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Mapping gold mines under the French Guiana rainforest: return of experience with different mobile lidar systems

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Gold is abundant in the greenstone belts of the Guiana shield, in South America, leading to alluvial mining in river sediments and in in-situ rocks. In French Guiana, legal mining takes place under strict environmental regulations and controls, but illegal operations also occur uncontrolled in the vast expanses of the rainforest. Here we describe a successful range of mobile lidar systems, acquisition schemes and processes to map the ground and underground mining operations in a rainforest context. We seek to detect illegal operations, supply and transportation pathways and base camps, using crewed planes and helicopters, uncrewed fixed-wing and multi-copter vehicles (UAV) and handheld lidar systems.

To sense ground elevation below the canopy, airborne lidar systems face three challenges: tree heights (some trees exceed 70 m in height), incised topography (requires performant terrain following capabilities), dark and wet ground surface largely absorbs lidar pulses requiring powerful sources. Tested uncrewed airborne vehicles (UAV) did not yet meet all of the flying autonomy, terrain-following capability, lidar range and on-board decision systems. At present, crewed systems adapt better to conditions and achieve mission objectives.

Over forested areas, observed canopy penetration rates is of the order of 1 ground point for 250 lidar pulses (0.4%). To generate a 1-m/pixel Digital Terrain Model (DTM) with a minimum of occluded pixels, acquisition density should exceed 250 pts/m² at canopy level everywhere. In Dorlin (central French Guiana), a helicopter flew 85-m-above ground-level, 70 % side-lap and 90° cross-lines, using a Riegl VUX-1LR lidar. Targeting 400 pts/m² at canopy-top for 95 % of the 220 ha territory, it reached a canopy-top density of 1400 +/- 750 pts/m² and 43 pts/m² ground density overall. On fully forested areas, ground density dropped to 22.4+/-22.6 pts/m² with 5% of the surface never receiving points at 1 m² level. This enabled interpolation of a 25cm/pixel DTM, which revealed narrow paths, quad tracks, and shaft platforms and head frames under the forest. 2-m kernel high-pass filtering enhanced features better than a standard hill shading. Base camp hut structures, invisible in DTM, are retrievable from native point clouds in a 4 to 5 m-above-ground elevation range. Huts covered in black tarpaulins stand out as rectangular hollow patches due to lidar photon absorption. But even without tarpaulin, hut wooden frames stand out particularly

well when point cloud subsets are lit up with the PCV filter of Cloud Compare. Ore-bearing quartz stockpiles however are too small and occluded for a reliable detection and volume computation.

Instead, SLAM-based handheld lidar systems (GeoSLAM Zeb-Revo and Zeb-Horizon) complement the detailed mapping of quartz stockpiles volume, shaft conduit geometry and gallery entrances. Then real-time, SLAM-based quadcopter UAV lidar (Flyability Elios 3) safely penetrates shafts from the surface to explore the underground gallery network. These new millimetre-scale density point clouds critically reveal spacing, orientation and dimensions of ore-bearing veins, which improves the metallogical understanding of the site and uniquely documents the way artisanal illegal miners operate.

Lidar acquisitions and processing are now being streamlined for systematic use in law enforcement operations and environmental protection actions.