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Open field soil moisture measurements with Radar

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Abstract: -As reported in [1], the Material Characteristics in Frequency Domain coupled with a 2 layer feed-forward Neural Network, MCFD/NN, has been successfully applied to soil moisture determination. The results were obtained under controlled laboratory conditions. Extension to open field soil moisture determination has been reported in [2] and it was shown that the MCFD/NN approach gives accurate results under an uncontrolled environment. In the present research, open field soil moisture determination based on the MCFD/NN algorithm is further explored with data obtained from a four-day campaign at the University of Puerto Rico Mayagüez Campus' baseball field.

Key-Words: - Ground-Penetrating Radar, Impulse Radar, Soil Moisture, Neural Network

1 Introduction

The use of GPR to obtain accurate soil moisture information has received increasing attention in the past few years due to the necessity of probing the soil in a time-efficient, non-invasive manner to aid in a wide variety of applications, such as precision agriculture programs, weather prediction, among others. Different techniques have been used [3] such as ground wave techniques [4], and [5]. The drawback of this technique is the need to operate in bi-static mode and at different transmitter-receiver offsets, which makes the process time-inefficient. Another technique that has been used is the surface reflectivity method, [6], but this has only produced good results under very controlled laboratory conditions since it depends on the amplitude of the received signal to calculate the reflection coefficient.

Electromagnetic inversion has recently gained much attention due to its capabilities to obtain very accurate estimates of the subsurface dielectric parameters, e.g., relative permittivity, conductivity, which in turn can be converted to moisture content. Such inversion methods are based on solving Maxwell's equations either in differential or integral form. An important contribution in this area can be found in [7].

As stated in the authors previous work [2], research efforts have been concentrated on open field soil moisture determination using the MCFD/NN approach [1]. The accurate determination of soil moisture out of laboratory conditions is complicated by different factors that contaminate the data and make the task that much difficult. These factors are, but not limited to,

1. *The soil under investigation not being homogeneous* – this may be the most important factor affecting the accuracy of the estimated soil moisture since the dielectric properties of the soil can vary drastically within the small area illuminated by the GPR. This may result in discrepancies between GPR determined moisture and Theta Probe readings.

2. *Effects of grass and non-soil items* – An open field will undoubtedly have grass and other non-soil items (clutter). The former can make the Theta Probe reading completely inaccurate and will greatly contaminate the GPR data, while the latter will mask the response of the soil, making it difficult to obtain accurate soil moisture.

The first factor we cannot control, while inaccuracies due to the second factor can be reduced with novel processing techniques.

The remainder of the paper will be concentrated on analyzing the results obtained from data that was collected during a 4-day field campaign at the baseball field located at the UPRM campus.

2 Material Characteristics in Frequency Domain/Neural Network (MCFD/NN)

The approach of obtaining the frequency characteristics of a material coupled with a 2 layer feed-forward Neural Network was proposed in [1] as a tool to obtain the type and moisture content of the soil illuminated by the GPR. A brief mention will be given here to make the paper self-contained; the reader is referred to [1] for further details.
The frequency characteristics of the soil under observation are obtained by considering the behavior of the soil as linear and using the well known result from linear systems theory, if we consider the systems representation of figure 1, we obtain (1) and (2). Equation (2) is referred to as the MCFD.

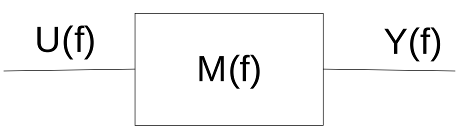

Fig. 1 System Representation

$$Y(f) = U(f)M(f) \qquad \textbf{(1)}$$

$$M(f) = \frac{Y(f)}{U(f)} \qquad \textbf{(2)}$$

3 Site Description and Data Collection

Data was collected during four days at the UPRM baseball field, precisely, inside the diamond area. The first two days date back to February and March of 2005 while the last two days of measurements were taken in September of 2005. During the span of this period, field conditions changed drastically. A total of 50 measurement points scattered around the field were used in this study. Soil moisture content values obtained during the campaign ranged from 6% to 37%.
Table I organizes the total number of measurements in their respective range of moisture content as read by a Theta Probe.

Moisture Range Distribution of Measurement Points

Moisture Percent Range	Number of Measurements
5% - 9%	15
10% - 15%	20
16% - 20%	7
21% - 25%	0
26% - 30%	2
31% - 35%	5
36% - 40%	1
Total Number of Measurement Points	50

Table 1

4 Data processing and Analysis

The data collected during the campaign was subjected to the MCFD/NN algorithm of [1], and [2]. Training of the Neural Network proceeded as to obtain the best possible configuration as follows; the training set is presented, and after training has converged the validation set is presented to assess the network's capability to generalize. If the validation set error is greater than or equal to some threshold, α, a neuron is added to the hidden layer, all weights are re-initialized and the network is trained with this new configuration. When the error in the validation set goes below α, then α is reduced by an amount, δ, and the network is saved as the best network so far. This ensures that after training is finished, the best network will have been saved. The described training procedure is depicted in figure 2 in the form of a flowchart.

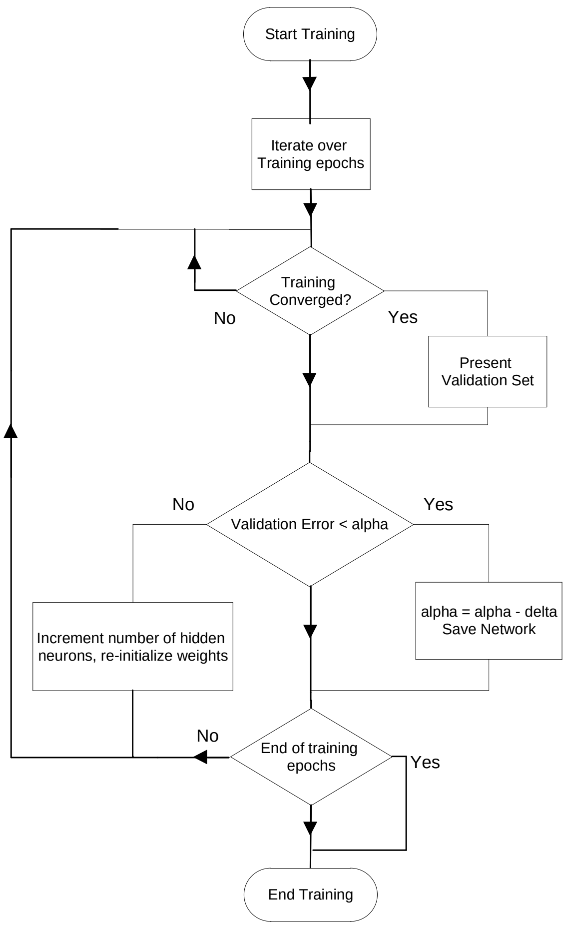

Fig. 2 NN Training Process

Due to the inhomogeneous nature of the soil in an uncontrolled environment, such as an open field, there can be sharp dielectric contrasts within a small area. Such contrast is observed in the readings obtained by the Theta meter when probing the area illuminated by the GPR; in order to measure true soil moisture that is to be used as target values in the NN training. To alleviate this problem, three Theta Probe readings were taken under the GPR footprint at each measurement point. The median value of these readings was used as target value. Only the points where the Theta Probe readings varied by less than 4% were used (see table 1), moreover, only the points where the Theta Probe readings varied by less than 3% were considered for training the NN. After having decided which data points were of acceptable quality, the MCFD/NN algorithm was run on these data points. The results of open field soil moisture determination are presented in figure 3.

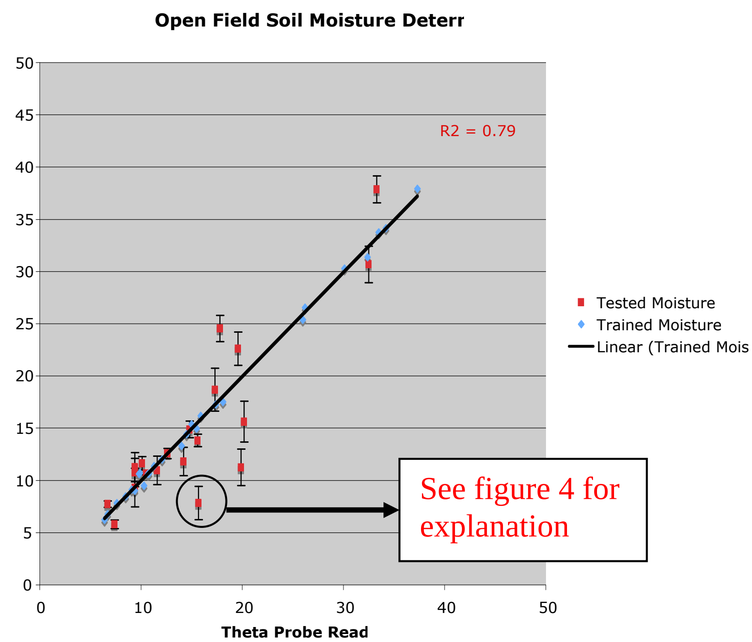

Fig. 3 Open Field Soil Moisture Determination Using GPR

5 Analysis of Results

Figure 3 presents the results of soil moisture determination obtained under uncontrolled, open field conditions using the MCFD/NN algorithm developed in [1]. The field conditions were characterized by inhomogeneities under the footprint of the GPR, and clutter, e.g. rocks and other items. The soil changed from having no grass to an almost outgrowth field by the end of the campaign. Soil inhomogeneities are represented by error bars in figure 2, where the size of the error bars indicate the variations in the Theta Probe readings under the area illuminated by the GPR. Measurement points that exhibit large errors are attributed to areas that were severely cluttered by grass and may have caused the Theta Probe to give inaccurate readings, which in turn affect the results obtained by the GPR, since the method of Neural Network requires target values to accurately match the actual soil moisture. Figure 4 shows a 15.7% moisture measurement point, this point is circled in figure 3 and it is noted that it had the largest error of all points that were used to test the NN. Such large error can be justified by noting that the Theta Probe can give inaccurate results under such cluttered conditions. Similarly, other points in figure 3 where there is a large error can be justified with the same argument.

Fig 4. Point circled in figure 3

6 Conclusions and Future Work

It has been shown that open field soil moisture determination is possible under severely cluttered conditions. Large errors can be attributed to inhomogeneous and grassy areas under the footprint of the GPR, which result in unrealistic Theta Probe readings, thus introducing additional errors to the Neural Network output.

Future work for the authors include development of efficient algorithms to reduce the effect of clutter, e.g. grass, rocks, etc. in the determination of open field soil moisture.

Also, preliminary work is being done with the goal of estimating the relative permittivity, in order to obtain soil moisture, through the development of an electromagnetic inversion scheme.

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