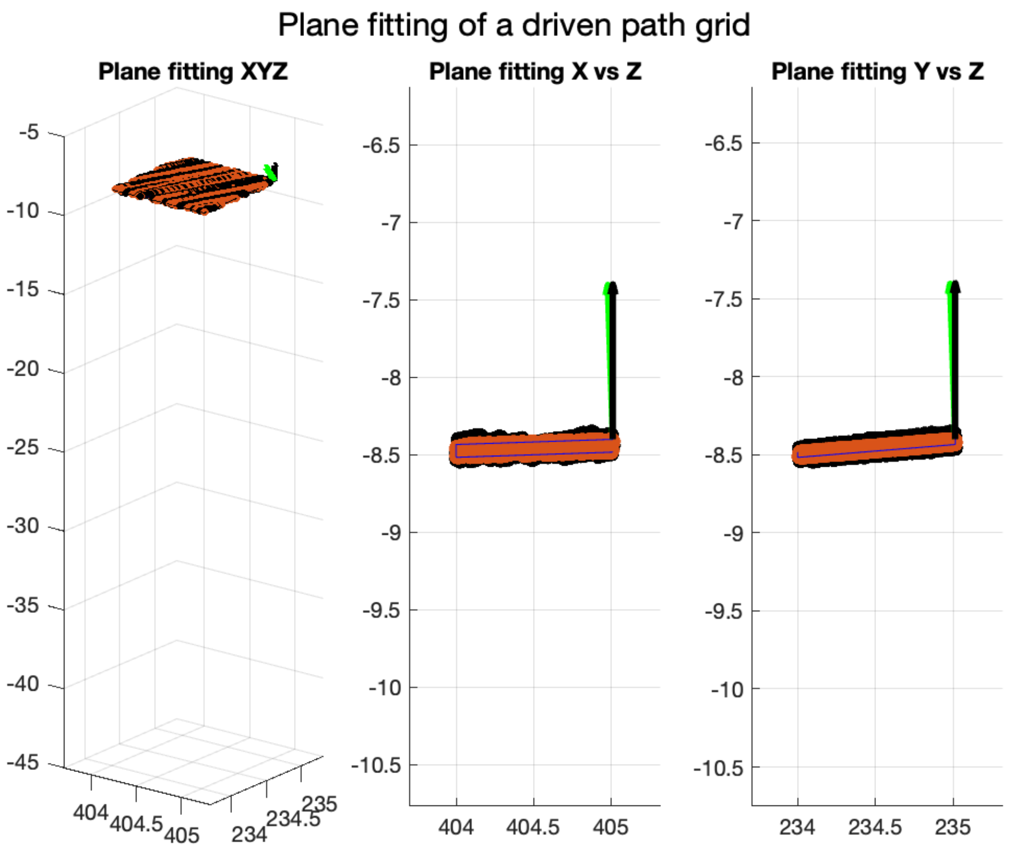


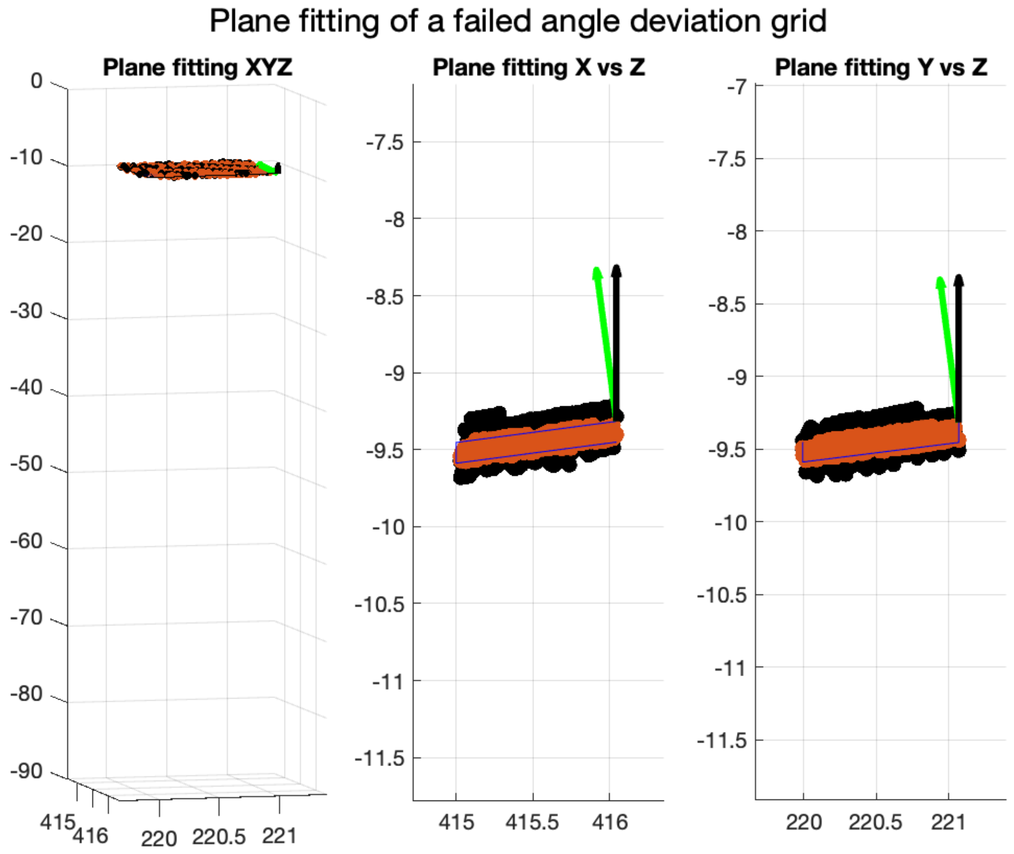



```
fcn_findEdge_determineSTDInZError

fcn_findEdge_histogramSTDinZError
```

Plane fitting of a driven path grid (standard deviation in z-error = 0.02 m and angle deviation = 5.03 degrees) and a grid with a standard deviation of 0.07 m, with an angle deviation of 10.29 degrees (the angle between the green vector and the unit vector [0 0 1]).

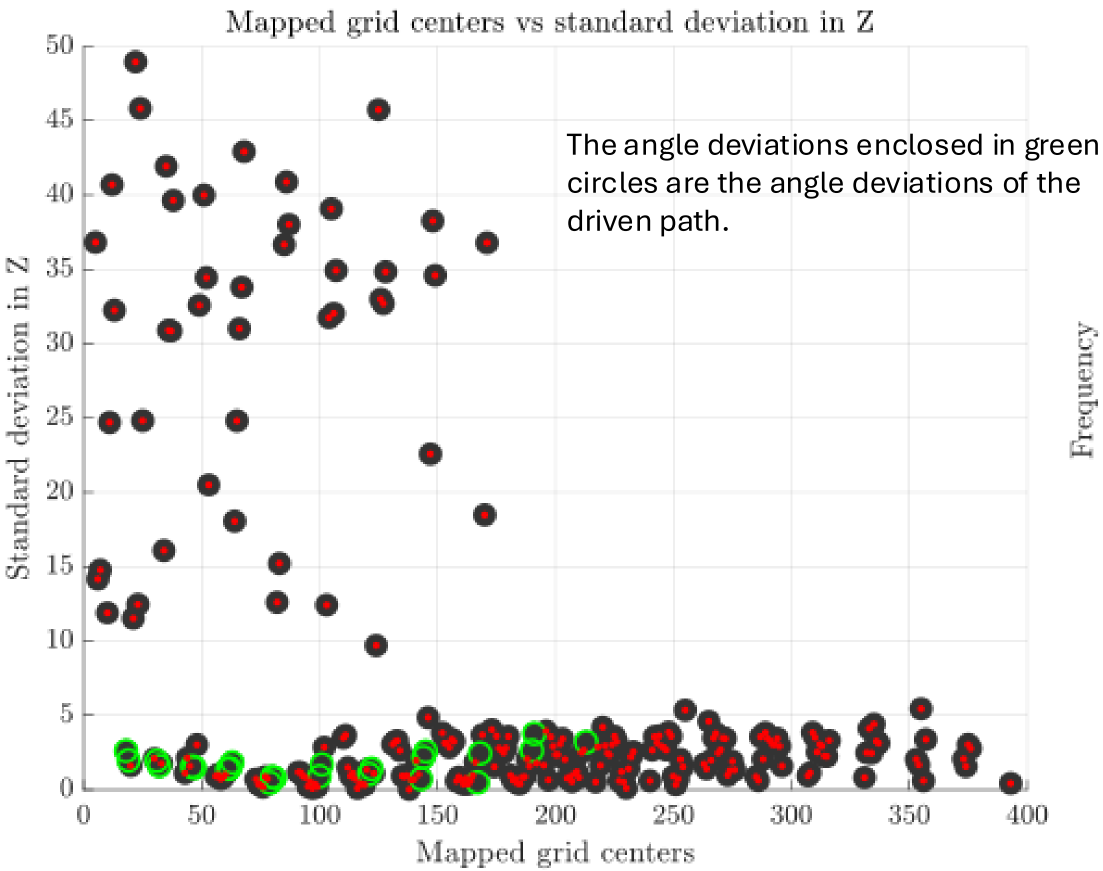


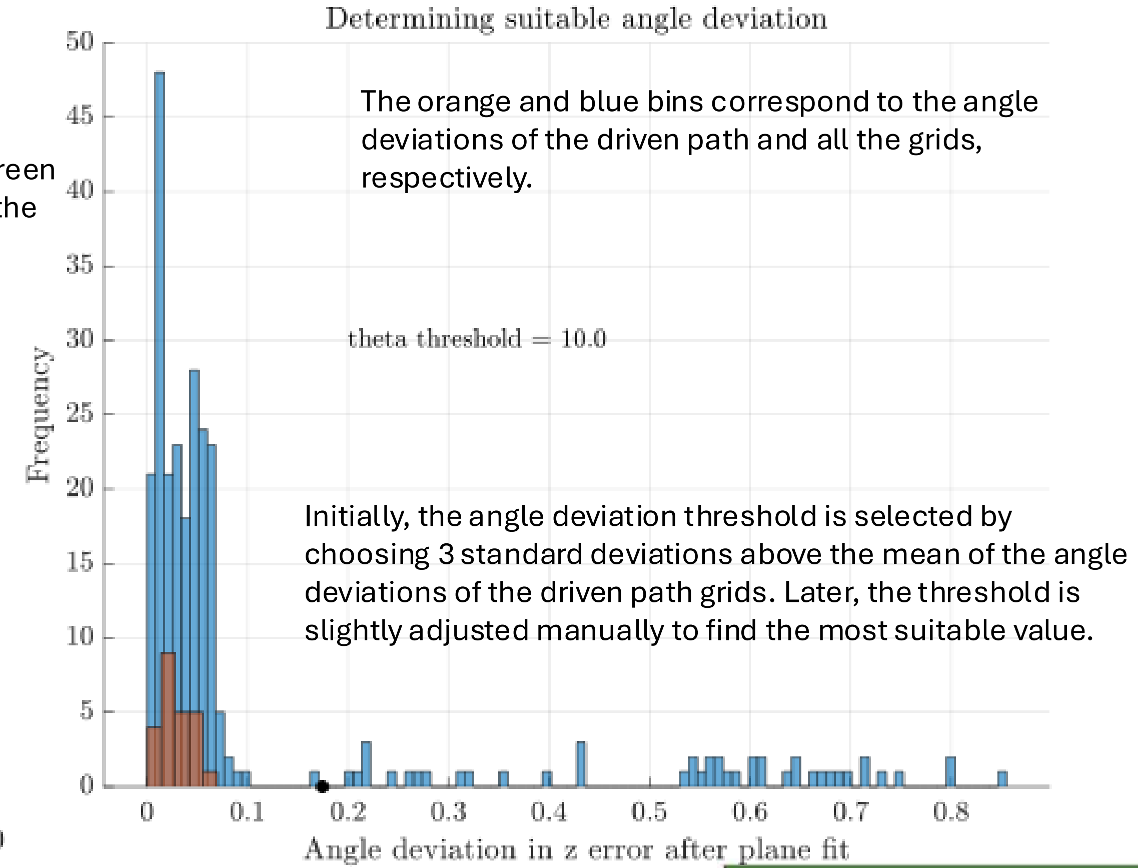



```
fcn_findEdge_determineAngleDeviation

fcn_findEdge_histogramAngleDeviation
```

Grid Condition: Find the angles between the unit normal vectors of the fitted planes and the vertical vector ([0 0 1]) for qualified grids and compare these angles with those of the grids in the driven path to determine a suitable theta threshold. This comparison has been conducted for multiple datasets with the same grid size.

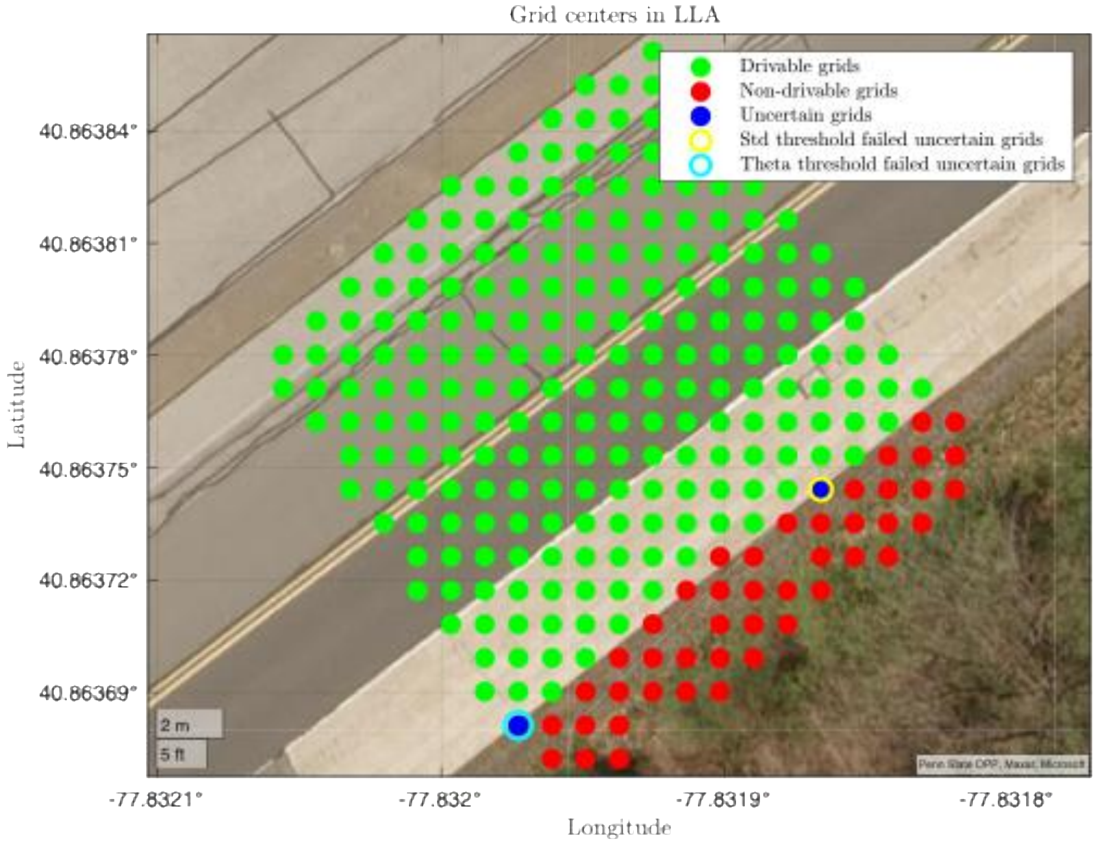




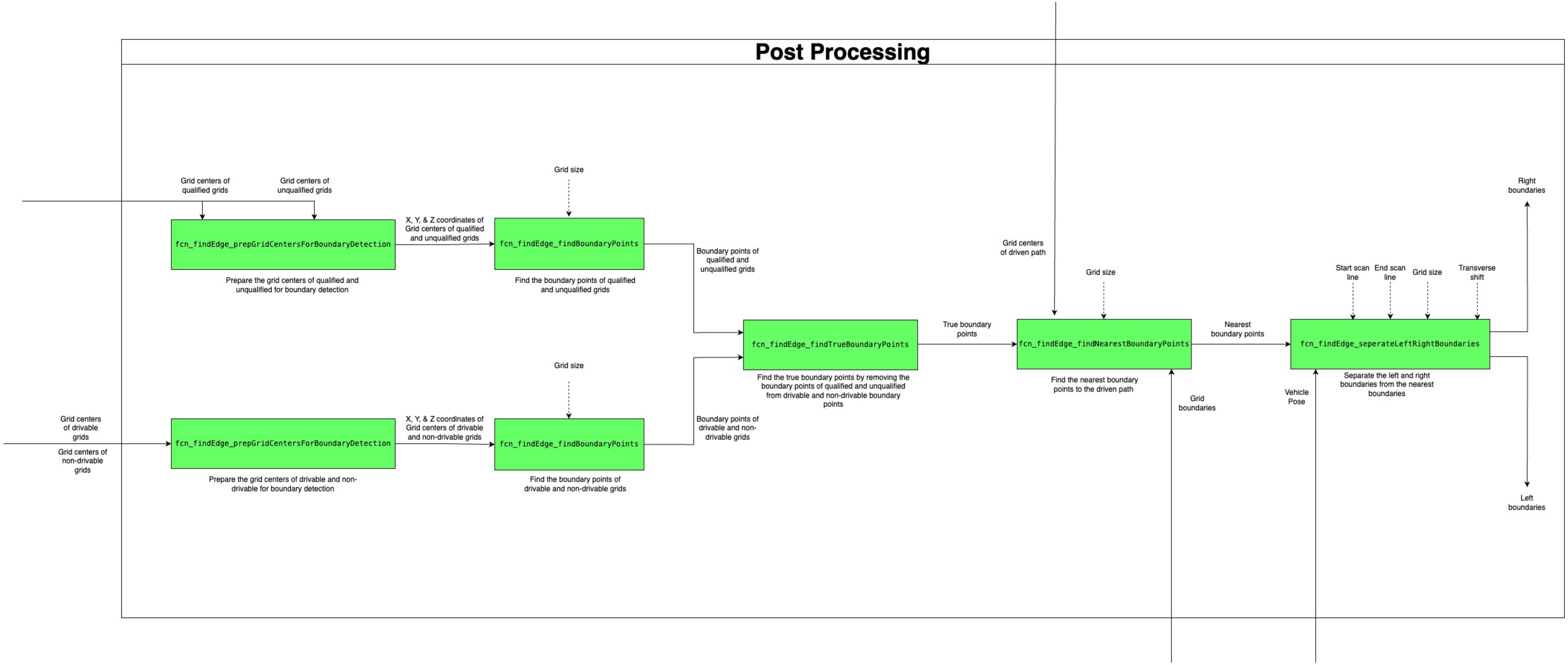

```
fcn_findEdge_determineAngleDeviation

fcn_findEdge_histogramAngleDeviation
```

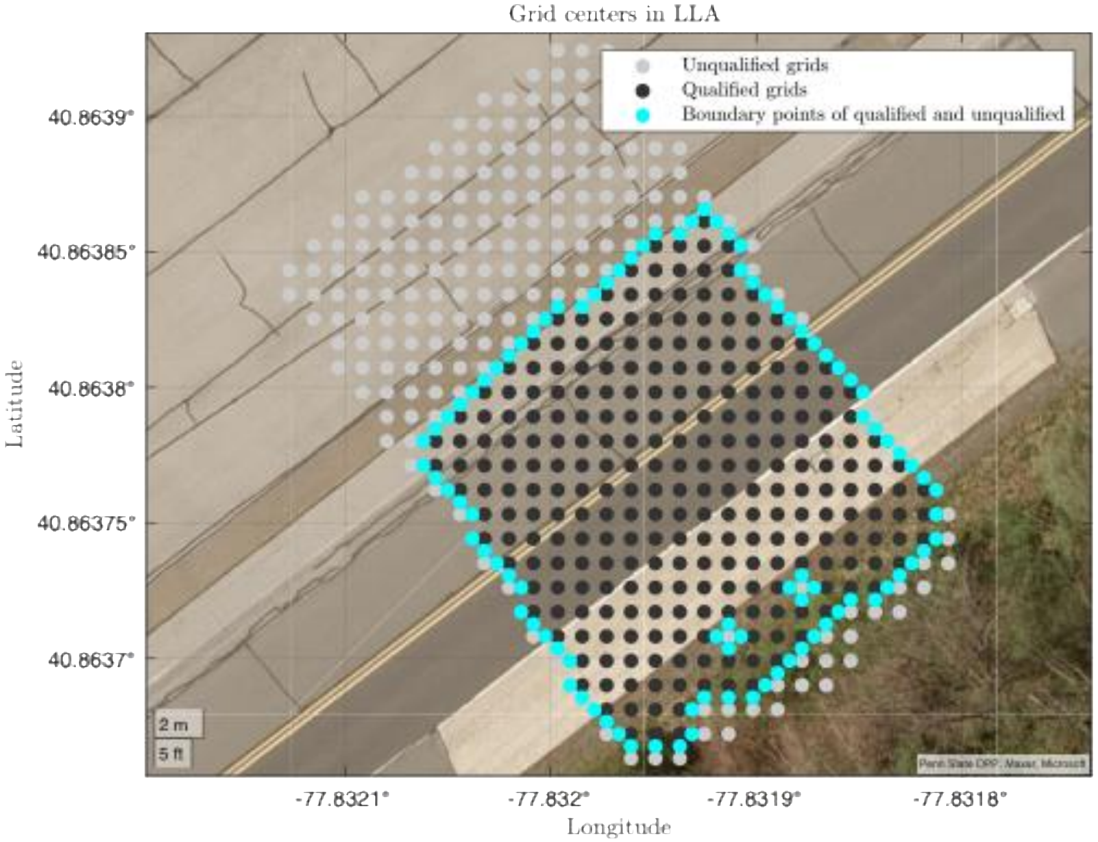
Voting: The qualified grids are classified as drivable, non-drivable, and uncertain grids.



Post Processing



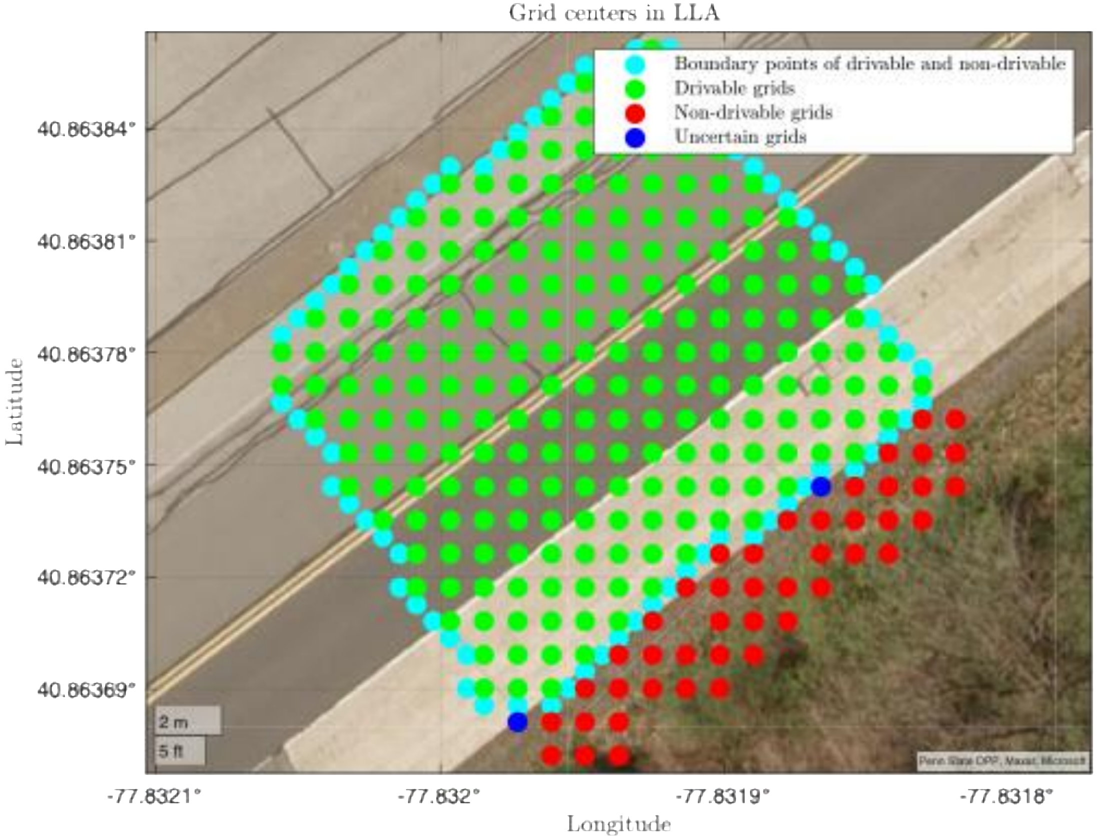
The boundary points of qualified and unqualified grids



fcn_findEdge_prepGridCentersForBoundaryDetection

fcn_findEdge_findBoundaryPoints

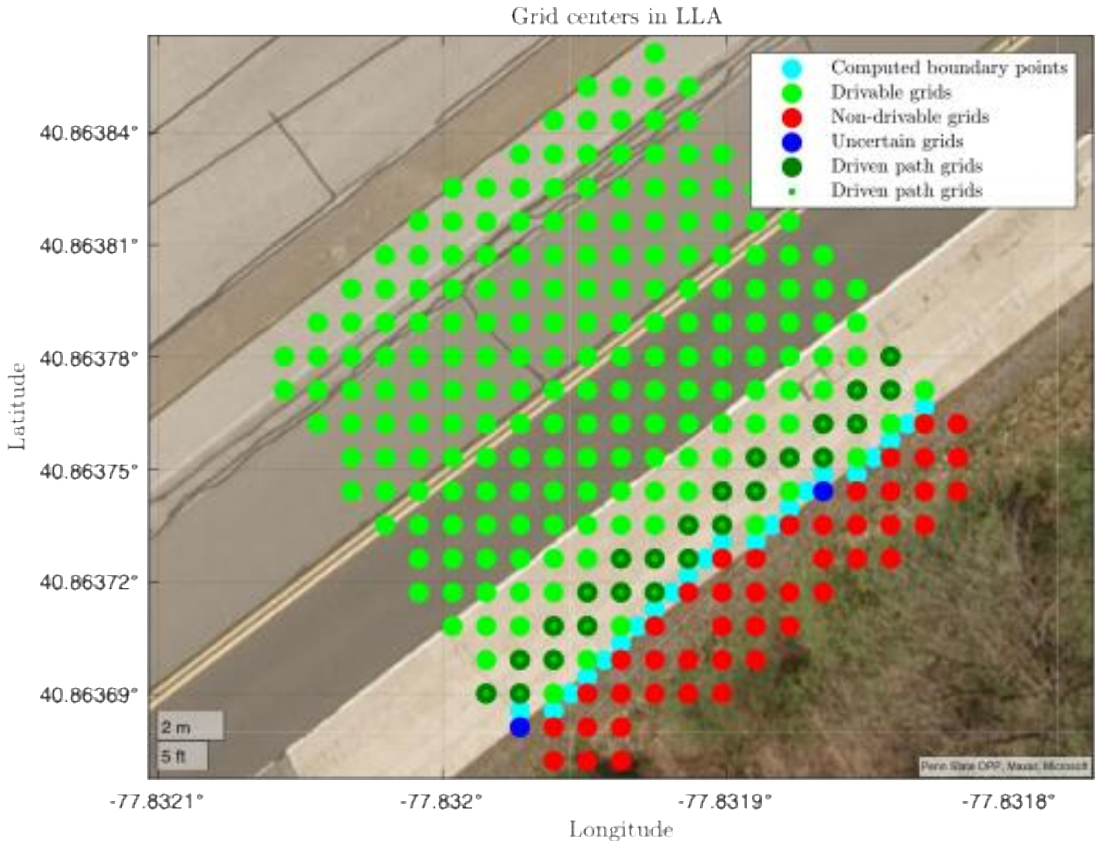
The boundary points of drivable and non-drivable grids

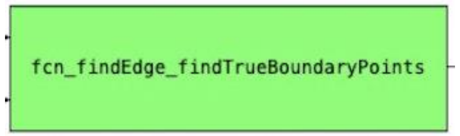


fcn_findEdge_prepGridCentersForBoundaryDetection

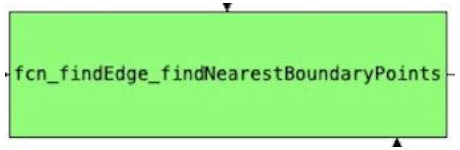
fcn_findEdge_findBoundaryPoints

The boundary points of qualified and unqualified are removed from the boundary points of drivable and non-drivable to find the true boundary points





The nearest boundary points are computed from the true boundary points



The nearest boundary points are separated into left and right boundary points. The right boundary points separate the pavement from the vegetation

- No left boundary points