

Noise Abatement Trajectories for a UAV Delivery Fleet



9th SESAR Innovation Days

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- I. Introduction
- II. Problem Description
- III. Mathematical Model
- IV. Resolution Approach
- V. Results
- VI. Conclusion and Future Work



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I. Introduction

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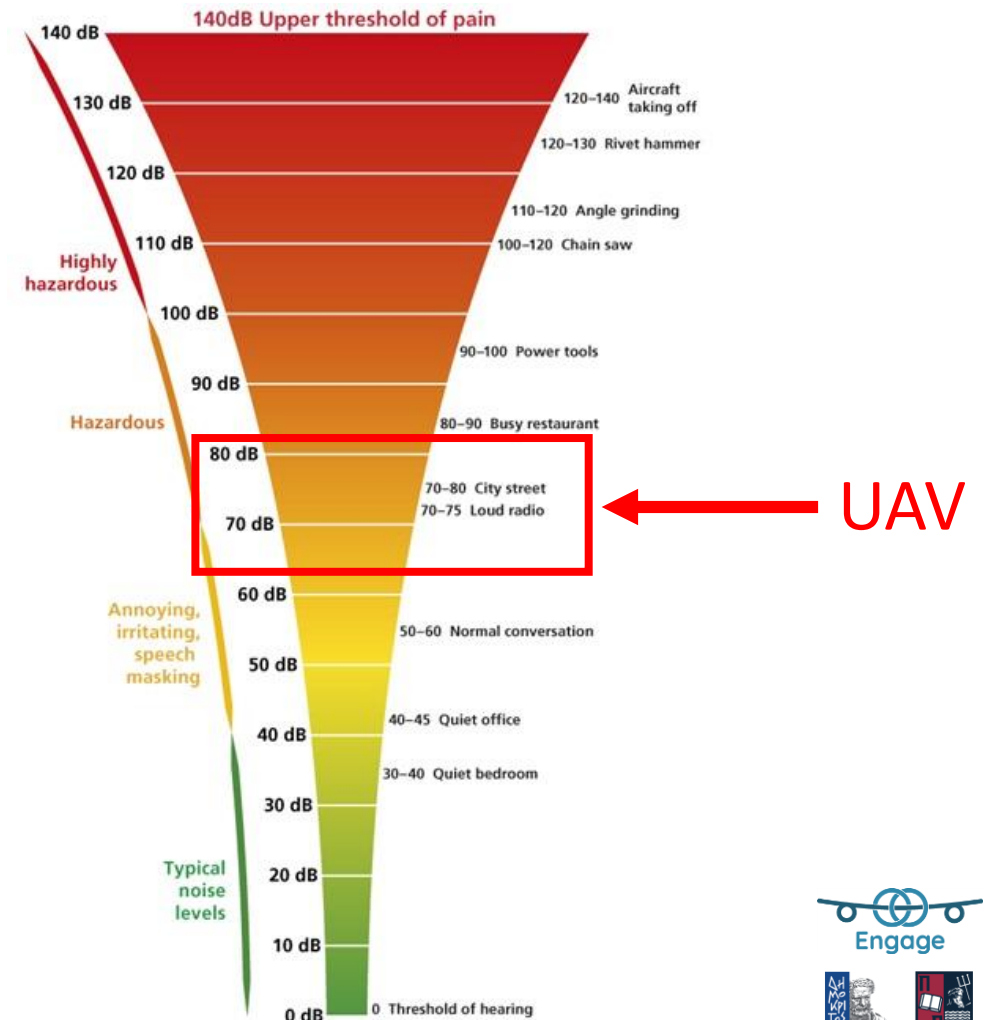
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I/Introduction



Wing's delivery drone





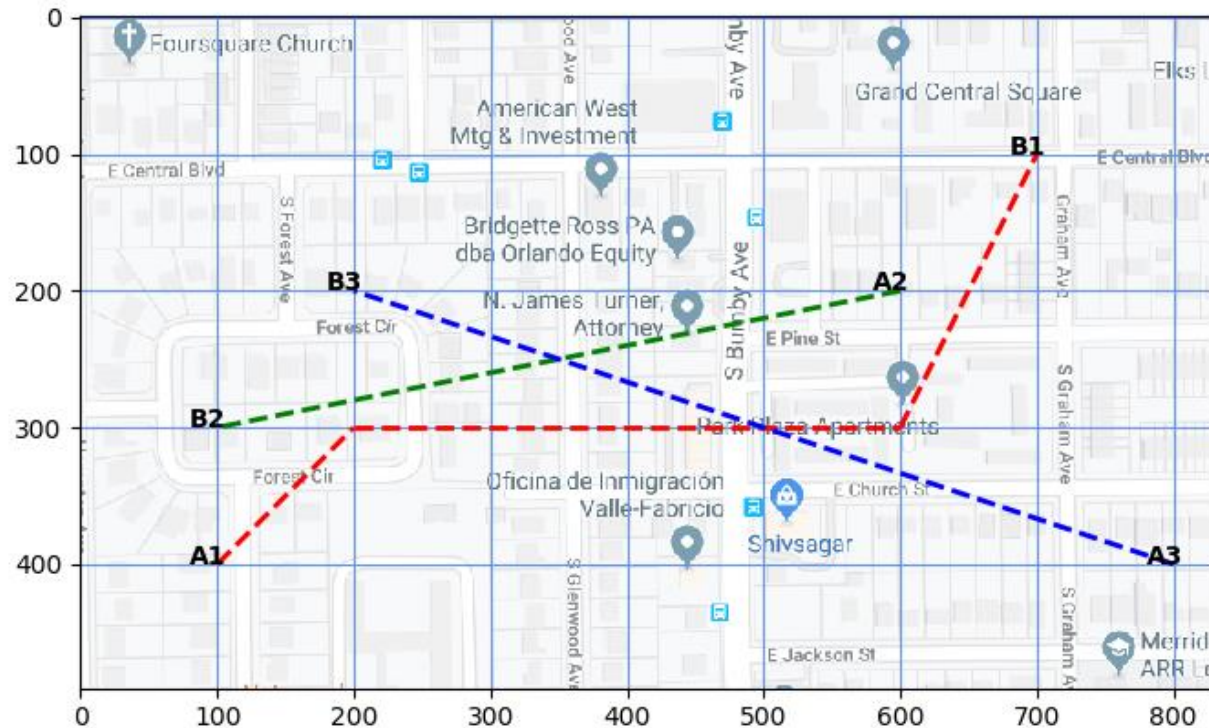
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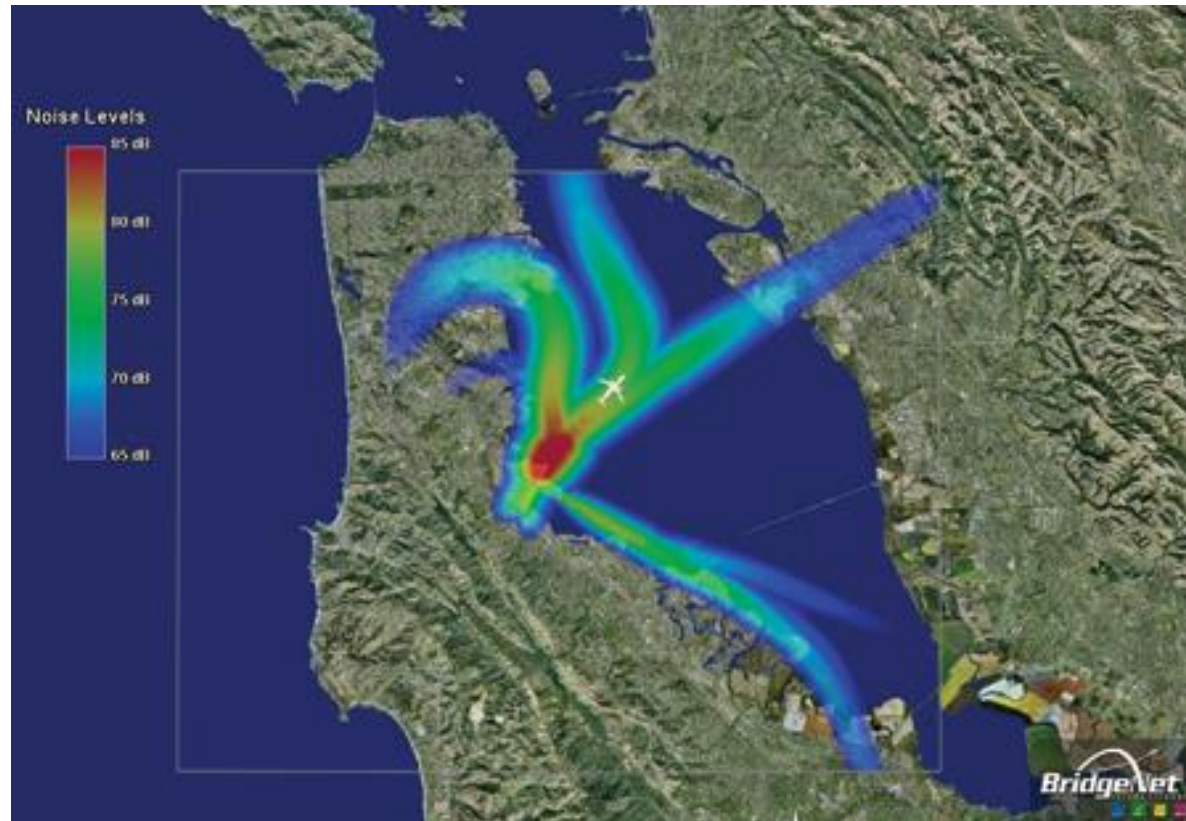
II/ Problem Description



City Map divided by grid with origin-destination pairs

- Set of Missions (A_i, B_i, D_i)
- Work with UAV flows
- Map discretized as a grid
- Noise accumulated on each grid cell
- Selection of a noise threshold
- Objective: Minimize the number of noise thresholds activated by modifying trajectories

II/ Problem Description



Noise footprint



I. Introduction

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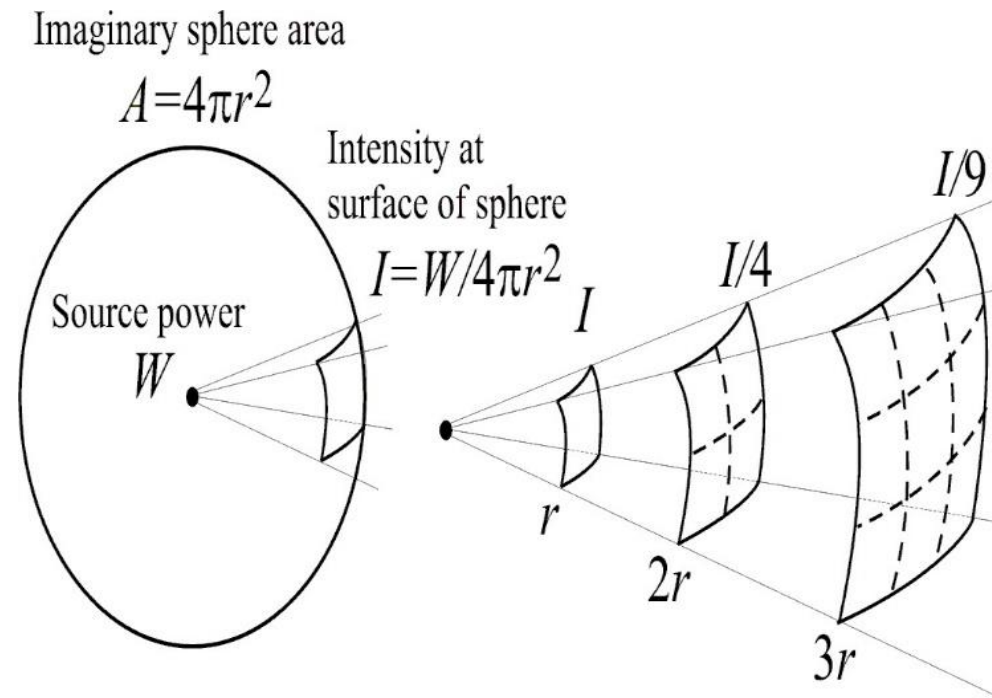
VI. Conclusion and Future Work



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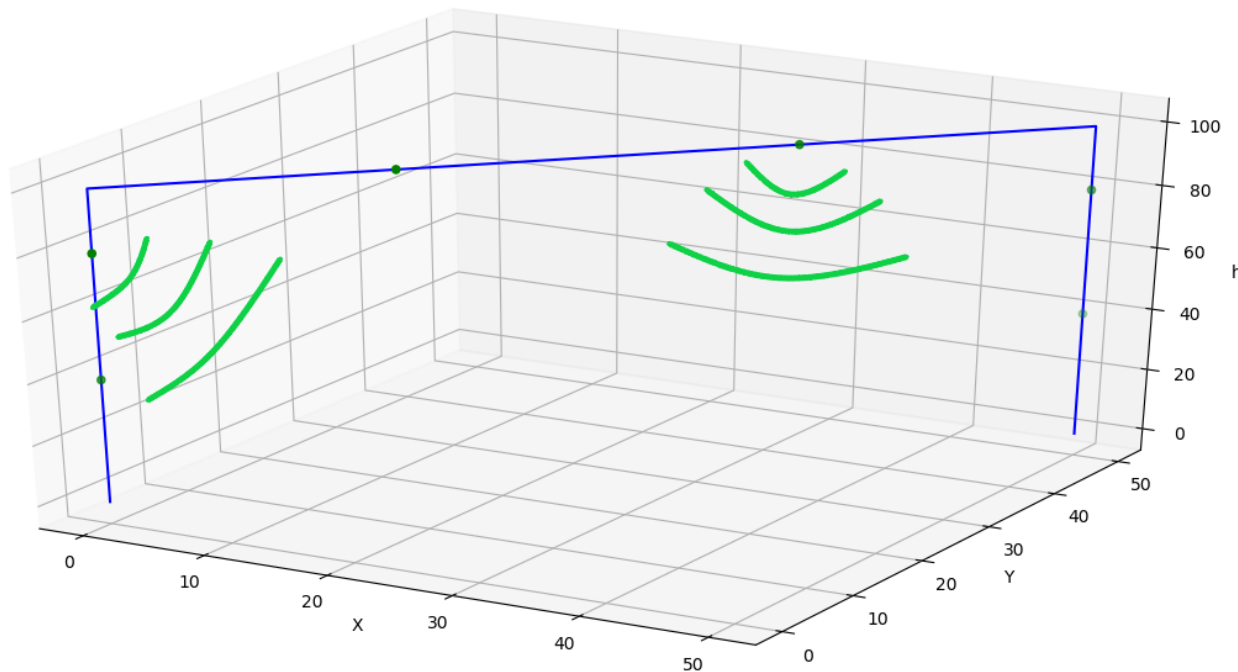


III/ Mathematical Model



Source point model with a spherical propagation

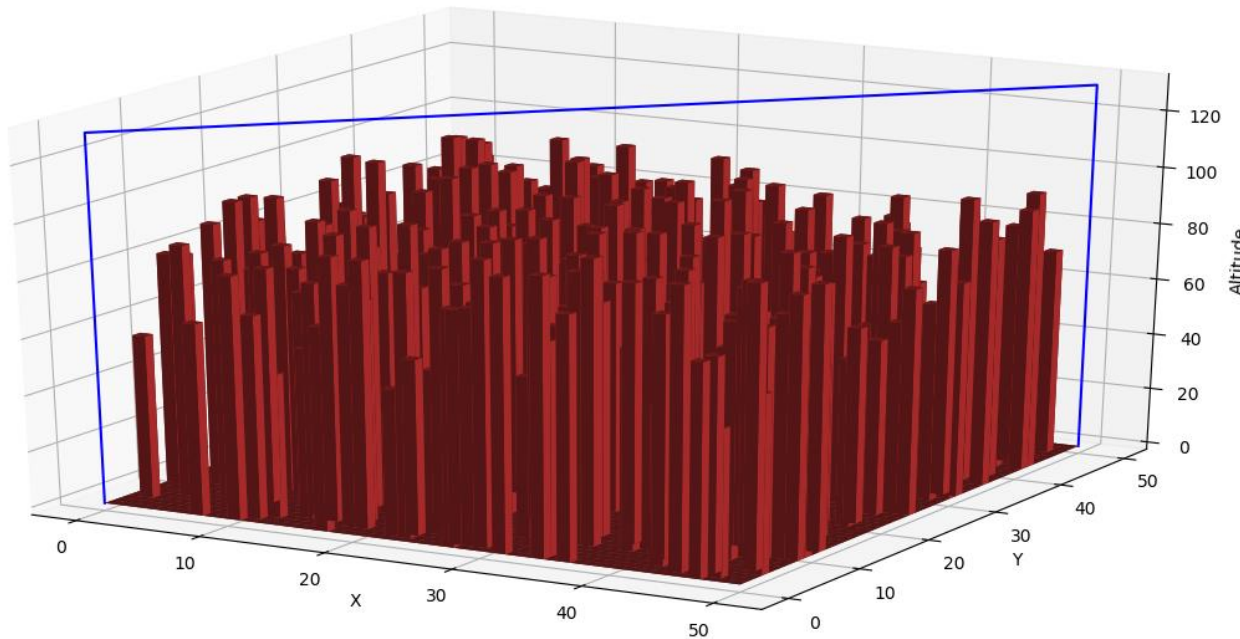
III/ Mathematical Model



Example of a trajectory between A and B

- Vertical Climb and Descent
- Grid cell defined by a position, a noise coefficient and an altitude
- Trajectory altitude calibrated to avoid buildings

III/ Mathematical Model



Example of a trajectory between A and B
put into the environment after altitude correction

- Vertical Climb and Descent
- Grid cell defined by a position, a noise coefficient and an altitude
- Trajectory altitude calibrated to avoid buildings



III/ Mathematical Model

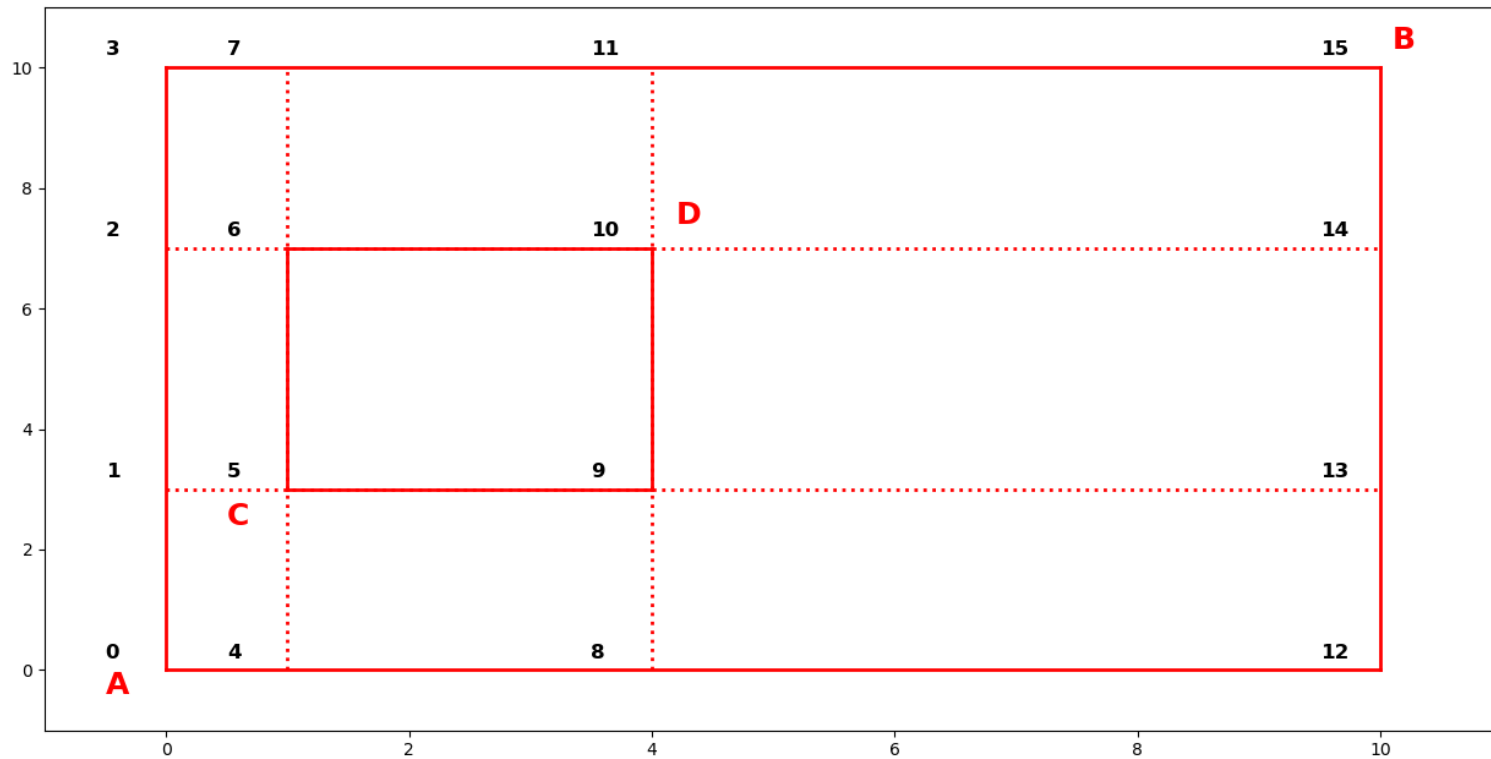
How can we create deviated paths ?



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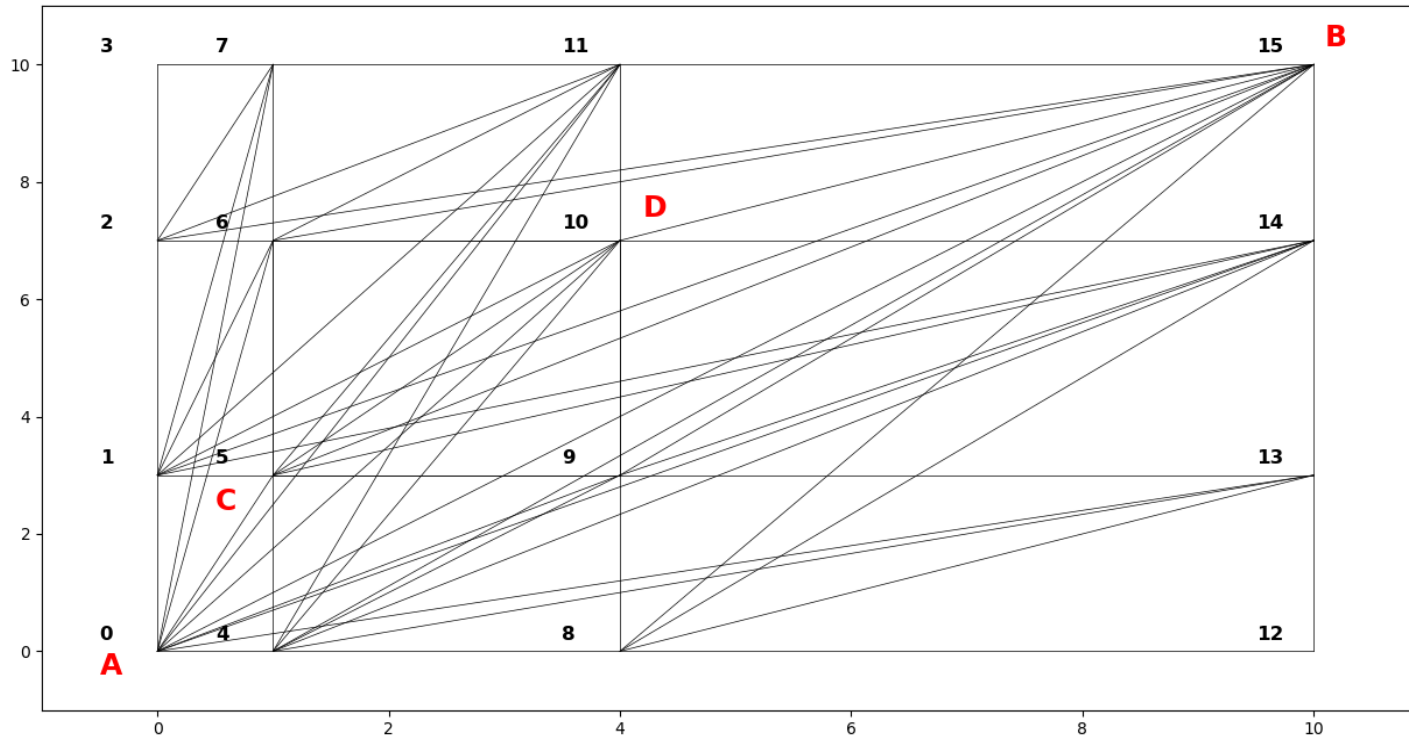
III/ Mathematical Model



Partial graph generated by A, B, C and D

- Origin/Destination points (A,B)
- Points (C,D) randomly selected within the rectangle (A,B)
- Creation of a 16-points graph

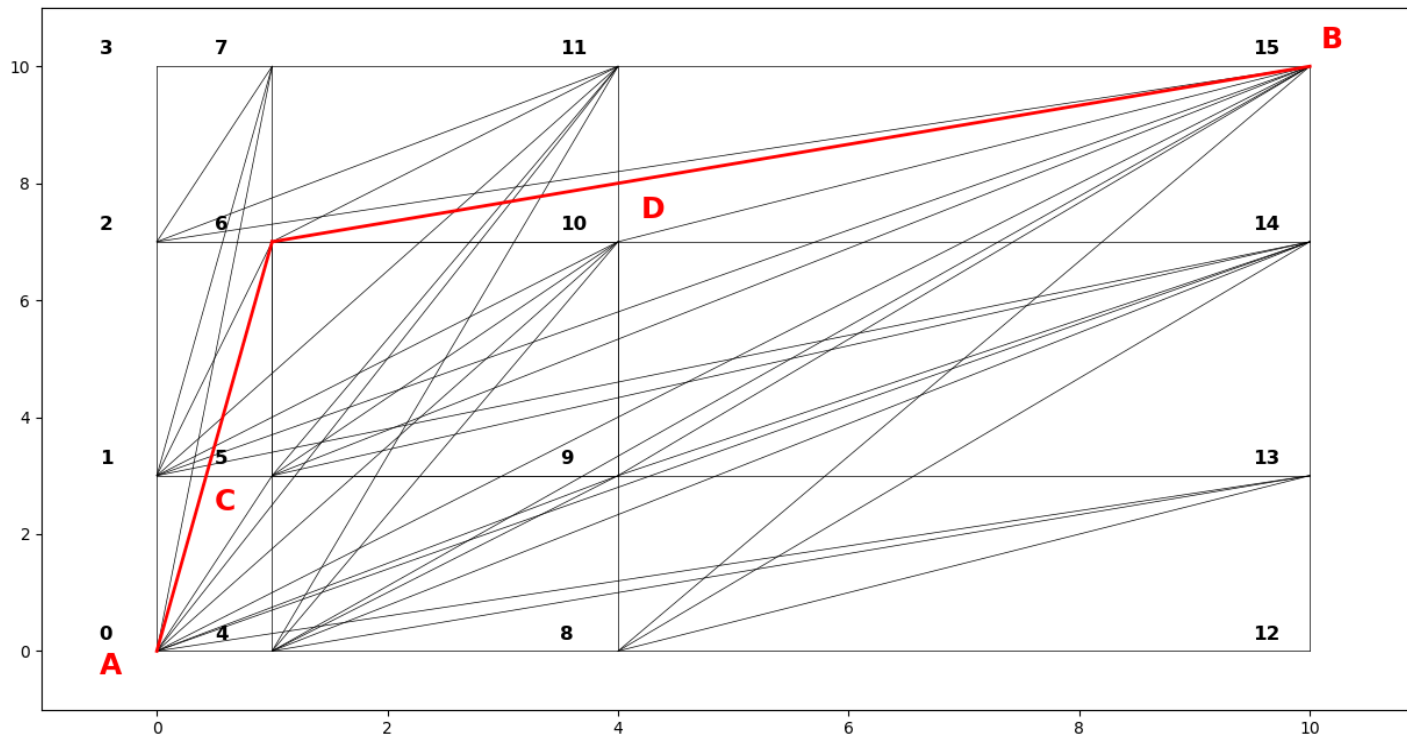
III/ Mathematical Model



Complete graph generated by A, B, C and D

- Addition of all edges which favor the movement from A to B
- 120 paths created from A to B

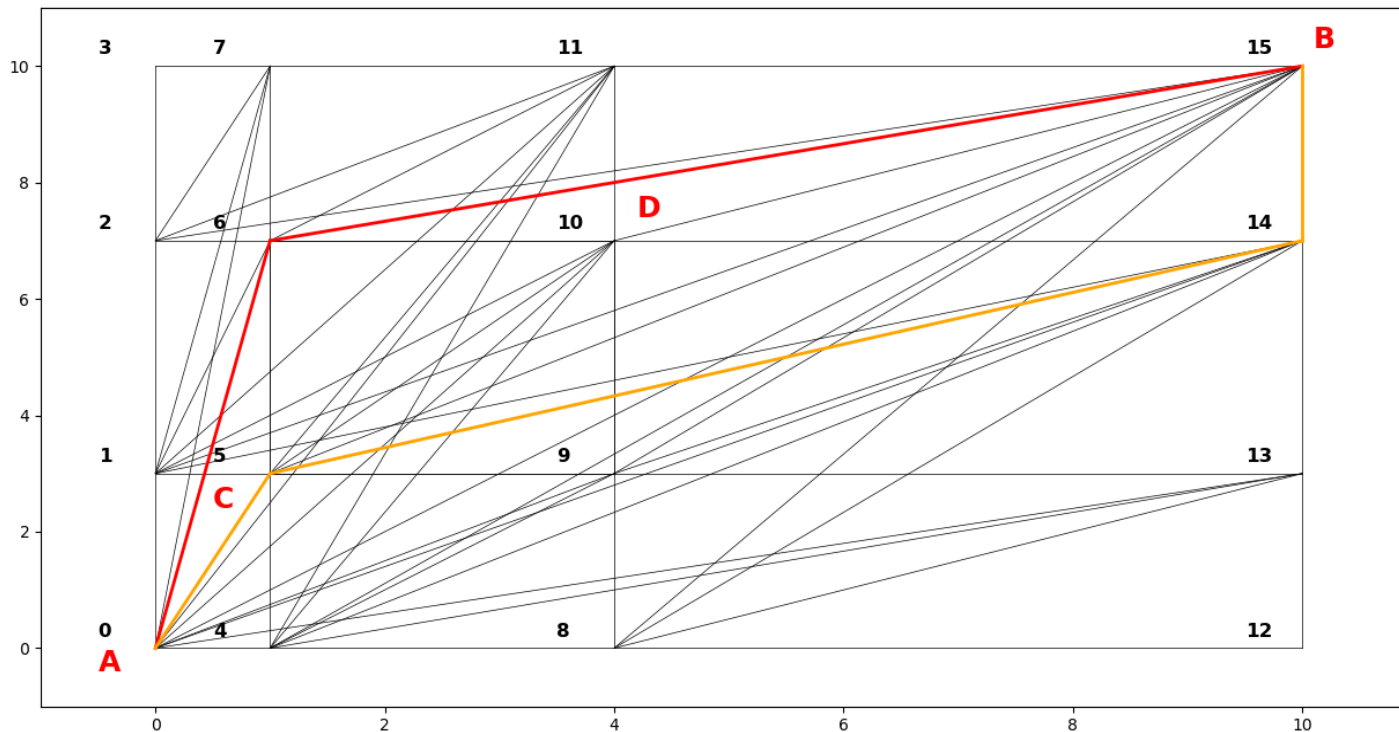
III/ Mathematical Model



Complete graph generated by A(0,0) B(10,10) C(1,3) and D(4,7)

- Addition of all edges which favor the movement from A to B
- 120 paths created from A to B

III/ Mathematical Model



Complete graph generated by A(0,0) B(10,10) C(1,3) and D(4,7)

- Addition of all edges which favor the movement from A to B
- 120 paths created from A to B



III/ Mathematical Model

- Problem Data

- 1) Dimensions of the map $n*m$
- 2) Set of N missions
- 3) Set of 120 possible paths
- 4) List of allowed altitudes for each route
- 5) Noise produced by a UAV



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III/ Mathematical Model

- Decision Variables

$$\vec{X} = [\vec{d}_1, \vec{d}_2, \dots, \vec{d}_N]^T$$

where $\vec{d}_k$:

- $(x_c; y_c)$
- $(x_d; y_d)$
- *path k*
- *h*

III/ Mathematical Model

- Constraints

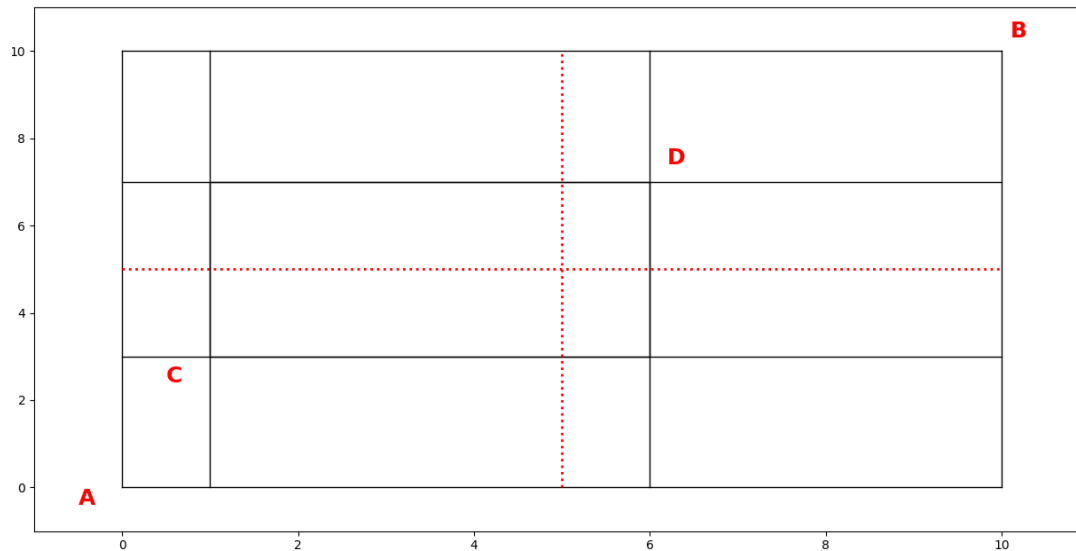
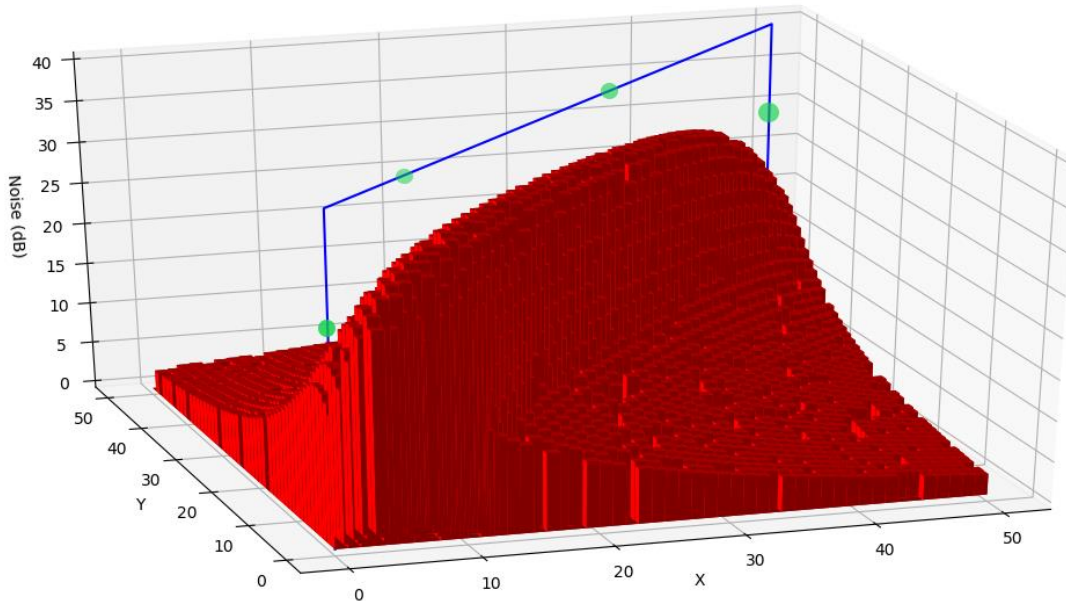


Illustration of the constraints on (X_c, Y_c)
and (Y_c, Y_d)

- $x_A < x_C < \frac{(x_A + x_B)}{2}$
- $y_A < y_C < \frac{(y_A + y_B)}{2}$
- $\frac{(x_A + x_B)}{2} < x_D < x_B$
- $\frac{(y_A + y_B)}{2} < y_D < y_B$
- $h_{min} \leq h \leq h_{max}$

III/ Mathematical Model

- Noise footprint modelling



Noise footprint of a trajectory

$$No_{p,c} = \frac{UAV Noise}{4 \times \pi \times d(p, c)^2}$$

$$No_c = \sum_{i=1}^N \sum_{p \in traj_{X_i}} No_{p,c}$$

III/ Mathematical Model

- Weighted path length:

$$L(\gamma_k) = K_1 \times d(\gamma_{k,1}, \gamma_{k,2}) + \sum_{i=0}^{M_k-2} d(\gamma_{k,i}, \gamma_{k,i+1}) \\ + K_2 \times d(\gamma_{k,M_k-1}, \gamma_{k,M_k})$$

$\gamma_{k,1}, \gamma_{k,2} \dots, \gamma_{k,M_k}$: *points of the trajectory γ_k*

K_1 : *cost weighted correction to the Climb*

K_2 : *cost weighted correction to the Descent*

III/ Mathematical Model

- Objective Function

performance of the decision k :

$$C(d_k) = \sum_{p \in \text{traj}_{X_k}} \sum_{c \in \text{range}(p)} \mathbb{1}(No_c) \times No_{p,c} + Q \times L(\gamma_k)$$

Finally :

$$f = \sum_{i=1}^N C(d_i)$$



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IV/ Resolution Approach

Simulated Annealing

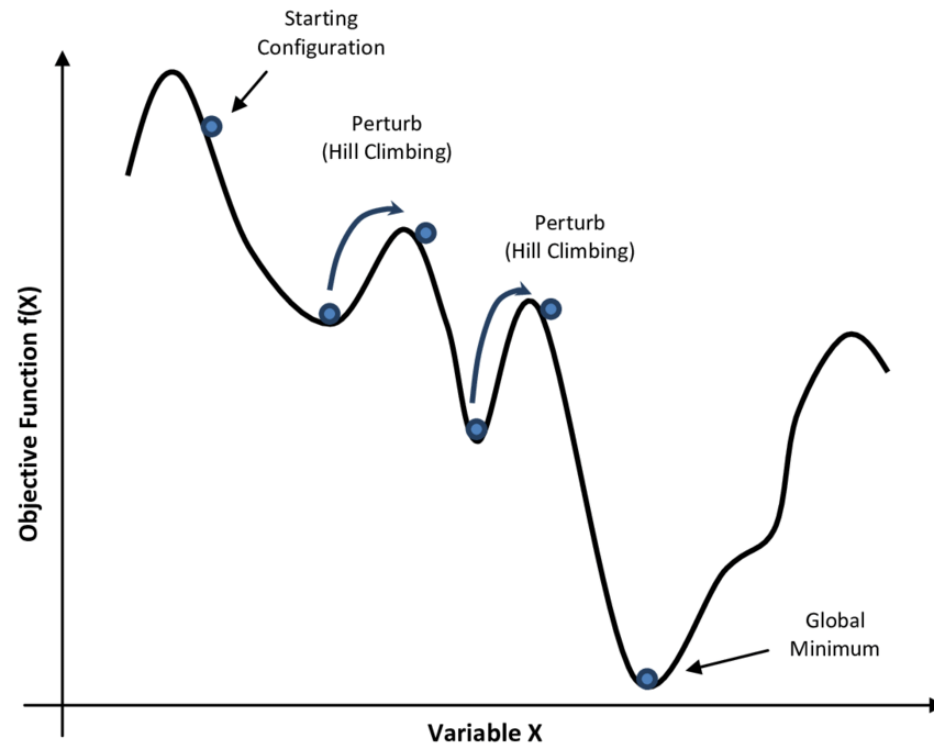
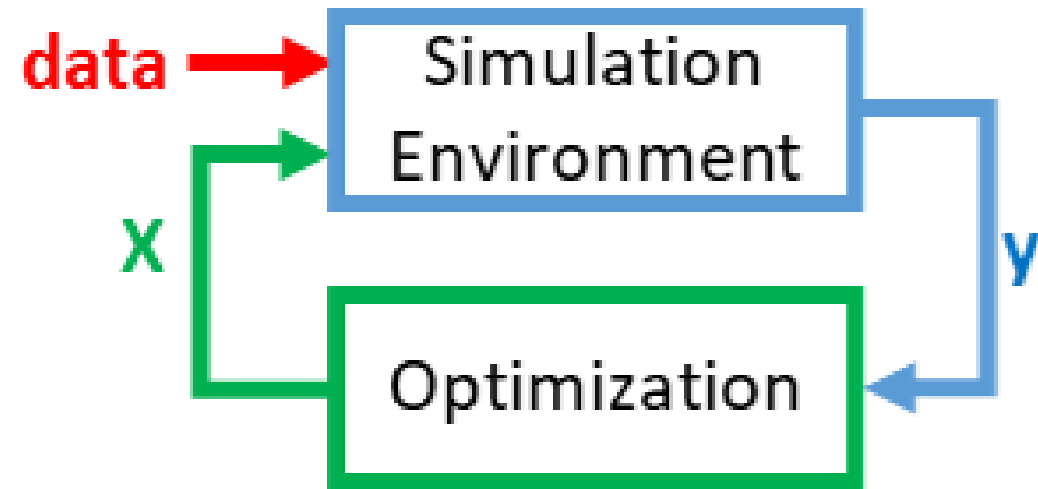


Illustration of Simulated Annealing

- Generate a neighbor j of the solution i
- If $f(j) < f(i)$: j becomes the current solution
- Otherwise j becomes the current solution with probability $e^{-\frac{(f(j)-f(i))}{T}}$
- $T \searrow$

IV/ Resolution Approach

- Initialize each decision by the shortest path
- Initial altitude as an input
- Evaluate the performance of each decision
- Select a decision with a high performance
- Generate a neighbor of the Solution



Objective evaluation function based on a simulation process



IV/ Resolution Approach

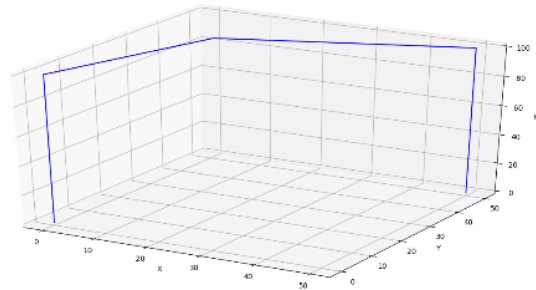
How a neighbor can be generated ?



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IV/ Resolution Approach



Change the Altitude

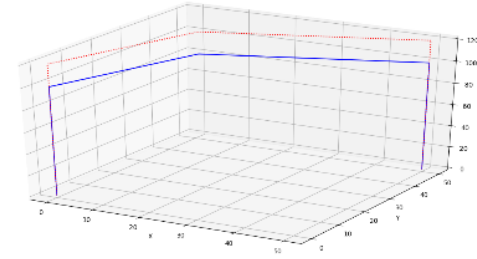
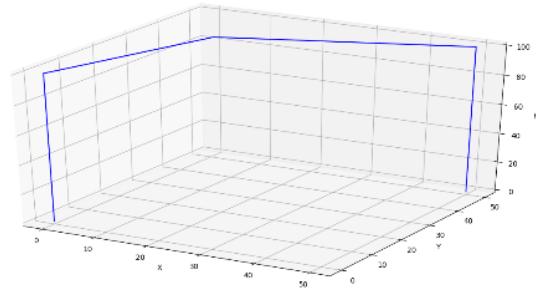
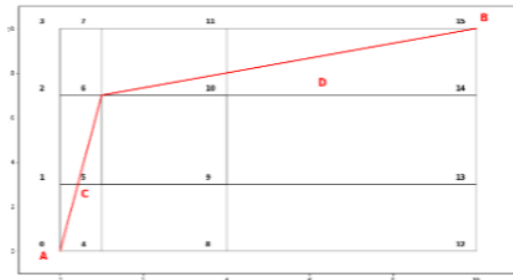
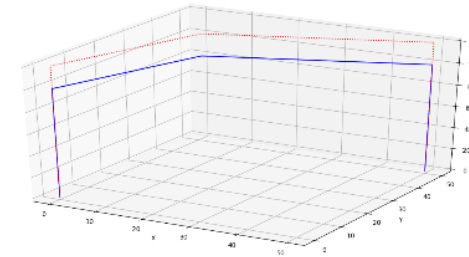


Illustration of the neighbor generation

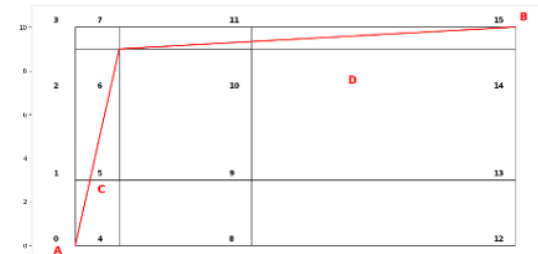
IV/ Resolution Approach



Change the Altitude



Change C or D



Change the path with
the same graph

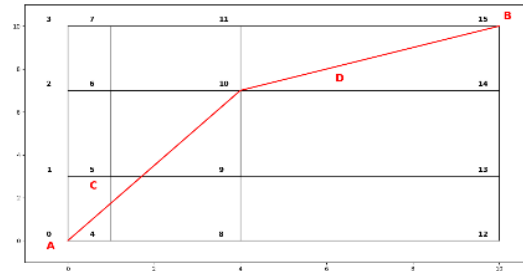


Illustration of the neighbor generation

IV/ Resolution Approach

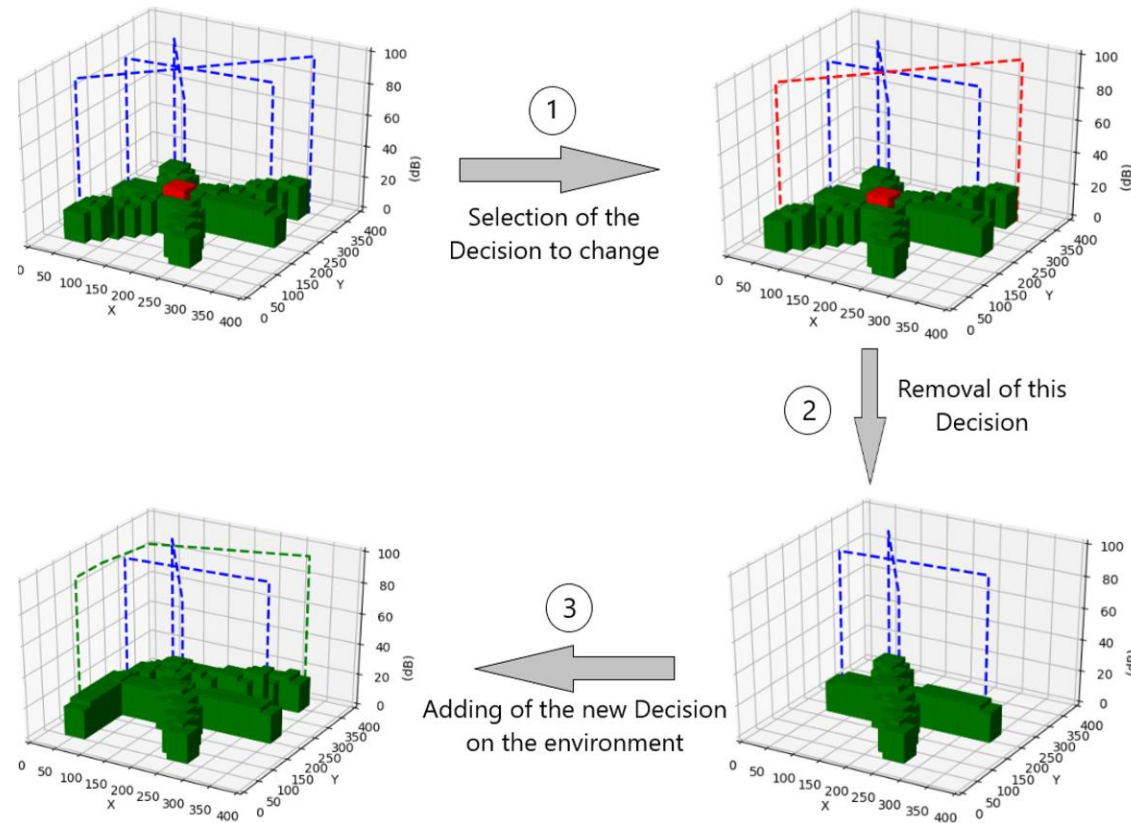


Illustration of the implementation process



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V/ Results

- Scenario I:



- map 50*50
- 50% Residential areas / 50% Building areas
- 500 missions
- Altitude $\in \{15, 20, 25, 30, 35\}$ m
- Initial altitude = 35m
- 90% of the objective function linked to the noise (10% to the trajectory length)



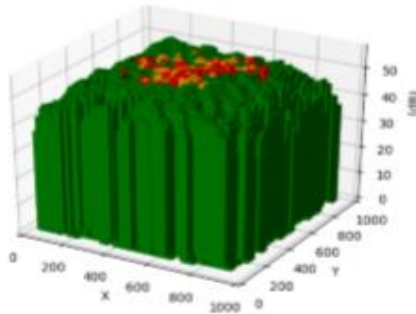
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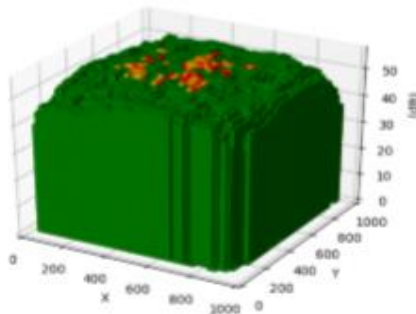
V/ Results

After Optimization Scenario I:

- +0% on the average altitude
- + 16,5% on the average distance
- -35,6% on noise thresholds activated in buildings areas
- -54,5% on noise thresholds activated in residential areas



(a) Noise Map Scenario I before optimization



(b) Noise Map Scenario I after optimization

V/ Results

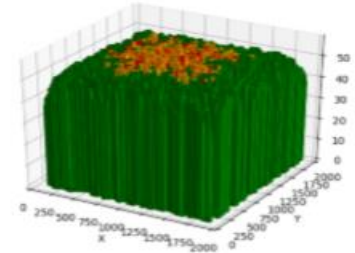
- Scenario II a):
 - map 100*100
 - 20% Residential areas / 80% Building areas
 - 1000 missions
 - Altitude $\in \{15,20,25,30\}$ m
 - Initial altitude = 30m
 - 95% of the objective function linked to the noise (5% to the trajectory length)
- Scenario II b): Same as a) except Altitude $\in \{15,20,25,30,35,40,45,50\}$ m



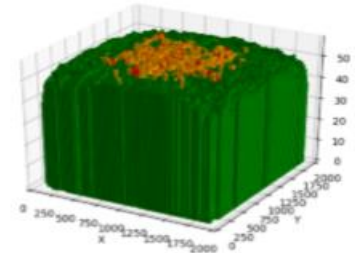
V/ Results

After Optimization Scenario II a)

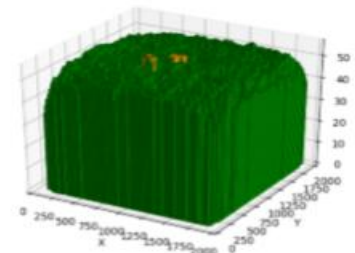
- +0% on the average altitude
- +15,4% on the average distance
- +7,7% on noise thresholds activated in building areas
- -27,7% on noise thresholds activated in residential areas



(c) Noise Map Scenario II before optimization



(d) Noise Map Scenario II a) after optimization

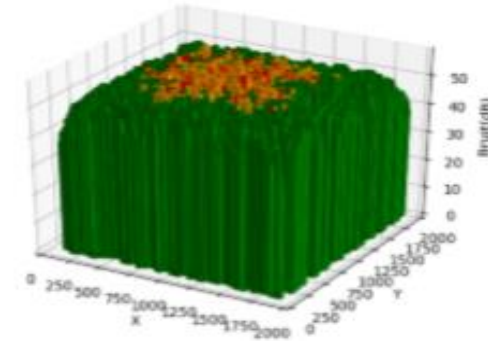


(e) Noise Map Scenario II b) after optimization

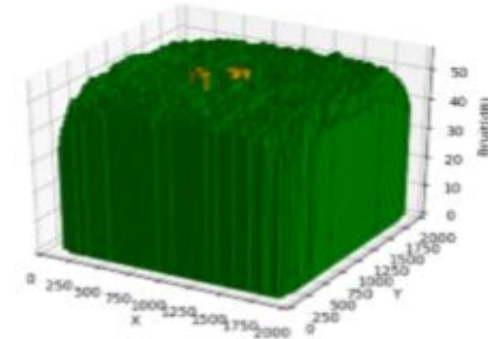
V/ Results

After Optimization Scenario II b)

- +31,8% on the average altitude
- +14,5% on the average distance
- -97,4% on noise thresholds activated in building areas
- -99,1% on noise thresholds activated in residential areas



(c) Noise Map Scenario II before optimization



(e) Noise Map Scenario II b) after optimization



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VI/ Conclusion and Future Work

- Presentation of a way to evaluate the noise footprint of a UAV fleet on an urban environment
- New method to generate quickly a set of trajectories
- Optimization of the trajectories with Simulated Annealing
- Results are encouraging with a reduction of the noise and a balanced impact on operating costs



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VI/ Conclusion and Future Work

- Improve the noise propagation model
- Take into account noise annoyance



- Add time to the simulation
- Take into account UAV airspace congestion
- Implement this work on a simulated environment based on a real city



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Thank you for your attention !



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