Supplemental Materials S1: Skydio 2+ drone system

Object avoidance and autonomous exploration of 3D spaces to determine a flight plan are two hallmarks of the Skydio drone series, including Skydio's entry-level, low-cost 2+ platform [28] (Supplemental Materials Figure 1). The Skydio 2+ includes obstacle avoidance in all directions as its default. Skydio safety documentation suggests that the drone can and will avoid anything over 1.27 cm (0.5 in) in diameter, although moving objects (e.g., branches moving in the wind, moving people or animals, moving cars) may not be identified correctly for avoidance. Obstacle avoidance is achieved through the use of six cameras with fish-eye lenses rigidly mounted on the body of the drone, with three facing upwards and three facing downwards. The continuous data from these six cameras feed an NVIDIA Jetson Tegra TX2, a processor capable of 1.3 trillion floating point operations per second. Software on the TX2 creates a near-real-time point cloud model of the environment surrounding the drone, used for situational awareness, flight planning, and obstacle avoidance. The base obstacle avoidance for the Skydio 2+ is approximately one meter in all directions. With the addition of Skydio's Enterprise firmware, this parameter can be adjusted by the user, down to 12.7 cm.

Supplemental Materials Figure S1. Skydio 2+. Skydio 2+ on top of the carrying case which also contains the batteries and controller, in the field in Black Mesa State Park, Oklahoma. The case was also used as the launching and landing pad.

The second distinct characteristic of the Skydio 2+ lies in its ability to use this internal model of its surroundings to autonomously create flight plans for 3D and 2D missions, through its 3D Scan software, which can be conducted without GPS or cell service. There are options for "3D Capture", "2D Capture", "3D Tower Capture" and even "Indoor Capture", all of which work on the same principle. The pilot

defines a volume of interest (or a polygon for 2D Capture) with the drone itself, selecting floor and ceiling altitudes. The pilot then manually flies the unit to define the corners ("pillars" in Skydio jargon) using the 12-megapixel gimbaled primary camera on the drone. Within 3D Scan, the user can customize additional parameters before or after the exploration flight including the degree of overlap, resolution, and height of the flight.

Once the pilot is satisfied, the "Explore" button is selected in the 3D Scan app. The drone utilizes the six cameras on its body to identify objects within the volumetric aera of interest and creates an optimized flight plan for capturing images from the angles necessary for photogrammetry. The drone reports the number of images required, estimated flight time, and the number of batteries (up to three) needed for the mission. Before data acquisition, the pilot can adjust the flight plan settings further as desired, e.g., to shorten flight time or reduce the number of images. If the pilot is satisfied, the "Scan" button in the app sends the drone into operation, autonomously capturing photos at each location with the main camera. If a battery change is required, the drone returns home and prompts the pilot to land and swap batteries.

The associated case study evaluated both the Skydio 2+'s built-in capacity for obstacle avoidance and for 3D flight planning using Skydio's 3D Scan software. It considered the contributions these technologies can make for field research in remote, rugged environments.