First-Ever Demonstration of Drone-Borne SAR Underground Tomography for Sub-surface Mapping

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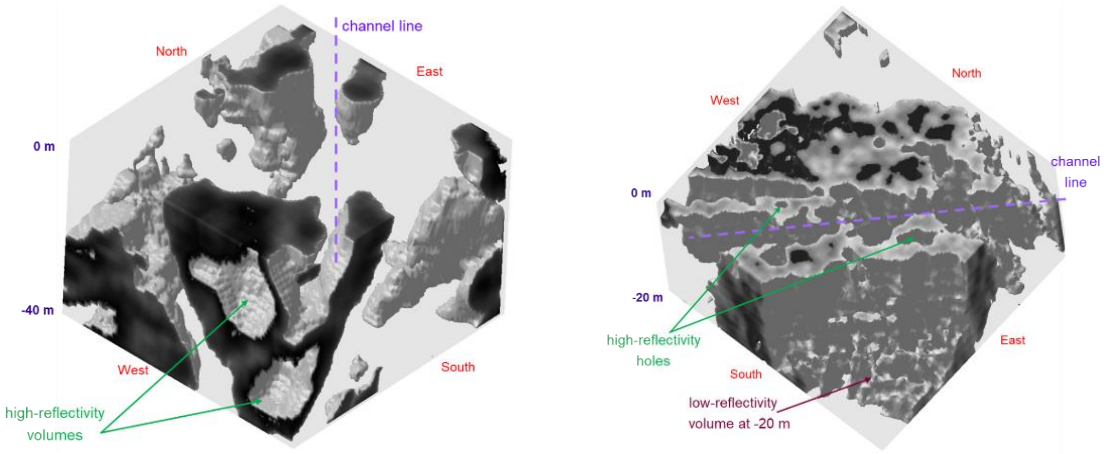
In this paper, we present the first-ever demonstration of subterranean structures survey using underground tomography with data obtained from a drone-borne synthetic aperture radar (SAR).

The first demonstration was performed on a natural underground cavity located in Abu-Dhabi, UAE. The 3D images were obtained using a drone-borne system equipped with a polarized P-band and a fully polarimetric L-band radar, producing details at depths of 40 and 20 meters, respectively.

The surface scanned consisted of 0.6 x 0.6 km^2 area. The drone performed three helical flight paths over the area (mean diameter of 250m, 3 turns, maximum height 120m, minimum height 90 m), totaling a survey time of 45 min.

The technique used to reconstruct the images is called vertical sub-aperture [1-3]. This technique exploits the repeated passes of the airborne SAR system to synthesize the image. Like the azimuth direction, a large antenna is also synthesized along the elevation direction to achieve a beam sharpening that reconstructs the vertical backscattering properties. To achieve the 3D imaging capability, the data processing involves two steps: the azimuth and range focusing on achieving planar (azimuth-rage) high resolution and the elevation focus to reach resolution capability in the third dimension.

Figure 1 presents the SAR subsurface images acquired. Figure 1(a) displays a P-band SAR tomography image from 0 to -40 m; Figure 1(b) shows a L-band SAR tomography from 0 to -20 m in the same area. These images show low-reflectivity surface areas related to the soil density in the region that presents the reflection of the electromagnetic waves. Additionally, high-reflectivity volumes are detected, indicating underground hollow cavities or a change in the soil density in the regions.



(a) (b)

Figure 1. Results of the first Demonstrator (a) P-band SAR tomography from 0 to -40 m. (b) L-band VV SAR tomography from 0 to -20 m.

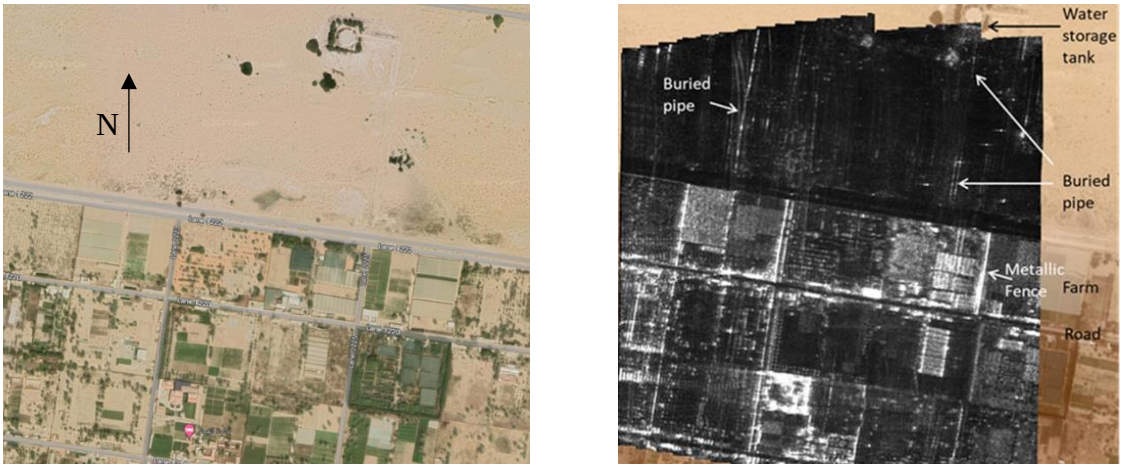


Figure 2. Results of the second demonstrator. (a) Optical Image, (b) SAR Image. See the location of the buried pipes going from the water storage tanks located in the north to the farms located in the south. The area shown is 1.2 x 1.2 km2.

The team successfully demonstrated the technique in a separate second study. In this case, the location and depth of underground pipes (water distribution steel pipes) were mapped; see Figure 2 for details. The surface scanned consisted of a 1.2 x 1.2 km^2 in an area of mixed-use irrigated farmland in Abu-Dhabi, UAE.

The results demonstrate the feasibility of subsurface imaging using drone-borne systems for inspecting underground natural-made cavities (such as sinkholes, aquifers, caves, among others) and man-made underground structures such as underground pipes.

Additionally, the results can be integrated with those obtained from space-based SAR, such as the SIRB constellation, recently announced by the UAE Space Agency [4], enhancing the versatility and applicability of surface and subsurface imaging systems.

References

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