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# A Novel Approach for the Determination of Moisture Content of Soil using Artificial Neural Network and Automatic Electronic Control

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## ABSTRACT

Moisture content plays a significant role in soil properties and is absolutely crucial for making decisions concerning structural design and stability. Most of the engineering properties of soil such as unit weight, shear strength, compressibility and expansion characteristics depend on its moisture content. It is formulated as the percent of weight of water present in the soil mass. The golden standard for its determination involves conventional oven but this endeavour is time intensive (requires approximately 24 hours for drying). Some microwave oven based fast methods have been realized recently but these require continuous manual interventions. In this paper, a new approach will be proposed in a view to suppress the limitations of existing methods while maintaining the better accuracy. This innovation incorporates an automatic electronic control and an artificial neural network (ANN) which acts as a brain for performing time optimization. The artificial neural network has been optimized and trained by mapping the weights of soil samples at specific time steps to the respective final moisture contents. As a result the system can predict the final moisture content by analyzing fewer data samples in the very beginning of the subsequent moisture content determination tests, so full drying of soil is not necessary as the existing methods require. Validation of the predictive results has also been performed in real time to ensure the system feasibility for laboratory and field use. Experiments show that this fully automatic system can exhibit the significant accuracy and precision for the evaluation of moisture content in about 33% reduced time compared to the standard microwave based method.

*Keywords:* moisture content of soil, microwave heating, automatic electronic control, artificial neural network, electronic balance

## 1 INTRODUCTION

Moisture content is one of the most influencing factors needed to be considered for evaluating the strength of soil. Any structure and its foundation planning demand an inevitable consideration of the shear strength, which comes out from the test results of underlying soil and highly dependent on moisture content. Without knowing the moisture content in advance, optimal strength of soil cannot be ensured reliably in the construction site by applying the so called 'soil compaction method' (Budhu 2011). So its influence propagates from design to completion as well as entire life span of any kind of structure.

ASTM D2216-10 outlines the technical knowhow for the determination of moisture content of soil and is the most widely exercised procedure. In this standard, weight of a suitable aluminium can with some soil sample is taken, which is then heated in a conventional oven at 110°C for 24 hours. After 24 hours of drying, the can with dry sample is weighed again and from the discrepancy between this measurement and the previous one, moisture content can easily be found. In this procedure, a small amount of energy is actually utilized in the drying process and the remaining significant portion is lost. So this is not an energy efficient method. Moreover, spending of 24 hours time may pose detrimental effects on the construction process if its evaluation is necessary during this time and the subsequent phases. Another standard procedure is based on ASTM D4643-08, where drying process of soil sample involves microwave energy absorption. In this method, first cycle of drying process of soil sample continues for 3 minutes under a constant microwave power of 700W and after that both weighing and mixing of the sample are done. For subsequent cycles, drying time is reduced to 1 minute and these cycles are repeated until the two consecutive weights are differed by 0.1% or less of the initial weight of the soil (ASTM D4643-08 2008). This microwave based moisture content determi-

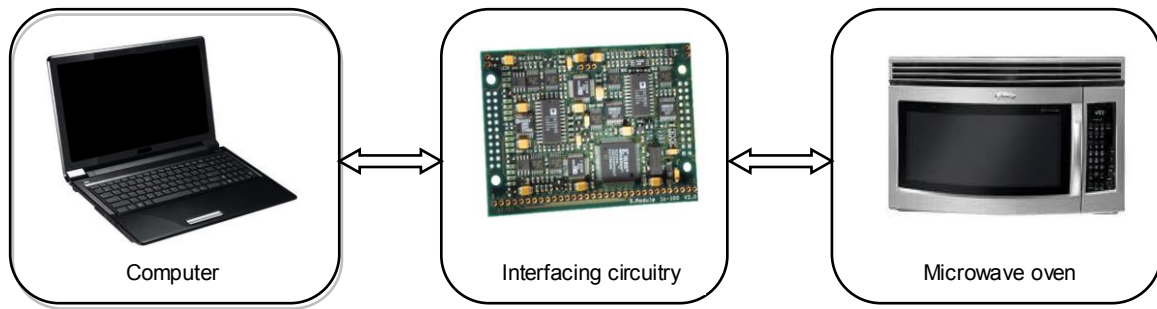


Figure 1. Illustration of the overall experimental setup

nation is quite faster than the conventional oven based method, but requires frequent manual interventions and there is no automatic control for data acquisition. As a consequence, inaccuracies arise from human factors. Some variations in the test process have been found in the literature, but all of these methods suffer from the same drawbacks mentioned earlier (Hagerty 1990a, Chung 2006).

In the last few years, artificial neural network has come to power in managing every field of modern world such as aerospace, automotive, telecommunications and transportation systems (Smith 1994, Demuth 2002, Chaturvedi 2004). In Geotechnical engineering, ANN has been applied successfully for the prediction of lateral load capacity of pile (Das 2006) and, for the modelling of maximum dry density and optimum moisture content of soil (Alavi 2010).

In this paper we are going to propose a novel approach for determining the moisture content of soil using a custom built system outlined in Figure 1. The main system components are a laptop computer, a microwave oven and an electronic interfacing circuitry. In this assembly, the computer runs our software which incorporates a neural network and a convenient graphical user interface, and the microwave oven acts as a drying machine. All the communications between the PC and the test equipments are handled by the interfacing data acquisition module (DAQ module). All these components together make the system fully automatic thus evading every manual interactions and possible inaccuracies arise from there. The fully trained embedded neural network offers an additional flavour of predictive capability which can provide the result in advance without going through the entire length of test period, thus moisture content determination procedure is facilitated both in terms of reduced test time and power consumption. Experiments show that time and power consumption are lowered to about 2/3 of the existing microwave oven based methods.

The remainder of this paper is organized as follows. Section 2 presents some background theory, the detail explanations of the system setup and the procedures are outlined in section 3. The test results with discussions are presented in section 4 and finally a conclusion with possible future directions is drawn in section 5.

## 2 BACKGROUND THEORY

### 2.1 Moisture content of soil

Soil is composed of solid particles, water and air. The ratio of the weight of water present in soil to the weight of solids is called the moisture content (Budhu 2011) and is formulated as follows–

$$w = (W_{wc} - W_{dc}) / (W_{dc} - W_c) \times 100\%. \quad (1)$$

where,  $W_{wc}$ ,  $W_{dc}$  are the weights of wet and dry samples of soil with container, and  $W_c$  is the weight of container respectively.

### 2.2 Microwave heating fundamentals

Microwave occupies the frequency of approximately 0.3 to 300 GHz in electromagnetic spectrum. The most common commercial microwave generators are in microwave ovens available in the market

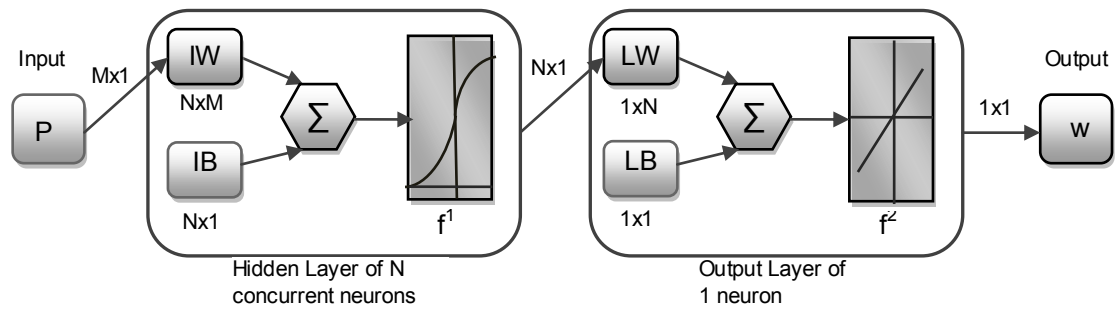


Figure 2. Neural network architecture (style inspired from MATLAB Neural Network documentation)

having a rated frequency of 2.45 GHz. This frequency is very close to the natural frequency of water. At this frequency vigorous vibration of water molecules in the soil sample cause intermolecular frictions which in turn generate heat (Cann 2011). As a result the temperature of the soil mass increases gradually towards the boiling point of water and eventually vaporizes the water in the soil allowing the sample to dry in a comparatively short time (ASTM D4643-08 2008). According to ASTM D4643-08, in the determination process of soil moisture content microwave oven drying gives rapid results and can be used when highly accurate results are not expected. As microwave has to penetrate the soil, attenuation of microwave power is occurred in every consecutive layer (Lord 1979). Due to the requirement of microwave penetration the dimensions of the sample should not be too coarse.

### 2.3 Neural network

Neural network can adapt with any nonlinear system to extract underlying patterns and detect the trends. This is achieved similarly *heuristic learning process* until the network will reach in steady state (MATLAB Neural Network Toolbox 1984-2011). Generalized neural network architecture is depicted in Figure 2. In this study, a feedforward backpropagation neural network has been incorporated because of supervised learning nature of the input datasets which propagate only in the forward direction to gain the moisture content as output.

The overall output of this trained ANN is the moisture content  $w$  and can be expressed in terms of input  $P$  (weights of soil mass), transfer functions ( $f^2$  and  $f^1$ ), weight functions ( $LW$  &  $IW$ ) and biases ( $LB$  &  $IB$ ) as follows:

$$w = f^2 \left[ \sum_{i=1}^N \left\{ LW_i f^1 \left( \sum_{j=1}^M IW_{ij} P_j + IB_i \right) \right\} + LB \right] \quad (2)$$

Hence,  $f^1$  is a log-sigmoid transfer function that maps the inputs (soil weights) to the normalised output of the hidden layer. Finally the linear transfer function  $f^2$  outputs the predicted moisture content ( $w$ ). The weights and biases stabilize the ANN to enhance the predictability by reducing mean squared error.

## 3 EXPERIMENTAL SETUP AND PROCEDURE

### 3.1 Setup

Experimental setup consists of a microwave oven, an electronic balance, a bi-directional data communication module and a laptop computer (2.66 GHz Intel i5 processor) is shown in Figure 3(a). A Panasonic Microwave oven NNSD691S having a dimension of 525mm x 401mm x 310mm has been used. It has rated input power of 700W, which meets the power requirement of ASTM D4643-08. An electronic balance of model 'CB-V Electronic Balance' having a precision 0.01 g and capacity 2000 g has been employed for measuring the weights of samples. 'USB-1602HS' data acquisition (DAQ) module from 'Measurement Computing' has been used as an interfacing board for bi-directional communication between PC, microwave oven, balance and temperature sensor. This module can sample voltage and temperature signals up to 1 Mega samples per second (Ms/s), and also can interpret the commands issued by the developed GUI to the microwave oven using opto-coupler (MOC5007). The opto-coupler isolates high voltage (230V) side of the oven from low voltage (5V) side

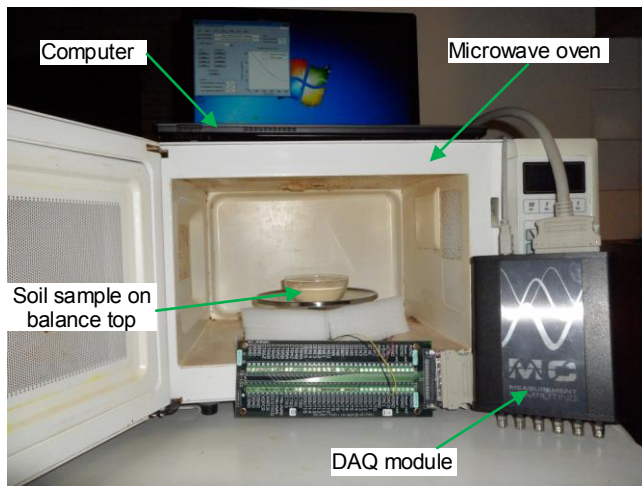


Figure 3(a): Experimental Setup

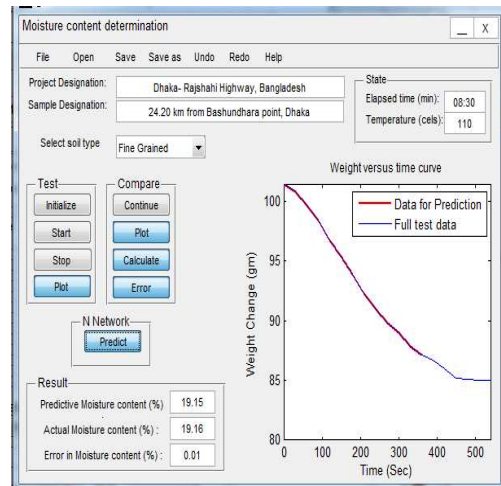


Figure 3(b): Developed GUI with a plotted sample dataset

of the computer and DAQ module. The GUI has been designed using MATLAB to act as an interface for the human operator to run the experiment successfully. A screenshot of the GUI is shown in Figure 3(b). The microwave oven bottom has been cut off and attached on a four leg stand so that the balance should be placed in between the stand and the oven. All these engineering works have been done to facilitate the continuous recording of the weight signal from electronic balance as voltage using DAQ module and passing to the computer for analysis. A temperature sensor has been placed in the microwave oven to protect the oven from extra heat in case of the sample being too dry or have some mineral which may react highly with microwave. If the temperature increases more than 110°C (which is the maximum acceptable temperature stated in the ASTM D2216) then the absorbed water is driven off from the soil mass, which is not accounted for moisture content determination. In this case the computer automatically stops the oven by analysing the data from temperature sensor to avoid any accidental damage.

### 3.2 Procedure

#### 3.2.1 Sample preparation

194 soil samples each of weight approximately 100 g have been collected in a 120 ml pyrex container successively following the criteria stated in ASTM D4643-00– sample weight should be 100-200 g with particle size < 2mm. Another 10 sample pairs (each sample weight of approximately 100 g) have also been taken for both microwave oven and conventional oven experiments separately. A Pyrex container has been chosen because of its microwave and thermal resistance and the shape of that container favours the effective vaporization of water. These soil samples have been collected from a road construction site nearby Rajshahi, Bangladesh which were "silty soils" as classified by AASHTO Soil Classification System.

#### 3.2.2 Data acquisition

The proposed system has been operated algorithmically by software incorporating the GUI. The data acquisition and storing in computer memory have been done for each sample as a data set. In the beginning of the experiment, the oven and the clock have been turned on and the computer started storing the weights of the sample at every 30 seconds as it progressively loses moisture. When the two successive weights differ by 0.1% or less, the process is automatically terminated and moisture content is calculated using equation 1 in software. The same experiment has been repeated for all of the 194 soil samples. For the last 10 samples, datasets (each set contains initial 15 records without performing full test) have been acquired separately for both microwave oven test and the conventional oven following the outlines of ASTM D2216-10. Each of these datasets not only contained the microwave test records but also the final moisture content reading from conventional oven test. The entire length of test time in microwave oven was about 11 to 15 minute for every sample due to its different moisture content.

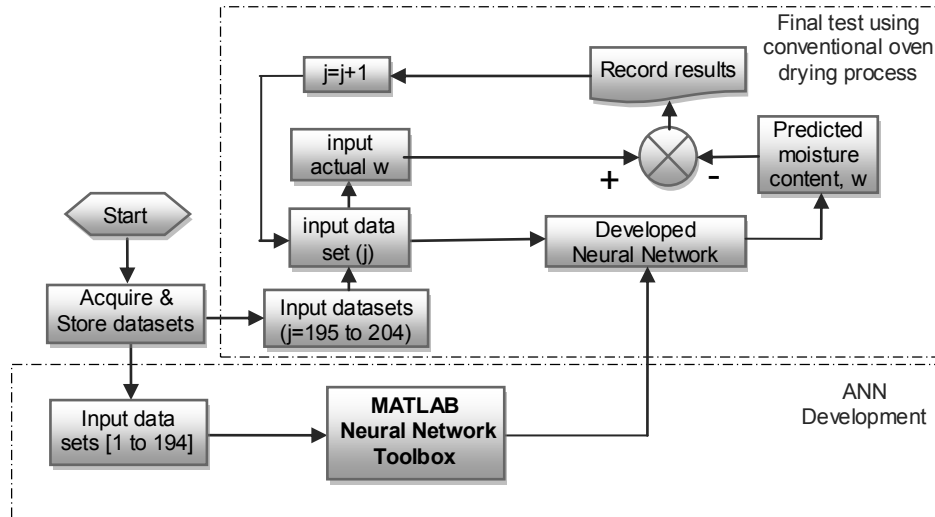


Figure 4. The algorithmic workflow of ANN development and final test

### 3.2.3 Training, validation and test of neural network

For this work a two layer (i.e. a sigmoid hidden layer and a linear output layer) feed-forward back propagation network has been developed. This network architecture has been chosen because of the fact that one hidden layer is sufficiently capable of resembling a function representing a continuous relationship between input and output (Heaton 2008). From a lot of available optimization algorithms, the Levenberg-Marquardt backpropagation algorithm has been nominated to optimize the errors due to its robustness, efficiency and handling capability of nonlinear problems (MATLAB Neural Network Online documentation 1984-2011). Initial 15 records (each dataset contains 22 to 30 records) from the first 194 datasets of soil sample have been considered for training the network by adjusting its weight function while aiming the lowest mean squared error (MSE) and the highest regression values ( $R^2$ ). The highest regression value  $R^2=1$  indicates an exact relationship between outputs and targets, while the lowest  $R^2=0$  means no relationship exists at all. The datasets have been passed through the MATLAB neural network fitting tool (MATLAB Neural Network Toolbox 1984-2011) which performed the training, validation and preliminary testing of the ANN and developed a trained ANN. As a rule of thumb, the optimum number of neurons in the hidden layer should be in between 2/3 to twice of the number of input layer elements (Heaton 2008). For this experiment the optimum number of neurons in the hidden layer has been found to be 16.

### 3.2.4 Final test using microwave and conventional oven data

The ultimate test has been started using the last 10 datasets obtained from microwave oven which has also had a counterpart attained from conventional oven drying. Datasets acquired from microwave oven testing have been passed through the developed neural network. The outputs of the network are the predicted values of moisture contents which have been compared with the moisture content of respective soil sample obtained from conventional oven drying process. The whole algorithmic workflow as shown in Figure 4 has been encapsulated inside the developed software. The discrepancy between the actual moisture contents from the conventional oven drying process and the predicted moisture contents is shown in Figure 5(b).

## 4 RESULT

The performance of the developed network for all the datasets (training, validation and test) is shown in Figure 5(a). The data points represent the neural network outputs to the targets. Hence the linear solid line indicates that the network outputs are equal to the target moisture contents. It is obvious from the relationship,  $R=1$  that there exists an exact linear relationship between the ANN outputs and targets, which is also a merit of the proposed system. From this graph, it is evident that the trained network worked precisely well with the soil samples having moisture content up to 70%. Figure 5(b)

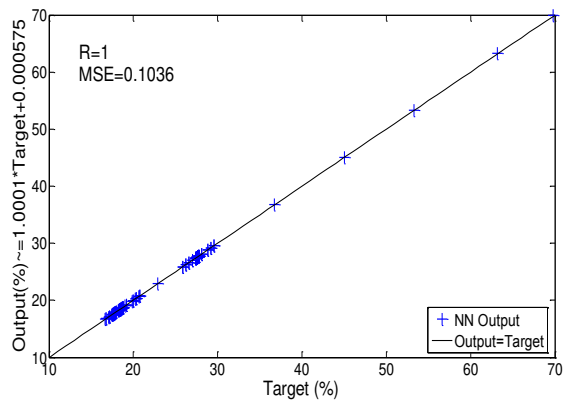


Figure 5(a): Target vs. NN Output

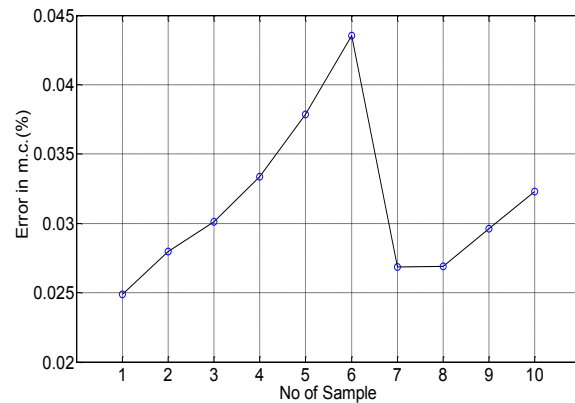


Figure 5(b): Discrepancy between actual and predicted moisture content

reveals the discrepancy between the actual moisture content obtaining from conventional oven process and the predicted moisture contents from ANN. It should be noted that the maximum difference is only 0.044% that can be overlooked considering the huge amount of time saving (almost 33% less than the existing microwave oven based method) during the test procedure using our proposed system.

## 5 CONCLUSION

The results of this work indicate that the soil drying process for moisture content determination can be realized efficiently using a group of algorithmic actions. The implemented system presents not only the precise results in the shortest possible of time but also it automates the whole test procedure. Nevertheless the microwave drying equipment and algorithm developed in this study have been operated safely in normal condition but careful monitoring should be required if the soil sample contains significant minerals because of their possible interactions with microwave. In this study soil samples with no unusual properties have been tested but in real scenario it may be different. So generalization of the proposed system while considering all types of soil samples with various minerals should be the ultimate goal for the future endeavour.

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