MOISTURE DETERMINATION BASED ON GROUND PENETRATING RADAR MEASUREMENTS

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ABSTRACT

In this research, we develop a method by which the electromagnetic reflection of a Ground Penetrating Radar (GPR) can become an indicator of the moisture level of different soils. It will be shown that by analyzing the GPR wavelet phase spectrum of the air-soil boundary reflection one can identify near surface soil moisture content.

The dielectric constant is a function of both the frequency and the actual soil moisture content. The equipment that uses active measurement of the soil moisture such as Time Domain Reflectometer, or Theta Probe give different moisture measurements based on equipment frequency of operation. An algorithm is developed which uses Neural Network (NN) method to determine the moisture content based on any desired method of moisture measurements such as the usage of a theta probe or a gravimetric method. Various experiments have been conducted on various types of soil, and they have been successful in determining moisture content of the soil.

1. INTRODUCTION

The Ground Penetrating Radar used in this research is composed of a transmitter and a receiver antenna with related electronics connected to a computer. The GPR with a central frequency of about 1.5 GHz has been run on the surface of different types of soils. It would be shown that different moisture levels can be distinguished by analyzing the reflection signature received from the air/soil boundary. In this work the hidden signatures (or codes) in the wavelet reflection are used for the classification of the moisture levels. These hidden signatures are namely: vectors that define the wavelet intensity as a function of depth (time), frequency spectral content, and phase spectral content. The present work has concentrated on one of these hidden vectors namely phase spectral content.

Work has been done to show that moisture values can be determined directly from a 2-layer back propagation Neural Network (NN), by training it for known phase spectral content signatures of several known soil moisture values. The experiment was performed on sand at different moisture contents. The actual sand moisture measurements for the NN training were obtained using a Theta Probe device which measures upper 4 inch soil moisture directly. The Theta probe internally uses Topp moisture model to calculate soil moisture at 100 MHz [1]. The NN can be trained with moisture values given by other instruments (as desired), since it has been shown that dielectric constant and therefore soil moisture content depends on the frequency of the instrument being used [2].

2. WAVELET REFLECTION ANALYSIS AND FREQUENCY AND PHASE SPECTRUM DETERMINATION

The GPR generates an electromagnetic pulse with a center frequency of approximately 1.5 GHz that is transmitted aimed towards the ground. This signal is reflected every time it encounters a change in dielectric constant in the soil beneath the antenna. This reflection is recovered by the receiving antenna, and then saved as a grayscale image by the GPR software. This image is composed of several vertical scans that represent the change in intensity of the reflected wavelet as a function of time (or depth), see Figure 1.

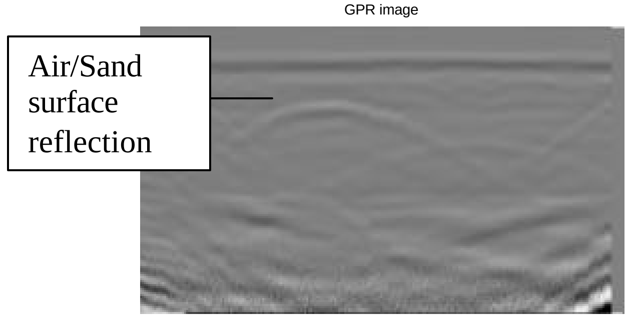

Figure 1. Example of grayscale image formed by vertical scans that represent the change in intensity of the reflected wavelet as a function of time (or depth).

The part of the wavelet that was used in this research represented the reflection that occurs in the air/soil surface boundary. This wavelet is carefully chosen and cut from the desired scan and then it's used to generate the frequency and phase spectrum needed for recognition of moisture values. Different moisture levels of the same soil create different reflections due to changes in soil dielectric constant. In this research, we decided to use the phase spectral content for distinguishing between the different moisture values.

The frequency and phase spectrum are calculated by applying Fourier transform to the intensity wavelets.

$$X(k) = \sum_{n=1}^{N} x(n)*\exp(-j*2*pi*(k-1)*(n-1)/N), \quad 1 <= k <= N.$$

The real and imaginary part of the Fourier transform of the wavelet gives us the frequency and phase spectrum, respectively: $X(k) = |Amplitude| \angle \Phi$. See Figure 2 and 3.

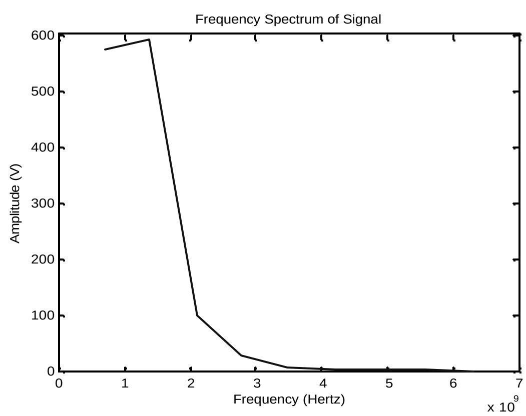

Figure 2. Frequency Spectrum of air/sand reflection wavelet.

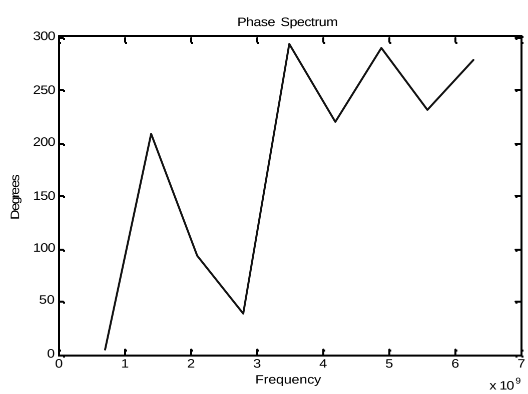

Figure 3. Phase Spectrum of air/sand reflection wavelet.

3. VARIATIONS OF HIDDEN SIGNATURES AS A FUNCTION OF MOISTURE

The plots of reflection intensity, frequency spectral, and phase spectral contents (Figures 4,5 and 6) for different moisture values of sand demonstrate the ability of these hidden signatures individually or collectively to distinguish between the moisture levels.

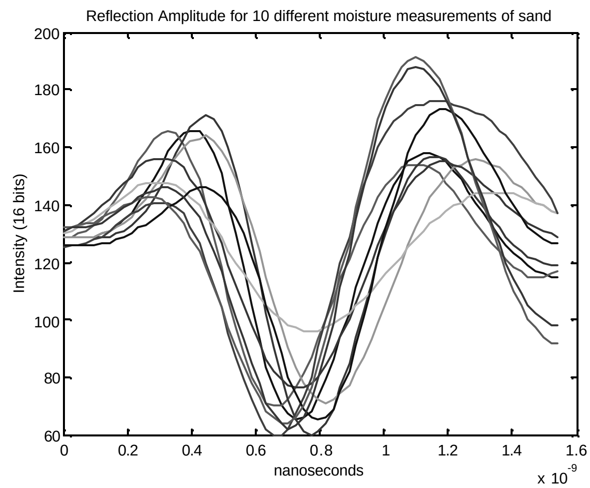

Figure 4. Reflection amplitude for 10 different moisture measurements of sand.

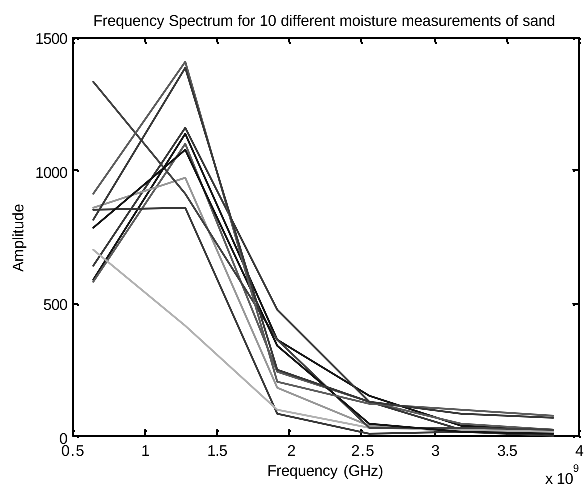

Figure 5. Frequency Spectrum for 10 different moisture measurements of sand.

The differences seen in the intensity and frequency spectral reflection as moisture changes could be used as indicators of moisture levels in any type of soil. But experience has shown us that the phase spectra shows more difference between the moisture values measured, so it's a better indicator.

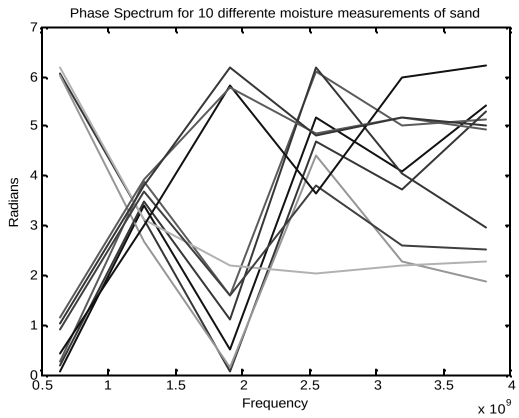

Figure 6. Phase Spectrum for 10 different moisture measurements of sand.

4. MOISTURE DETERMINATION BASED ON A 2-LAYER BACKPROPAGATION NEURAL NETWORK

In a sand experiment, GPR surface reflections were obtained for 10 different sand moisture contents. The moisture contents were measured with a Theta probe.

Sand moisture values, as obtained by Theta probe
2.40 %
4.2 %
9.82 %
13.1 %
16.3 %
20.90 %
25.8 %
34.3 %
35 %
38.1 %

Table 1

Phase spectral vectors of 6 points were calculated for each moisture value using Table 1, as shown in Fig. 7. Table 1 values were used for the training of NN, see Figure 8.

5. TESTING OF THE TRAINED NN

An unknown sample of sand was selected. Its moisture was measured using a Theta probe which read a value of 2.45%. GPR was passed over the same sample and the phase spectrum vector of 6 points was applied as input to the trained NN [3]. The response of NN was a moisture value of 2.5%. Close results obtained are shown in Figure 7.

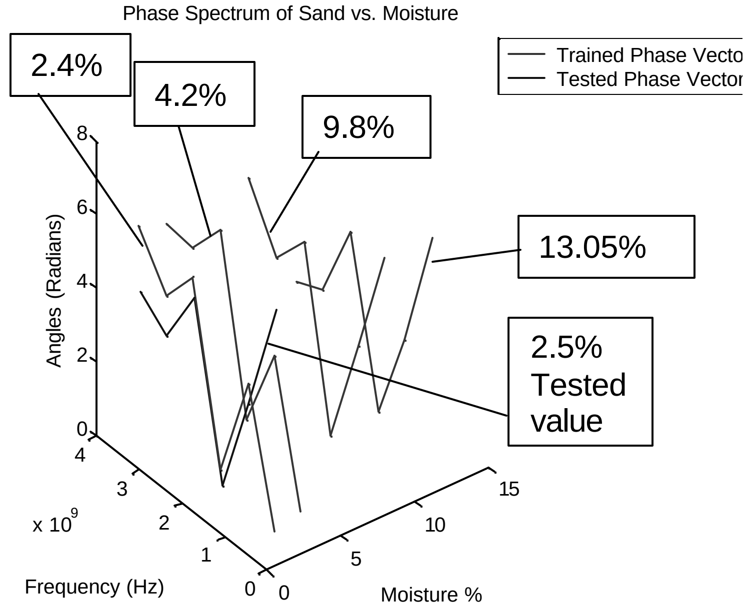

Figure 7. Phase spectral content vectors corresponding to moisture values for sand, based on Probe measurements.

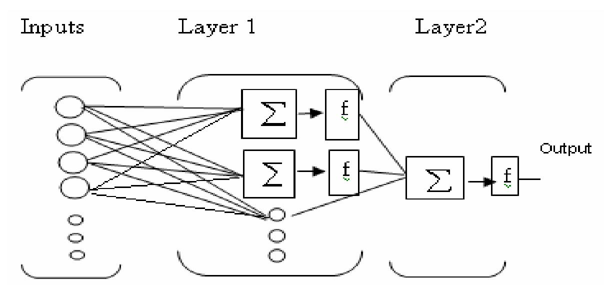

Figure 8. Representation of a two layer Neural Network.

6. MOISTURE MEASUREMENTS AT DIFFERENT ALTITUDES

One of the main goals of this research is to be able to validate soil moisture measurements at different altitudes, as obtained by airborne, or satellite sensors. An experiment was designed, using GPR, to study the changes in intensity, frequency spectra and phase spectra of the surface reflections at different altitudes. The surface for this experiment was a land covered with grass.

The reflection amplitude is measured by GPR as depicted in Figures 9 thru 11 (for elevations values of 2, 3, and 4 feet, respectively).

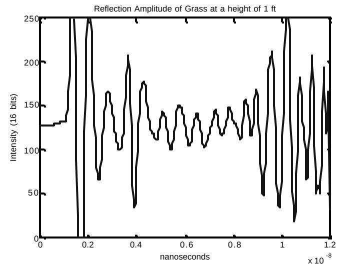

Fig. 9 Reflection at 2 feet

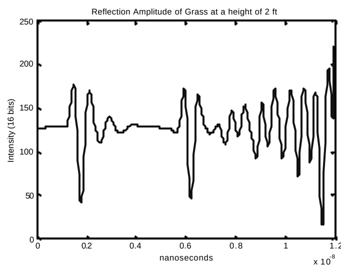

Fig. 10 Reflection at 3 feet

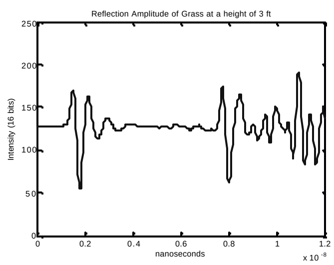

Fig. 11 Reflection at 4 feet

The images at different GPR altitudes look different, even though they all refer to the same grass land. The major differences are in amplitude, but as it can be seen their phase spectrum remains about the same, see Figures 12, 13 and 14.

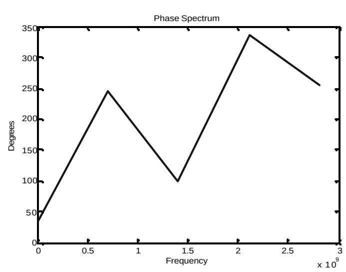

Figure 12. Phase spectrum of wavelet at 2 ft.

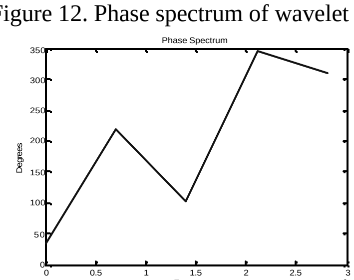

Figure 13. Phase spectrum of wavelet at 3 ft.

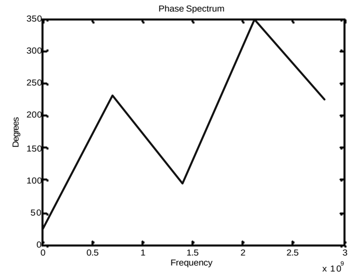

Figure 14. Phase spectrum of wavelet at 4 ft.

7. CONCLUSION

It was shown that GPR reflections converted to phase spectra are good representations of soil moisture. The Neural Network was trained to give actual soil moisture as measured by a desired soil equipment. In this research, the training was based on a Theta probe as desired equipment, but it could be easily replaced by the test measurements as obtained by a gravimetric method.

It was also shown that electromagnetic reflections at different heights also offer information about the surface and subsurface under study. The height limit for GPR-SIR-20 used in this research was about 4 feet, due to attenuation of signal to noise ratio.

REFERENCES

[1] Eric Harmsen, Hamed Parsiani and Maritza Torres, "Evaluation of Several Dielectric Mixing Models for Estimating Soil Moisture Content in Sand, Loam and Clay Soils." Paper No. 032278. 2003 Annual International Meeting of the American Society of Agricultural Engineers, Las Vegas, Nevada, USA, July 26-30, 2003.

[2] Hamed Parsiani, E. Harmsen, D. Rodriguez and R. Diaz. " Validation of an inverse procedure for estimating soil moisture content using GPR" . Proceedings of the NOAA-CREST Remote Sensing Conference, Tallahassee, Florida, March 30-April 1, 2003.

[3] Hamed Parsiani, Leonid Tolstoy , " Neural Network classification of the subsurface reflected waves and media velocity determination", NOAA-CREST/NASA-EPSCoR Joint Symposium for Climate Studies 2003, University of Puerto Rico - Mayagüez Campus, January 10-11, 2003.