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16. Abstract: Research Project 0-4415 "Development of a soil moisture sensor for measuring moisture content in pavement subgrade" developed several types of soil moisture sensors including parallel-wire transmission-line sensors, ring resonator sensors, microstrip line sensors, parallel-plate transmission-line sensors and integrated PCB sensors. The parallel transmission line sensors have been installed in Bryan, Waco districts at the SPS-8 sites and Texas APT site to monitor moisture contents in the pavement. These sensors are low-cost, small in size and remotely accessible. Measured sensor data is then either remotely downloaded via modem or directly from the site. The system can store data for 12 months between two downloads. The lately developed PCB sensors have more features: 1) both sensor heads and sensor electronic circuits are built on the same rigid PCB board, so that the uniformity of sensors can be guaranteed in both manufacturing and installation processes; 2) the operation mode is upgraded to digital mode from analogue mode; 3) an on-board microprocessor is introduced to control and manage sensor performance; 4) a unique address ID is assigned to each sensor to facilitate the communication, data transportation and sensor network building; 5) a communication transceiver and driver are added to realize the communication among sensors as well as between the sensor and the data collection box; 6) an adjustable phase shifter is installed on board to insure the optimal initialization; 7) an on-board power down mode is designed to save power in field applications. The PCB sensors will provide more convenience in application.			
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Remote Monitoring Moisture Content in Test Pavement
in Waco and Bryan Districts

by

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Technical Report 0-4415-2

Project Number: 0-4415
Remote Monitoring Moisture Content in Test Pavement
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Performed in Cooperation with the
Texas Department of Transportation
and the Federal Highway Administration

by the

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Department of Electrical and Computer Engineering
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CHAPTER 1: INTRODUCTION

Moisture content in the subgrade of pavements has a great effect on the strength and deformation properties of the road structure. Continuously monitoring the moisture content under pavements can provide significant information for pavement condition evaluation and maintenance. Such application requires the moisture sensors to be reliable, accurate, water resistant and long-lasting.

The **Capacitive (CP) Sensor** has a simple structure. It is based on the measurement of capacitance between two electrodes implanted in the soil. Since the CP sensors usually operate at a low-frequency band (2MHz), the measuring accuracy is quite limited.

The **Time-Domain Reflectometry Sensor (TDR)** is a kind of conventional sensor. A TDR sensor usually has two or more short metal rods sticking out of the sensor enclosure for thrusting into the soil to be measured. When a pulse wave is transmitted onto the metal rods, it will propagate along the metal rods and be reflected at the end of the metal rods. By measuring the wave propagation time back and forth along the metal rods, the dielectric constant of the soil that holds the metal rods can be calculated, and then the moisture content of the soil can be obtained. However, the high cost and the complicated electronics of TDR sensors must be considered.

The **Parallel-Wire Transmission-Line Sensor (PWTL)** employs a segment of parallel-wire transmission line as the sensor head that will be buried into the soil to be measured. The transmitter and receiver of a PWTL sensor are connected at two ends of the transmission line respectively. Hence PWTL sensors measure the phase shift of a transmitted wave along the transmission line, instead of detecting a reflected wave as

TDR sensors do. Compared to the TDR sensor's reflected pulse, the transmitted signal in the PWTL sensor is much more reliable and stable. Because the PWTL sensor has an open structure, the whole energy that propagates along the PWTL sensor head has to pass through the soil, so that the PWTL sensors are very sensitive to moisture variation but can only provide a relatively small measuring dynamic range.

The **Parallel-Plate Transmission-Line sensor** (PPTL) has the same working principles as the PWTL sensors. The only difference between the PWTL and PPTL sensors is in their structures. A PPTL sensor is composed of two parallel copper plates separated by a layer of low-loss dielectric material, within which part of the wave energy will be confined. This design not only guarantees stable and reliable transmitted signals, but also compromises the sensors' sensitivity and measuring dynamic range, so that a PPTL sensor is able to accurately measure the moisture content of soil from 0 to 100%. These sensors were installed in Bryan, Waco districts at the SPS-8 sites and the Texas APT site to monitor moisture content in the pavement. These sensors are low-cost, small in size and remotely accessible.

The **Microstrip Resonator** (MR) sensor has different working principles than the transmission-line sensors and TDR sensors. MR sensors are based on the measurement of the sensors' resonant frequencies in the presence of different moisture content. Simulations and experimental studies illustrate that MR sensors are also good candidates for soil moisture measurement.

In this project, the researchers developed and manufactured three types of different moisture sensors: the parallel transmission line (PTL) sensor, the integrated PCB sensor and the ring resonator sensors. These sensors operate at 1-GHz to 2-GHz

microwave frequencies for accurate moisture measurement. The researchers also developed and prototyped corresponding data acquisition systems including wired and wireless data transmission devices. The developed electronics of new sensors are all digitized and ready for both wired and wireless sensor networks.

CHAPTER 2: THE DEVELOPED MOISTURE SENSORS

2.1 Parallel Transmission-Line Moisture Sensors (PTL)

A parallel transmission-line moisture sensor is composed of three subunits as shown in [Figure 2.1](#): 1) sensor electronics, including transmitter, receiver, amplifier, filter, power supplies, etc; 2) sensor enclosure that protects the sensor from crushing, water invading and eroding; 3) sensor head made up of a segment of a parallel-plate transmission line that usually sticks out of the sensor enclosure to directly contact with the soil to be measured. The sensor electronic board is installed inside the enclosure.

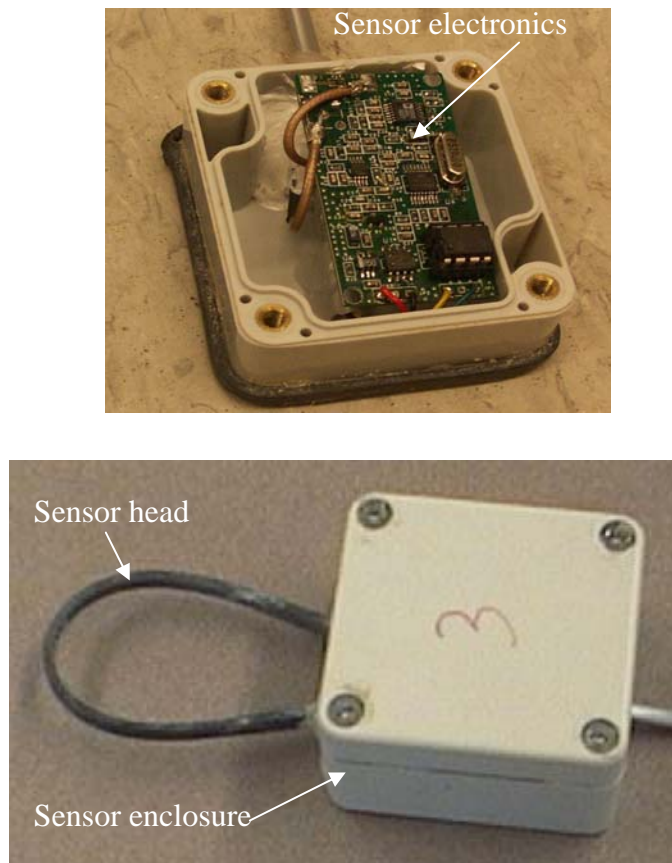


Figure 2.1 PPTL sensor

The sensor shown in [Figure 2.1](#) operates at the frequency of 1GHz. The simulation and experimental results have demonstrated that the output voltage of the sensor is proportional to the moisture content in soil. [Figure 2.2](#) gives the sensor's calibration curve in sand.

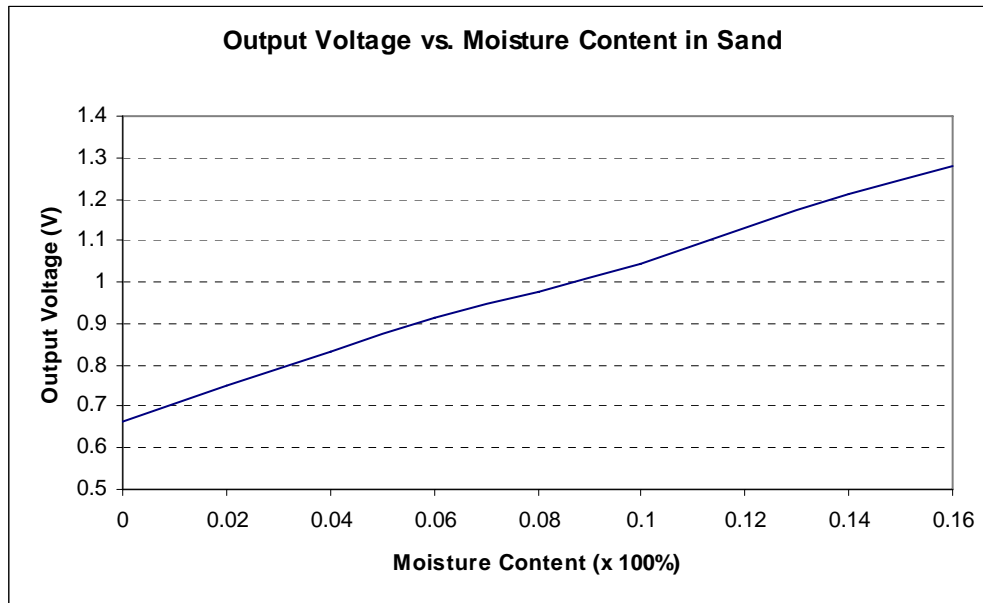


Figure 2.2 Calibration curve of PPTL sensor in sand

After calibration, the PPTL sensors are able to accurately measure soil moisture content. Twelve PPTL sensors were installed in Bryan SPS-8 Site in April, 2002 and eight sensors were installed in the Waco site in August, 2002. These sensors monitor moisture every 15 minutes and store the data. Data is then either remotely downloaded via modem or directly from the site. The system can store data for 12 months between two downloads. Part of the recorded weather data will be given in [Chapter 5](#).

2.2 Integrated PCB Sensors

Integrated PCB sensors directly print the sensor onto the circuit board to reduce cost and increase uniformity of the sensors during manufacturing. This kind of sensor

works at 2.4GHz and is constructed on a flat dielectric board. The integrated PCB sensors have the same operating principle as PPTL sensors, i.e. the phase shift along a transmission line is a function of the medium dielectric constant that is related to the moisture content. To facilitate the manufacturing and sealing work, different PCB sensor designs were investigated, including PCB microstrip line sensors and PCB parallel-plate transmission line sensors.

2.2.1 PCB Microstrip Line Sensors

The PCB microstrip line sensors are fabricated on a four-layer FR4 PCB board. The sensor heads occupy the second and the third layers of the PCB board. The second layer has a copper strip as shown in [Figure 2.3](#) (a) and the third layer is simply made of a copper sheet. These two layers form a section of microstrip line. The top layer is a coat made of waterproof dielectric material and the bottom layer serves as the base of electronic components. Only the top layer will be exposed to the soil to sense the moisture in it, and the bottom layer will be sealed in a watertight box to protect electronic circuits from eroding.

The mechanism of PCB microstrip line sensors is the same as the PPTL sensors; i.e. the phase shift along the microstrip line depends on the moisture content of the medium surrounding the sensors. By measuring the phase shift over the microstrip line, the moisture content can be obtained.

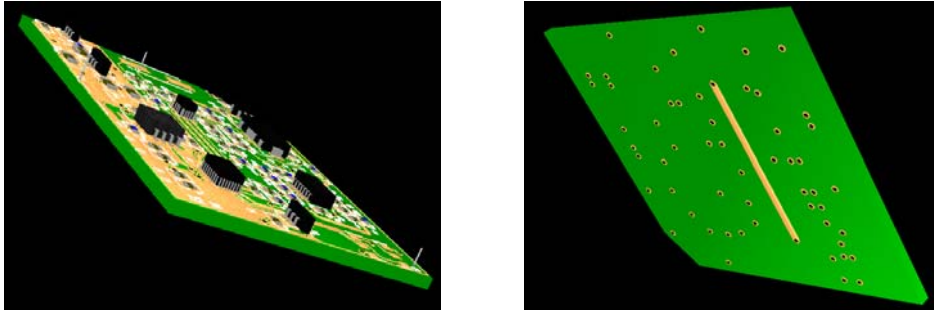


Figure 2.3 PCB microstrip line sensors (a) bottom view (b) top view

Figure 2.4 is the measured result of a PCB microstrip line sensor. The measured data illustrates that the phase shift of the sensor is a monotone function of the moisture content in the medium to be measured. After calibration, the PCB microstrip line sensor should be able to measure the soil moisture content accurately.

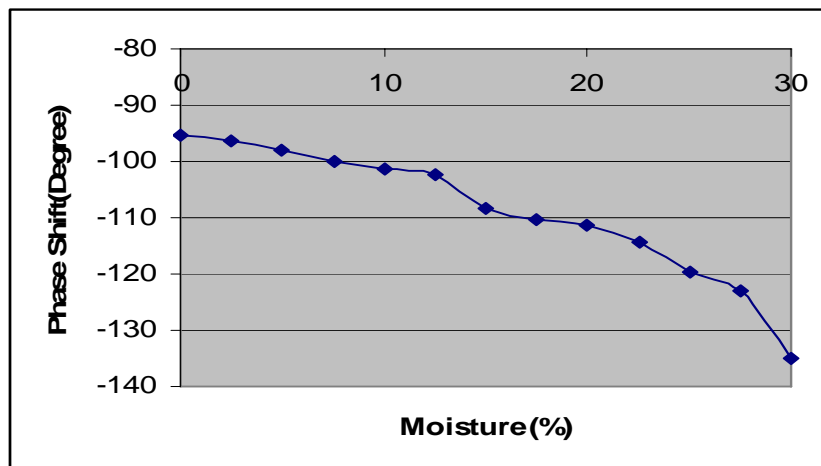


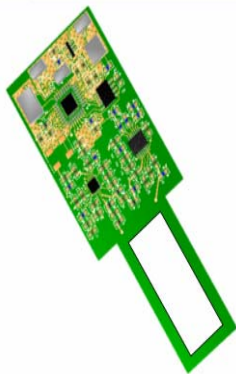
Figure 2.4 Performance of PCB microstrip line sensors

Compared to the old PPTL sensors, the PCB microstrip line sensors have a solid and firm structure, so that the shape and size will not be easily deformed by external pressure after being buried in soil; the manufacturing of the PCB microstrip line sensors

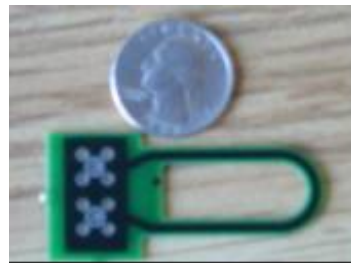
can be fulfilled by computer-controlled machines, so that the sensors' consistency can be greatly improved. However, since the PCB microstrip line sensors confine a big part of its EM energy inside the transmission line, the sensitivity is limited unless the sensor size is enlarged.

2.2.2 PCB Parallel-Plate Transmission-Line Sensors

To achieve higher sensitivity while keeping a small sensor size, the PCB parallel-plate transmission-line (PCB PPTL) sensors are developed. The PCB PPTL sensors are also fabricated on a four-layer FR4 PCB, (see Figure 2.5), where electronic parts and circuits occupy half of the PCB board, and the other half is a U-shaped frame whose second and third layer construct a parallel-plate transmission-line sensor head. The first and the fourth layer of the sensor head are made of waterproof dielectric material. Figure 2.5 (b) shows a curved sensor head and its actual size. In the implementation, the circuit part of the sensor board will be sealed within a watertight box; the head part exposes to outside soil.



(a) Sensor



(b) curved sensor head

Figure 2.5 PCB parallel-plate transmission line sensor

The sensor head of the PCB PPTL sensor works in the same way as the previous PPTL sensor head does, but is fabricated on a rigid structure. The relationship of the

phase shift of the PCB PPTL sensor vs. medium moisture content is measured by burying the sensor head, the U-shaped frame, into moistened sand with the known moisture content. The measured data is given in [Figure 2.6](#). The data illustrates that the phase shift of the PCB PPTL sensor has a quasi-linear relationship with the moisture content in the sand to be measured.

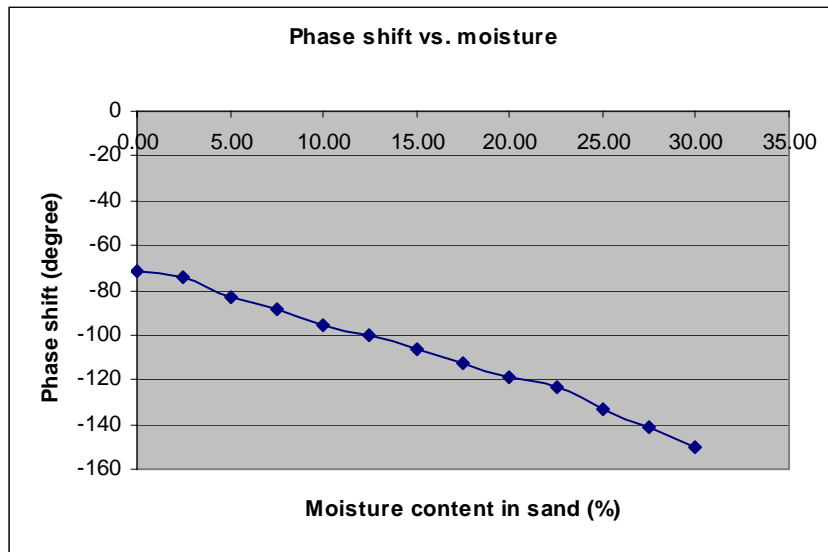


Figure 2.6 Performance of PCB parallel plate transmission line sensors

Comparing [Figure 2.4](#) with [Figure 2.6](#), one can find that the phase shift range of the PCB PPTL sensor is almost twice that of the PCB microstrip line sensors, which states that the PCB PPTL sensors have a higher sensitivity and a higher resolution.

2.3 Microstrip Resonator Sensor

The microstrip resonator (MR) sensors are also built on a flat dielectric board. They have different working principles than the transmission-line sensors and TDR sensors. The MR sensors are based on the measurement of the sensors' resonant frequencies in the presence of different moisture content. The resonant frequency of the

resonant sensors varies with the change of moisture content in the soil to be measured. By measuring the resonant frequency or the amplitude at resonant frequency of the MR sensors, the moisture content can be obtained.

2.3.1 The Ring Resonator Sensor

Figure 2.7 shows the sensor head of a microstrip ring resonator sensor, with a ring width of 0.3 cm and a radius of 1.34 cm. A layer of PCB board separates the copper ring and the bottom conducting ground plane. The ring resonant sensor is usually fed by a coaxial cable whose outer conductor is soldered on the ground plane of the sensor, and the center wire of the coaxial cable goes through the holes on the ring. The center wire of the coaxial cable is not electrically connected with the ring, but is isolated by a gap. The capacitance formed by the gap will vary with the moisture content of the medium, like soil or sand that surrounds the resonator ring. Because the gap capacitance changes the resonant frequency of the sensor, the soil moisture content can be obtained by measuring the resonant frequency of the ring resonator sensors.

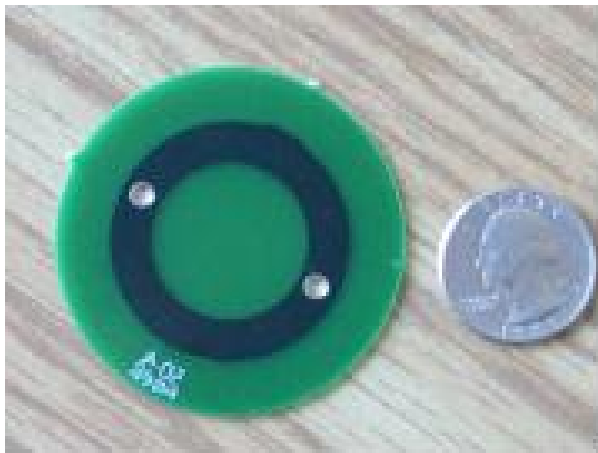


Figure 2.7 The sensor head of a microstrip ring resonator sensor

Table 2.1 Microstrip ring resonator sensor test results

Moisture (%)	Frequency (GHz)	Amplitude (db)
0.0	2.4045	-14.124
2.5	2.3905	-15.425
5.0	2.3835	-16.377
7.5	2.3765	-16.641
10.0	2.3695	-18.817
12.5	2.345	-19.744
15.0	2.338	-20.341
17.5	2.331	-22.357
20.0	2.3135	-23.058
22.5	2.2785	-24.446
25.0	2.2015	-26.371
27.5	2.2015	-27.558
30.0	2.156	-28.779

Table 2.1 gives the measured data of the ring resonator sensor while the sensor was buried in sand with different moisture contents. The frequency and amplitude in Table 2.1 are the sensor's resonant frequency and the signal amplitude at the resonant frequency, respectively. The data in Table 2.1 illustrates that both the resonant frequency and the signal amplitude at the resonant frequency are correlated with the sand's moisture contents.

The relationship of the amplitude and the resonant frequency versus moisture content are presented in Figure 2.8.

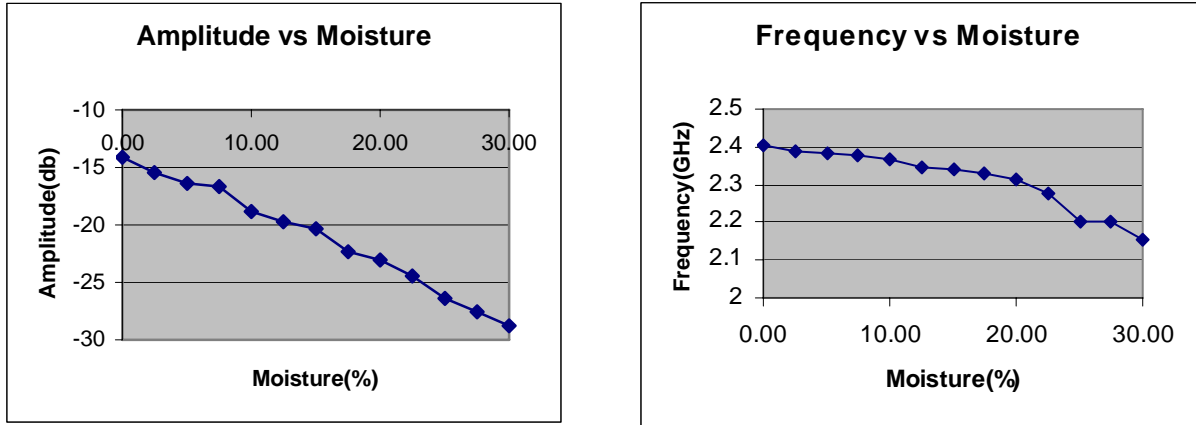


Figure 2.8 Performance of the circular ring resonator sensor; a) amplitude vs. moisture; and b) frequency vs. moisture

From [Figure 2.8](#), it can be seen that both the frequency and the amplitude have a linear monotone relationship with the moisture content. After calibration, either frequency or amplitude of the ring resonator sensor can be used as an indicator of moisture content in the medium to be measured.

To fully understand the effects of the sensor shape to its performance, square-shaped resonator sensors are also studied below.

2.3.2 Square-Shaped Resonator Sensors

The square-shaped resonator sensor head is shown in [Figure 2.9](#). The resonant frequency is 2.553 GHz when the sensor is placed in air. Similar measurements were carried out in the ring resonator sensor test. The measured data is shown in [Table 2.2](#).

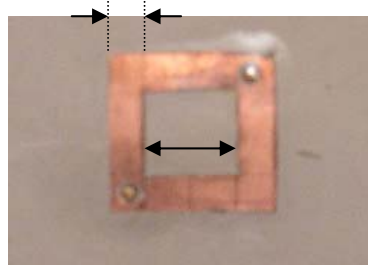


Figure 2.9 Square-shaped resonator sensor

Table 2.2 The test results of square resonator sensor

Moisture (%)	Frequency (GHz)	Amplitude (db)
0.0	2.539	-12.645
2.5	2.534	-13.707
5.0	2.531	-14.223
7.5	2.525	-14.536
10.0	2.517	-15.866
12.5	2.509	-17.926
15.0	2.509	-18.377
17.5	2.503	-19.944
20.0	2.503	-20.771
22.5	2.492	-21.174
25.0	2.467	-21.322
27.5	2.464	-21.961
30.0	2.456	-24.297

Figure 2.10 shows that the square-shaped resonator has a fairly similar relationship between the signal amplitude and resonant frequency vs. the medium moisture content as ring resonator sensors do. Hence both ring resonator sensors and square-shaped resonator sensors can be used in our applications.

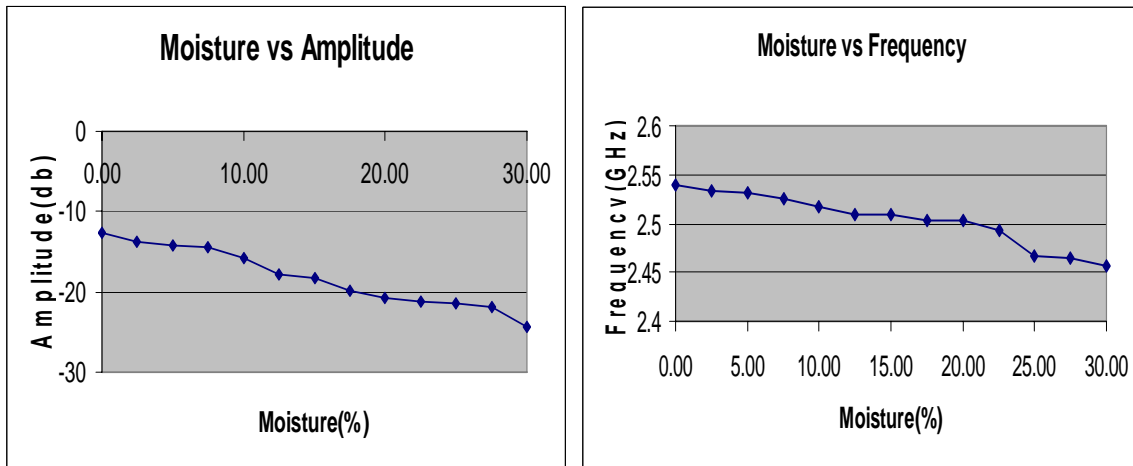


Figure 2.10 Performance of square-shaped resonator sensor; a) amplitude vs. moisture and b) frequency vs. moisture

2.4 Prototyped Wireless Transmission Device for Sensors

The researchers also developed and prototyped wireless data transmission devices for moisture sensors and the corresponding data acquisition system. With wireless capability, these sensors are able to transmit measured data to the data collection system wirelessly and thereby make sensor installation quite easy.

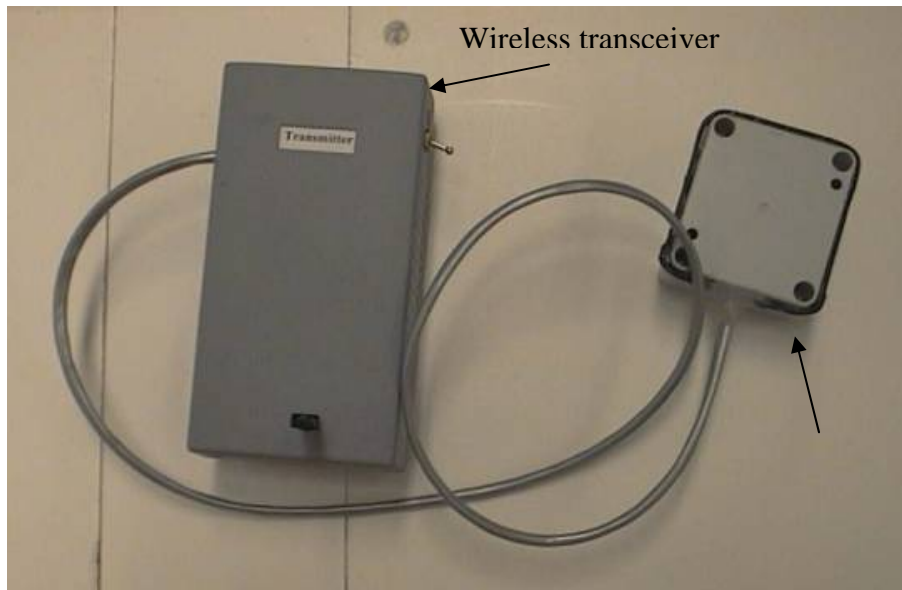


Figure 2.11 PTL sensor with wireless data transmitter

The software for the wireless data transmission device is also developed, with which the wireless device can communicate with and send sensor data to the control computer.

CHAPTER 3: SENSOR CIRCUIT DESIGN AND HARDWARE INTEGRATION

3.1 Circuit Model of New Sensors

The investigations in [Chapter 2](#) have demonstrated that the PCB PPTL sensor head is one of the best sensor heads for soil moisture sensors. It has a high resolution, rigid structure and is ready for automatic machining. To maximally utilize the features of the PCB PPTL sensor heads, new matching circuits are developed, a block diagram of which is drawn in [Figure 3.1](#).

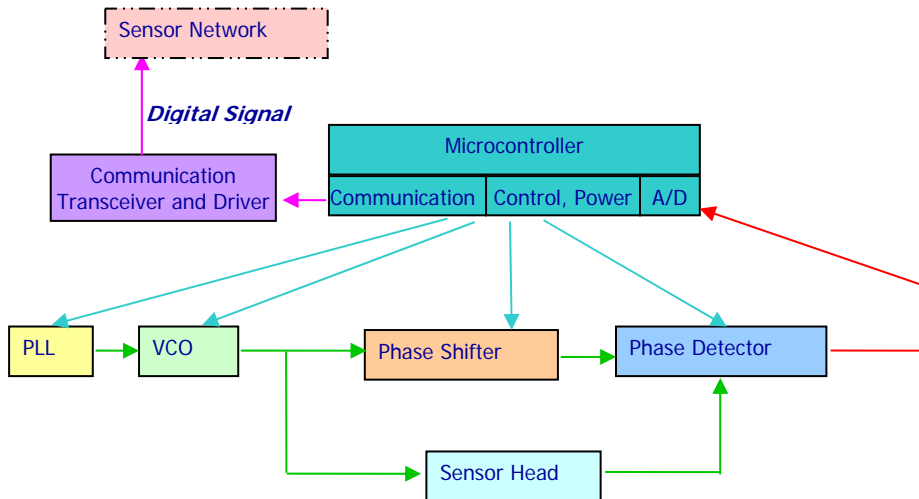


Figure 3.1 Sensor circuit model

Compared to the previous versions of moisture sensor circuits, the new circuits added a lot of new features: 1) adjustable phase shifter, which provides initial phase calibration to insure the optimal initialization of the measured phase shift and the outside moisture content so as to implement the maximum usage of the dynamic range of the moisture sensor; 2) signal digitization on board, which greatly facilitates data storage and data transfer from sensor to host computer; 3) communication transceiver and

driver, with which the sensors become able to communicate with each other as well as the data collection box (or control box); 4) on-board microcontroller, which is the brain of the whole sensor system, making the phase-lock loop, the VCO, the adjustable phase shifter, the phase detector, communication transceiver and A/D unit work harmonically; 5) unique address ID assigned to each sensor, which not only enables the sharing of communication lines within sensor groups, but also makes it susceptible to building large-scale wireless sensor networks; 6) on-board power down mode, to save power in field applications.

3.2 Control Box Development

The multifunction data acquisition console boxes (also named control boxes) are developed for collecting and storing the measured data of a group of sensors. The current control box uses RS485 protocol to communicate with individual sensors and collect measured moisture data. The on-site control box can be remotely controlled or operated by a computer at an office through a telephone wire or a direct cable. Therefore, the in situ moisture condition can be monitored. The firmware in the onsite computer can also be updated through the phone wire. The control box as shown in [Figure 3.2](#) includes:

- Power: 5VDC, 400mA; 12VDC, 60mA(Sleeping), 150mA(Measuring)
- Date storage: one year period for every 15 minutes measurement
- Operating temperature: 0°C ~ +60°C
- LCD display: 20 column, 4 row
- Dimension: Sensor, 130mm(L) X 55mm (W)
- A/D: 10 bits

- Channels: 20 Sensors
- Data access methods: serial port, modem, internet

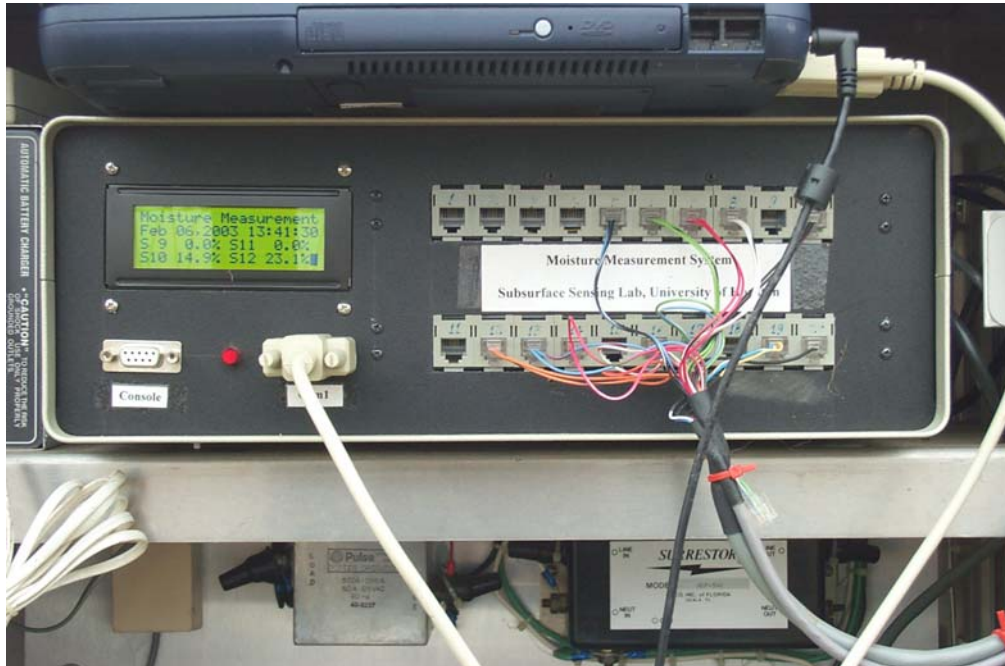


Figure 3.2 Control box

CHAPTER 4: SOFTWARE DEVELOPMENT

4.1 Software System

The moisture sensor system totally involves three processors: the microcontroller on the sensor board; the Stand Alone Biscuit PC in the control box; and the desktop PC in the office. Therefore, the software work also includes programming for the three processors. The structure of the software system is illustrated in [Figure 4.1](#).

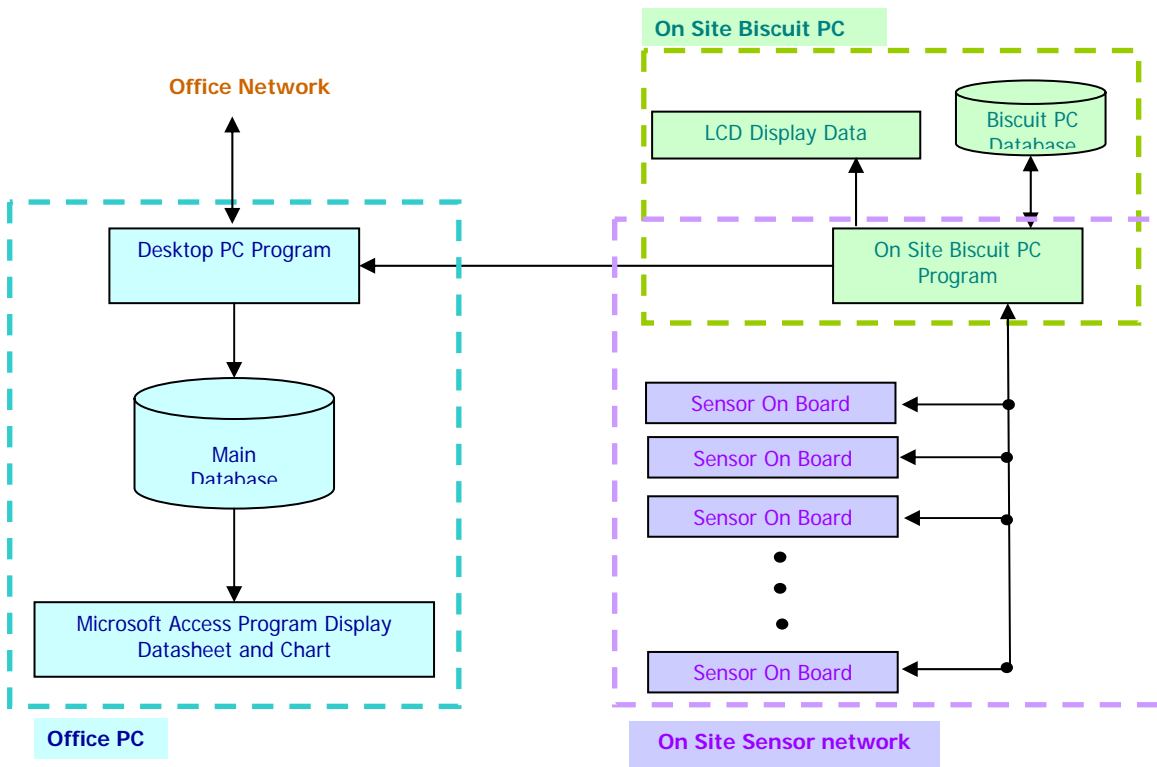


Figure 4.1 Software system

4.2 Microcontroller Software

Microcontroller Software is used to control the function of the on-board sensor and sensor network implementation.

4.3 Stand Alone Biscuit PC Software

Since the onsite PC is a 386EX with DOS environment, the acquisition and control programs are implemented by object-oriented program (OOP) under a Visual C++ 1.52, 16-bit version. These applications include Loader program and MoisSite.

The loader program is used to remotely upgrade the program on the onsite PC through modems. The diagram of the loader process is shown in Figure 4.2. If the onsite PC program needs to be upgraded, we can remotely instruct the MoisSite program to quit. Then after 100 seconds the computer will restart and launch the loader.

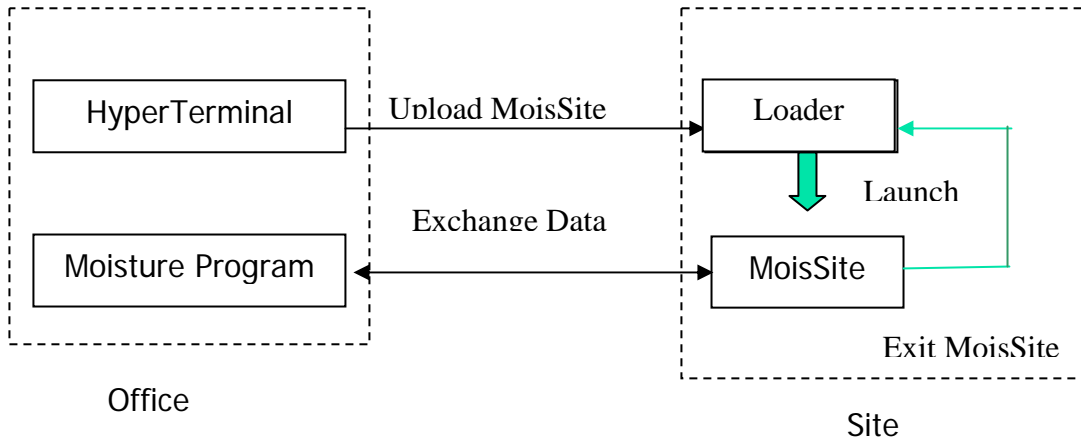


Figure 4.2 Diagram of the loader process

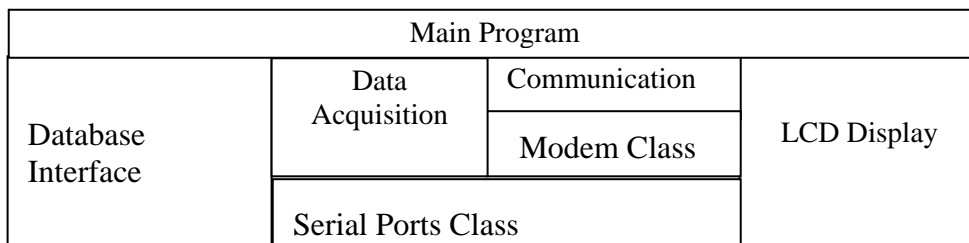


Figure 4.3 Function modules of MoisSite program

The measured moisture data is first stored in a temporary database in the Biscuit PC in the control box. Because of the limited size of the flash disk in the Biscuit PC, the records in the temporary database must be transferred to a permanent storage (an office PC) periodically and the flash disk must be refreshed for saving new moisture data. The relationship diagram of this database is shown in [Figure 4.4](#).

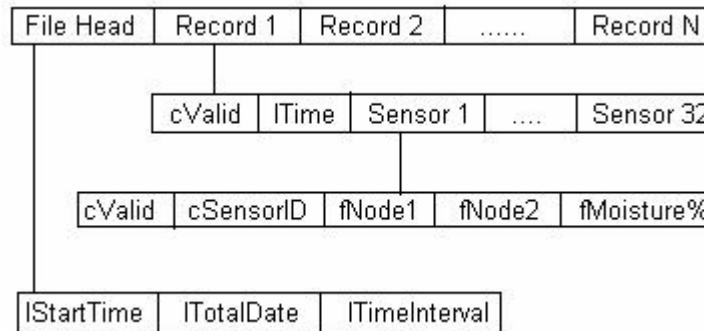


Figure 4.4 Relationship diagram of database of onsite PC

4.4 Remote PC Software

4.4.1 Remote Moisture Program

The computer program of the moisture system for the remote PC is developed under a Visual C++ 6.0 Win32 environment. There are three major tasks for this application. The first one is to communicate with the onsite Biscuit PC. The second one is to transfer moisture data from the Biscuit PC to the office's permanent database. The third task is to monitor the status of the onsite PC and display the measured moisture data. The communication implementation is shown in [Figure 4.5](#), and the operation interface is shown in [Figure 4.6](#). The moisture software also manages site and sensor information, such as site name, dial-up number and active sensors, etc.

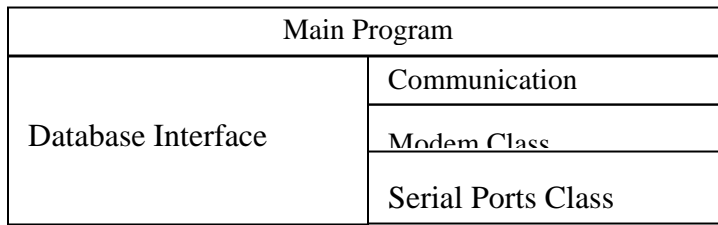


Figure 4.5 Remote PC communication implementation

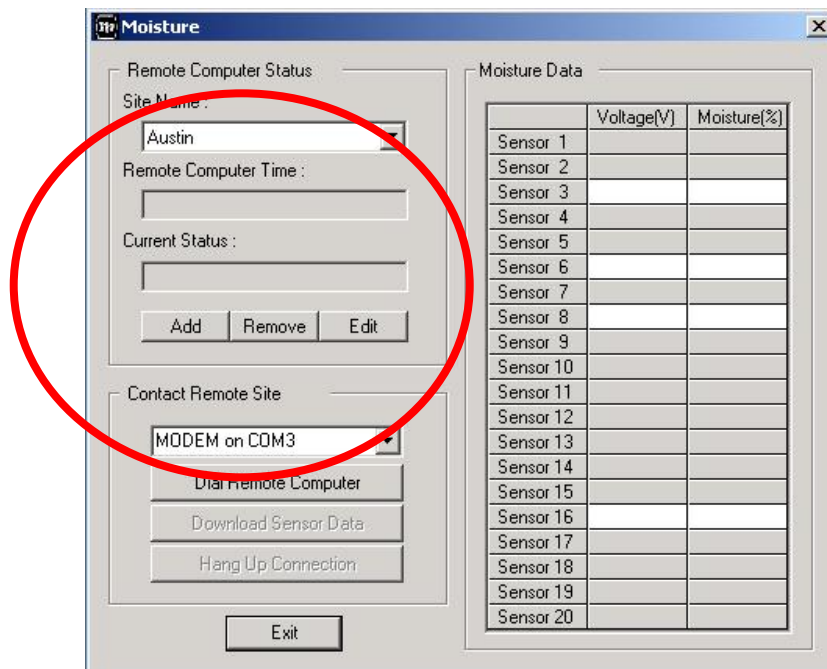


Figure 4.6 Software interface of the remote moisture program

4.4.2 Moisture Database

The other part of the software is the moisture database. This is a Microsoft Access 2000 database that stores all the data, provides a simple analysis and displays moisture graphs. A copy of the software must be installed into the office desktop computer. The components of the database and moisture.mdb are listed in [Table 4.1](#).

Table 4.1 Components and structure of the moisture database

Tables	Site
	Sensor
	SensorData
	Switchboard Items
Forms	Daily Moisture Datasheet
	Daily Moisture Chart
	Monthly Moisture Chart
	Switchboard
Query	Hourly Average
Macros	Switchboard Macros

Based on the database structure shown above, each site contains many sensors and each sensor has many sensor-data records. The switchboard is the main interface to access each active sensor of each site. The relationship of the table structure is illustrated in [Figure 4.7](#).

- Site (SiteID, SiteName, PhoneNum, LastUpdate, Description)
- Sensors (SiteID, SensorID, SensorOpen, Description)
- SensorData (SiteID, SensorID, SampleTime, Voltage, Moisture)

The fields underlined are the primary keys of the table. These fields identify the specific record of the sensor data for each sensor of each site.

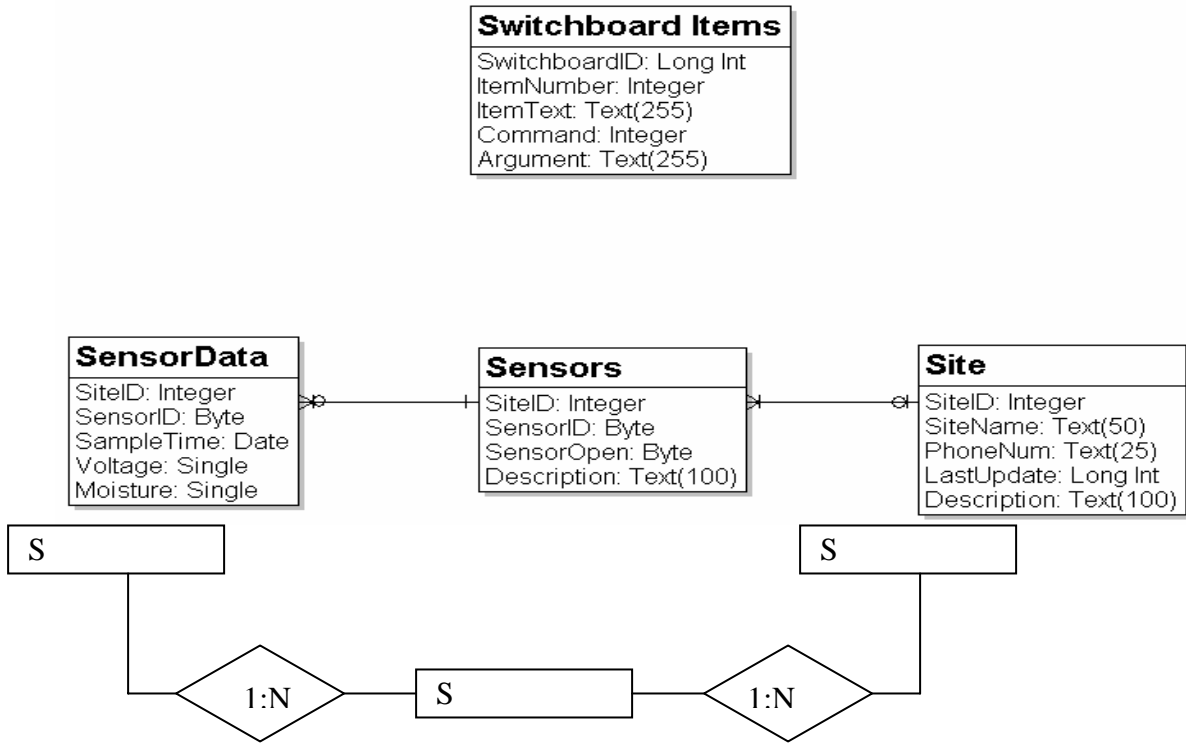


Figure 4.7 Diagram of the relationship of table structure of moisture database

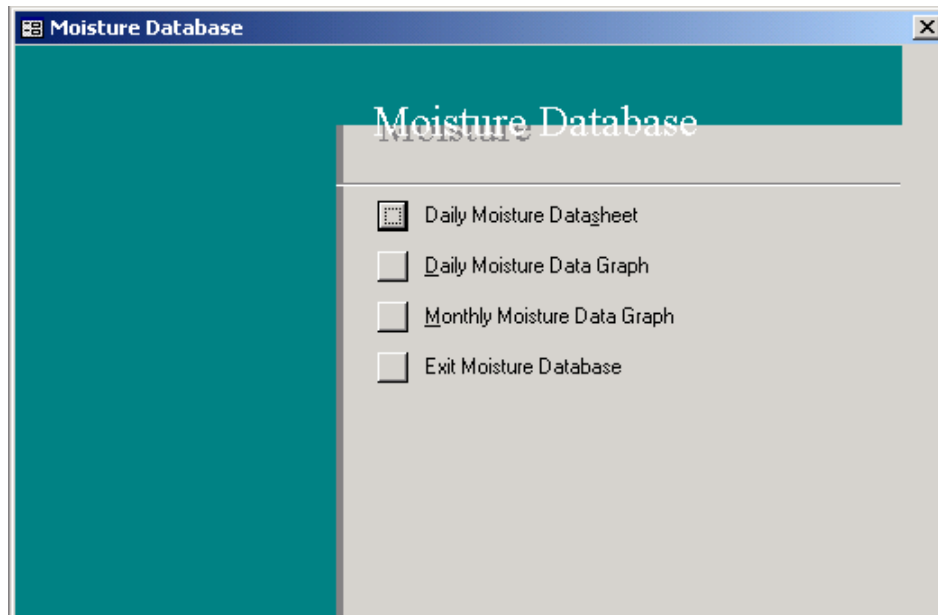


Figure 4.8 Moisture database main switchboard interface

The main switchboard menu contains four buttons. Except for the last one, “Exit,” each of these buttons directs the display of moisture data with the specific criteria. For instance, Figures 4.9, 4.10 and 4.11 illustrate the daily datasheet, daily chart and monthly chart, respectively.

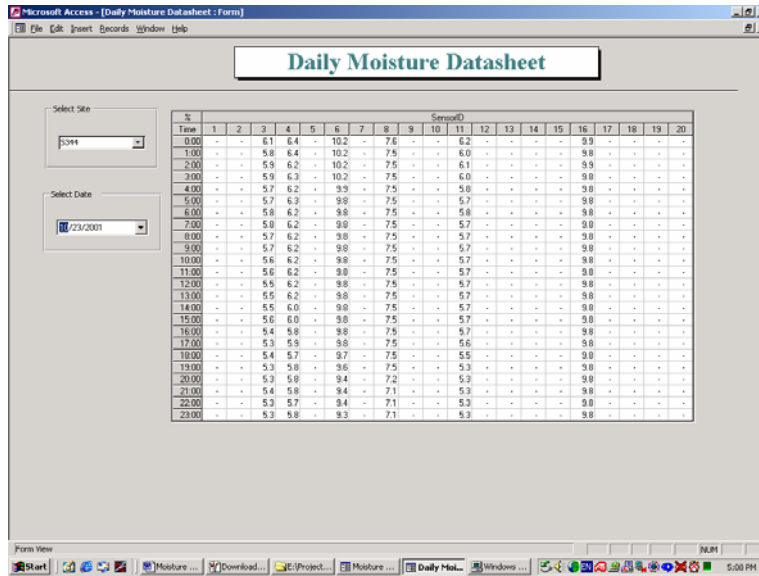


Figure 4.9 Sample of daily moisture datasheet

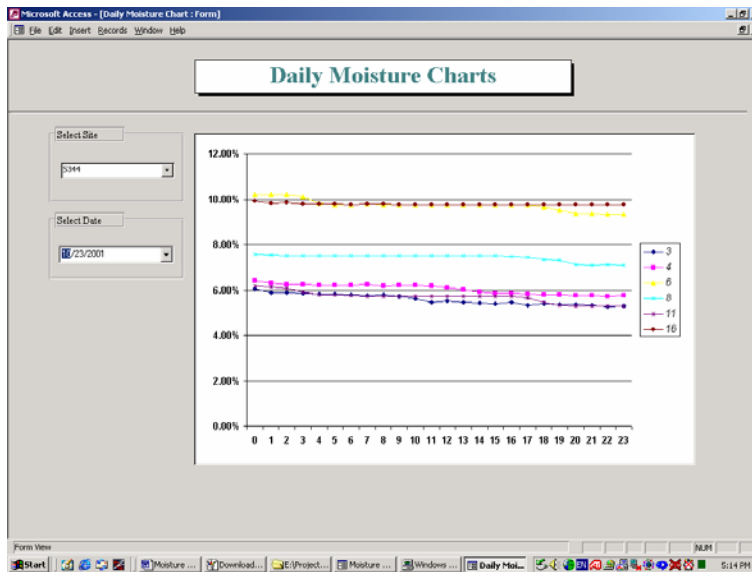


Figure 4.10 Sample of daily moisture chart

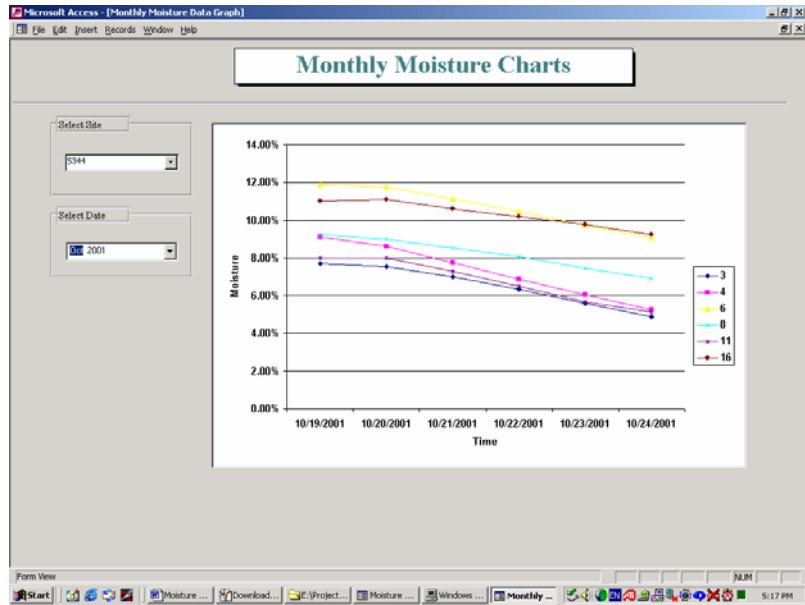


Figure 4.11 Sample of monthly moisture chart

CHAPTER 5: FIELD INSTALLATION AND MEASUREMENT

In the field installation, sensors were installed using core drilling as shown in [Figure 5.1](#). In the Bryan site, the sensors were buried in different pavement layers.



Figure 5.1 Field installation at Bryan District SPS-8 Site

[Figure 5.2](#) shows sensor installation layout at the Waco SPS-8 site. The numbers are addresses of the sensors. Two core holes were drilled to the depth of 34 inches.

After field installations, the data at these two sites has been continuously monitored. Data was obtained every 15 minutes. Measured data was downloaded from the site via a telephone line. [Figure 5.3](#) shows some of the measured data at the Waco site during the period of August 14, 2002 to February 6, 2003. [Figure 5.4](#) shows the measured data at the Bryan site during the period of April 11, 2002 to February 6, 2003. The figure also plots rainfall data in the broader area in Waco as a reference. From [Figures 5.3](#) and [5.4](#), we can see that most of the moisture data peaks at the position of rainfall. Frequent rainfall during the period of mid-October and mid-November made average moisture in the pavement reach 13-14%. There was a relative dry period in mid-November and mid-December. From mid-December to February, the pavement moisture was relatively high

due to the rainfall that occurred. Therefore, the data we collected reflects the amount of rainfall with high accuracy.

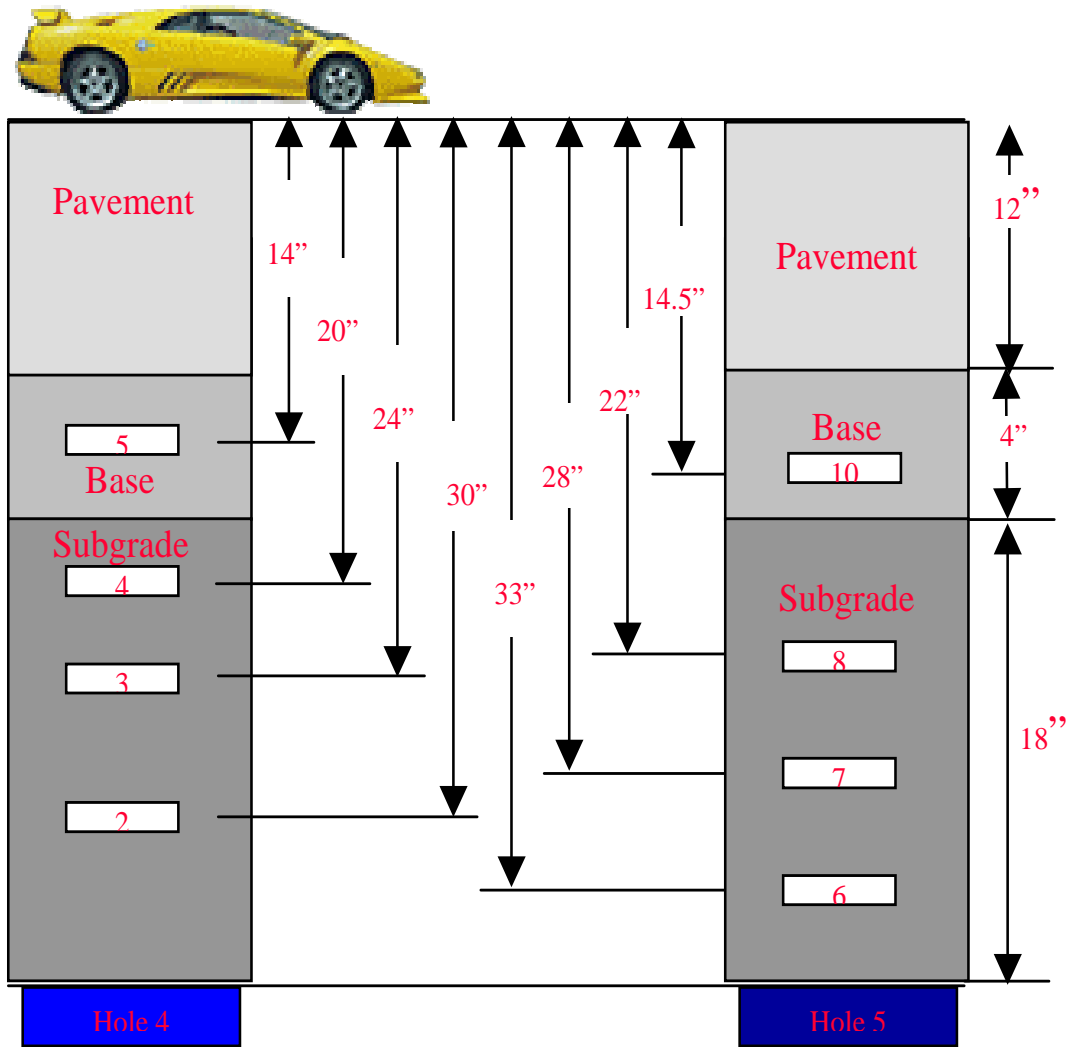


Figure 5.2 Sensor layout in Waco District SPS-8 Site: 8 sensors were installed in base and subgrade in two holes. The depth of the sensors in two holes is slightly different.

From the sensor point of view, the developed sensors are small in size, low-cost (estimated cost for mass production is about \$30 each; the data acquisition box is about \$500 each). The installation process is rather straightforward. A list of the specifications of these sensors is as follows:

Sensor accuracy: $\pm 2\%$

Moisture range: 0 – 100%

Power consumption: 30 mA, 6V

Operating temperature: -30°C to 70°C .

Network: 32 sensors per box

Data transmission: wired or wireless (2.4GHz)

Remote access: Modem

Local access: Serial port

Data storage: 6 months for 15 minutes interval.

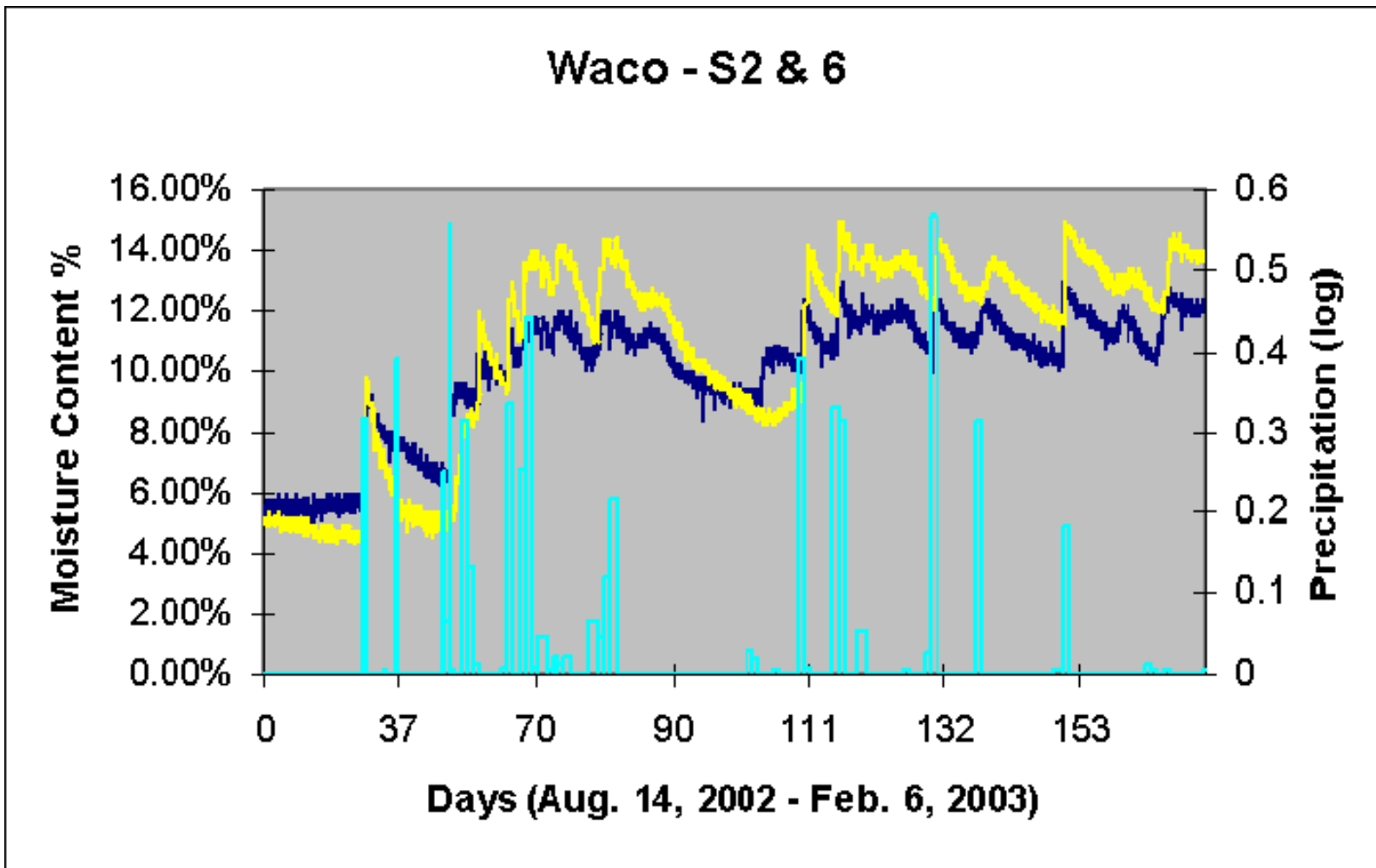


Figure 5.3 Recorded data of Sensors 2 and 6 in Waco District SPS-8 Site: The horizontal axis is in days with 0 representing August 14. The green lines are precipitation in the general area of the Waco area obtained from a public website. It can be seen that the rainfall data is closely correlated with the peaks of moisture data.

Moisture and weather data between 04/11/02 - 02/06/03, Bryan, Texas, Sensor -17

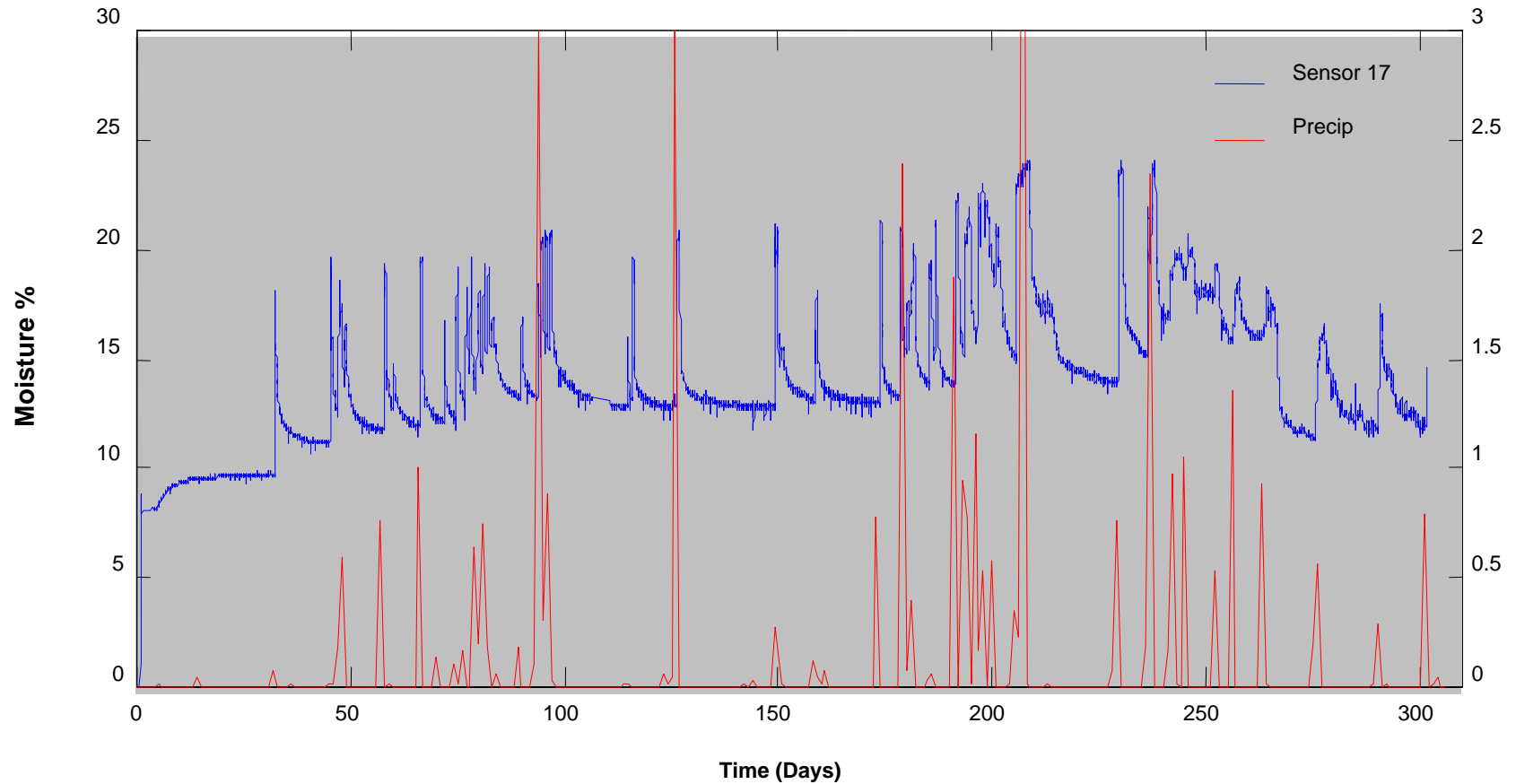


Figure 5.4 Recorded data of Sensor 17 in the Bryan District Site: The horizontal axis is in days with 0 representing April 11. The red line is precipitation in the general area of the Bryan area obtained from a public website. It can be seen that the rainfall data is closely correlated with the peaks of moisture data.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

In this project, the researchers systematically investigated and developed several types of moisture sensors, including parallel-wire transmission-line sensors, parallel-plate transmission-line sensors, ring resonator sensors, square-shaped resonator sensors, integrated PCB microstrip line sensors and PCB parallel-plate transmission-line sensors. The parallel-plate transmission line sensors have been installed in Bryan, Waco districts at the SPS-8 sites and Texas APT site to monitor moisture content in the pavement. These sensors are low-cost, small in size and remotely accessible. Data is then either remotely downloaded via modem or directly from the site. The system can store data for 12 months between two downloads.

The PCB parallel transmission-line sensors and ring resonator sensors were also developed. The electronics of the PCB sensors have been digitalized with new features including: 1) operation mode is upgraded to digital mode from analogue mode; 2) on-board microprocessor is introduced to control and manage sensor performance; 3) a unique address ID is assigned to each sensor to facilitate the communication, data transportation and sensor network building; 4) communication transceiver and driver are added to accomplish the communication with each other as well as the data collection box; 5) adjustable phase shifter is installed on board to insure the optimal initialization; 6) on-board power down mode is designed to save power in field applications.

A multifunction data acquisition console box (also named control box) is also developed for collecting and storing the measured data of a group of sensors. The current control box uses RS485 protocol to communicate with individual sensors and collect measured moisture data. The on-site control box can be remotely controlled or

operated by a computer at an office through a telephone wire or a direct cable. Therefore, the in situ moisture condition can be monitored. The firmware in the onsite computer can also be updated through a phone wire.

Recommendations:

The moisture sensors developed in this project are very accurate and inexpensive. Compared with existing capacitive sensors, the developed sensors are far more accurate. Compared with TDR sensors, the developed sensors are very low-cost (TDR sensor costs about \$600 each). The sensors are very small in size, easy to install and durable. Implementation of these sensors will greatly benefit TxDOT.

Appendix

Moisture Sensor Software User Manual

Subsurface Sensing Lab
University of Houston

1. Introduction

The purpose of the moisture sensor software is to download moisture data from the onsite computer and analyze this data.

The moisture sensor software consists of two parts. The first part is the moisture program. This is a Win32 program to download data from the onsite computer. The other part is the moisture database. This is a Microsoft Access 2000 database which stores all the data and displays moisture curves.

The installation is quite simple. Just click the **setup** program on the CDROM and follow all the instructions; the program will be installed on your computer.

In order to use the moisture database, a copy of Microsoft Access 2000 must be installed.

If this program is installed on Windows 98/95, a Microsoft database component should be installed. The Microsoft database component setup program is included on the installation CDROM.

2. Moisture Program

The Moisture Program

The moisture program allows you to download the moisture data from the remote biscuit PC and store it in the local database--moisture.mdb.

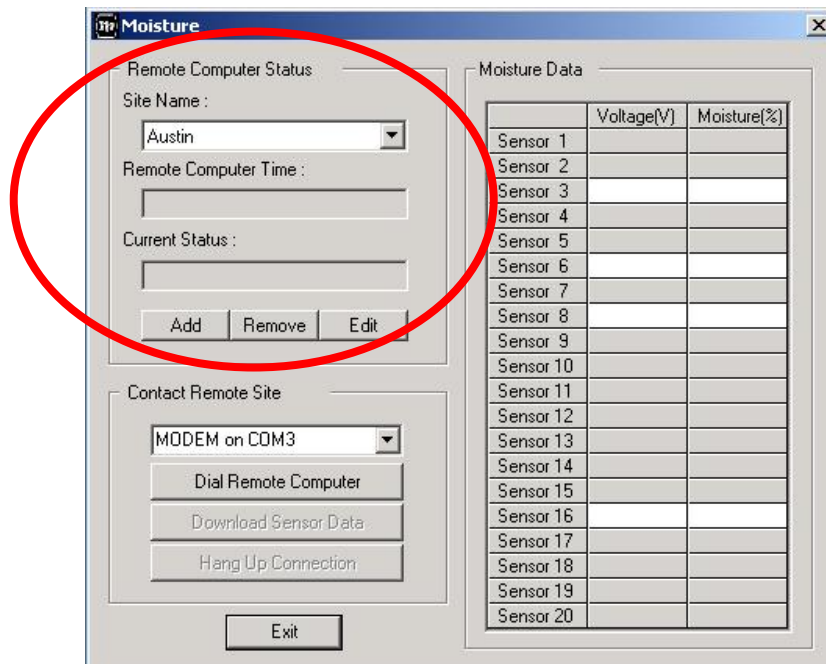
Launch the program

Click the **Moisture Program** in the Moisture folder in your start menu.



Manage Site Information

After you successfully start the program, the main dialog will appear. In the group box in the red oval you can add, delete or edit remote site information.



Site Name :

This combo box indicates which site you are going to connect. This is also the current site from which you can edit site information or delete. If you have multiple sites, you can click the pull-down arrow on the right side of the combo box to choose different

Remote Computer Time :

When the moisture program connects to the remote biscuit PC through the modem or serial port, this text box shows the current time of the remote PC.

Current Status :

When the moisture program connects to the remote biscuit PC through the modem or serial port, this text box shows the current status of the remote PC.

Add

Clicking this button will open the site dialog to input the new site's

Remove

Clicking this button will delete all the data in the current site including all the moisture data in the database.

Edit

Clicking this button will open the site dialog to modify the current site's information.

After clicking and you will open the site dialog:

Site Dialog

Site Name :

Telephone Number :

Description :

Choose Sensor

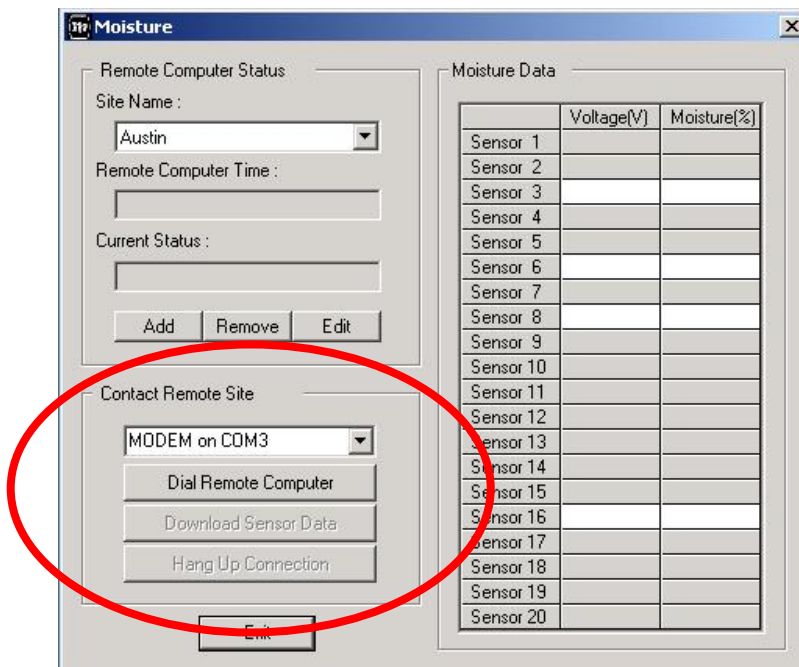
<input type="checkbox"/> Sensor 1	<input checked="" type="checkbox"/> Sensor 6	<input type="checkbox"/> Sensor 11	<input checked="" type="checkbox"/> Sensor 16
<input type="checkbox"/> Sensor 2	<input type="checkbox"/> Sensor 7	<input type="checkbox"/> Sensor 12	<input type="checkbox"/> Sensor 17
<input checked="" type="checkbox"/> Sensor 3	<input checked="" type="checkbox"/> Sensor 8	<input type="checkbox"/> Sensor 13	<input type="checkbox"/> Sensor 18
<input type="checkbox"/> Sensor 4	<input type="checkbox"/> Sensor 9	<input type="checkbox"/> Sensor 14	<input type="checkbox"/> Sensor 19
<input type="checkbox"/> Sensor 5	<input type="checkbox"/> Sensor 10	<input type="checkbox"/> Sensor 15	<input type="checkbox"/> Sensor 20

You can give a name to the site you want to contact and its telephone number, which will be used to dial using modem in the respective text box on this dialog window. The description text box is an optional input. Then you can click on the corresponding check box where the sensors are connected to the board. On the moisture data group box in the main dialog box the sensors you chose are enabled (white) and the others are disabled (gray). Press **OK** button to save the modification or **Cancel** button to quit this dialog without saving.

Please note the site name and the telephone number must be unique. Otherwise an error message will show up.

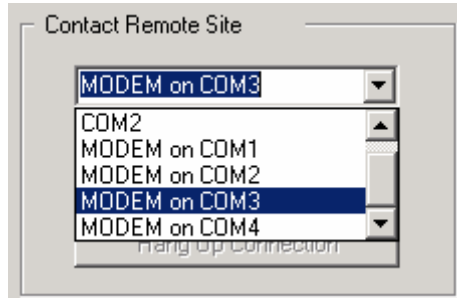
Download Moisture Data


The Contact Remote Site group box contains all the buttons you need to download moisture data from the on-site computer.

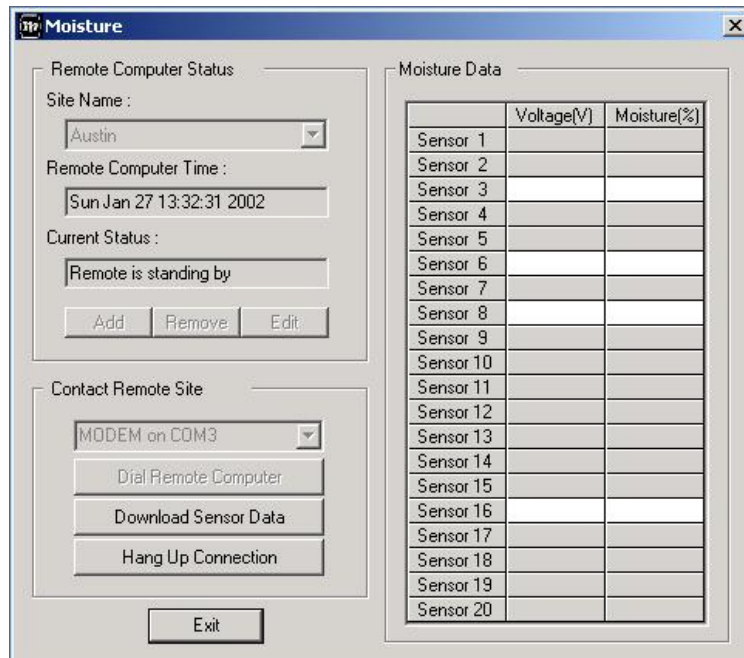


1. Pressing the arrow on the combo box will show you a list of available connection ports. If you are going to dial the remote computer using a modem, you need to find out which **COM** port your modem is using. In the Windows2000 operation

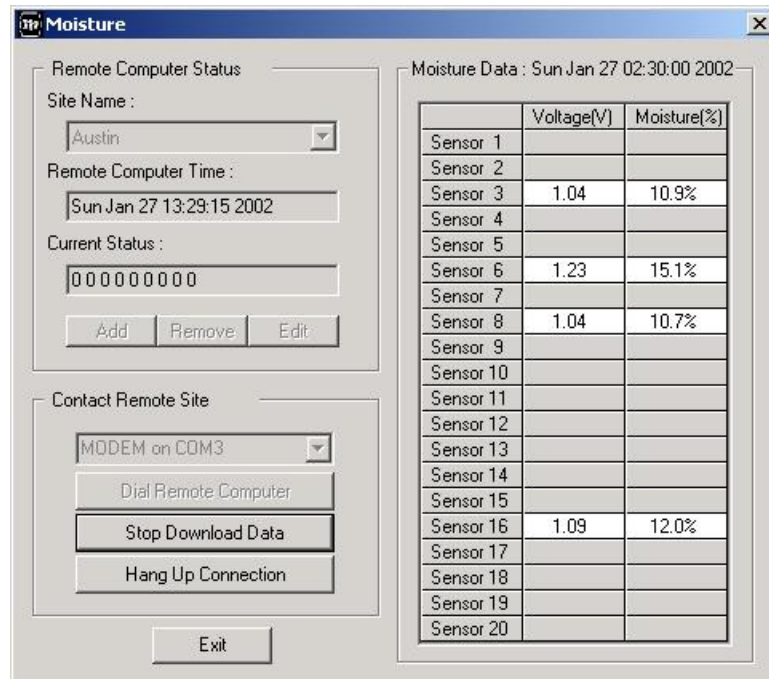
system, you can open the **control panel** window and double click the **phone and modem option** icon. Then click on the **Modem** tab and you can see which **Com port** your modem is attached to.



- Now you can press the  button to connect to the site indicated in site name combo box. If this button is disabled (gray), this means you did not add any sites. You should first add site information before you can press this button. After you click this button, all the controls in **Remote Computer Status** group will be disabled. If your modem speaker is on you will hear the hand shake sound.



3. When the **Current Status** is “**Remote is standing by,**” you can press the **Download Sensor Data** to start download data. All the downloaded data will be shown on the **Moisture Data** group. You can press the **Stop Download Data** button at any time to stop the download process.



4. After the data is downloaded press **Hang Up Connection** button to disconnect communication with the remote computer.

3. Moisture Database

The Moisture Database

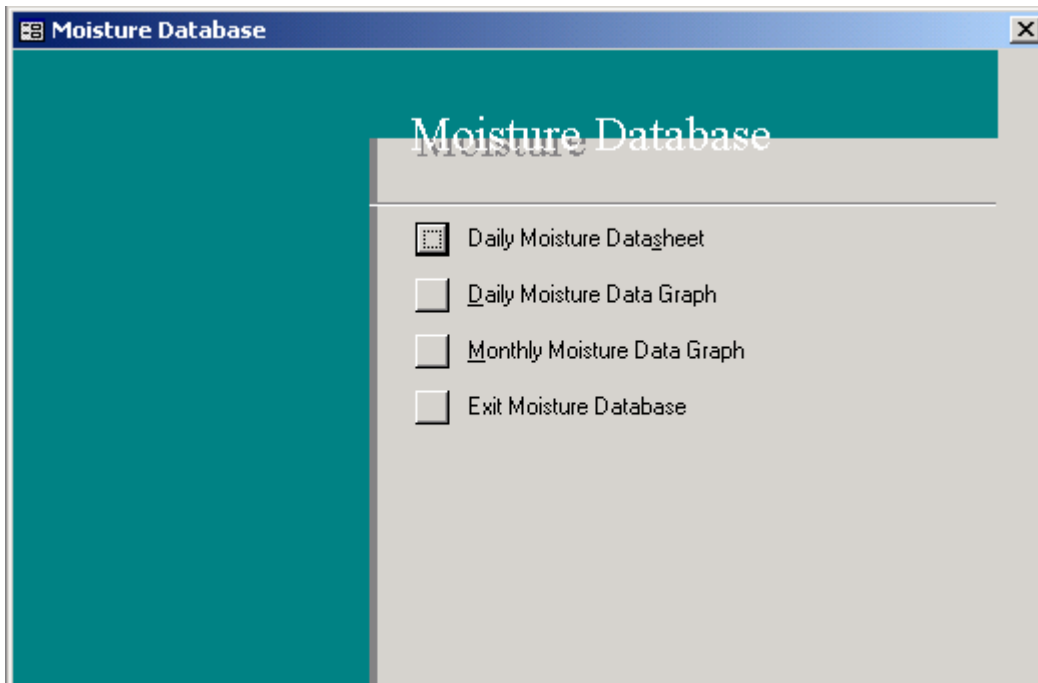
This database is used to store and analyze all the moisture data.

Launch the Database

With Microsoft Access 2000 installed, click the **Moisture Database** in the moisture folder of your start menu.



Main Interface



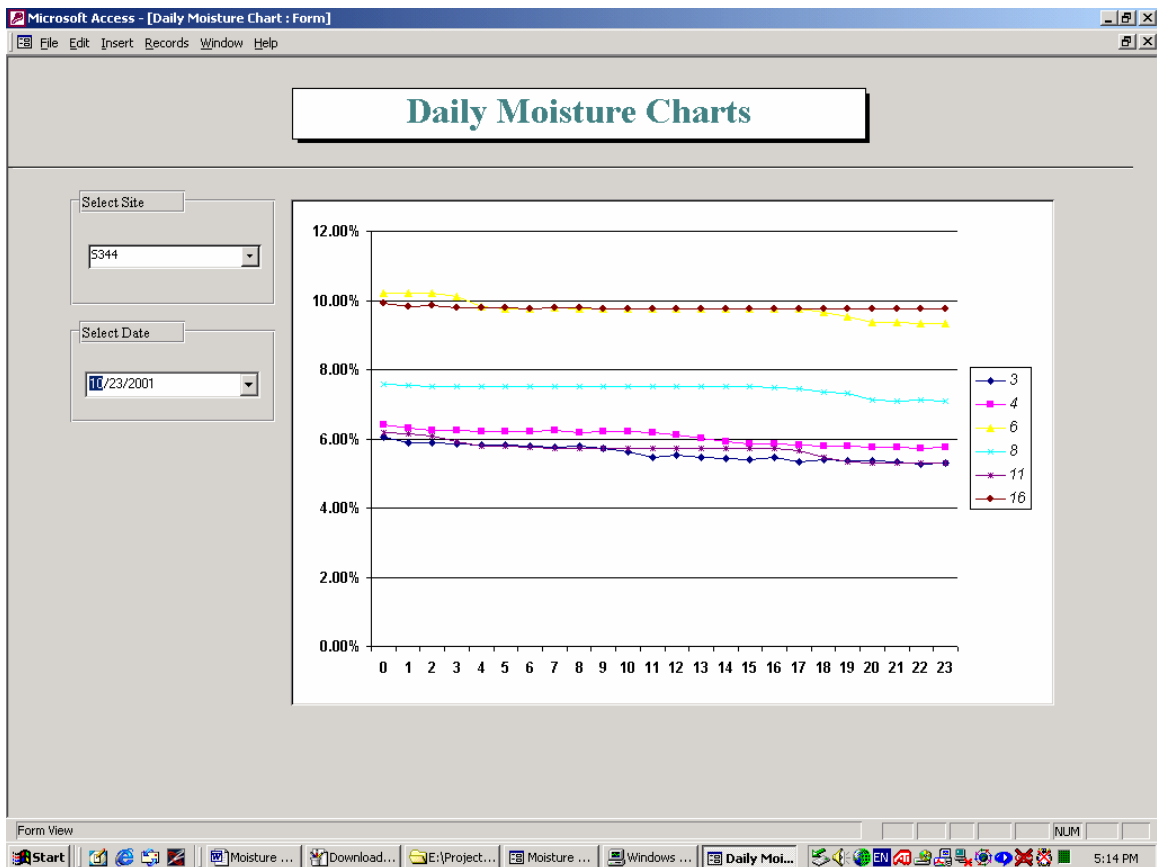
Daily Moisture Datasheet

Pressing the button on the left of **Daily Moisture Datasheet** will open the following form. This form shows the moisture data of the selected day. You can change the site and date using the two combo boxes on the left. Closing this form will return you to the main interface.

%	SensorID																			
Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0:00	-	-	6.1	6.4	-	10.2	-	7.6	-	-	6.2	-	-	-	-	9.9	-	-	-	-
1:00	-	-	5.8	6.4	-	10.2	-	7.5	-	-	6.0	-	-	-	-	9.8	-	-	-	-
2:00	-	-	5.9	6.2	-	10.2	-	7.5	-	-	6.1	-	-	-	-	9.9	-	-	-	-
3:00	-	-	5.9	6.3	-	10.2	-	7.5	-	-	6.0	-	-	-	-	9.8	-	-	-	-
4:00	-	-	5.7	6.2	-	9.9	-	7.5	-	-	5.8	-	-	-	-	9.8	-	-	-	-
5:00	-	-	5.7	6.3	-	9.8	-	7.5	-	-	5.7	-	-	-	-	9.8	-	-	-	-
6:00	-	-	5.8	6.2	-	9.8	-	7.5	-	-	5.8	-	-	-	-	9.8	-	-	-	-
7:00	-	-	5.8	6.2	-	9.8	-	7.5	-	-	5.7	-	-	-	-	9.8	-	-	-	-
8:00	-	-	5.7	6.2	-	9.8	-	7.5	-	-	5.7	-	-	-	-	9.8	-	-	-	-
9:00	-	-	5.7	6.2	-	9.8	-	7.5	-	-	5.7	-	-	-	-	9.8	-	-	-	-
10:00	-	-	5.6	6.2	-	9.8	-	7.5	-	-	5.7	-	-	-	-	9.8	-	-	-	-
11:00	-	-	5.6	6.2	-	9.8	-	7.5	-	-	5.7	-	-	-	-	9.8	-	-	-	-
12:00	-	-	5.5	6.2	-	9.8	-	7.5	-	-	5.7	-	-	-	-	9.8	-	-	-	-
13:00	-	-	5.5	6.2	-	9.8	-	7.5	-	-	5.7	-	-	-	-	9.8	-	-	-	-
14:00	-	-	5.5	6.0	-	9.8	-	7.5	-	-	5.7	-	-	-	-	9.8	-	-	-	-
15:00	-	-	5.6	6.0	-	9.8	-	7.5	-	-	5.7	-	-	-	-	9.8	-	-	-	-
16:00	-	-	5.4	5.8	-	9.8	-	7.5	-	-	5.7	-	-	-	-	9.8	-	-	-	-
17:00	-	-	5.3	5.9	-	9.8	-	7.5	-	-	5.6	-	-	-	-	9.8	-	-	-	-
18:00	-	-	5.4	5.7	-	9.7	-	7.5	-	-	5.5	-	-	-	-	9.8	-	-	-	-
19:00	-	-	5.3	5.8	-	9.6	-	7.5	-	-	5.3	-	-	-	-	9.8	-	-	-	-
20:00	-	-	5.3	5.8	-	9.4	-	7.2	-	-	5.3	-	-	-	-	9.8	-	-	-	-
21:00	-	-	5.4	5.8	-	9.4	-	7.1	-	-	5.3	-	-	-	-	9.8	-	-	-	-
22:00	-	-	5.3	5.7	-	9.4	-	7.1	-	-	5.3	-	-	-	-	9.8	-	-	-	-
23:00	-	-	5.3	5.8	-	9.3	-	7.1	-	-	5.3	-	-	-	-	9.8	-	-	-	-

Daily Moisture Data Graph

Pressing the button on the left on **Daily Moisture Data Graph** will open the following chart. This chart shows the moisture data curve of the selected day. You can change the site and date using the two combo boxes on the left. Closing this chart will return you to the main interface.



Monthly Moisture Data Graph

Pressing the button on the left on **Monthly Moisture Data Graph** will open the following chart. This chart shows the moisture data curve of the selected month. You can change the site and date using the two combo boxes on the left. Closing this chart will return you to the main interface.

