Aerial Robots for Rapid Response: Remote Autonomous Exploration and Mapping

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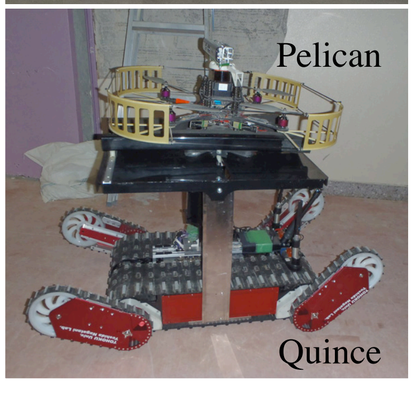
Abstract: We report recent results from field experiments conducted with a team of ground and aerial robots toward the collaborative mapping of an earthquake-damaged building. The goal of the experimental exercise is the generation of 3D maps that capture the layout of the environment and provide insight to the degree of damage inside the building. The experiments take place in the top three floors of a structurally compromised engineering building at Tohoku University in Sendai, Japan that was damaged during the 2011 Tohoku earthquake. We provide details of the approach to the collaborative mapping and report results from the experiments in the form of maps generated by the individual robots and collaboratively.

The building suffered significant structural damage due to the earthquake.

Panoramic images depicting the interior of the building. These images are representative of the clutter found throughout the experimental areas.

Objective: We consider the problem of cooperative mapping of an earthquake-damaged building with ground and aerial vehicles. The goal of the project is to develop rich 3D maps of multi-story buildings in search and rescue scenarios.

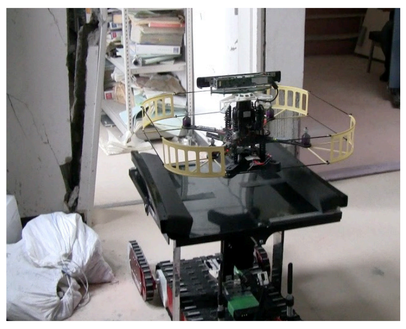
Approach: We first deploy a tele-operated ground robot (Kenaf) equipped with an onboard 3D laser scanner to generate a 3D map of the environment and identify locations inaccessible to the ground robot. We then deploy a second ground robot (Quince) that carries an aerial robot (Pelican) to the inaccessible regions to complete the map. The aerial robot autonomously takes-off and lands on an automated landing pad that also secures the aerial robot during transport.

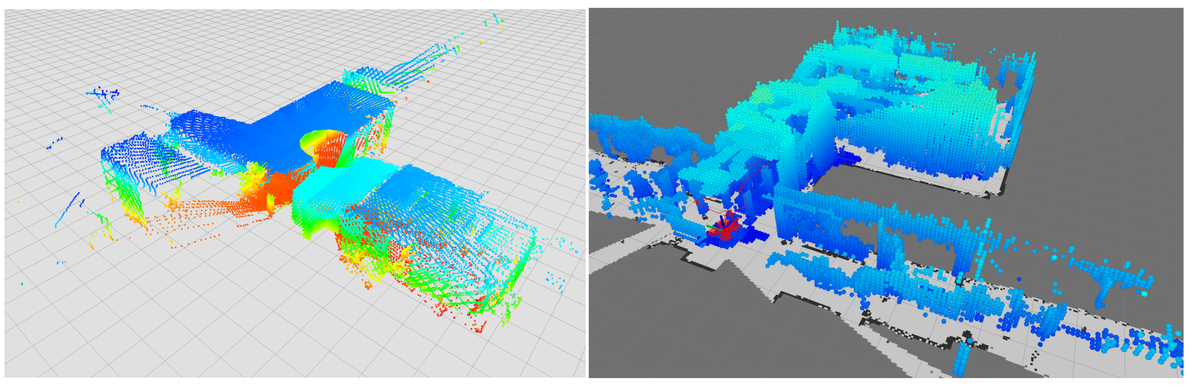


Motivation for Heterogeneous Robots: The experiment design highlights the need for heterogeneity. Ground robots do not suffer as greatly from the same payload limitations as quadrotors and are therefore able to carry larger sensor payloads, maintain tethered communication links, and operate for longer periods of time. However, quadrotors provide mobility and observational capabilities unavailable to ground robots. Hence, to build a rich 3D representation of the environment, we leverage the advantages of each platform and in doing so, mitigate the platform limitations.

The aerial robot flies through cluttered regions of the environment that are inaccessible to the ground robot and builds a 3D map that will be merged with the maps made by the ground robot.

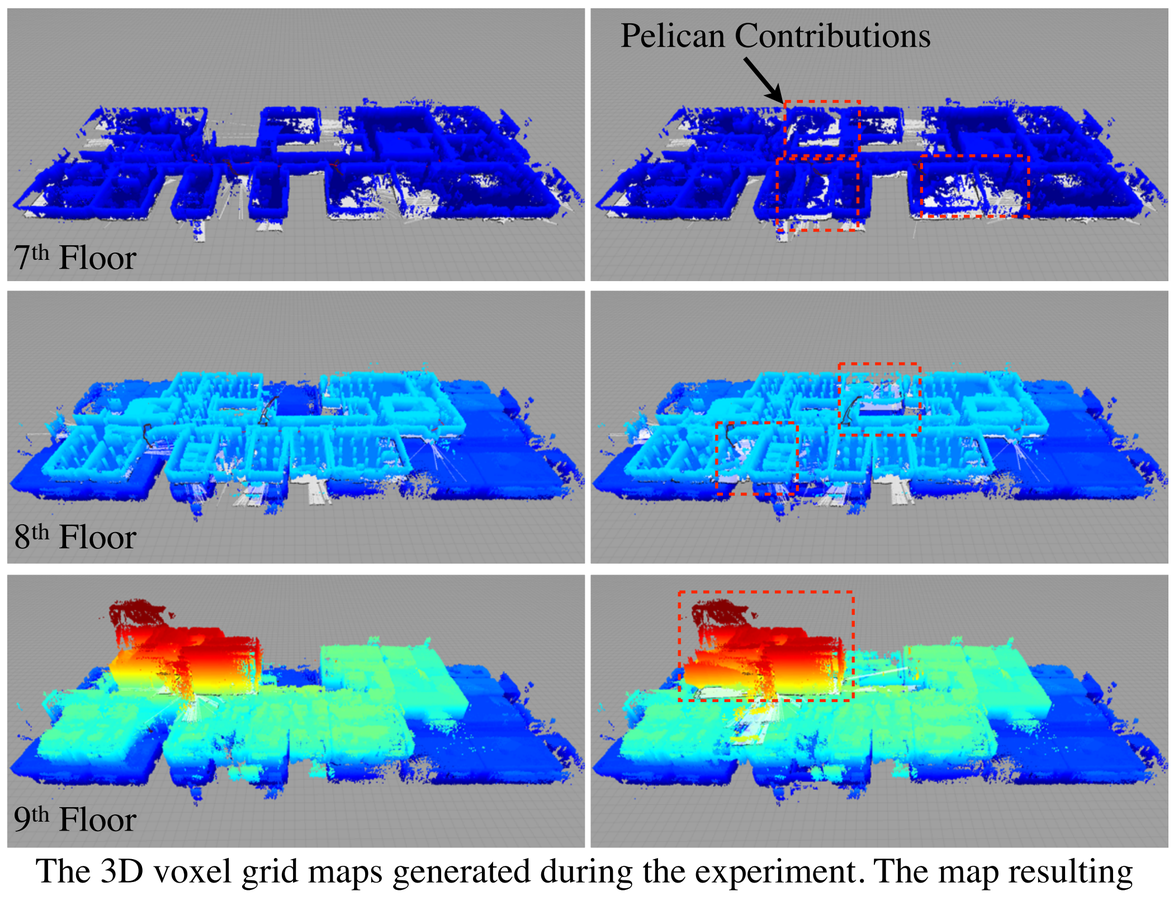
Autonomous Take-Off and Landing: After the ground robot transports the aerial robot to regions of interest, the aerial robot signals the automated landing pad to open and autonomously takes-off. Upon completion of the mapping and inspection, the aerial robot autonomously lands and signals the pad to close.





Sensor Data: (Left) The 3D rotating laser scanner on the Kenaf generates feature-rich 3D point clouds. Here we show the full output from a single revolution of the scanner. (Right) A representative 3D map generated by the aerial vehicle during flight. A 2D occupancy grid map is also generated at all times. The vehicle and its trajectory are shown as a red mesh and line, respectively.

Experimental Results: The collaborative mapping between the aerial and ground robots yields consistent 2D and 3D maps across the 7th, 8th, and 9th floors of an earthquake-damaged building. The maps provide insight into the layout of the building and show details such as structural reinforcements and broken windows.



The 3D voxel grid maps generated during the experiment. The map resulting from the Kenaf sensor data is shown on the left while the merged maps resulting from both the Kenaf and Pelican sensor data are shown on the right.

References:

N. Michael et al. Collaborative mapping of an earthquake-damaged building via ground and aerial robots. In *Proc. of the Intl. Conf. on Field and Service Robot.*, Matsushima, Japan, July 2012. Submitted.

N. Michael et al. Collaborative mapping of an earthquake-damaged building via ground and aerial robots. *J. Field Robot.*, Jan. 2012. Submitted.