Impact of Soil Roughness in Underground Focusing SAR Images

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April 13, 2010

Introduction: Problem Identification

Underground tunnels present both military and homeland security threats:

- Smugglers have turned tunnels into transit routes for trafficking weapons, people, drugs, and other illicit materials.
- Assailants might use tunnels to burrow under high security facilities to detonate lethal explosives.
- Tunnels can be utilized to avoid security checkpoints (especially on country borders).

Tunnel detection and real-time monitoring is a desired solution to these national security problems.

Figure 1: A tunnel near Otay Mesa, California (Sandy H, Getty Images, 2006); and another starting in an abandoned house in Tijuana, Mexico (David Maung,AP, 2004)

- Detecting and imaging the presence of tunnels in any given region of ground is possible because the air that fills them is materially quite different from anything else underground.
- A sufficiently strong and distinct signal from the target greatly improves the probability of finding tunnels in the field .
- This work explores the impact of surface roughness in **Underground Focusing Spotlight Synthetic Aperture Radar** (UF-SL-SAR) imaging for tunnel detection applications in two different scenarios: non-dispersive sandy soil and dispersive clay loam soil.

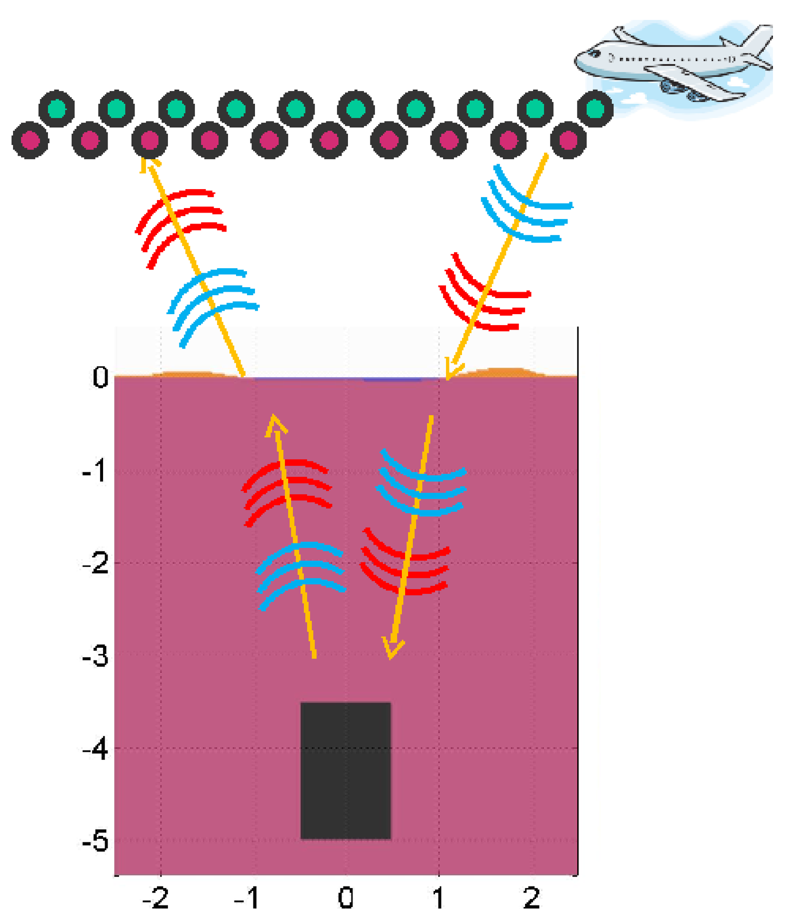

Figure 2: **Trajectory of wave** from the 19 sources to the 19 receivers

Experiment Configuration

- Consider UF-SL-SAR applied to detect tunnels as shown in Fig. 3. A radar mounted on a plane flights over a certain region with a suspected buried tunnel. Fig. 3(a) presents the baseline configuration used in this work. It consists of a rectangular tunnel with height and width dimensions of 1.5 m and 1 m respectively.
- The interface between air and ground is rough with random horizontal bumps arranged with correlation factor of 1 m and amplitude characterized height factor of 0.1 m. A typical UF-SL-SAR configuration [1] uses multiple view angles to achieve adequate **cross range resolution** (see Fig. 3 (b)), while multiple frequencies at each aspect angle is used for **range resolution** (see Fig. 3 (c)).
- The UF-SL-SAR process used 19 equally spaced view angles, ranging from $\theta_{ini} = -45°$ to $\theta_{end} = 45°$; and a set of a hundred and twenty eight frequencies, ranging from $f_{ini} = 50$MHz to $f_{end} = 550$MHz.
- The SAR images were created with a Underground Focusing algorithm [2] that followed a **mono-static radar configuration** (19 collocated transmitters and receivers) with the antennas positioned at **100 m above the surface.**

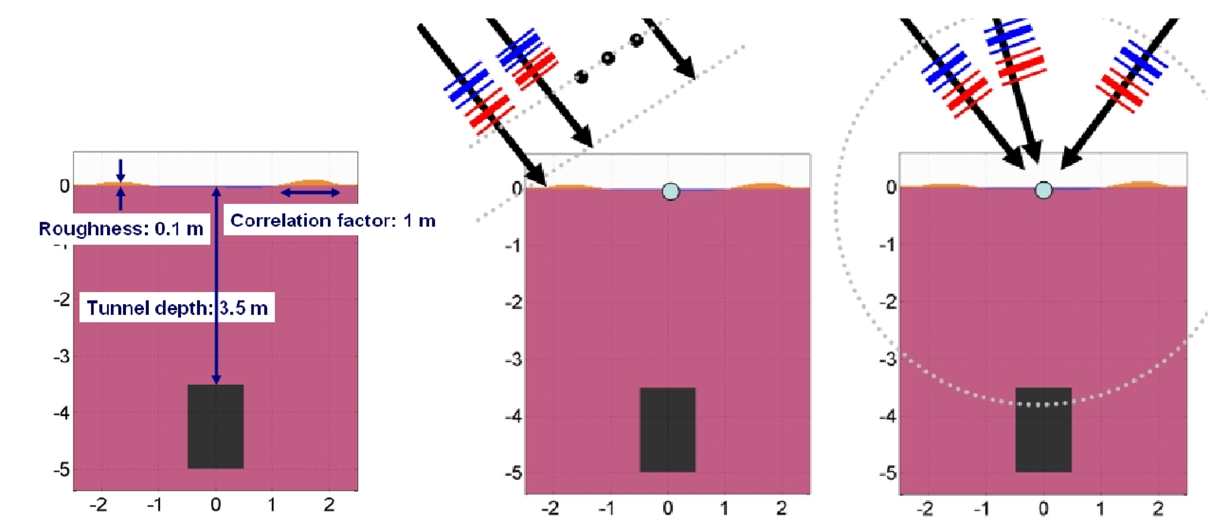

Figure 3: **Spotlight Synthetic Aperture Radar configuration**: (a) example of tunnel configuration, (b) schematic of a multiple aspect angles, (c) schematic of a multiple frequencies per aspect angle. *Horizontal axis is Transverse Position [m], Vertical axis is Depth [m]*

Results

- In order to generate a focused SAR image, the algorithm takes into account the constitutive parameters of both media and the wave refraction at the air/ground surface interface [3].
- This study simulated tunnel imaging on 2 different soils: non-dispersive sandy soil and dispersive clay loam soil.

Non-dispersive sandy soil

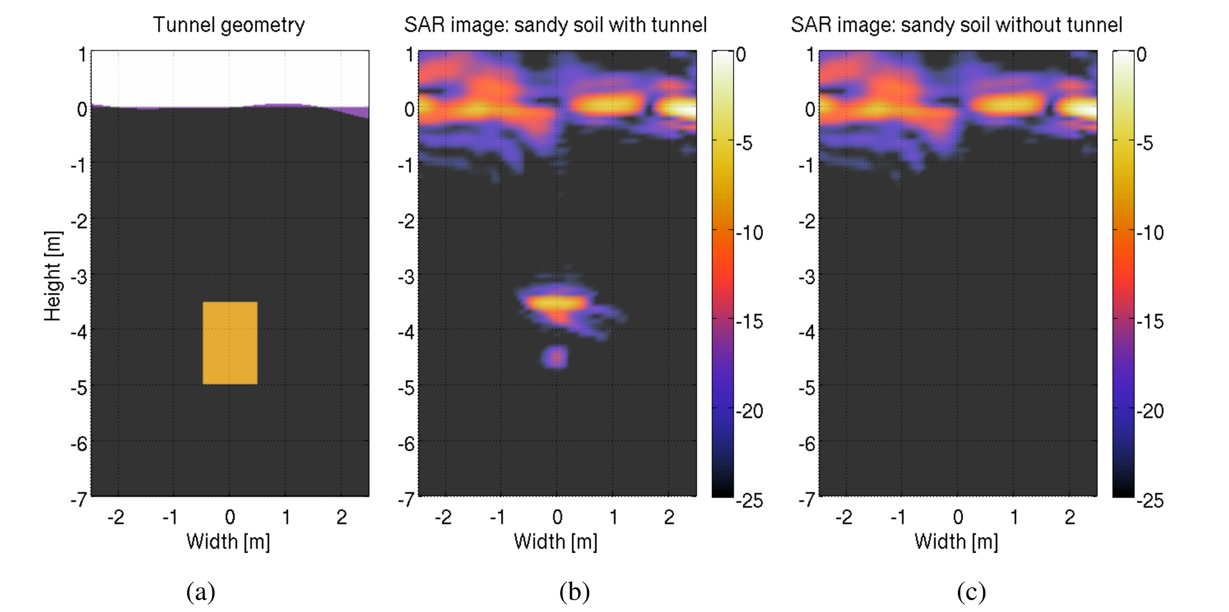

Figure 4: (a) Geometry with roughness = 0.1 *m* (b) **Tunnel reconstruction at 100 m** from ground with tunnel, (c) **Tunnel reconstruction at 100 m** from ground without tunnel.

- In order to quantify the impact of the surface roughness on tunnel detection, the SAR imaging process was performed on **sandy soil with a surface with roughness of 0.1 m**.
- Fig. 4 shows the geometry simulated and the SAR images for a case with a tunnel buried underground and a case without it.
- Since the tunnel was easily detectable in this particular case, the **surface roughness** was then increased to **0.5 m**.
- Fig. 5 shows the SAR imaging process implemented on sandy soil with a roughness of 0.5 m.

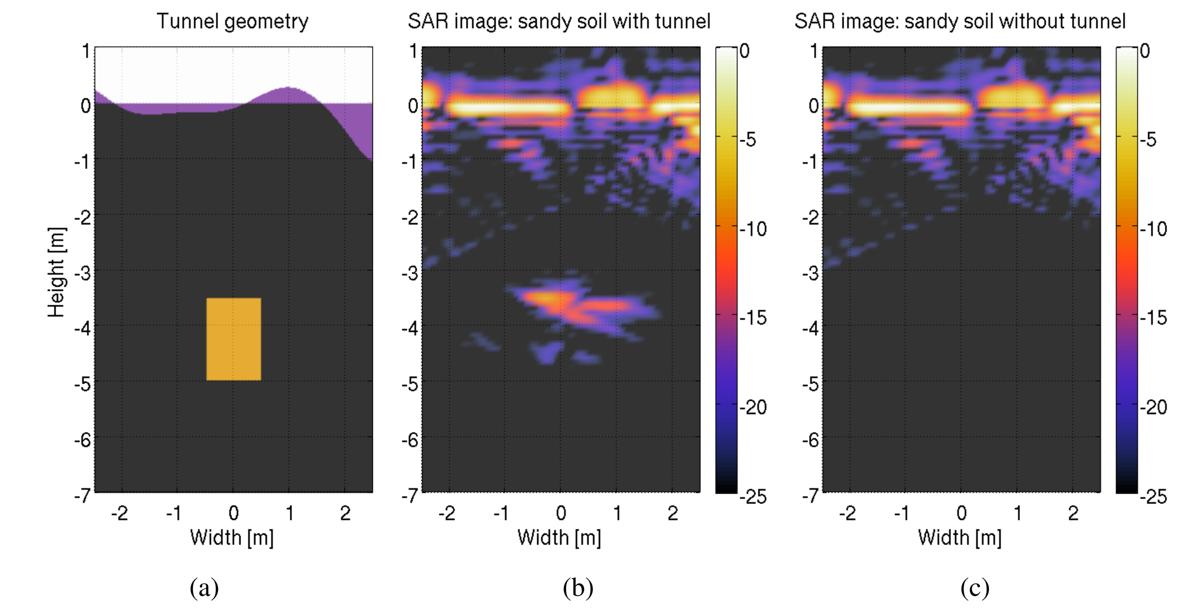

Figure 5: (a) Geometry with roughness = 0.5 *m* (b) **Tunnel reconstruction at 100 m** from ground with tunnel, (c) **Tunnel reconstruction at 100 m** from ground without tunnel.

- In this case, the tunnel image became distorted.
- The increased surface roughness deformed the shape of the buried tunnel.

Dispersive clay loam soil

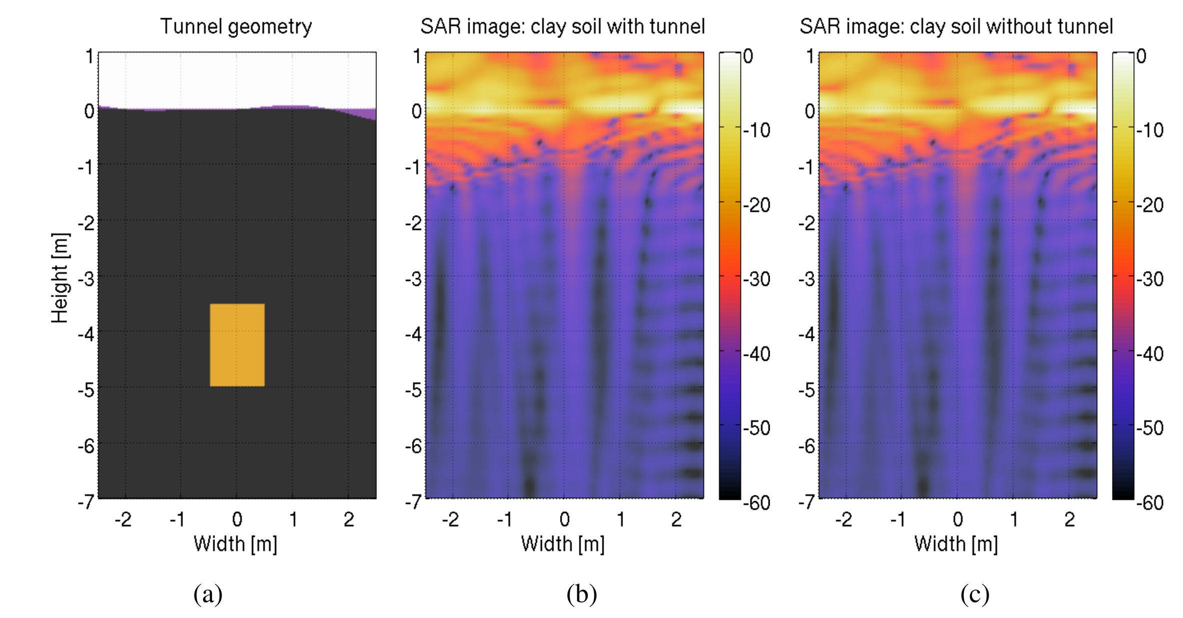

Figure 6: (a) Geometry with roughness = 0.1 *m* (b) **Tunnel reconstruction at 100 m** from ground with tunnel, (c) **Tunnel reconstruction at 100 m** from ground without tunnel.

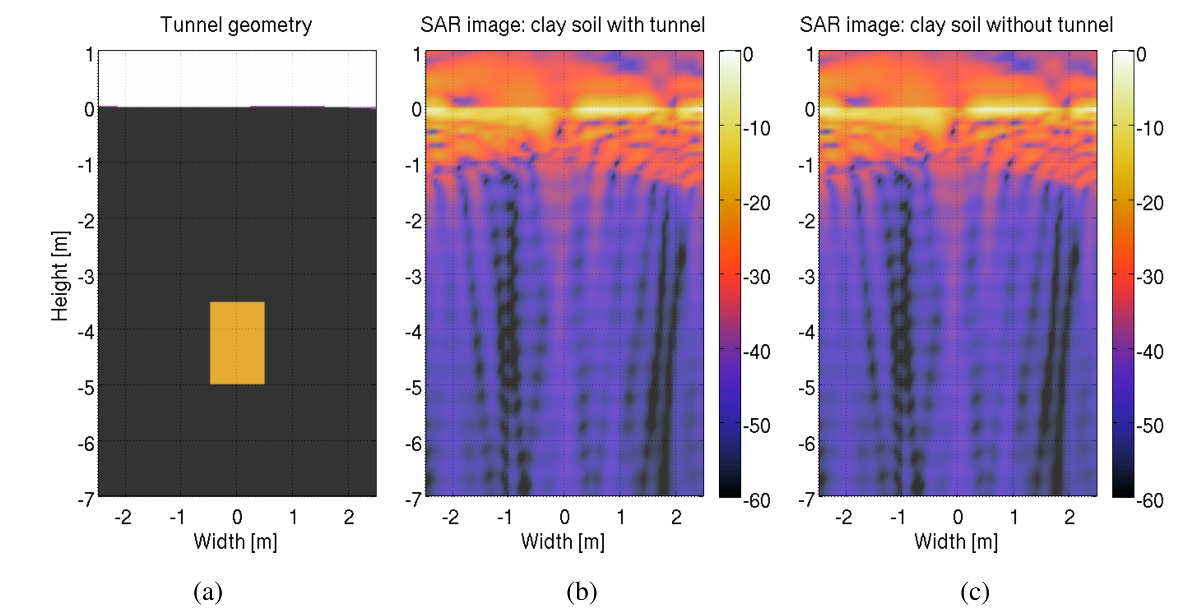

Figure 7: (a) Geometry with roughness = 0.02 *m* (b) **Tunnel reconstruction at 100 m** from ground with tunnel, (c) **Tunnel reconstruction at 100 m** from ground without tunnel.

- The next part of the study, involved simulating tunnel detection on a **dispersive clay loam soil with a surface roughness of 0.1 m.**
- Fig. 6 shows the imaging done on ground with and without a tunnel.
- With this soil characteristics, the tunnel cannot be differentiated from the background.
- Fig. 7 shows that even with a **surface roughness of 0.02 m**, the tunnel was not recognizable.

Conclusions

This work demonstrates that increased surface roughness degrades the quality of the reconstructed image, thus making the tunnel more difficult to detect. Detecting tunnels underground using UF-SL-SAR processing with a monostatic radar configuration located at 100 m above the ground has several limitations. Increasing the surface roughness of non-dispersive sandy soil beyond 0.5 m will distort the tunnel image and make its detection almost impossible. Nevertheless, tunnel detection is still possible for sandy soils with roughness less than 0.5 m. In addition, this work demonstrates that decreasing the surface roughness of dispersive clay loam soils to 0.02 m still does not permit succesful detection.

Acknowledgment: This work is supported by CenSSIS, the Gordon Center for Subsurface Sensing and Imaging Systems under the ERC Program of the NSF (Award number EEC-9986821), and Lockheed Martin ATL HiRFAR (Program PO-TT0709877.

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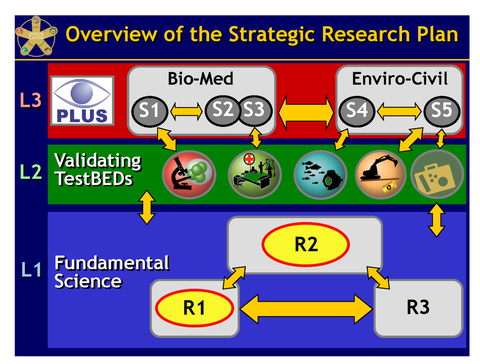

This project incorporates the first thrust level since it is a basic research project (Level L1), with elements of fundamental electromagnetic modelling (Finite Difference in Frequency Domain analysis) and signal processing (Synthetic Aperture Radar).