Online Roadmaps for Task-based Navigation in Urban Terrain

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Sensor-based navigation in a priori unknown terrain is a challenging problem, even if one could assume perfect obstacle sensing and vehicle state estimation. Especially in urban terrain or rescue scenarios, the terrain topology is fully three dimensional, i.e. overhangs from power lines, bridges or debris exist that invalidate the common assumption of the terrain being a 2D height map. It is a challenging problem to perform computationally efficient planning from higher level task planning down to the effective flight control actions. This is particularly a concern on board embedded computers of small aerial platforms (Figure 1).

Figure 1: Unmanned rotorcraft midiARTIS.

Hence, in this presentation we focus on sensor-based planning in urban example scenarios. We briefly present our Mission Planning and Execution (MiPlEx) framework that comprises an online roadmap approach for multi query planning in 3D terrain [1]. Simply stated, due to its multi-query property the amount of collision checking is reduced, such that a persistent free space representation allows to spare computing resources for the task planning and vehicle guidance. Although roadmaps were initially developed as a static a priori path planner, it now needs to be continuously updated during sensor-based navigation through complex terrain topologies. Challenges addressed by our approach deal with an online capable search graph update method, to find a suitable set of sampling parameters as well as a local connection strategy that accounts for the limited obstacle sensor field of view(s) and the aircraft dynamic limits.

We show results from closed-loop simulations in urban scenarios. Results are based on the high resolution terrain data from the inner city of down town San Diego (Figure 2) and Berlin (Figure 3). Approximate sensor field of view models of commonly used LIDAR-based pseudo-3D range sensors are used as perception model and to close the loop between perception, control and navigation [2]. Furthermore the obstacle mapping module is modeled and parameterized according to flight tests onboard our rotorcraft[1].

The first application of this concept allows an online trajectory planner to reduce the trajectory during en-route navigation while the computation overhead remains low [3]. The trajectory planner benefits from the persistent free space representation of the roadmap. Comparisons of our approach to other state of the art obstacle field navigation performances indicate the quality of our approach with respect to motion safety, performance and smoothness. Although the roadmap represents an initially coarse approximation to the search space, results indicate that it is safe, yields a good trajectory time performance and is computationally efficient (Figure 2).

The second approach shown in [4] utilizes the same online roadmap concept but with different sampling and guidance parameters, such that a locally constrained exploration of an a priori unknown task volume can be achieved (Figure 3). A greedy mapping algorithm is used on top of our roadmap for online coverage planning. It benefits from defining the roadmap as a persistent unification of the path planning layer with the task planning. Modified edge costs allow for a task-based guidance, i.e. mapping a given volume with unknown terrain. The roadmap's sample resolution relates to its terrain coverage precision for this exploration task. As a

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[1] ARTIS' online obstacle mapping video, http://www.youtube.com/watch?v=z1sj1BZmXJQ

result, the perception is directly integrated with the connection strategy of the roadmap and the exploration's coverage metric.

The presentation will briefly summarize possible future directions, e.g. how to use more detailed sensor field of view models, other sampling techniques and ideas to account for state estimation uncertainties during path planning.

MiPlEx is the core planning component for sensor-guided online planning that has been tailored for our rotorcraft platform ARTIS (Autonomous Rotorcraft Test bed for Intelligent Systems) with a MTOW of less than 15 kg (here: „midiARTIS“ rotorcraft, Figure 1). More details about the approaches shown during the presentation are listed in the references.

[1] Adolf, Florian-M. + Andert, Franz (2011) "Rapid Multi-Query Path Planning For A Vertical Take-Off and Landing Unmanned Aerial Vehicle". AIAA Journal of Aerospace Computing, Information, and Communication, 8 (11), pages 310-327. American Institute of Aeronautics and Astronautics, Inc.. DOI: 10.2514/1.52692.

[2] Adolf, Florian-M. + Dittrich, Jörg (2012) "Evaluation Of The ARTIS Sampling-based Path Planner Using an Obstacle Field Navigation Benchmark". AHS Forum 68, 1st – 3rd May 2012, Fort Worth, TX.

[3] Adolf, Florian-M. + Abou-Hussein, Mohamed + Goerzen, Chad (2013) "Trajectory Time Reduction using Field of View-based Smoothing of Roadmap-based Paths". AHS Forum 69, 20th – 21st May 2012, Phoenix, AZ (*to appear*).

[4] Adolf, Florian-M. (2012) "Multi-Query Path Planning for Exploration Tasks with an Unmanned Rotorcraft". AIAA Infotech@Aerospace, 19th – 20th June 2012, Garden Grove, CA.

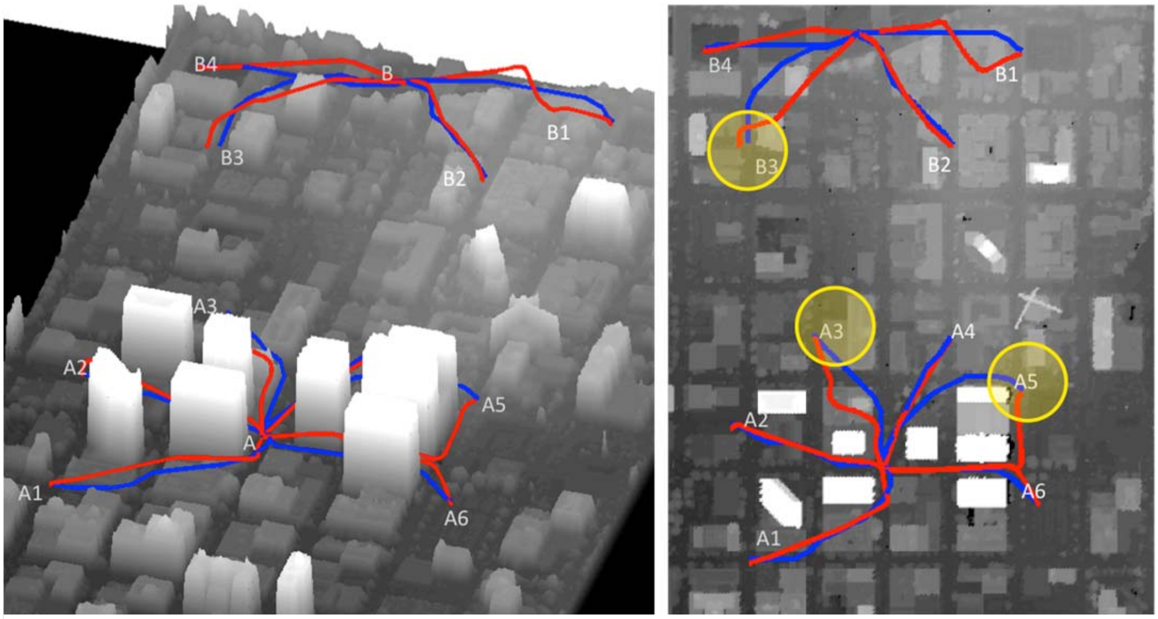

Figure 2: Trajectories of two sets of urban test case scenarios ("A" and B"). Results are shown for the benchmark's baseline (blue) and MiPlEx (red) at d_{sample}=20 m that was configured with a LIDAR obstacle sensor d_{range}=70 m.

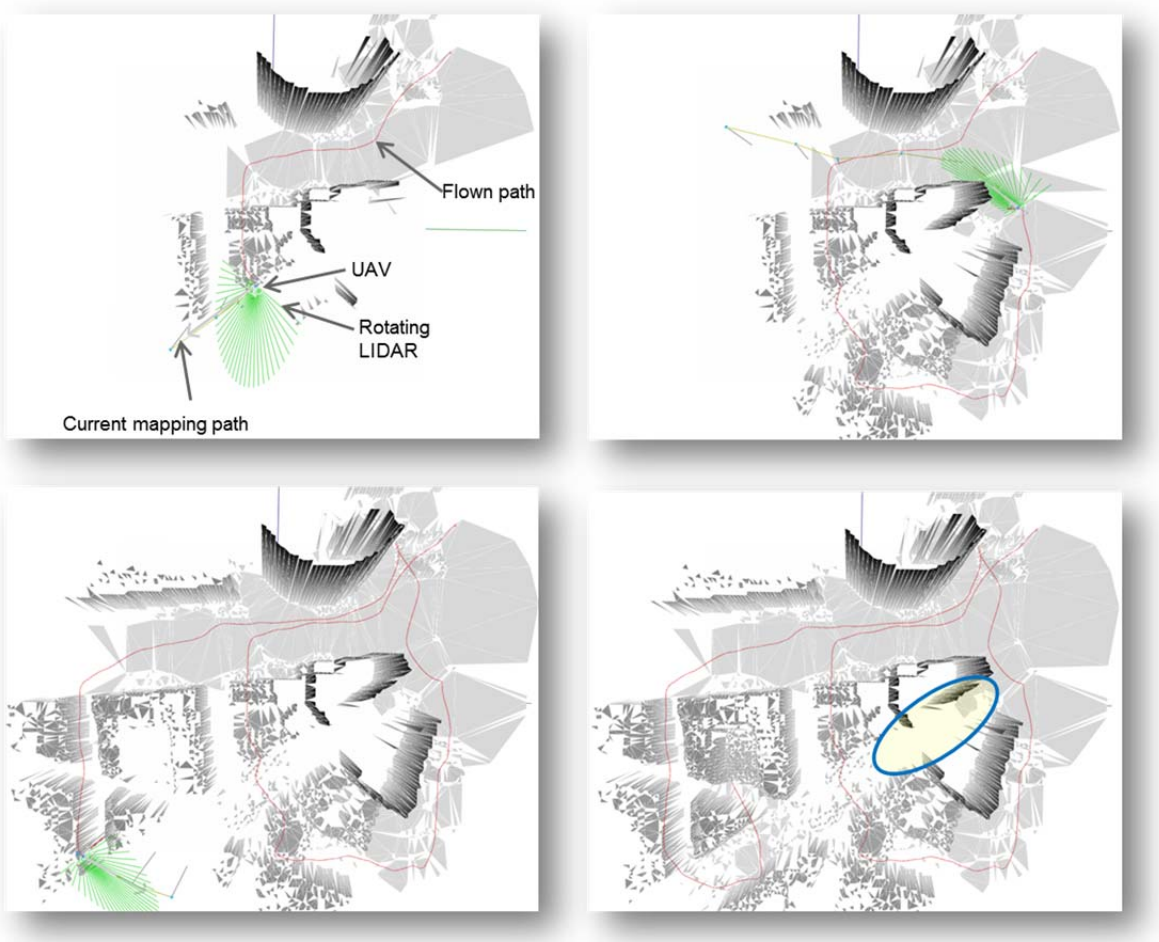

Figure 3: Top view of the exploration progress (from upper left to lower right). Example scenario shows city of Berlin at Potsdamer Platz: The rotorcraft decides for each temporary waypoint based on a cost-modified roadmap.