IGERT Intelligent Diagnostics

Square One | Systems Design

Modeling the Detection and Localization of Anti-Personnel Landmines using Ground-Contact Antennas for Ground-Penetrating Radar

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Motivation

- Landmines cause 15,000-20,000 casualties / year > 40% to children
- Landmines prevent use of land for farming effecting economical growth
- Plastic mines are hard to detect, especially in the presence of scrap metal or explosive residue
- Inexpensive detection is essential for humanitarian purposes

Project Goals

- Develop ground-penetrating radar for humanitarian demining to detect and localize both metal and plastic anti-personnel (AP) mines
- Use a robotic platform with ground contact antennas to autonomously detect and mark potential landmines

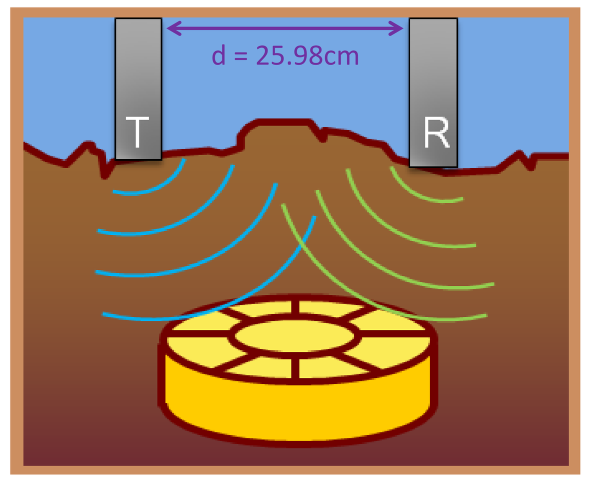
Modeling GPR with FDTD

- EM computational model discretizes Maxwell's equations to quickly and accurately predict electromagnetic field behavior
- Circular polarization is used for target enhancement, created using two out of phase orthogonal dipole excitations
- Finite Difference Time Domain (FDTD) spatial resolution and temporal resolution: 0.4 cm and 2 ps

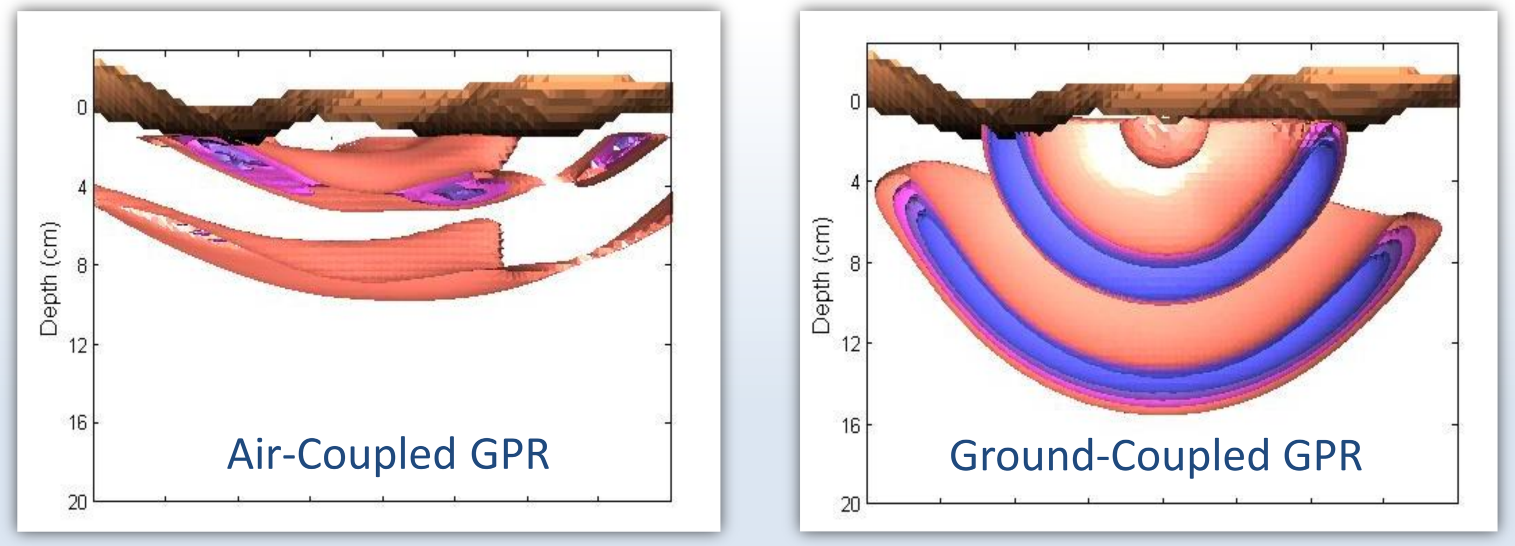
Advantages of Ground-Coupled GPR

How do ground-contact antennas simplify GPR analysis when the air-soil interface is rough?

- GPR images below a ground surface
- GPR is a relatively inexpensive mature technology
- Rough air-soil interface defeats traditional GPR by scattering waves randomly, making the received data difficult to analyze



- Non-metallic mines have weaker signals: harder to pick out from surface clutter
- When the antennas are in contact with the ground, the subsurface waveform is nearly unaffected by the roughness of the soil and therefore is predictable and easy to analyze, even for plastic landmines

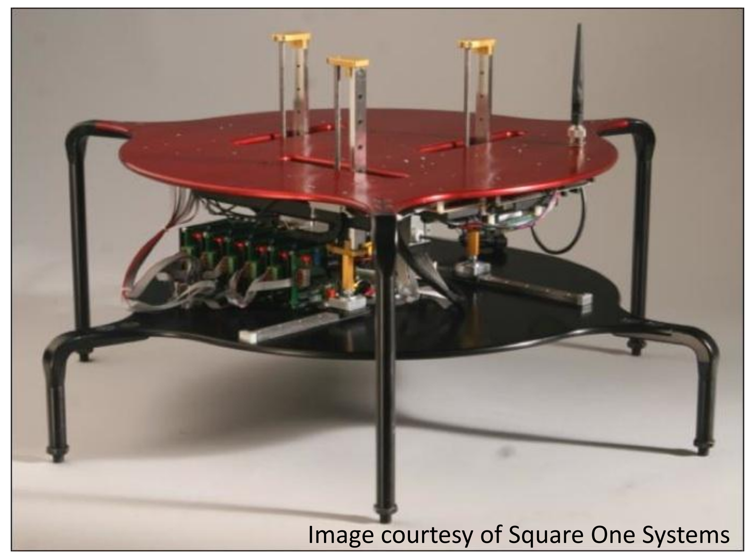


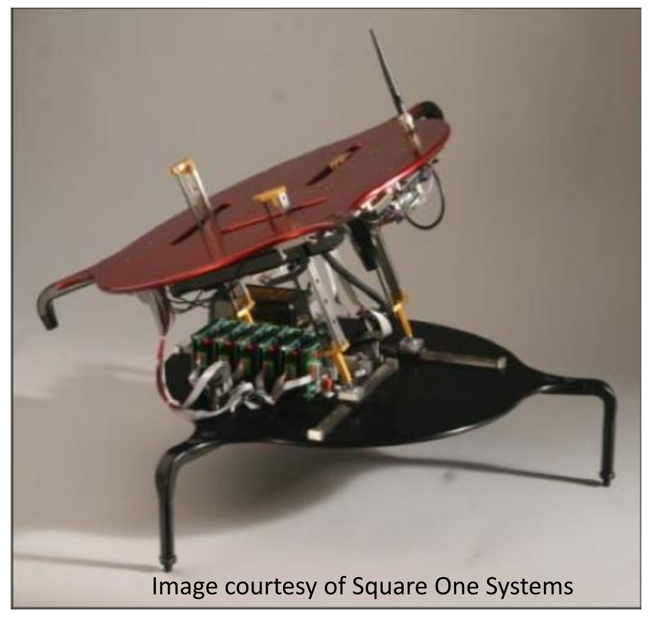
Comparison of the subsurface waveform after 7.5ns of an air-launched GPR system and a ground-launched GPR system for the same dispersive soil with a rough surface.

Autonomous Localization Method

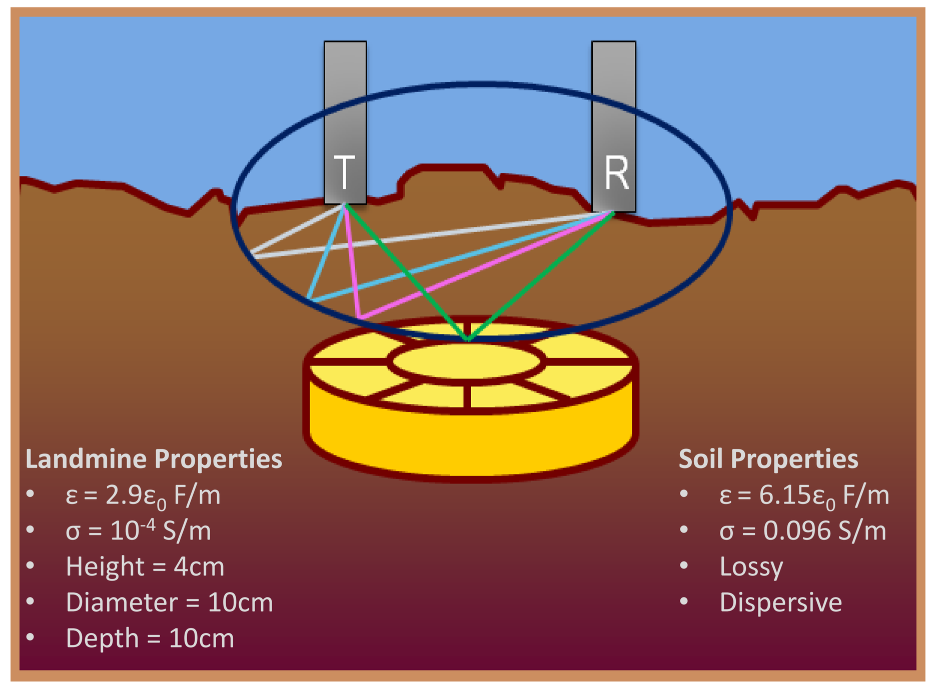
How can we triangulate a landmine's position without any human interaction?

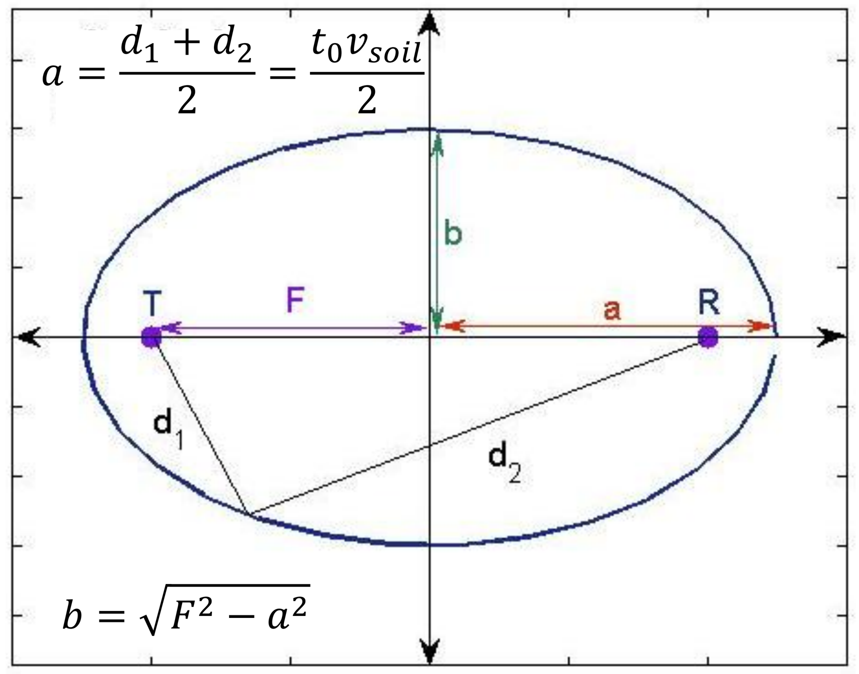
- Ground-contact is achieved using the walking Tri-Sphere robot developed by Square One Systems Design





- The target reflection dictates a full-path travel time t_0, the sum distance to the target is then $d_s = t_0 v_{soil}$
- The transmitter and receiver act as foci of an ellipsoid of potential target locations



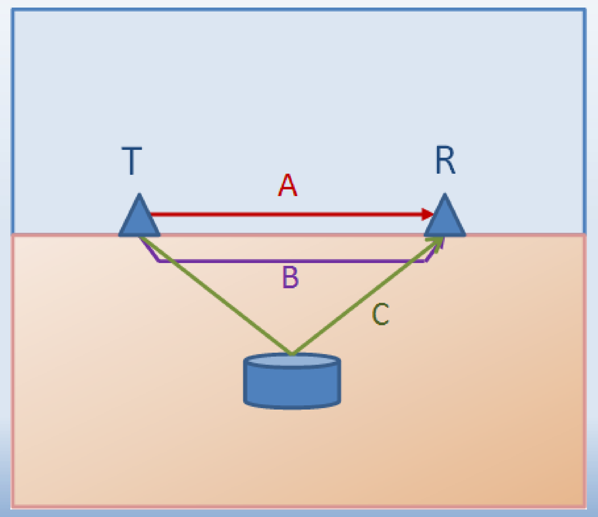


- Three pairs of antennas results in three ellipsoid equations, which can be evaluated to determine the (x,y,z) coordinates of the target

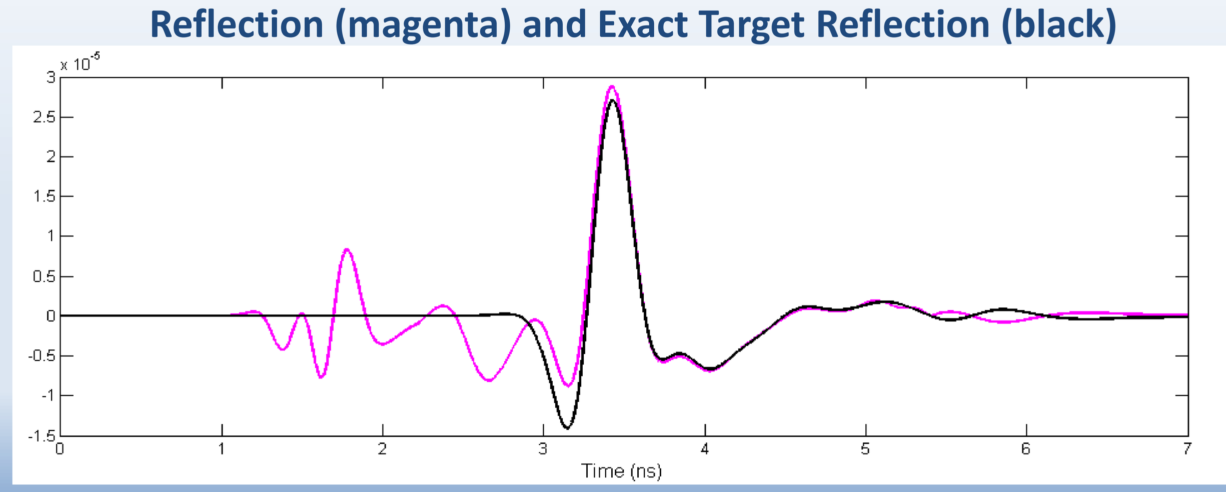
Extracting the Target Signal

How do we isolate the target reflection in the received GPR signal?

- This process is background removal, though the true background response is unknown
- The received signal for a flat surface with the same electrical properties can be simulated and then statistically altered to well approximate the true background



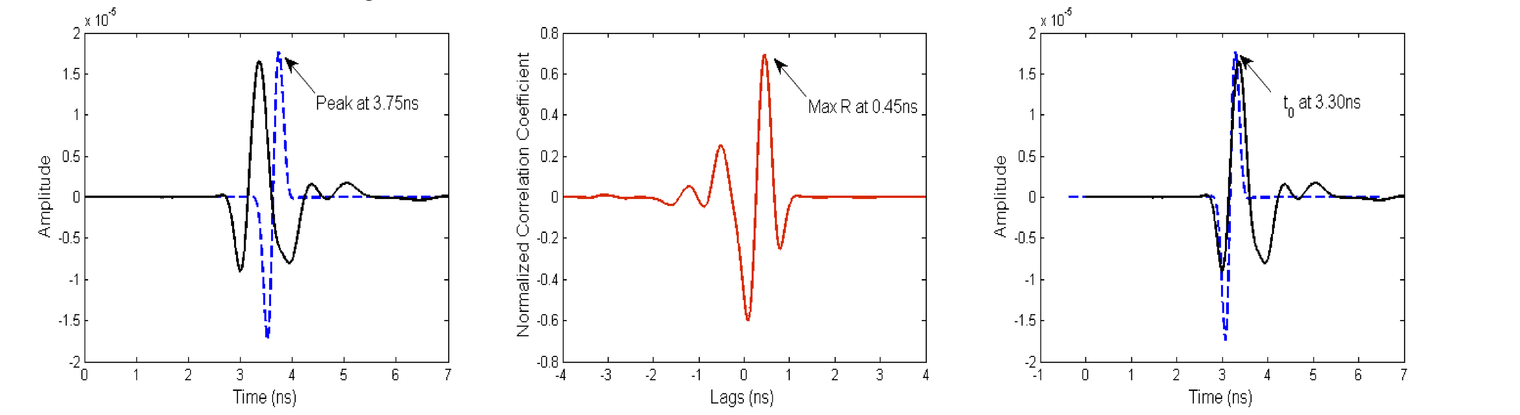
Comparison of Approximated Target Reflection (magenta) and Exact Target Reflection (black)



Determining the Time-of-Flight

How do we determine the arrival time of the target reflection?

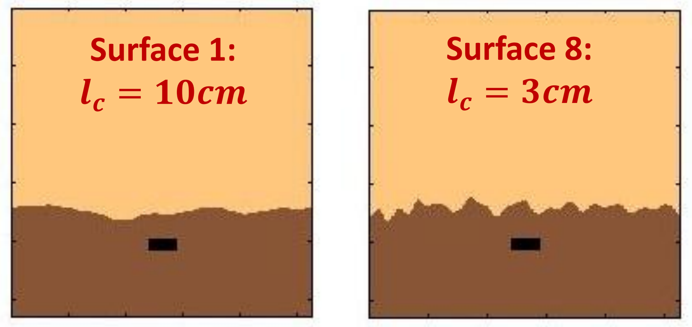
- To determine t_0, a reference signal is correlated with the target signal

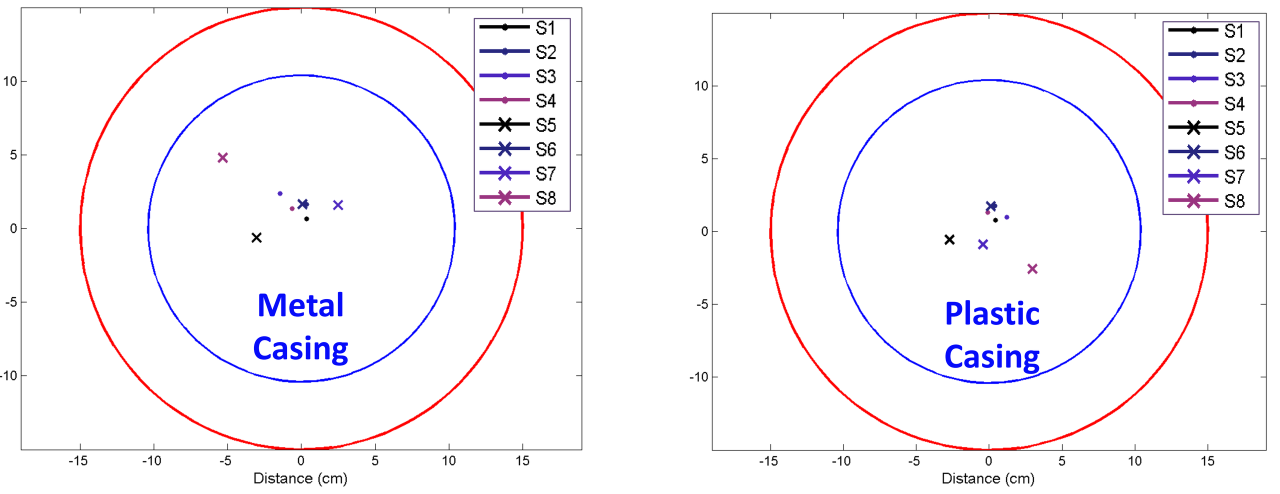


Computational Results

Can this method effectively triangulate a landmine buried directly below the Tri-Sphere robot?

- Eight rough surfaces examined, each with a $\sigma_h = 2$cm and correlation lengths decremented from 10cm (least rough) to 3cm (most rough)
- Plastic and metal mines simulated below the center of the robot
- 100% of targets detected
- 100% of targets localized within target region





- Red circle = the robot platform ;
  Blue circle = target region defined by simulated landmine position;
  Markers = predicted (x,y,z) location for target position of each surface

Conclusions

- Using three GPR pairs an AP landmine can be successfully detected
- The localization results are accurate within a reasonable margin of error and do not heavily depend on the surface roughness due to the ground-contact of the antennas
- Both metal and plastic mines can be analyzed using only one method
- The presented data processing is fully autonomous and could be evaluated by a data processing unit positioned on the robot
- Overall there is a high potential for an autonomous detection method, which is indiscriminant to target casing and is relatively inexpensive

References

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3. M. El-Shenawee, and C. Rappaport, "Quantifying the Effects of Different Rough Surface Statistics for mine Detection Using the FDTD Technique", *Detection and Remediation Technologies for mines and minelike Targets* **V,** 2000

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