

Introduction

Problem:

In industrial inspection, agricultural monitoring, and search-and-rescue missions, existing unmanned aerial vehicle (UAV) inspection systems encounter two critical challenges: (1) limited reliability in complex, unstructured, and GNSS-denied environments, and (2) a pronounced dependency on skilled operators.

Features:

We presents a LiDAR-based UAV inspection system employing a dual-phase workflow: human-in-the-loop inspection and autonomous inspection.

Human-in-the-loop Inspection

Untrained pilots are supported by autonomous obstacle avoidance, enabling them to generate 3D maps, specify inspection points, and schedule tasks. Inspection points are then optimized using the Traveling Salesman Problem (TSP) to create efficient task sequences.

Autonomous Inspection

The quadrotor autonomously executes the planned tasks, ensuring safe and efficient data acquisition.

Method

Human-in-the-loop Inspection

The quadrotor is guided by the pilot's joystick commands and data inputs from onboard sensors (e.g., LiDAR and IMU) to perform inspection tasks in an unknown and cluttered environment. The pilot controls the quadrotor to reach the inspection points and records the position $\mathbf{p}$, yaw angle ϕ , and gimbal pitch angle θ at each inspection point $\mathbf{q} = (\mathbf{p}, \phi, \theta)$. Simultaneously, the quadrotor autonomously avoids obstacles during flight to ensure flight safety. After completing the human-in-the-loop inspection flight, inspection points optimization solves the Traveling Salesman Problem (TSP) to reorder the recorded N inspection points $\mathbf{Q}_{ins} = [\mathbf{q}_{ins,0}, \mathbf{q}_{ins,1}, \dots, \mathbf{q}_{ins,N-1}]$ based on the shortest path criterion. The optimized N inspection points $\mathbf{Q}_{opt} = [\mathbf{q}_{opt,0}, \mathbf{q}_{opt,1}, \dots, \mathbf{q}_{opt,N-1}]$ are subsequently used as inputs for the autonomous inspection phase.

Autonomous Inspection

The quadrotor, relying on LiDAR and IMU sensors, autonomously executes repetitive inspection tasks within the environment previously explored during the human-in-the-loop inspection phase. The quadrotor navigates to the optimized inspection points in sequence, collecting image and LiDAR data for subsequent detailed analysis.

System Overview

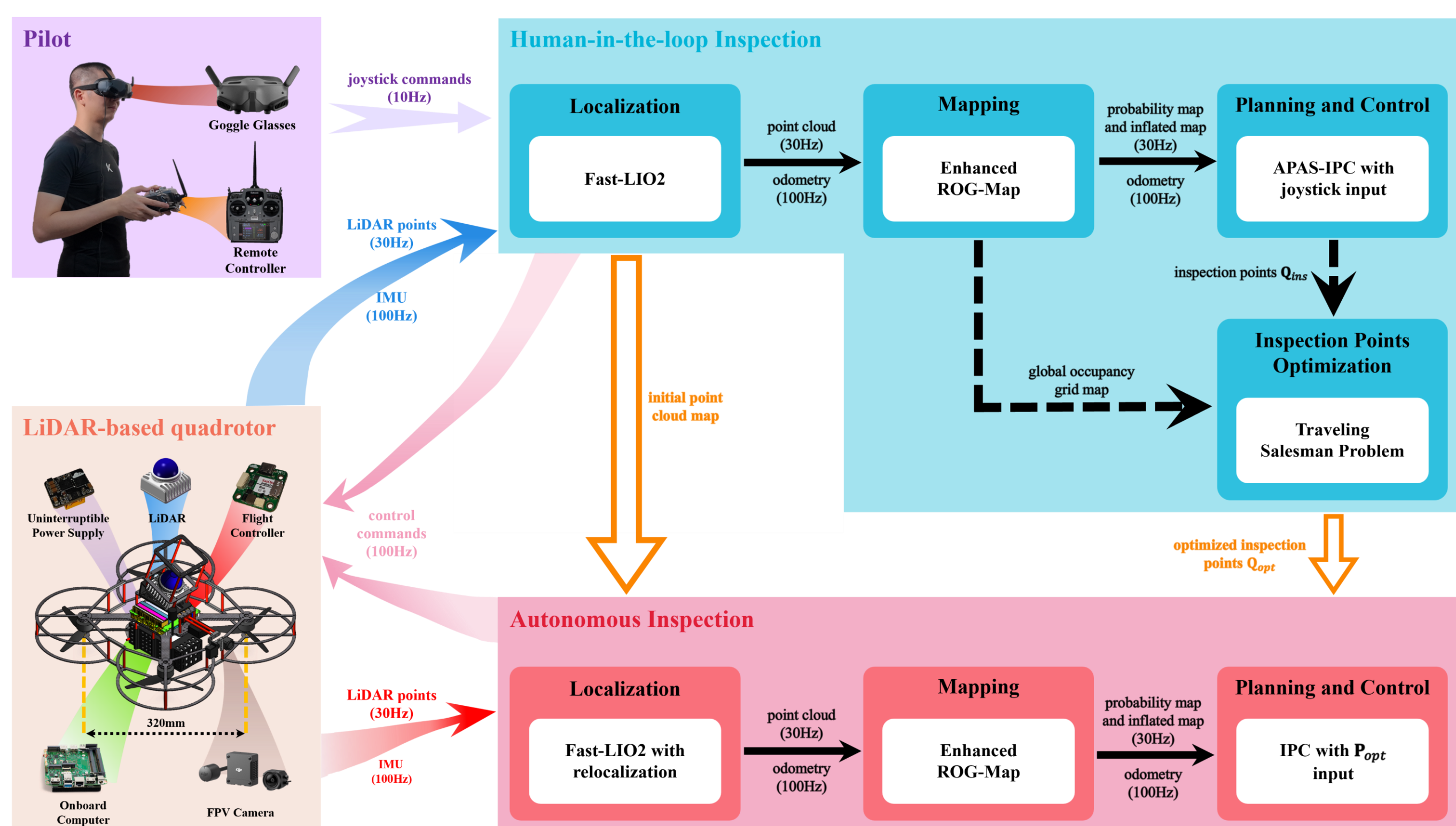


Fig. 1. The system overview of our LiDAR-based quadrotor Autonomous Inspection System.

Hardware Structure

Our quadrotor features a motor-to-motor distance (i.e., wheelbase) of 320mm and overall dimensions of 422mm in length, 422mm in width, and 270mm in height. With a total mass of 2kg, the quadrotor achieves a thrust-to-weight ratio of 3, ensuring efficient and stable flight performance. Additionally, the maximum flight endurance is measured to be 12 minutes.

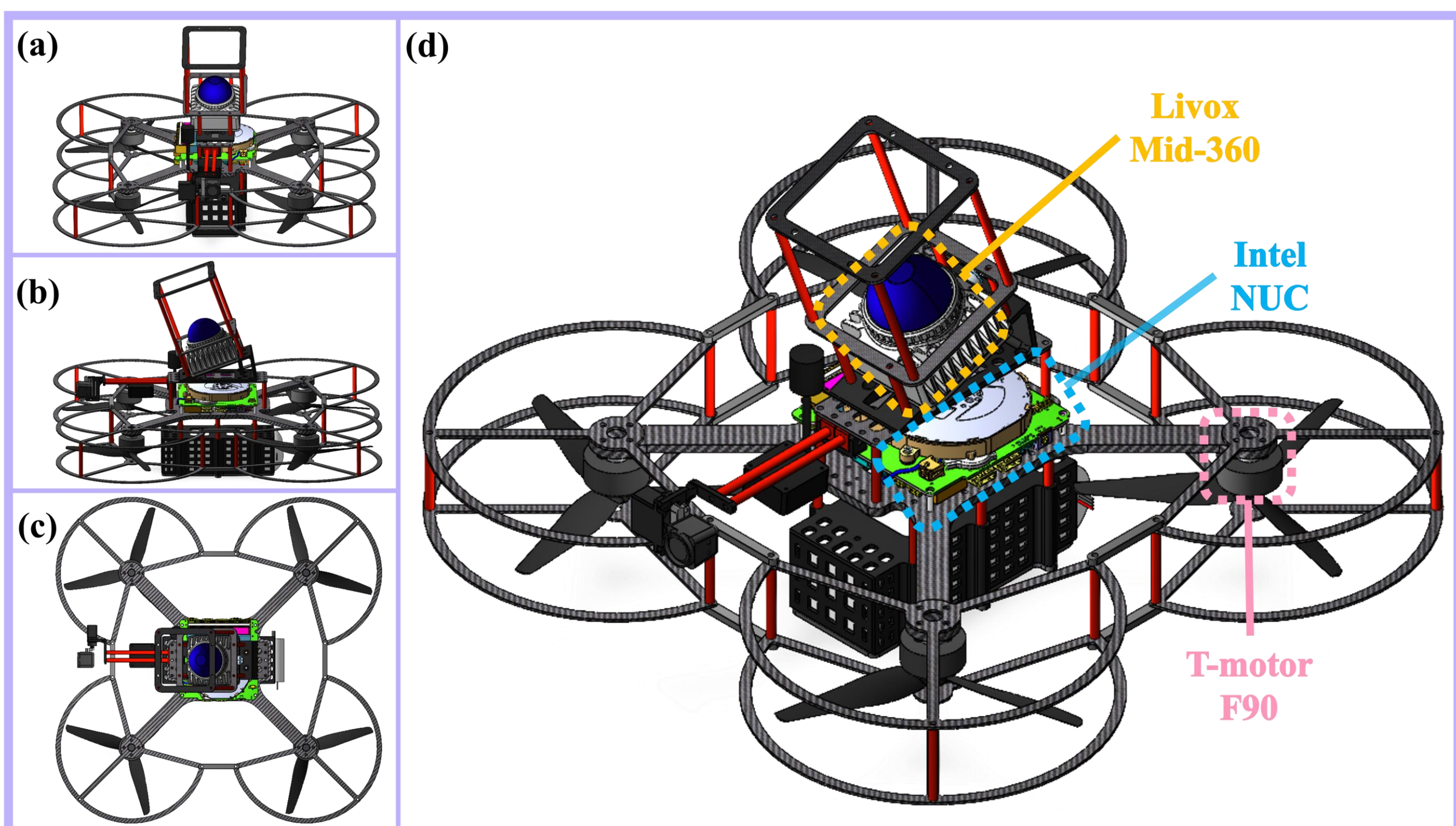


Fig. 2. Different views of our LiDAR-based quadrotor.

Field Experiments

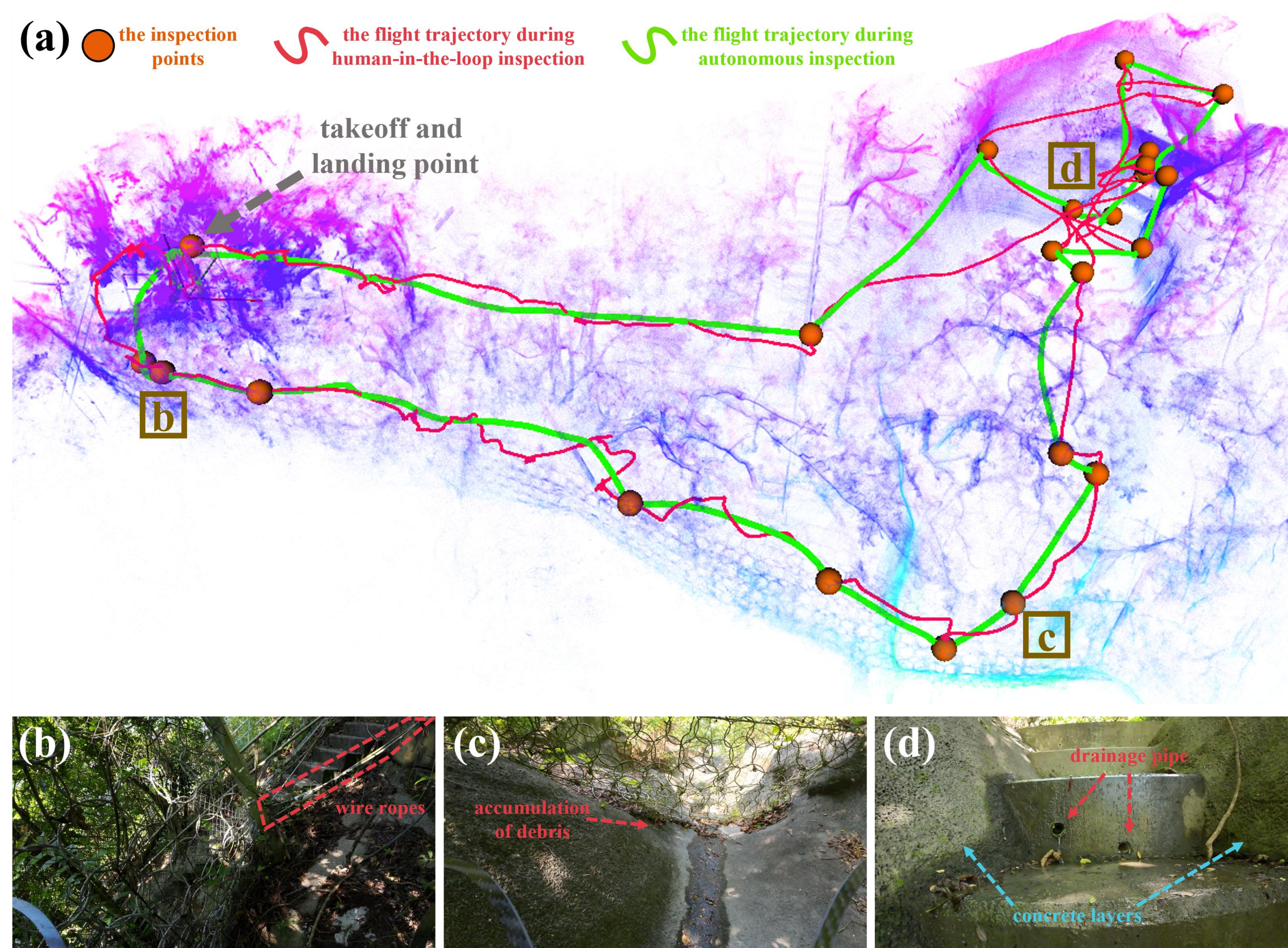


Fig. 3. Overview of the quadrotor inspection system in slope task. (a) Point cloud map constructed during the inspection. (b) Image captured of the corrosion of the wire ropes supporting the barriers. (c) Image captured of the accumulation of debris behind barriers. (d) Image captured of the condition of the blocked drainage pipe and corrosion within the concrete layers.

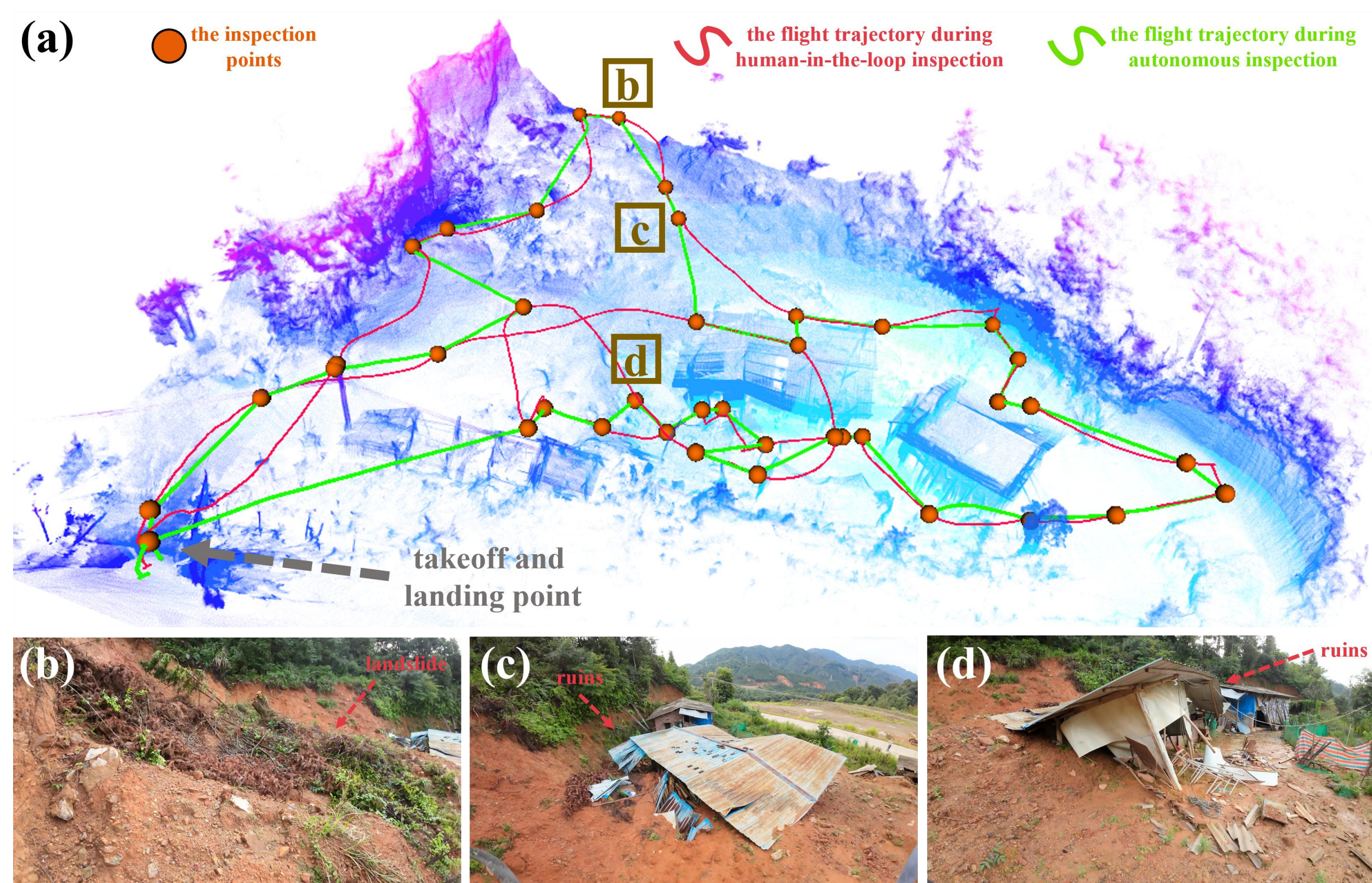


Fig. 4. Overview of the quadrotor inspection system in landslide task.. (a) Point cloud map constructed during the inspection. (b) Image captured of the surface characteristics of the landslide. (c-d) Image captured of the condition of the ruins.

