Silesian University of Technology

A PRELIMINARY STUDY ON LOCAL PATH PLANNING ALGORITHMS FOR HIGH-ALTITUDE LONG ENDURANCE UAVS

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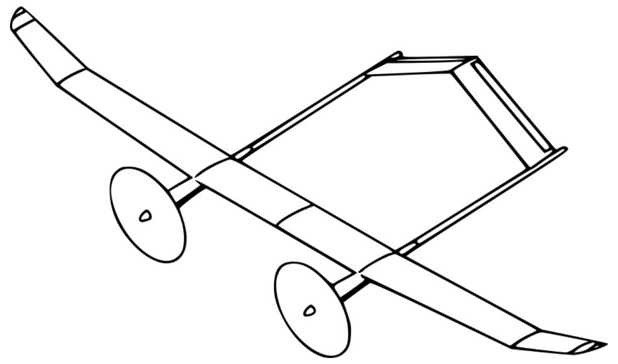
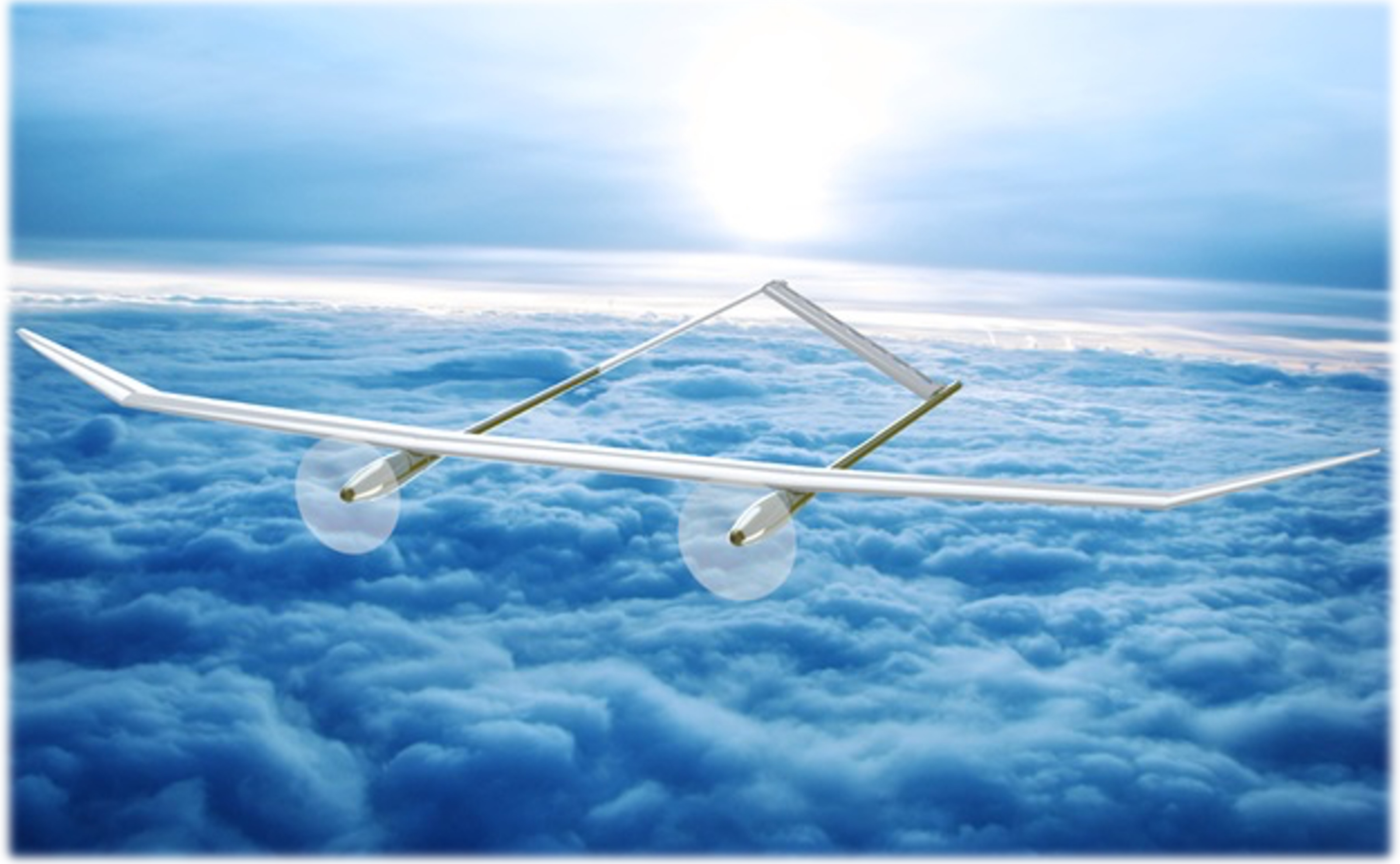
AGENDA



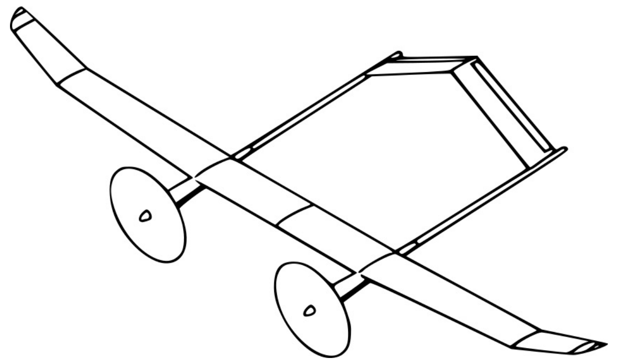
LEADER PROJECT

"Long-endurance UAV for collecting air quality data with high spatial and temporal resolutions"

- Design, optimize and construct an autonomous stratospheric HALE UAV
- Perform long-term flights to gather premiere quality spatial and temporal pollution data
- Air pollution profiling over Poland and Svalbard (Norway)
- Implemented under Programme "Applied Research" under Norwegian Financial Mechanisms 2014 – 2021

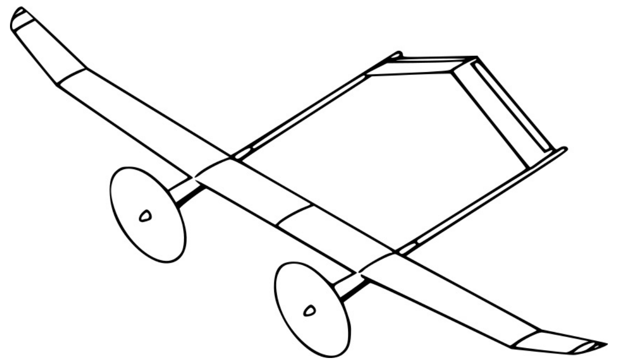


Source: https://polnor-leader.eu



Scientific problem

The research addressed the development of the adaptive path planning algorithm for a HALE UAV. The algorithm must provide a feasible obstacle-free flight path used for collecting high-quality pollution data with subsequent optimization of energy consumption and other optimization criteria of the UAV.

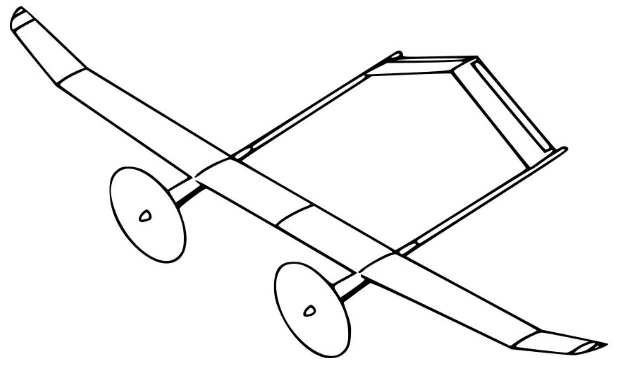


Main considerations of the Adaptive Path Planner (APP)

- APP consists of Global Path Planner (GPP) and Local Path Planner (LPP)

- GPP runs offline in Ground Control Station (GCS) and generates an initial path optimized for minimal energy expenditure

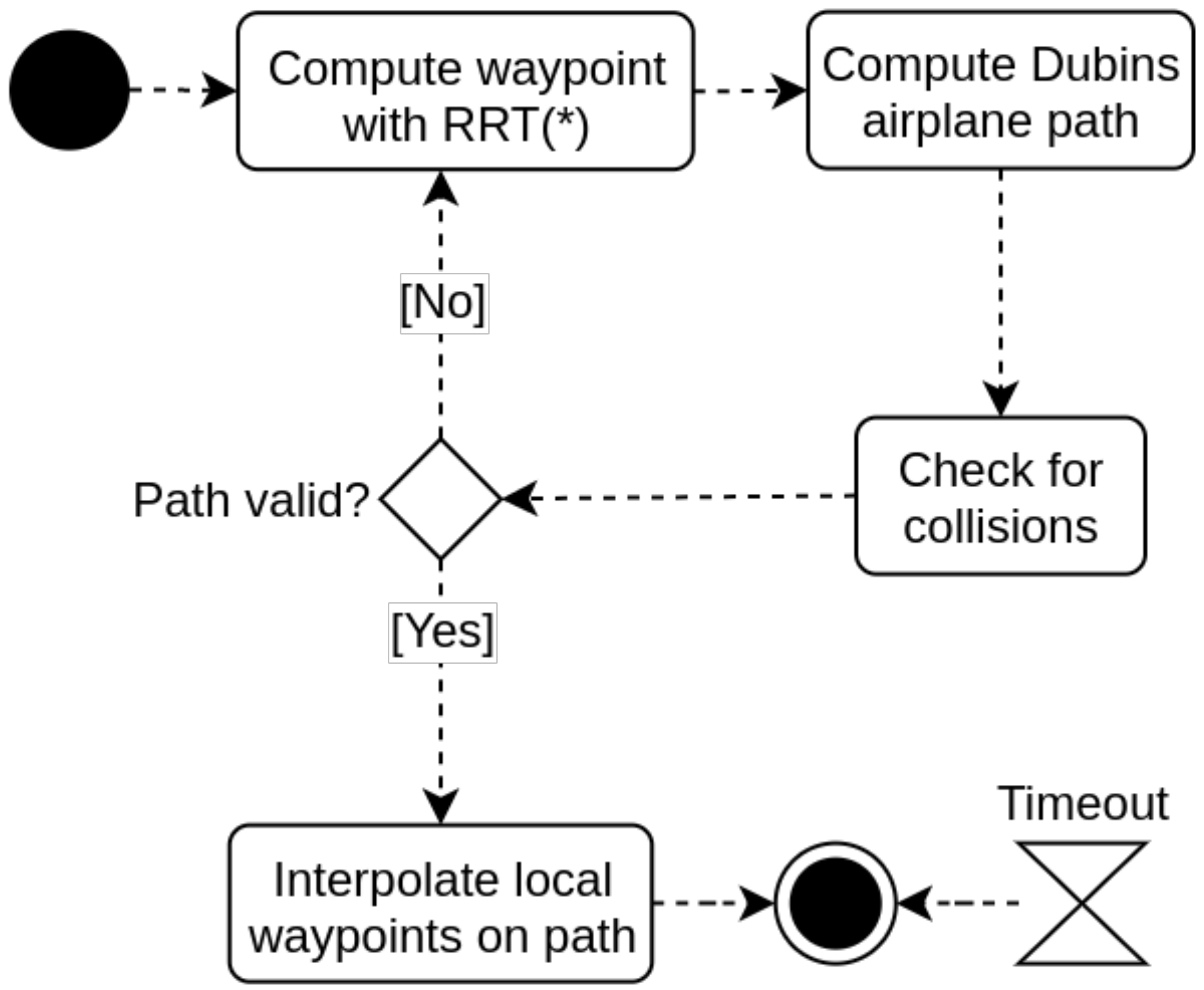
- LPP runs online in GCS or directly on the UAV and rapidly recomputes the local path to adapt to any further changes required during the flight



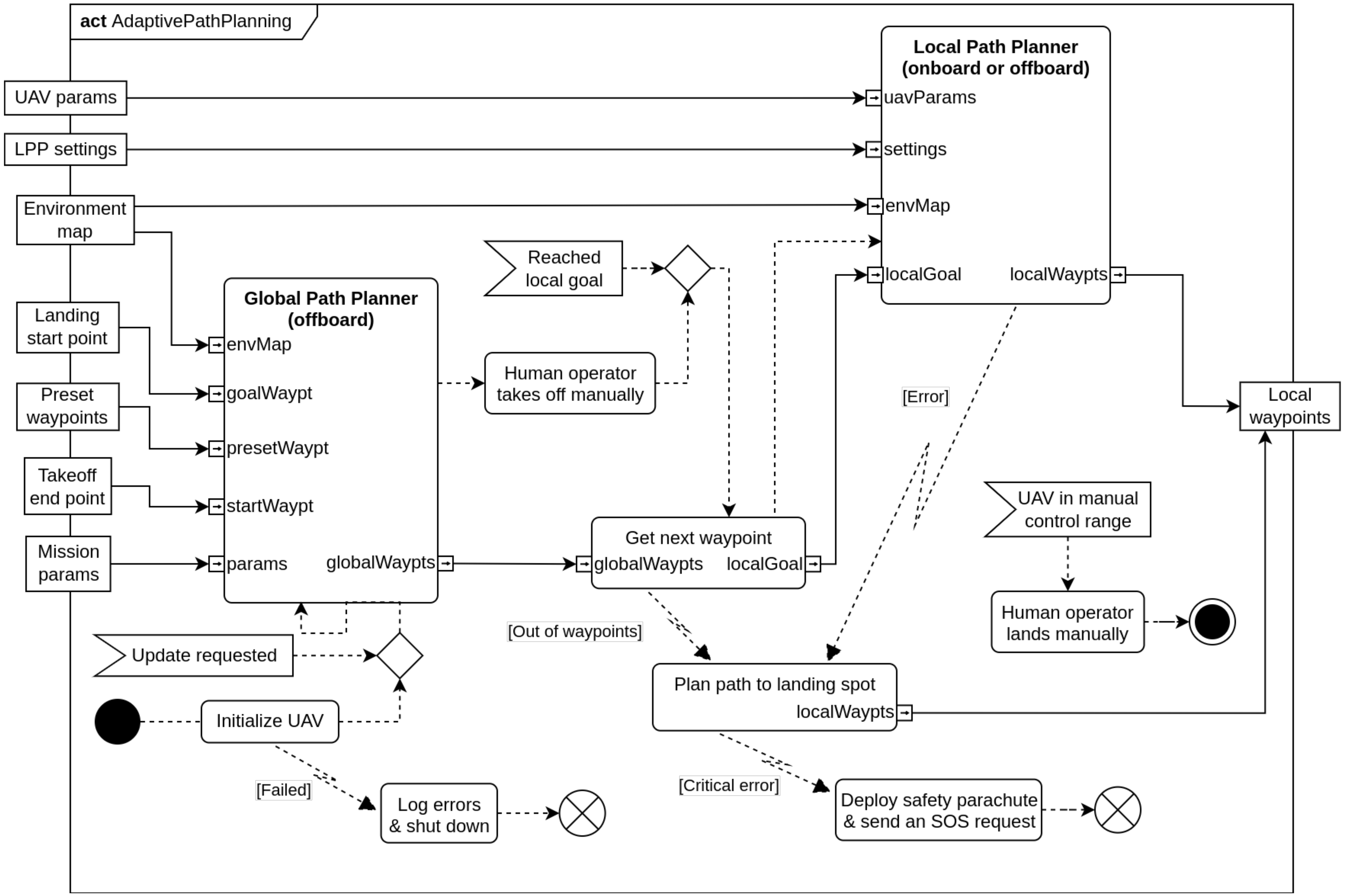
Local Path Planner (LPP) in details

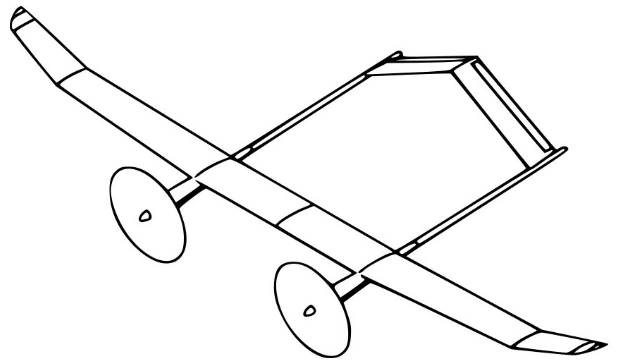
- While LPP is not required to provide an energy-optimized path (it is the task of GPP), the path must be feasible and fast to compute

- Fast but non-optimal stochastic algorithms (RRT, RRT*) were used instead of exact but slow to compute deterministic algorithms (e.g., Dijkstra’s, A*, D* etc.)



Adaptive Path Planner (APP)

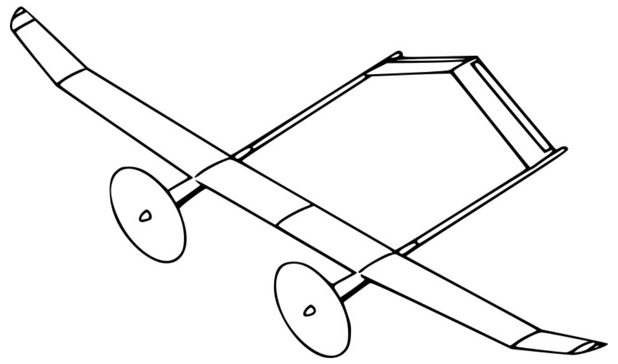




Kinematic guidance model of TS17

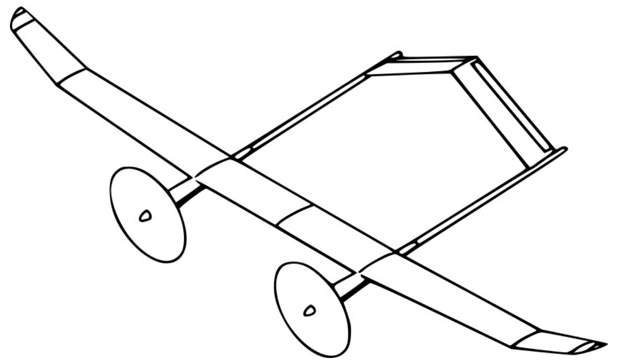
#	Parameter	Value	#	Parameter	Value
1	Wingspan $[m]$	3.6	**10**	$X_{c.g.}$ $[m]$	0.478
2	Wing area $[m^2]$	0.896	**11**	$Y_{c.g.}$ $[m]$	0
3	Mean aerodynamic chord $[m]$	0.238	**12**	$Z_{c.g.}$ $[m]$	0.237
4	Wing sweep [°]	0	**13**	I_x $[kgm^2]$	0.0062
5	Wing dihedral [°]	0	**14**	I_y $[kgm^2]$	0.0199
		HQ/W2.5/12	**15**	I_z $[kgm^2]$	0.0242
6	Wing profiles	HQ/W2.5/11	**16**	h (flight) $[m]$	5000
		HQ/W3/10	**17**	ρ $[{}^{kg}/_{m^3}]$	0.738
7	Fuselage length $[m]$	1.86	**18**	α [°]	0
8	Max. take-off weight $[kg]$	11.69	**19**	β [°]	3
9	Empty weight $[kg]$	9.19	**20**	Min speed $[{}^{m}/_{s}]$	19

$$
\begin{cases}
\dot{x}_e = V_g \cos\chi \cos\gamma \\
\dot{y}_e = V_g \sin\chi \cos\gamma \\
\dot{h} = V_g \sin\chi \\
\dot{\chi} = \dfrac{g\cos(\chi-\psi)}{V_g}\tan\phi \\
V_g \sin(\gamma^c) = \min\left(\max\left(k_h(h^c - h), -V_g\right), V_g\right) \\
\dot{\gamma} = k_\gamma(\gamma^c - \gamma) \\
\dot{V}_a = k_{V_a}(V_a^c - V_a) \\
\dfrac{g\cos(\chi-\psi)}{V_g}\tan(\phi^c) = k_\chi(\chi^c - \chi) \\
\ddot{\phi} = k_{P_\phi}(\phi^c - \phi) + k_{D_\phi}(-\dot{\phi})
\end{cases}
$$

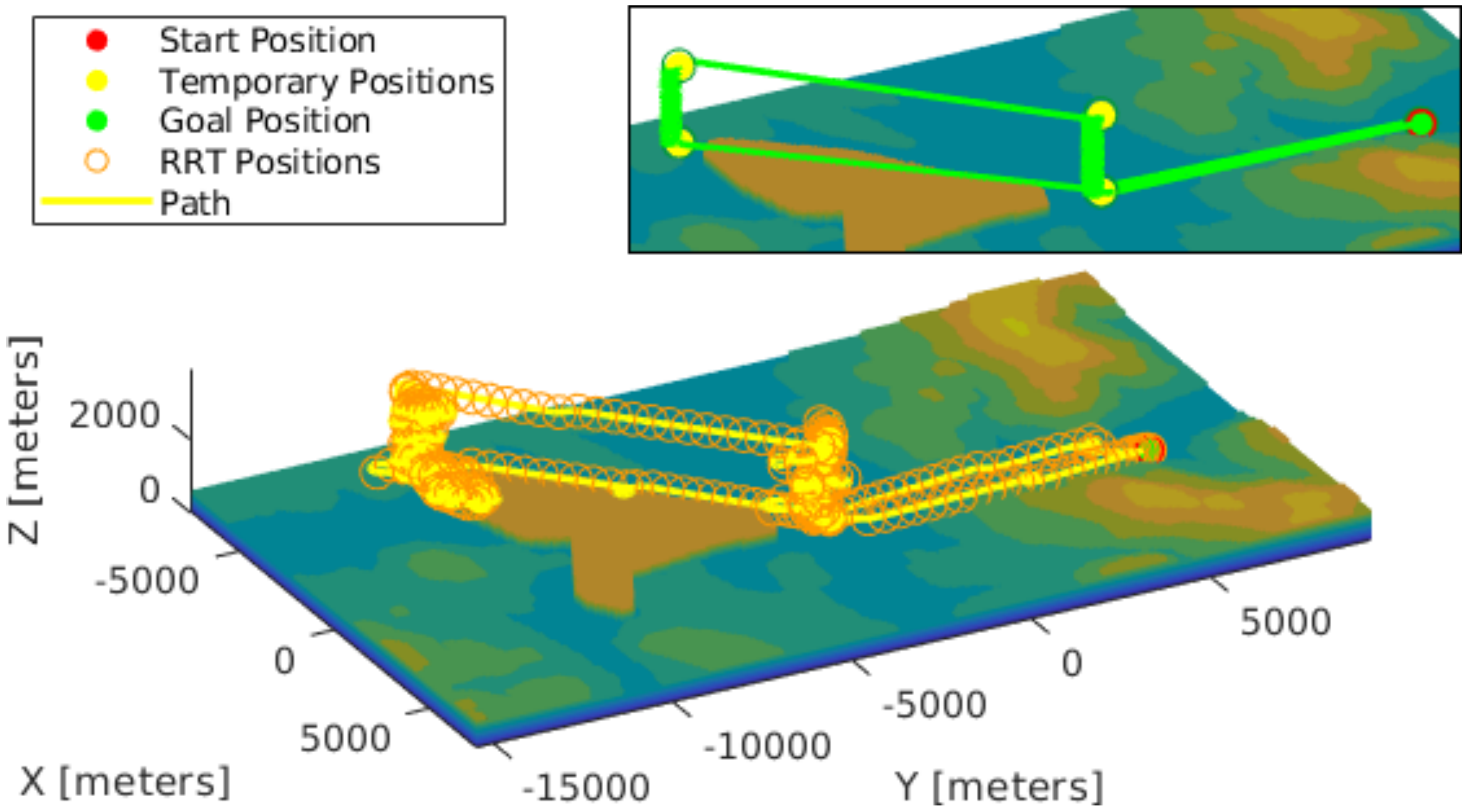


Summarized results for RRT with and w/o smoothing

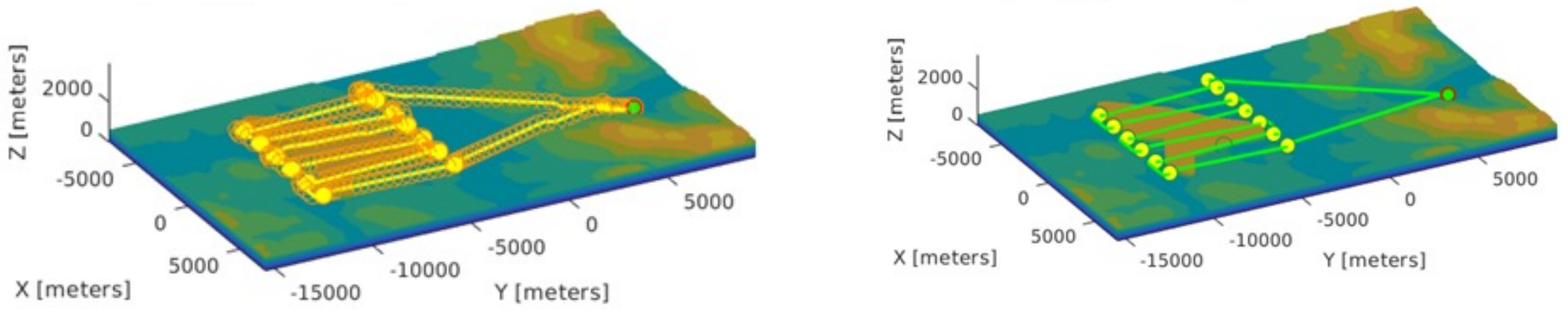
#	Use case	Raw RRT path		Smoothed RRT path			
		Length $[km]$	RRT nodes	Length $[km]$	RRT nodes	Planning $[s]$	Smoothing $[s]$
1	Approach emergency landing	58.92	57	27.51	2	2.0	114.2
2	Landing with tailwind	71.14	70	18.19	3	2.0	70.0
3	Circle around the landing site	6.23	43	6.23	7	0.9	25.4
4	One-level zigzag profiling over a city	88.06	237	79.44	17	6.4	230.2
5	Two-level line profiling over a city	230.22	275	112.41	7	8.5	340.2



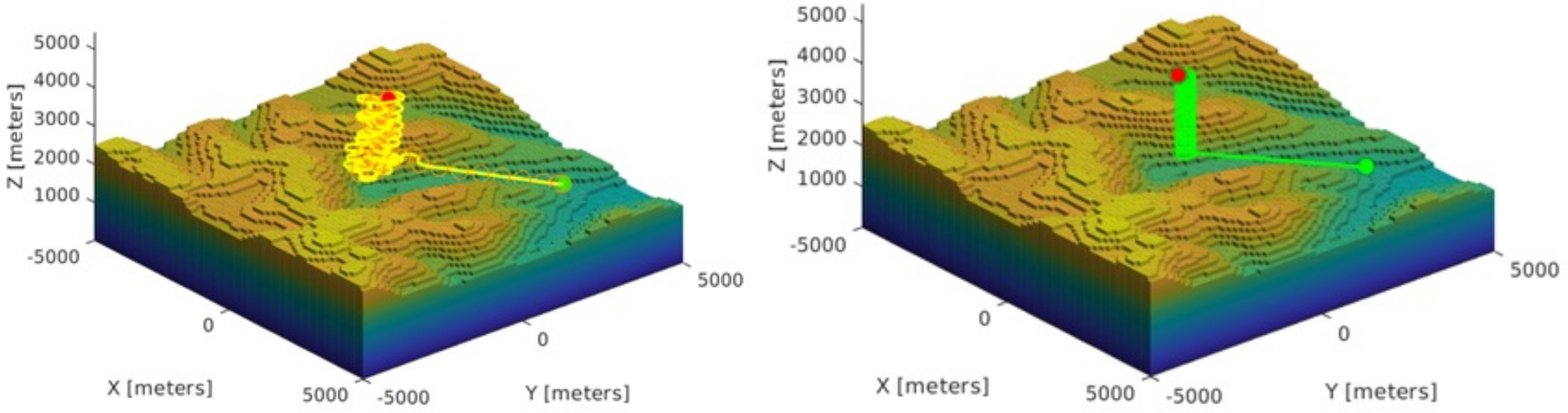
RRT with and without smoothing – chosen use cases



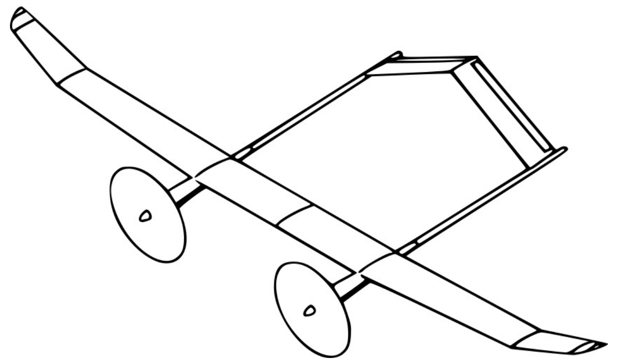
5) Two-level line profiling over a city of Żywiec



4) One-level zigzag profiling over a city of Żywiec

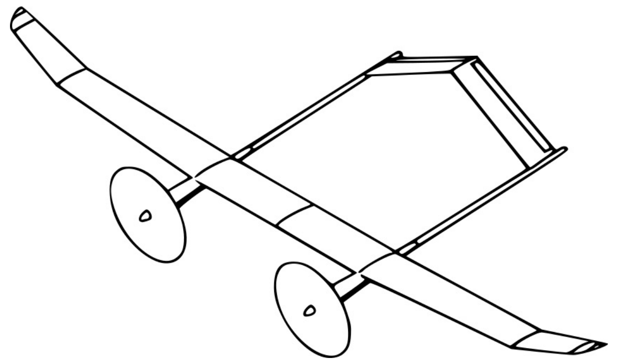


1) Approach emergency landing



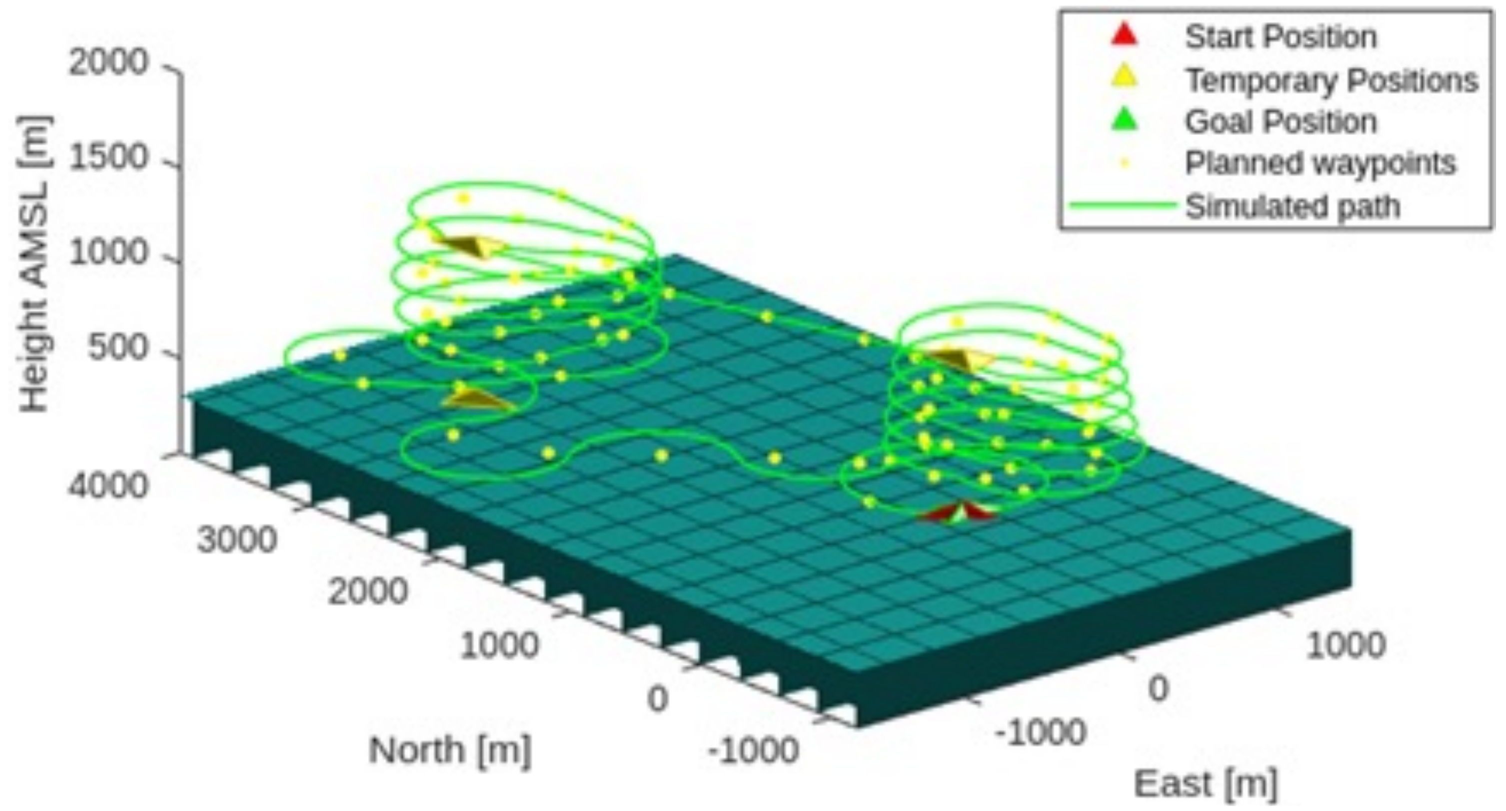
Summarized results for RRT*

#	Use case	Smooth RRT* path		Windless simulation		Windy simulation	
		Length $[km]$	Planning $[s]$	Length $[km]$	Planning $[s]$	Length $[km]$	Planning $[s]$
1	One-level profiling around a city	45.67	5.0	46.13	68.7	46.42	112.7
2	Airport-city-airport profiling	43.53	1.1	52.23	87.6	75.75	215.6
3	Vertical profiling above an airport	112.44	3.5	128.18	232.7	228.03	681.2
4	Aerosol profiling in urban-rural area	39.11	1.1	46.15	70.5	61.97	169.1
5	Aerosol layer identification on Svalbard	96.33	3.8	113.66	189.5	148.93	295.7
6	Black carbon on the Kongsvegen Glacier	162.84	5.8	182.39	305.6	214.68	443.1
7	Fly east-to-west across Spitsbergen	441.67	57.1	451.54	793.6	495.26	1 075.1

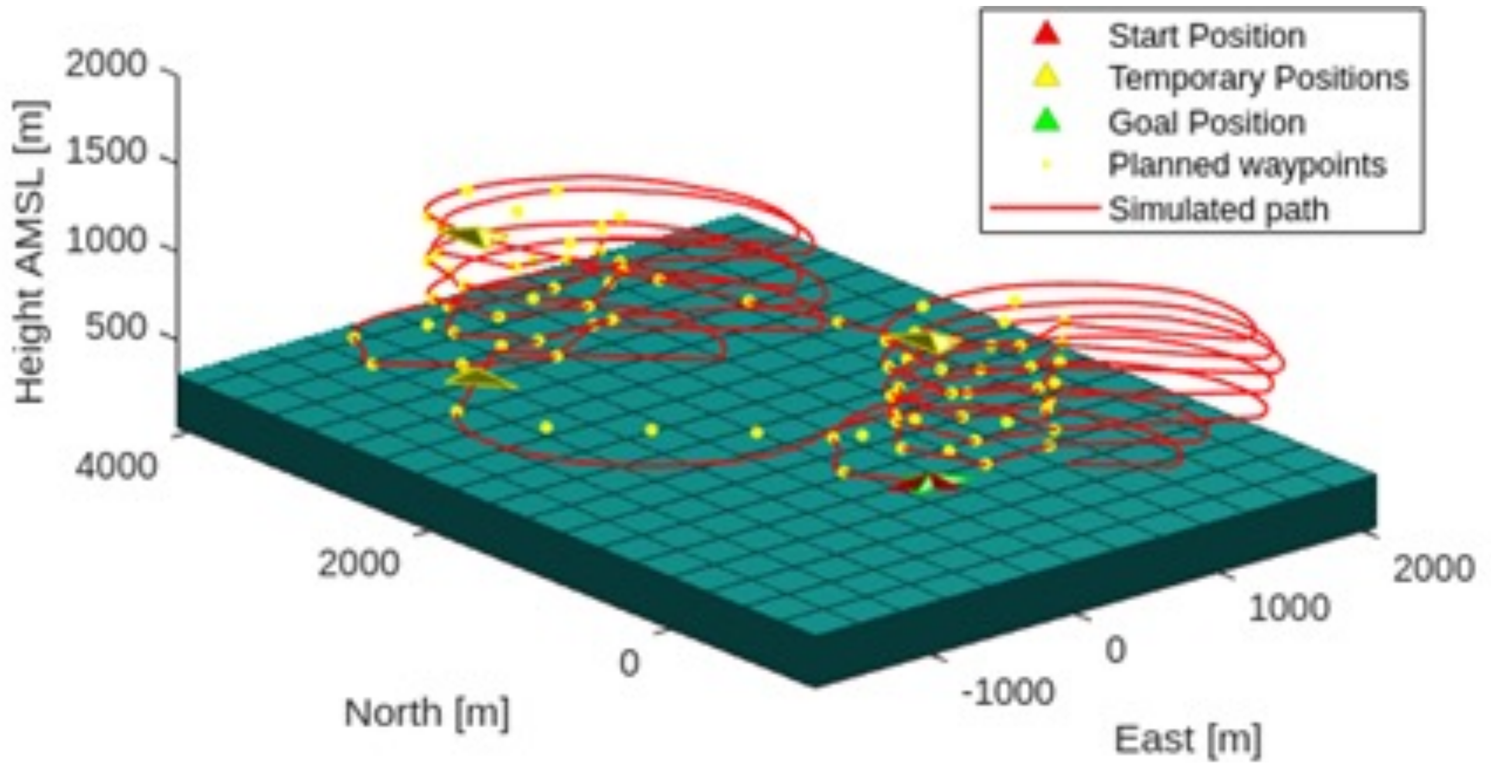


Results for RRT* – use cases 4 & 5

4) Aerosol profiling in urban-rural area

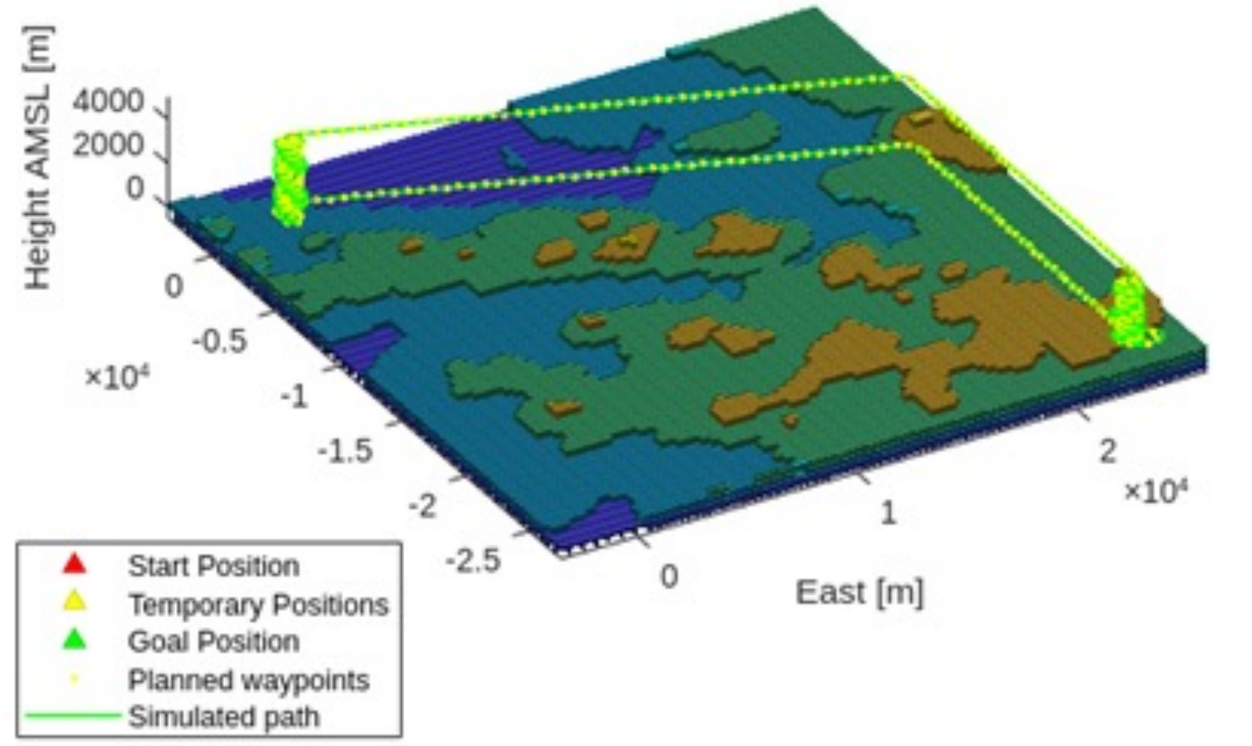


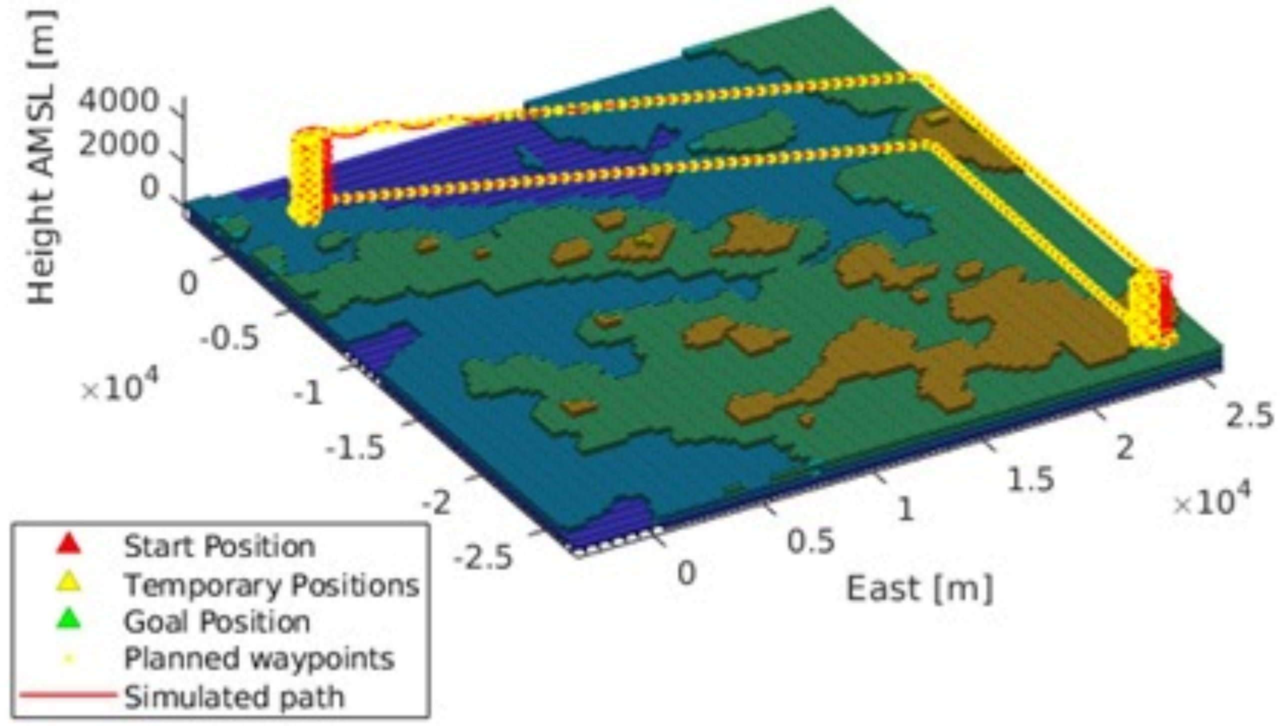
windless

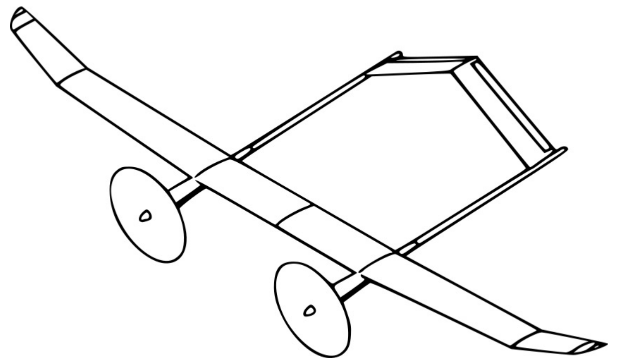


wind 3 $^{m}/_{s}$ to east and 3 $^{m}/_{s}$ to south

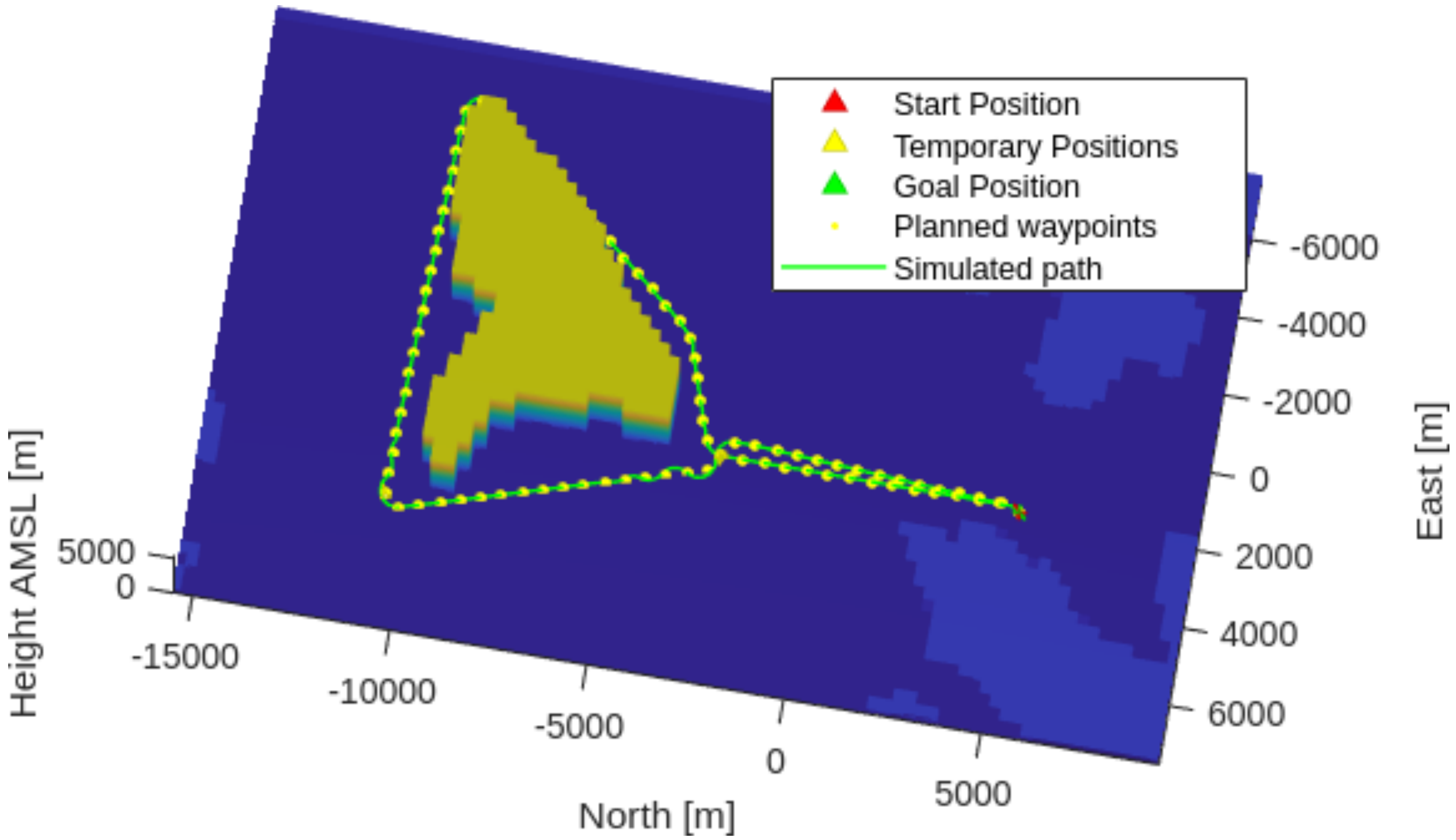
5) Black carbon on the Kongsvegen Glacier



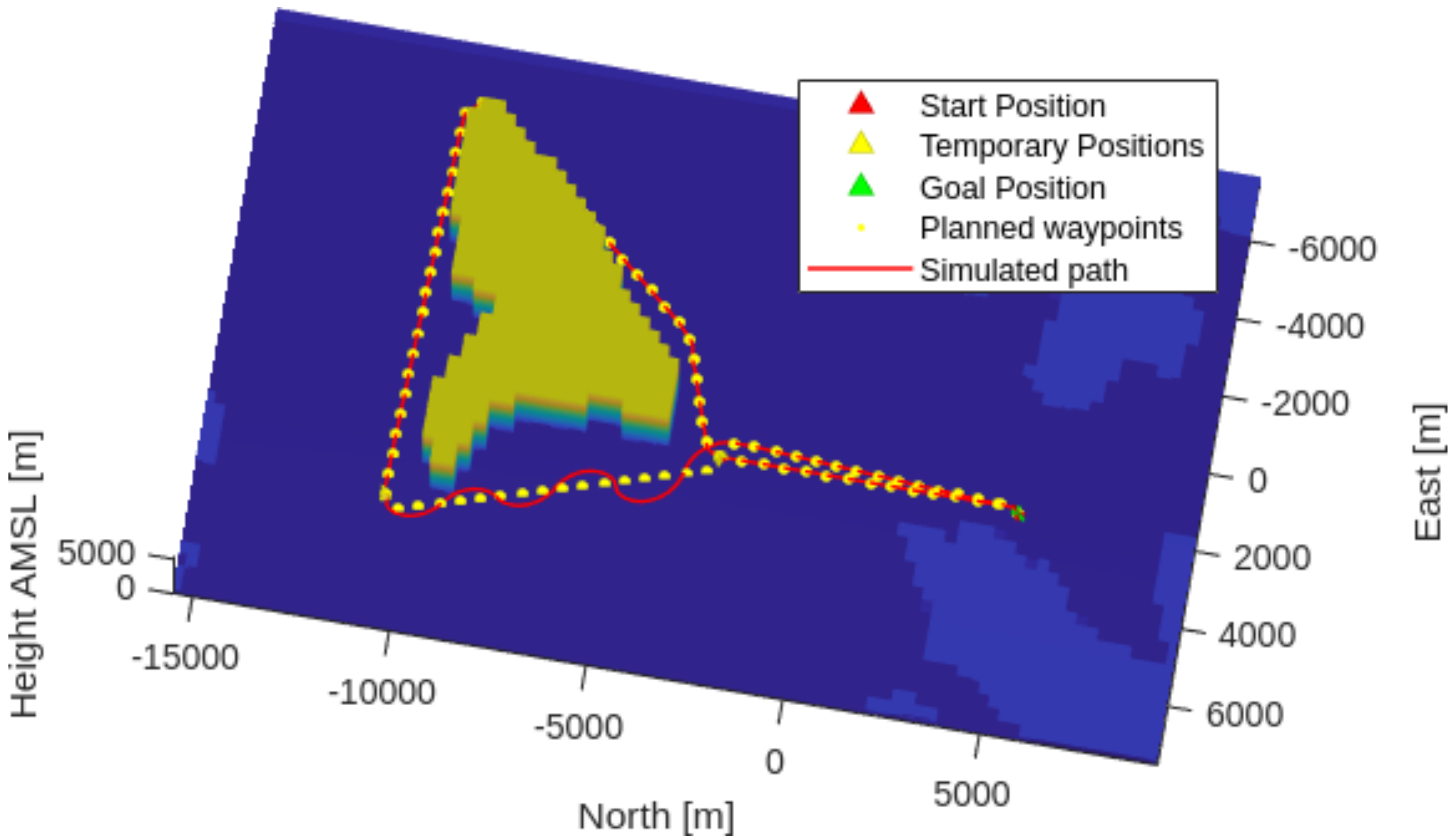




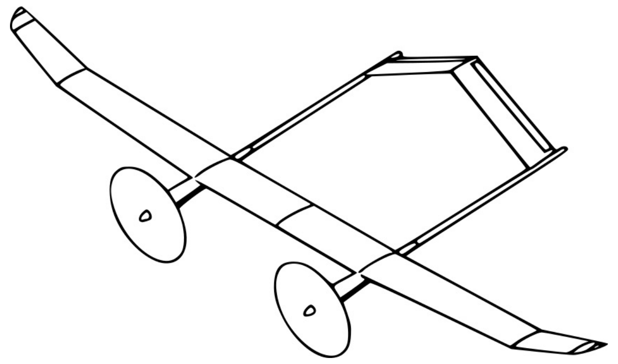
Results for RRT* – use case 1



One-level profiling around a city of Żywiec
(windless conditions)



One-level profiling around a city of Żywiec
(wind 3 $^{m}/_{s}$ to east and 3 $^{m}/_{s}$ to south)



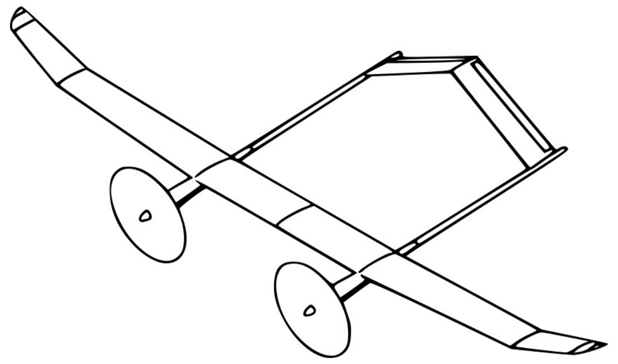
Conclusions

- Combining RRT(*) with Dubins airplane paths resulted in an efficient algorithm for planning obstacle-free kinematically feasible flight path for a HALE UAV.

- The experiments proved the algorithm's ability to provide a static obstacle-free path in time acceptable for soft real-time path planning applications.

- The kinematic guidance model is sufficient for rough verification but ultimately should be replaced with a model, which considers the aircrafts aerodynamic.

- Applying a tree-pruning algorithm resulted in significant reduction of path complexity and length without noticeable computation cost.



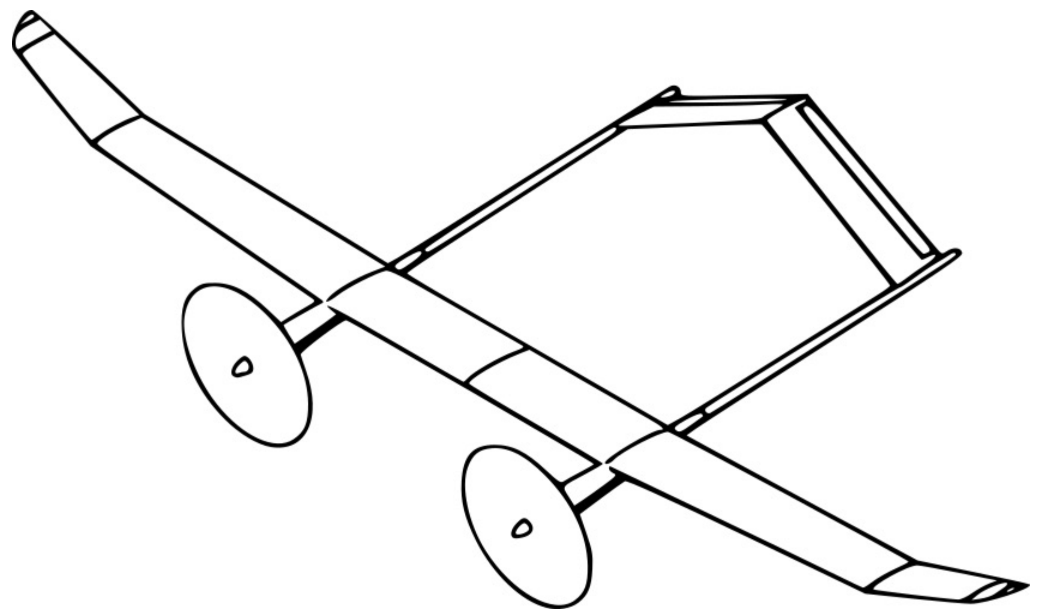
Future research

- LPP should be validated using Processor-in-the-Loop and Hardware-in-the-Loop prior to implementing it on the target UAV

- Further research will address global path planning and finding energy-optimal flight paths.

- Alternatively, LPP can be implemented by employing simplified 3D visibility graphs instead of RRT(*). This will be tested in further research.

THANK YOU FOR YOUR ATTENTION



A Preliminary Study on Local Path Planning Algorithms for High-Altitude Long Endurance UAVs

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