

Vision-based Autonomous Landing in Catastrophe-Struck Environments

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Control Problems in Robotics: Modeling and control of multi-rotor UAVs

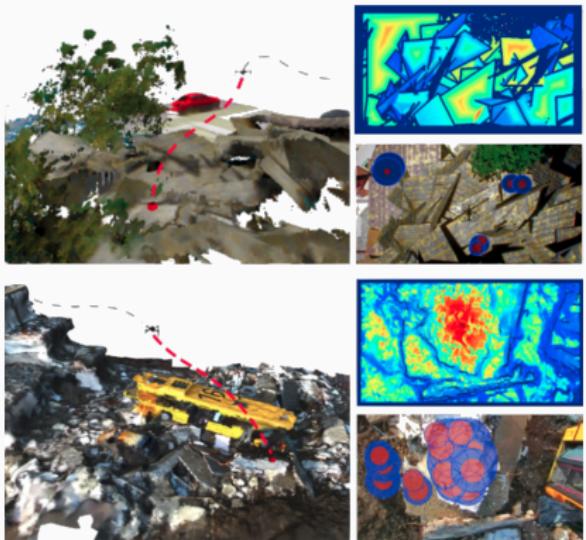
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Introduction

Intro.

- Why it's important
(bioradiolocation, also
emergency landing)
- previous work



Technical Approach

Brief introduction to ch. 3, describe approach and then discuss details.

- State Estimation
- Landing Site Detection
- 3D Volumetric Mapping
- Landing Trajectory Estimation

Technical Approach: State Estimation

- downward-facing stereo camera
- **ORB-SLAM2** (oriented FAST and rotated BRIEF)
- multi-sensor fusion (EKF) using IMU, barometer and GPS
- sensor precalibrated with Kalibr toolbox

Technical Approach: Landing Site Detection

Confidence in DEPTH INFORMATION J_{DE} :

$$J_{DE}(p) = 1 - \frac{D(p)^2 - \min\{D^2\}}{\max\{D^2\}}$$

with D depthmap obtained from the stereo camera and $p = (x, y)$ pixel in the depthmap.

Technical Approach: Landing Site Detection

FLATNESS INFORMATION J_{FL} :

$$di(B, p) = \min \left\{ \|p - q\| \mid B(q) = 1 \right\}$$
$$J_{FL}(p) = di(Canny(D), p)$$

with B binary image and p, q pixels in the image plane. *Canny* applies the Canny edge detector over the depthmap D .

Technical Approach: Landing Site Detection

STEEPNESS INFORMATION J_N :

- point cloud from the depthmap in global frame
- average 3D gradients algorithm to estimate normals map N
- evaluate deviation of the normalized surface normal \hat{n} wrt z-axis \hat{z} in the world frame: $\theta = \cos^{-1}(\hat{n}^T \hat{z})$
- compute $n(p)$ steepness score for each pixel p given $\theta_{th} = \pi/12$ maximum tolerable slope

$$n(p) = \exp \left\{ -\frac{\theta^2}{2\theta_{th}^2} \right\}$$

Technical Approach: Landing Site Detection

ENERGY CONSUMPTION INFORMATION J_{EC} :

$$J_{EC}(p) = \int_{t_0}^{t_f} P(t) dt$$

with t_0 and t_f time of flight to reach p and $P(t)$ instantaneous battery power. Approximate the integral with Euclidean distance between the UAV and p .

Technical Approach: Landing Site Detection

Scale the costmaps to the same range through min-max normalization and compute the final decision map J taking a weighted sum:

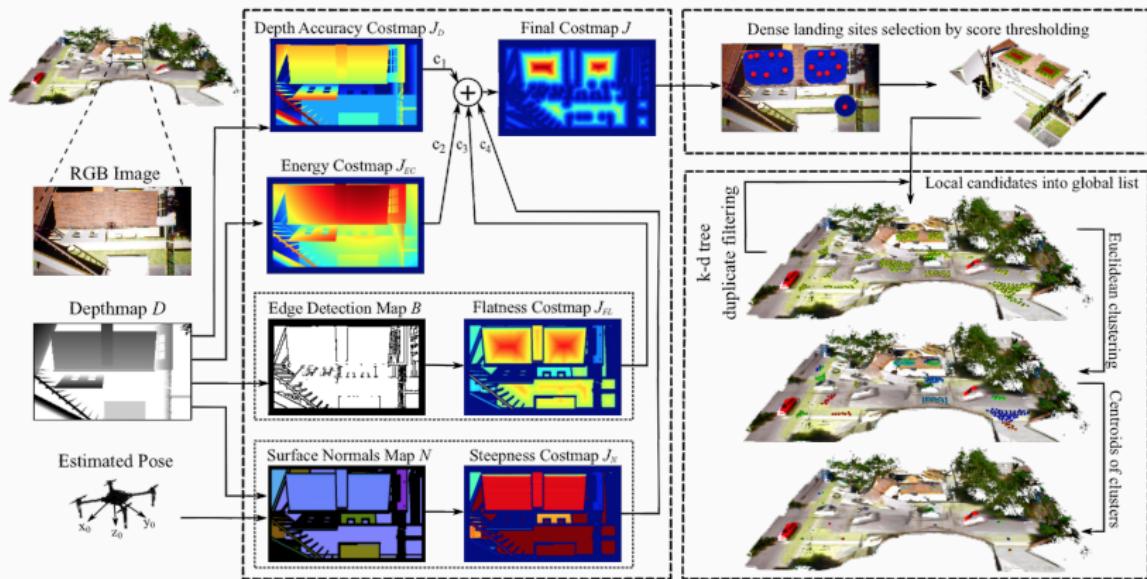
$$J = c_1 J_{DE} + c_2 J_{FL} + c_3 J_N + c_4 J_{EC}$$

$$c_i \in [0, 1] \quad \sum_i c_i = 1$$

- keep the sites checking whether the UAV could actually land
- k-d tree to efficiently store new landing sites
- hierarchical clustering algorithm to agglomerate sites

Technical Approach: Landing Site Detection

Figure 1: Overview of the landing site detection algorithm. In the costmaps, red indicates high score while blue indicates a lower score. Detected landing sites are projected onto a 3D reconstruction of the environment.



Technical Approach: 3D Volumetric Mapping

Probabilistic volumetric map:

- navigation and planning
- low-resolution map (0.5m) using **OctoMaps**
- faster trajectory planning

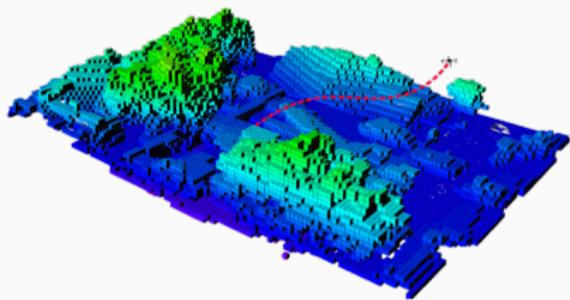
3D textured mesh:

- dynamic map growing using **Voxblox**
- high-resolution mesh transmitted to the rescue team

Technical Approach: Landing Trajectory Estimation

Minimum-jerk trajectory generator with non-linear optimization:

- RRT* for collision free path
- line-of-sight for waypoints
- minimum-snap polynomial trajectories using differential flat model
- high speed arcs in obstacles free regions
- low velocities in tight places



Experimental Evaluation

Description:

- Hyperrealistic Simulation
 - Real-World Outdoor (Training Center for Rescue, Germany)
- + computation costs

Experimental Evaluation: Hyperrealistic Simulation

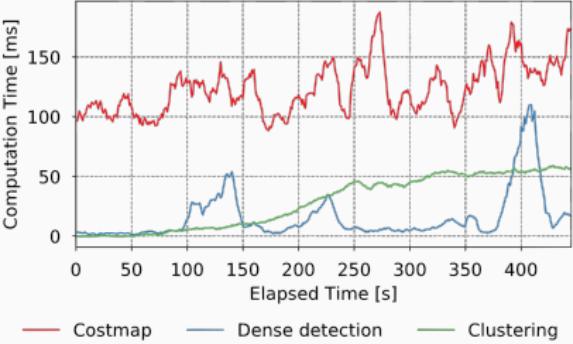
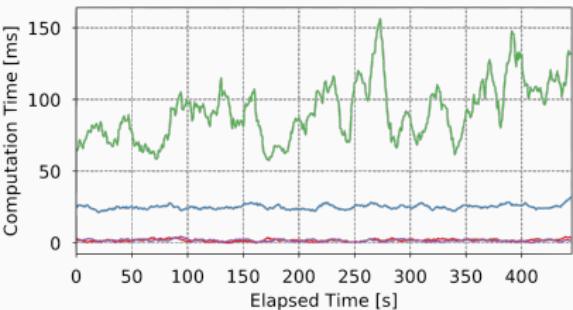
Hyperrealistic Simulation Experiments

Experimental Evaluation: Real-World Outdoor

Real-World Outdoor Experiments

Experimental Evaluation: Computation Costs

Computation costs



Conclusion

Conclusion.

Q&A

References

-  M. Mittal, A. Valada, and W. Burgard, “Vision-based autonomous landing in catastrophe-struck environments,” *CoRR*, vol. abs/1809.05700, 2018.