InSAR GPR System on Drones

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1 Introduction

The ability to nondestructively determine what exists below the ground is one with numerous applications. The most pressing perhaps being the increased territory that has been rendered unusable from explosive mines in war-zones such as Ukraine. Successful mine (or other target) detection, whether performed by humans or autonomously greatly benefits from images that have higher resolution.

One goal of this work is to investigate a method to increase the resolution of GPR (Ground Penetrating Radar) images. A proposed approach is to apply Interferometric Synthetic Aperture Radar (InSAR) system principles typically employed in space, to the ground instead. The platform onto which to apply this is to a group of 2 or more flying drones each equipped with a GPR and performing a formulated InSAR algorithm. The algorithm will be tested on MATLAB-based simulations, with the results placed in a final report. In addition, the simulation code will be made available on GitHub.

The project goals are the following:

1. Understand how radar technology works, particularly InSAR
2. Formulate a theoretical regime for the drones to fly together and stich their observations
3. Implement a sophisticated (highly detailed) simulation of the system in action and collect results
4. Propose future work to be further refinement of technique and implementation on real hardware

2 Previous Work

Radar (Radio Detection and Ranging) is a technology with almost a century of development. Counting on the emission of EM waves from an antenna, their reflection off of objects and their return to a receiving antenna allows for the calculation of distance from the radar the object is located. We focus on the setting where EM waves are emitted towards the ground to detect objects beneath. This is a tricky problem because the ground attenuates signals at much shorter distances than the air. Different scattering and shifting effects are incurred from a variety of factors including the soil makeup and moisture content.

GPR scans are ordinarily performed on ground vehicles with antennas pointed close to the ground, and move very slowly to generate a 2D scan of the ground below.

3 Simulation Considerations

Since I am not equipped at the moment with time and resources to set up a full hardware implementation to test in a field, the simulation component of this project will have to account for different scenarios and be capable of answering many different questions.

1. Resolution in different soil types and object (metallic and non) depths
2. Increasing the number of vehicles - what does it do to the performance?
3. How long does it take to cover a certain amount of ground?

4. Metric for system computations required

We assume that the drones know their relative locations at all times, and that the targets in the ground remain stationary.

Initially my inclination was to build a simulator for EM wave propagation in 3D space that would have to account for interface scattering in nonhomogenous media such as soil. This resulted in me learning about the Finite Difference Time Domain method (FDTD) which outlines a way to divide the space and perform discrete computations to approximate Maxwell's equations. This is a fascinating set of techniques that device designers make use of, but require having a clear idea of the kind of effects that waves undergo underground and how to include them in computation, I felt that I needed to rely on previous work by those who have more familiarity with the theory and have had time to develop a sophisticated platform. In the project therefore I will use the package

`gprMax`

which employs the FDTD method precisely in the GPR context so that I can focus on antenna collaboration. However, I will include my notes of the literature and understanding of the topic as that was where a lot of time was spent regardless.

Another aspect of the simulation will be to model the conditions electromagnetic waves will encounter in the ground. This requires learning and applying dielectric mixing models for soil, which is itself a topic full of literature to parse through.

4 Design Goals

We would like to be able to discern objects that are 3 cm in diameter at a depth of up to 100 cm into the ground in various soil types, and the location of the objects is no more than 5 cm away from the actual location. We will allow for some inaccuracy in the location given due to the inevitable skewing effects that take place in GPR systems. However, I would like to see if my method minimizes this skewing.