Progress Report - 15 July 2023

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1 Technicalities of GPR Imaging

GPR involves emitting radio waves usually between 10 MHz - 2.6 GHz with one or more transmitting antennas and receiving part of the signals back as reflections caused by the waves hitting *interfaces* between different materials, which the ground, being a heterogeneous medium, encounters many such interfaces. The principle is to record the time when the partial reflections return to the receiving antenna(s).

As implied, a GPR system requires one antenna to transmit and one to receive. One in total is sufficient, as an antenna can both transmit and receive. Part of the discussion regarding antennas is their directivity, or the description of what direction they transmit/receive the most energy. Antenna transmission and reception signals are visualized as amplitude vs. time graphs. If one such graph for the received signal is generated at a given location, it is known as an A-scan. Continuously and slowly changing[1] the position of the transmitting/receiving antennas will generate multiple A-scans that can merge into a so-called B-scan, which provides key insight into what lies underneath the ground, and where.

An A-scan, which just records the amplitude of the signal received from the antenna, does not really convey the direction of the object(s) that caused the reflection. Several A-scans from different but adjacent locations can provide more information about the relative location of the object. Therefore, a B-scan is necessary not just for visual convenience but also for practical reasons, as it applies a kind of triangulation to determine the location of the culprit object from multiple points of incidence. The aim of my work will be to increase the resolution of the B-scan. The resolution of a B-scan increases when we are able to identify more of the reflections that are a result of incidence of light between different media, such as when an object of interest is encountered.

2 Work Accomplished This Week

This week I wanted to get a sense of how to use the infrastructure of gprMax to set up the simulations and collect GPR images. Just to make sure everything works and I genuinely understood the software, I set up a $0.7 \times 0.38 \times 0.7m^3$ space with a metal (actually Perfect Electric Conductor - PEC) cylinder with its center 10 cm below the ground. Due to some ambiguities in the documentation, I had some trouble obtaining images at first because I had misunderstood the coordinate system conventions used by the software, so it took time to get "proof-of-concept" images.

[1] The formulation we are going to explore aims to make the scanning speed larger

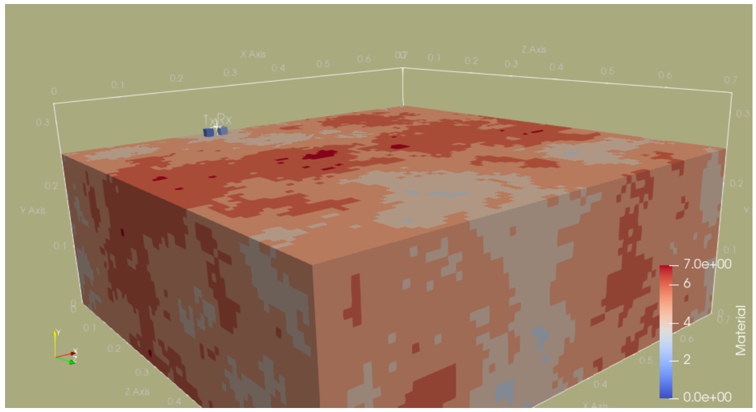

Figure 1: PEC cylinder placed directly below the transmitter (Tx) and receiver (Rx)

A Hertzian Dipole, a "soft source" of EM waves (an idealized transmitter), was placed 5 cm above the ground, and an idealized receiver was also placed 1 cm above the ground and 2 cm along the x-axis away from the transmitter. I obtained several A-scans which are spaced out by 1 cm each and then merged them together into a B-scan. The transmitter/receiver pair moved along a straight line parallel to the x-axis and captured an A-scan per every centimeter for 18 traces, giving a picture of a 2D slice. There is very low resolution in the resulting B-scan by construction.

The idealized receiver simply gives the calculated value of the E and H fields that the simulation had to calculate. A real receiver would have noise and would not be able to give the values of the fields along each direction, but rather just the amplitude of the power of the incoming waves, losing directionality. Nevertheless, this "nice" A-scan gives some sense of how a real A-scan would be. We can pretend that we only received one of these amplitude graphs, most likely Ey or Hz. Furthermore, notice that the return signals are very faint in comparison to the transmitted signals, which are the initial peaks in each graph. As I set up a more sophisticated simulation, while the relative amplitude of the return signal will be lower, it will likely not be this faint. This is merely to show how the system works.

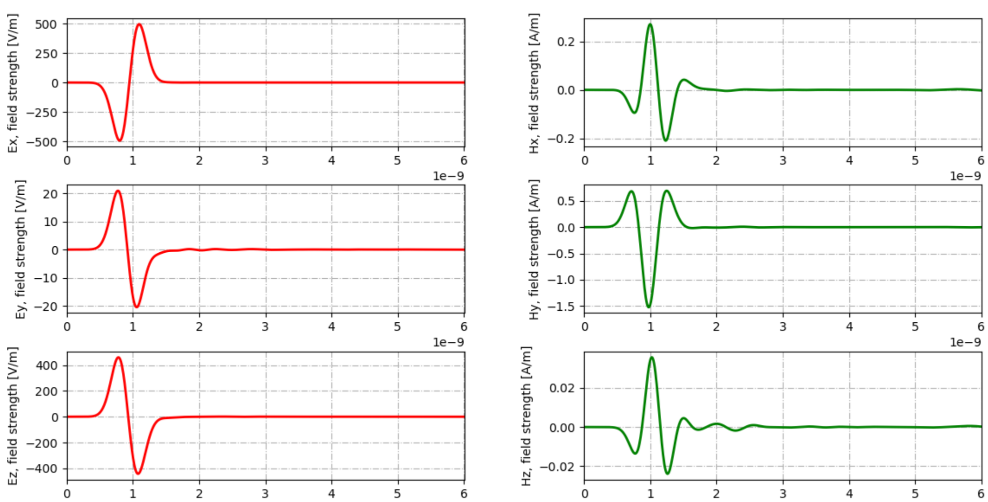

Figure 2: One A-scan above the metallic cylinder

The B-scan shows a fairly bad representation of what is underground, again because the antennas are not realistic and it was more about capturing *an* image rather than a good one. If the physical space between each A-scan is smaller and the antennas are better, the image would capture a lot more clearly.

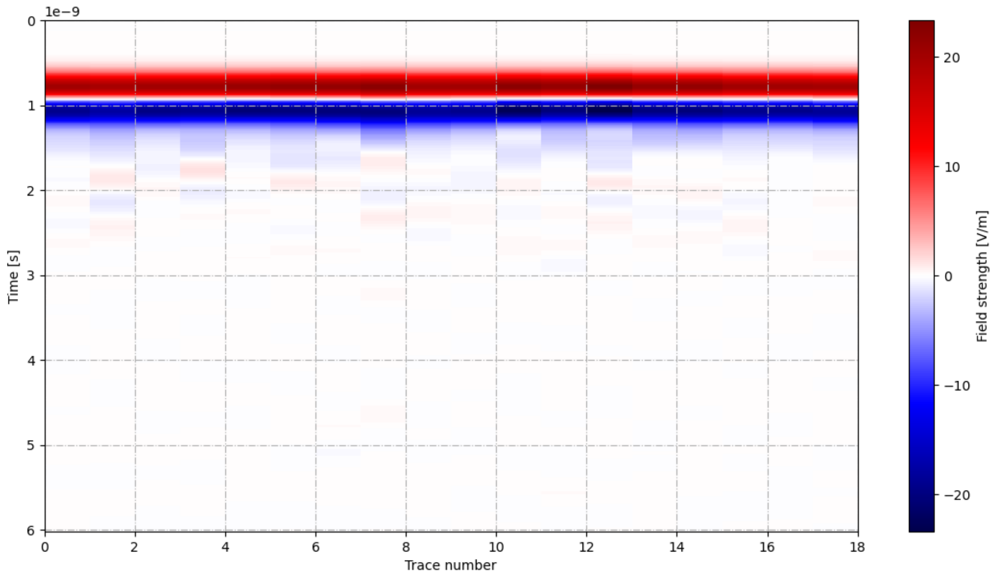

Figure 3: B-scan above the metallic cylinder combining 19 A-scans

Because the space is small and no sophisticated processing or capture is applied, this kind of simplified simulation will be mainly to do preliminary testing of actual data collection and processing approaches I will formulate before proceeding to a more complicated scenario, as a it takes a lot longer to compute (even for powerful machines) and I would like to be sure that before running anything for days that no "silly mistakes" were made in the setup. Regardless, a better transmitter and receiver will have to be put in place, as the current A and B scans are not good. Again, these are just to show the principles at play.

3 Next Steps

As mentioned, my goal is to formulate and demonstrate a multiple GPR scenario increasing the resolution of the obtained B-scan. Having multiple GPR systems moving together to transmit and receive waves I hypothesize will allow for more capture of a scattered signal, synthesizing a larger aperture because the smaller apertures of the GPRs can act together. Combining and reconciling what each GPR system received could increase resolution as a single large aperture would, but the idea is that the multi-GPR approach would operate faster in the field to obtain the data.

One way to think about the idea I have is the following: suppose a GPR in the center of the formation emits a pulse into the ground. Once it reflects, multiple receivers in different locations will receive parts of that original signal, as the scattering would likely be in many directions due to the material heterogeneity of the ground. In the post-processing stage, the collective data from these GPRs could be used to make a better B-scan. Although not quite the same as making more A-scans from one GPR, it is similar.

The main way to judge the performance of the configuration will be through the B-scan that is generated. Being able to unambiguously (term to be defined later) identify the location of all objects of varying sizes underneath the soil within an error tolerance and, depending on how far along I get, also make out the shape of the object enough to distinguish important features. This is all very loosely put still, and I certainly aim to define all of this more concretely.