# Progress Report - 27 July 2023

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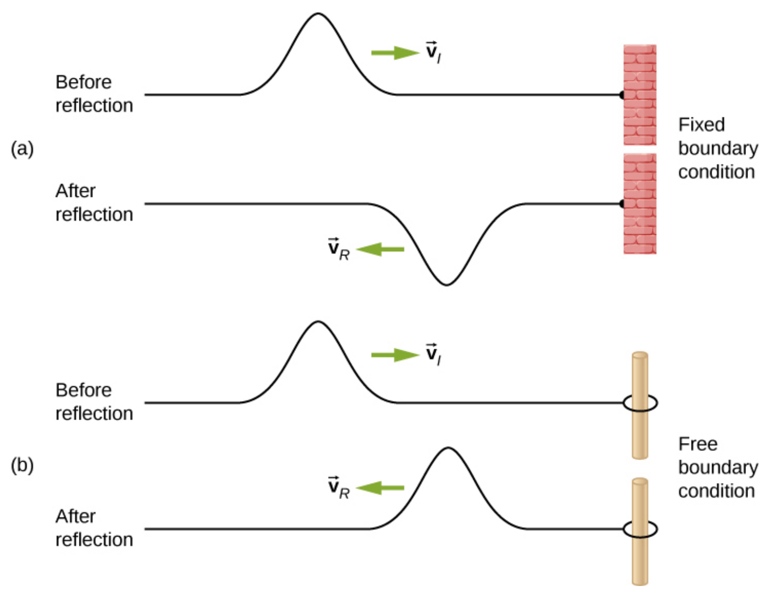
July 2023

## 1 Overview of GPR Image Capture

Radar in general relies on the behavior of waves that takes place on encountering the interface between two different media. In summary, the a so-called "incident wave" will have part of it cross traverse the boundary, and another part reflect. Material characteristics determine how large these reflections are. The reflected part has amplitude with opposite sign of the incident/traversing wave. Over repeated encounters with media interfaces, the reflections get attenuated, and thus the original wave has a maximum penetration depth from which detectable, above noise-level reflections can be received.




The effect is of course visible in resulting GPR scans. In this example B-scan, the reflections have opposite signs, hence the color alternation illustrated, as well as fade the longer time it takes for a reflection to come back.

A bit of a side note: when GPR scans take place, a very important measurement the system is taking is the time between the shooting of a pulse and the arrival of a partial reflection. The longer it took for a particular reflection to come back, the deeper underground are its origins. Without knowing the attributes of the soil, determining the corresponding depth from the time measurements is not very easy. Therefore, state-of-the-art military GPR systems incorporate systems to learn about the soil characteristics to perform as good of a depth translation as possible. This is an open and challenging field of research.

### 1.1 Sample scenario: Realistic GPR antenna over soil with metallic objects below

Before proceeding to explore ways to improve GPR image resolution, we should first see what kind of images we can get in a normal case. The following setup aims to demonstrate this, as well as verify the

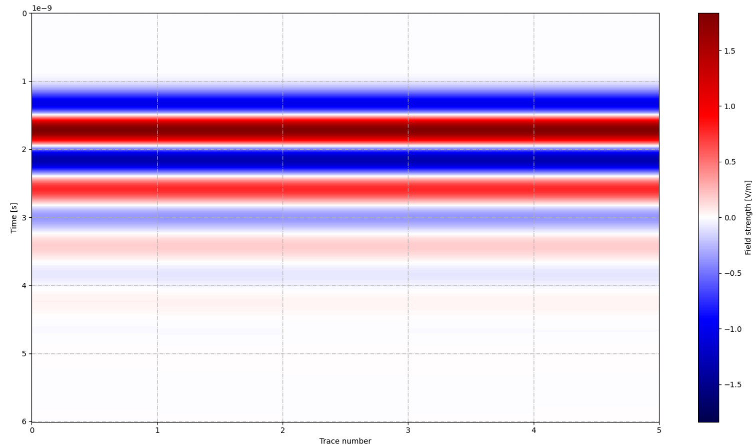



Figure 1: Sample B-scan over heterogeneous soil

operation of the use of gprMax and the Harvard Research Computing Cluster for future experiments. Since each simulation takes time and computational resources, smaller trial ones can be used as opportunities to work out any technical problems that may arise, such as learning aspects about the software that are not necessarily indicated in the documentation.

The constructed scenario consists of a $0.3 \times 0.8 \times 0.4m^3$ (XYZ) 3D space with a heterogeneous soil of 0.25 m depth, and within the soil being 4 objects made of PEC (Perfect Electric Conductor) with varying sizes, shapes, and depth. The GPR antenna is gprMax's implementation of a MALA 1.2 GHz industry one placed 5 cm above the ground and going along the width of the box (z-axis with the conventions used, illustrated in images), transmitting pulses orthogonally to the ground (or along the y-axis here). Each A-scan is taken every 2 mm, which is also the antenna resolution that we set (could be set to either 1 mm or 2 mm). 362 A-scans were taken, going therefore 0.76 m along the z-axis. Attached in this document is also the input file used for the simulation (see gen_wd.in). The antenna is the rightmost rectangular box in the following images, and will sweep through the scene.

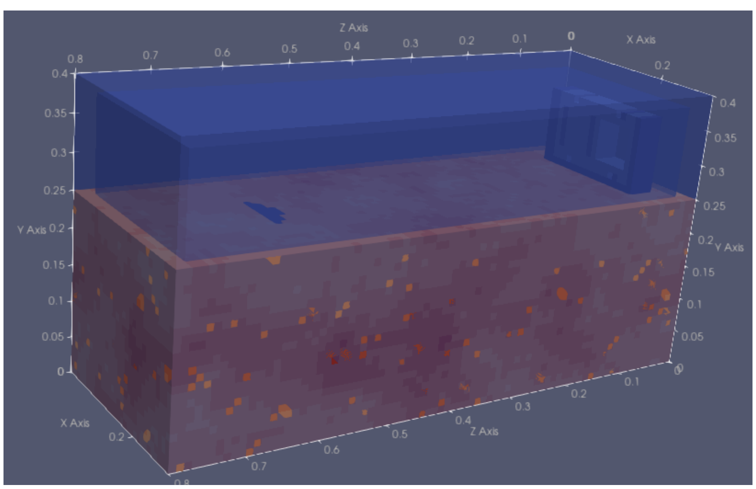



Figure 2: Above-ground view of sample scenario. Note: one object is slightly uncovered

To keep the graphical rendering reasonable, the images are pixelated here but in the numerical simulation the details are a lot finer (down to 2 mm). The B-scan obtained is one along a 2D slice of this 3D scene.

The following B-scan shows a typical case of what is seen in a GPR image: upon encountering one of the objects, noticeable "distortion" of the image takes place. Depending on the dielectric properties of the materials and the shape of the object, the way the distortion looks is affected. Being that GPR is about capturing the reflection of waves that are emitted from a source, so understanding what the object actually could be is not straightforward.

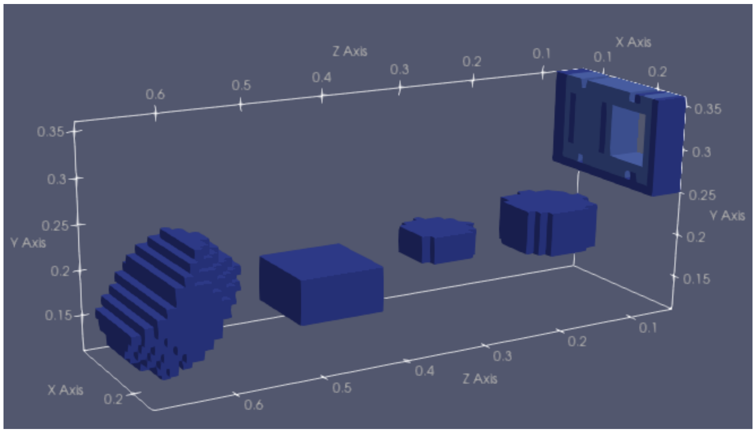



Figure 3: Same scenario with objects to be imaged underground revealed

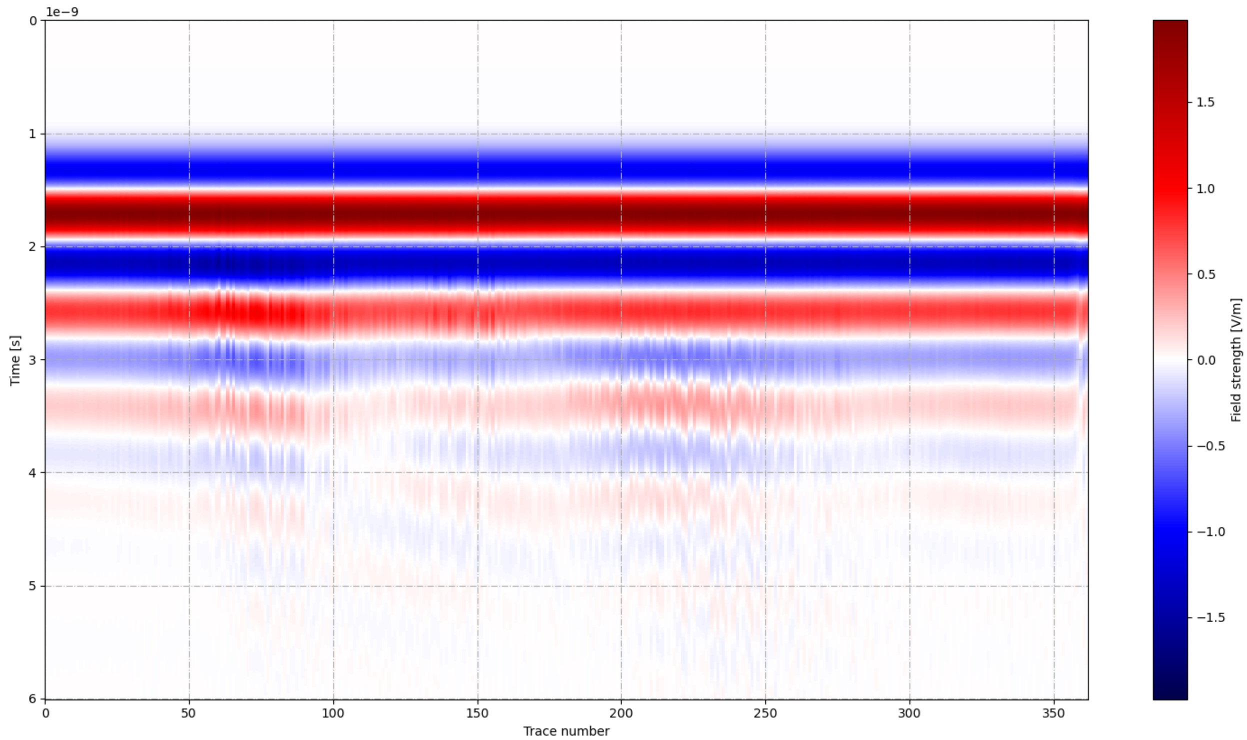



Figure 4: Bscan obtained

# 2 Next Steps

As I have been working on this project, the gprMax developers announced that they are beta-testing a new version of the software with some interesting new features. Because it was released on July 18, and I am sure a lot of problems are to be uncovered, I will be sticking with the latest stable version for now. However, one feature of interest I want to check out there is their new implementation of some common landmine material models, since landmines tend to be a specific mix of materials (both metallic and non-metallic) hard to describe with the basic tools provided.

Therefore, in the next steps I will generate a scenario utilizing these given landmine models, and employ some approaches to improve landmine detection using some my own assortment of receivers and transmitters. I realized that after using the industry GPR antenna models, while they represent what surveyors use, it does not leave much room for exploring other configurations as they are large and hard to move in a specified motion *in the simulation*, which is part of the approach I was looking into for increased image resolution. So, I will use the ideal transmitters and receivers, which are small point-sized objects in gprMax that just inject waves or output exactly what the fields were calculated to be in the simulation. The ideal transmitters and receivers can be placed in an array, which for our purposes should accomplish what is needed.