Pre-Proposal
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ECEN 403 – Capstone (Senior) Design
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Subterranean Mapping with Ground Penetrating Radar

Abstract

The goal of this project is to design a remote ground penetrating radar (GPR) system to serve the Texas A&M Agriculture Department in their studies of tree root systems. The current process for mapping root systems is a very time costly process requiring people to manually excavate a square plot around the tree to map the depth and positioning of roots. Such a process includes potential human error in incorrect measurements and accidentally cutting root systems. The entire process can also be damaging to a tree by removing the soil it depends on, reducing the possibility of accurately measuring the growth of root systems with minimal invasion.

The remote GPR system consists of four modular components. These components are the recharging station for the RC vehicle, the RC vehicle containing antennas and a storage device for the generated data, a remote computer for data collection and visualization, and software for the backscatter processing into readable data. The recharging station contains all necessary features to return the RC vehicle to full power and will also be used to monitor weather conditions. This is crucial to prevent the data collection in adverse weather such as rain that can result in inaccurate results. The RC vehicle must be capable of towing antennas used for ultra-wide bandwidth (UWB) pulses. Due to the lower frequencies needed to penetrate the ground, these antennas are large and have the potential of weighing a significant amount that the RC vehicle must have a large enough towing capacity. After the antenna executes UWB pulses, the gathered data is stored in an onboard Intel NUC until return to the recharging station.

On the remote end, the data collection software will pull all data from the NUC when it arrives at the recharging station. The data will be stored in databases and organized with relation to GPS positioning and the timing for the reflections of the signals with respect to the frequency used in the pulse. The newly organized results in the database will be used by the processing software to convert the backscatter into readable data. This generated data can be used to create a visual 3D image of the root systems for research purposes.

The total cost of all components in this project is expected to not exceed $1000. However, due to access to several devices already needed in the project through the professors supporting the design project, the new total expected expenditures are estimated to be $700. The final design is expected to serve as a functional prototype for use by the Texas A&M Agriculture Department with continued reliability.

I. INTRODUCTION

A. Need Statement

Antenna systems have many implementations due to the wide range of frequencies capable of being produced. With the improved processing of computers, terrain mapping and other features are now possible. In addition to terrain mapping, an increasingly popular use of radar is that of ground penetrating radar (GPR). Similar to synthetic aperture radar (SAR), ground penetrating radar produces pulses that are reflected at various positions, and the reflected signals are analyzed to determine a distance from the transmitter [2]. Whereas SAR produces high resolution images after processing of the signals, it lacks the ability to penetrate surfaces. This is great in getting accurate imaging of an area concerning tree density and variations in terrain altitude. GPR is capable of producing ground penetrating signals, and it does so by emitting an ultra-wide bandwidth pulse. The general frequency range used for GPR is from 10MHz to 3GHz. The average frequency range for SAR is around 8GHz-12Ghz. The lower frequencies used by GPR means that images will not carry as high of a resolution. However, the lower frequencies produce longer wavelengths that allow them to penetrate deeper into the earth. The wide range of frequencies used in the pulses allows frequencies to penetrate and different depths and return the results. With the primary purpose of the design project being to help the Texas A&M agriculture department map out root systems, the use of GPR was a must. Several researchers have expressed interest in this technology to help understand why tree roots grow in specific directions and how those root systems affect nearby crops. Using the polarimetry of signals, a 3D image can be generated to map out the roots of trees more accurately and without the wasted time and resources of the traditional method of excavating the plot of land. The total system consists of four subsystems.

B. Proposed System

The proposed ground penetrating radar system will consist of four modular systems working together. The four subsystems are a recharging station for the RC transportation vehicle, the RF antenna subsystem, data collection and visualization, and backscatter processing. These four subsystems can be seen in Figure 1 along with the processes occurring within each subsystem. Each subsystem operates individually but shares results. The recharging station is entirely separate in terms of data used for generating the 3D images. Its purpose is to monitor and recharge the vehicle to keep it operational as long as possible. By monitoring weather conditions, it can determine if the terrain will be dry enough for testing. If weather permits, the vehicle will tow the antenna system to the desired testing region. Upon arrival, the onboard Intel NUC will activate the transmitter and receivers to perform an ultra-wide bandwidth pulse. The pulses will penetrate to various depths of the surface and return to the receiver. After receiving the data, it will be stared into the NUC before moving to another position to repeat the process until the entire region has been mapped. Upon returning to the recharging station, the NUC will connect with a computer for collection and dump all data. The computer will then run designed backscatter processing code to turn the data into readable results concerning depth and polarimetry. Polarimetry will come into play with distinguishing a root from various kinds of earth. After all data is processed, the new readable data will be used to generate a 3D visualization of the root systems under the surface.

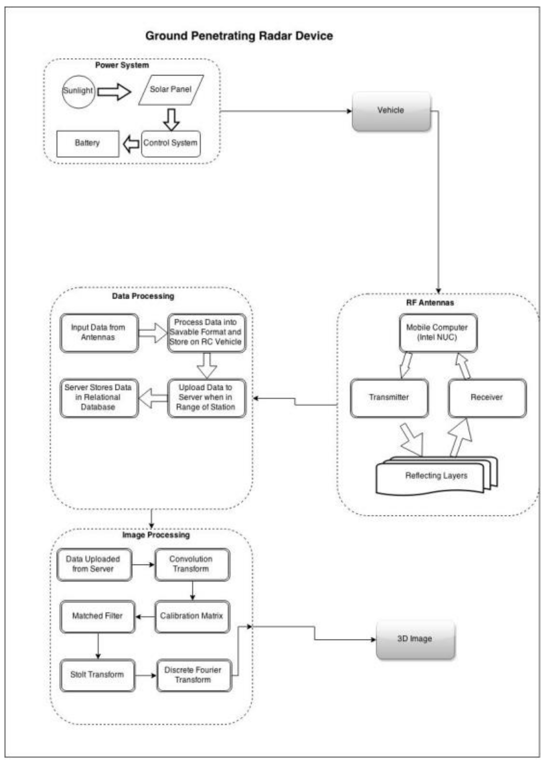

Figure 1. System Block Diagram

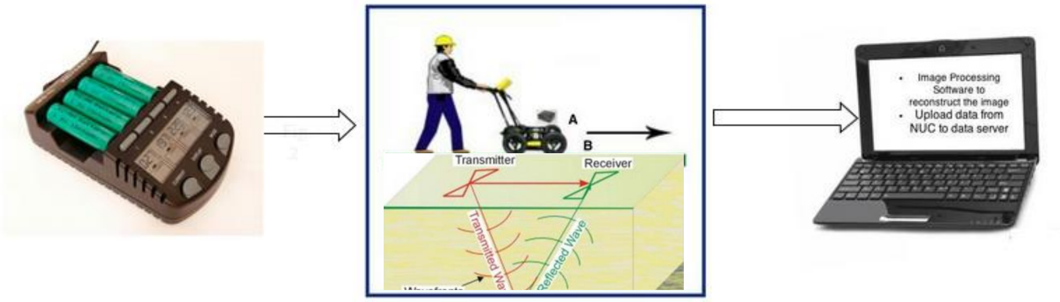

Figure 2. Physical Sketch of the System

The physical sketch in figure 2 shows the physical separate components. The battery recharging system will be used to charge the vehicle. In the middle image, the component A will be the Intel NUC where data will be stored. Figure B is the actual representation of the vehicle towing the GPR system. The transmitter and receiver are visible beneath the vehicle generating pulses and receiving the backscatter. All data will be wirelessly dumped to the separate computer for processing.

II. Conceptual Design Description

A. Implementation

The subsystem responsible for generating and receiving all signals includes the RF antenna design. The primary function of the antenna subsystem is to obtain all components needed to transmit and receive waves carrying a signal for interpretation by the processing subsystem while being light enough to be towed by the remote controlled vehicle (RCV). The major components needed to be carried on the RCV will be the antenna, the radar control unit, and the Intel NUC.

For the antenna design, the design of choice is a horn antenna. A horn antenna is ideal in this case due to its wide bandwidth it can producing a narrow beam of focus. The horn antenna will also cover the correct range of bandwidths needed to penetrate the correct distance into the ground with a bandwidth range of 300 MHz to 1.9 GHz [8].

The antenna will be connected to a radar control unit handling the majority of the amplification and modulation needed to properly map out the terrain. The most ideal radar control units right now are manufactured by the company GSSI and will be a variation of their SIR products. The SIR will be a median between the horn antenna and the Intel NUC. The SIR is required to have GPS integrated to correctly map all GPS locations with respect to the processed 2D slices of the sampled area. Integrating all the 2D slices over a region will generate a 3D map of the root system around the tree. Before the images are processed, all the data generated has to be stored. The SIR will be collecting data simultaneously from multiple channels, results in high performance data without sacrificing speed.

All data generated will be stored on the Intel NUC to be offloaded onto the server using the wireless card integrated into the NUC. Removing the data generated in raw form allows for detailed processing of the image once the data is retrieved by the image processing subsystem.

B. Analysis

Many components need to be taken into consideration for the design of the antenna and its integration with the radar control unit. The amount of loss into the earth, the dielectric value of the materials, the penetration depth, and the resolution and its corresponding Rayleigh criteria all matter for the subsystem to function properly enough to generate as high quality of an image as possible that remains accurate.

As you can see in Figure 3, the composition of the material with relation to the frequency used will result in various depths that the wavelengths can travel. One concern here is that lower frequencies used will result in lower resolution. One method we are considering is injecting the tree with a harmless substance capable of raising the dielectric constant of the roots to a high enough level to make a distinguishable image on the screen. Table 1 is a table from the book written by Daniels, and it showcases very well how the attenuation and permittivity range varies for different kinds of soils [3]. This information will be used in conjunction with the rest of the design to help researchers understand how the roots choose to move through the earth with respect to the type of soil surrounding the tree.

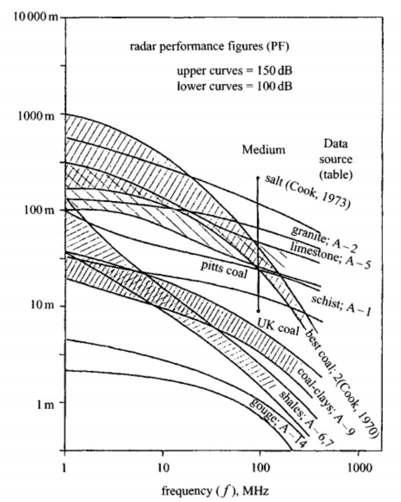

Figure 3

Material	Attenuation, dB m^{-1}	Relative permittivity range
Air	0	1
Asphalt dry	2–15	2–4
Asphalt wet	2–20	6–12
Clay dry	10–50	2–6
Clay wet	20–100	5–40
Coal dry	1–10	3.5
Coal wet	2–20	8
Concrete dry	2–12	4–10
Concrete wet	10–25	10–20
Freshwater	0.01	81
Freshwater ice	0.1–2	4
Granite dry	0.5–3	5
Granite wet	2–5	7
Limestone dry	0.5–10	7
Limestone wet	1–20	8
Permafrost	0.1–5	4–8
Rock salt dry	0.01–1	4–7
Sand dry	0.01–1	2–6
Sand wet	0.5–5	10–30
Sandstone dry	2–10	2–5
Sandstone wet	4–20	5–10
Sea water	100	81
Sea-water ice	1–30	4–8
Shale dry	1–10	4–9
Shale saturated	5–30	9–16
Snow firm	0.1–2	6–12
Soil clay dry	0.3–3	4–10
Soil clay wet	5–50	10–30
Soil loamy dry	0.5–3	4–10
Soil loamy wet	1–6	10–30
Soil sandy dry	0.1–2	4–10
Soil sandy wet	1–5	10–30

Table 1

After understanding the types of materials the waves from the antenna have to enter, it is important to design a way to improve the resolution of the image. The depth resolution according to Daniels is expected to be between 5 and 20cm in the 500MHz to 1GHz frequency range. A 500MHz to 1GHz ultra wide bandwidth pulse will penetrate the surface to roughly 1m according the antenna testing done by GSSI [1] and the information provided by RadarTutorial [8]. This is all susceptible to change based on the type of soils already discussed in figure 3 and table 1. The autocorrelation function used for the resolution creates a wavelet to determine a receiver bandwidth. This autocorrelation function is given by Equation 1.

$$R_{11} = \int_{-\infty}^{\infty} f(t)f(t-\tau)d\tau$$

Equation 1

As a material penetrates the earth, the attenuation loss of the signal will affect the image and the understanding of which material it has tried to penetrate [7]. This can be quite difficult to calculate in advance and would require soil testing for accurate results to gain an understanding of the value for the relatively permittivity and susceptibility, both of which affect the result of the value of the attenuation loss. Much research has been done on the topic though, and there are tables showcasing the attenuation loss with the respect to the type of the material. These constant values allow us to accurately predict which soils we are currently over based on the measured attenuation loss retrieved.

For the horn antenna, the values of the size of the antenna will need to be calculated. Since the horn antenna is a rectangular waveguide with a flared end, there is an equation that can be used to describe the magnitude E-field distribution across the opening [6]. This equation is below in Equation 2:

$$|\mathbf{E}| = \frac{k}{4\pi r}(1+\cos\theta)\int_{-B/2}^{B/2}\int_{-A/2}^{A/2} E_A(x,y)e^{jk(x\sin\theta\cos\phi + y\sin\theta\sin\phi)}dxdy$$

Equation 2

Since horn antennas are basically apertures, radiation occurs [5]. This needs to be taken into consideration for safety concerns. The current best dimensions discovered for a horn antenna capable of covering the frequency range needed for best resolution while still maintaining a deep enough penetration are those of a short axial length double-ridged horn. With approximated dimensions of length, width, and height being 36.7in, 28.7in, and 38.5in, the horn antenna is expected to be both the largest and heaviest component on the RCV.

REFERENCES

[1] "Antennas." Ground Penetrating Radar. GSSI, n.d. Web. 11 Mar. 2015.
[2] Arnevik, Arik, and University Of Wisconsin: Eau Claire - Geography 36. Introduction to Ground Penetrating Radar and Its General Use Applied to Fault Investigation (n.d.): n. pag. Web.
[3] Daniels, D. J., and D. J. Daniels. Ground Penetrating Radar. London: Institution of Electrical Engineers, 2004. Print.
[4] Daniels, Jeffrey J. Ground Penetrating Radar as a Quantitative Tool with Applications in Soil Hydrology. N.p.: U Heidelberg, 2008. Department of Geological Sciences, 25 Nov. 2000. Web.
[5] "Far Field Radiation from Electric Current." Fourier Transform Applications: Radiation from Electric Currents. N.p., n.d. Web. 11 Mar. 2015.
[6] "The Horn Antenna." Horn Antenna. Antenna-theory.com, n.d. Web. 11 Mar. 2015.
[7] Warhus, John P., Jeffrey E. Mast, Erik M. Johansson, and Scott D. Nelson. "Advanced Ground Penetrating Radar." Advanced Ground Penetrating Radar. Lawrence Livermore National Laboratory, n.d. Web. 11 Mar. 2015.
[8] Wolff, Christian. "Radar Basics." Radar Basics. Christian Wolff, n.d. Web. 11 Mar. 2015.