ISSN: 2321-7782 (Online)
Volume 4, Issue 3, March 2016
International Journal of Advance Research in Computer Science and Management Studies
Research Article / Survey Paper / Case Study
Available online at: www.ijarcsms.com

Development of Calibration Model for Wireless Sensor Nodes: A Case Study of measuring Soil Moisture using MicaZ Sensor motes

Dr. Kamlendu Kumar Pandey
Dept. of Information and Communication Technology
Veer Narmad South Gujarat University
Surat, India

Abstract: Wireless Sensor Networks have emerged as new option for solving various problem domains which involve the system operation and control based on some control data. This involves the process of data acquisition, collection, dissemination, and processing. WSNs due to its inherent nature accuracy and speed of transmission can give real time benefits. A case of sensing soil moisture from the field using a sensor mote is presented in this paper. This involves the multiple sensor interfacing with its electronic circuitry, field data sampling, sensor operations, calibrations and working out the equations for use in the programming logic to be deployed on the sensor motes.

Keywords: wireless sensor mote, soil moisture sensing, MicaZ motes, sensor calibration, TinyOS, sensor data sheet.

I. Introduction

The technology of using wireless sensors and its network to improve the efficiency of many operational systems has gained a new momentum. Now WSNs are employed to solve problems in areas like irrigation water supply, weather monitoring, structural monitoring, flood forecasting, health monitoring and medication, logistics, production pipelining etc. This paper aims to educate the users of WSNs as how to start and employ the sensors to be used in solving a problem. This paper is focusing on a single mote rather than a network. The application considered is soil moisture sensing which will help the farmers and engineers to decide the irrigation interval and irrigation discharge to be supplied to the area as to replenish the soil moisture stress as to avoid wilting of crops or orchards. The WSN sensor node cannot be used unless it is calibrated with the environment and devices with which it shall be interfaced. A soil moisture sensor from IRROMETER® is interfaced with a MicaZ mote. This paper describes all the steps and thereby presents a model to be followed in such cases. The entire work is described in sections as Related Work, Working of WSN node and Soil Moisture Sensor, Sensor Interfacing, Sensor Calibration, Application Deployment.

II. Related Work

The technology and working of sensor networks was explained by I. Akyildiz et al [1]. The paper explains the complete working of a wireless sensor node and also mentions several types of sensors being used in the real world. The aspect of ad hoc routing protocol, data packet communication was also discussed. To view the problem in totality some of the works done for the use of wireless sensor networks in agriculture or irrigation were refereed Martinez, K. et al [2] described the way of environmental monitoring by ALERT a system deployed in the US. Rainfalls, water level, weather sensors are used in this system to detect, predict and hence prevent floods. Burrel [5] uses sensors to control vineyards, and also records and analyzes movements during the work of farmers. The whole experiment is done in the green house under highly controlled environment. Wang. et al [6] described the use of sensor based agricultural information system and concluded that sensor based system can be useful in proper planning of agricultural activities. Balendonck, J et al [8] have used sensor networks for the project FLOW-AID.

The deficit moisture conditions were recognized by the sensors deployed and a dynamic irrigation management was proposed. Cardell-Oliver et al [11] described a reactive soil moisture sensor to measure moisture stress. This paper uses a gypsum based electric analog sensor to measure the soil moisture. This sensor was interfaced with the sensor mote and the electrical analog reading was calibrated to the soil moisture reading. Although effort is made to apply the sensors in agriculture but it is still in the pilot or experimental stages no real implementation is still in the field. It is therefore required to study every aspect of sensor networks which will be useful in the field implementations.

The Physical layer consists of interfacing the physical wireless sensor mote with the soil moisture sensor. It was important to study the type of soil moisture sensor available in industry. Hanson B et al [7] described effectively as how tensiometer and soil electrical resistance meter can be used for automated sensing and water delivery in irrigation management. Robert Evans et al [9] gave an in-depth sight into how in situ soil moisture measurement can be so helpful to irrigation scheduling. Ling [10] give a detailed description of all possible moisture sensors being used in soil moisture measurement. It describes various methods and instruments to be used which includes gravimetric methods, Empirical methods, tensiometers, soil water resistance meter, Dielectric sensors etc. However they don't comment on how these equipments can be interfaced with sensor boards. Cardell et al [14] provide a field testing of wireless sensors for environmental monitoring in which Xbow mica motes are used to study environmental parameters. This paper also shows the way to interface a tensiometer with the sensor board and its calibration. Razvan Musaloiu.E et al [16] give a very exhaustive insight into how these wireless sensors can be used to interface the several environmental sensors. Interfacing the sensor has to deal with the problem of calibration and then to modify the application sitting on the sensor board ROM chip to get the actual calibrated data on the sink. This required an in-depth study into the operating system, senor pin layout and the language in which the application is written. As xbow Mica motes were to be taken into consideration the literature corresponding to them was surveyed. Tiny OS is the most popular operating system and work on most of the motes including xbow Mica family. Levis et al [17] gives a detailed note on organization and working of Tiny OS, It also describes the packet structure and the language features supported by it. All OS feature like memory management, synchronization, process scheduling, thread management etc. are discussed in length. The parent web site of Tiny OS [18] is really useful to have authentic and detailed understanding of this embedded operating system. Hill Json et all [19] has discussed the requirements and implementation of an embedded and multi-threaded operating system for small sensor in the perspective of Tiny OS. They have also evaluated the real sensor motes in various configuration running Tiny OS as sensor OS. Levis [20] again describes the Networking abstractions and techniques in Tiny OS facilitating users to interface external sensors and the caution taken to perform this operation. This paper studies the hardware platforms, single hop and multi-hop communication, AM Stack implementation, intra-network routing, time synchronization and power management techniques. The programming language used on these motes is nesC, a dialect of C which is modified for writing application on embedded systems. Gay et al [21] one of the creators of nesC has given holistic description of the purpose, architecture, inter-process communication, syntax, structures of NesC to educate the programmers so that one can write application for different motes. It has got the complete compatibility with TinyOS.

Once the interfacing is done the calibration is required for the sensed values and actual moisture content. Papers [22, 23, and 24] deals with the calibration of soil moisture meter for various soils and weather parameters. A graph of resistance and moisture stress in Kpa or Moisture content in % is plotted from saturated mass to oven dry mass. A five time's calibration gives a reliable curve. This curve can be used to interpolate the electrical resistance in Kohms to Moisture content in mm or %. A better way is to have a thorough regression analysis and come out with formulae to establish the relationship. This formula can be used in the nesC application sitting on sensor board. As soon as digital resistance is sensed from sensor the application will convert it into moisture content and will send the data packet through UART or radio link.

III. The Working of Sensors

A. The Assembly of Wireless Sensor Mote and Sensor Board

Wireless Sensor Mote Board

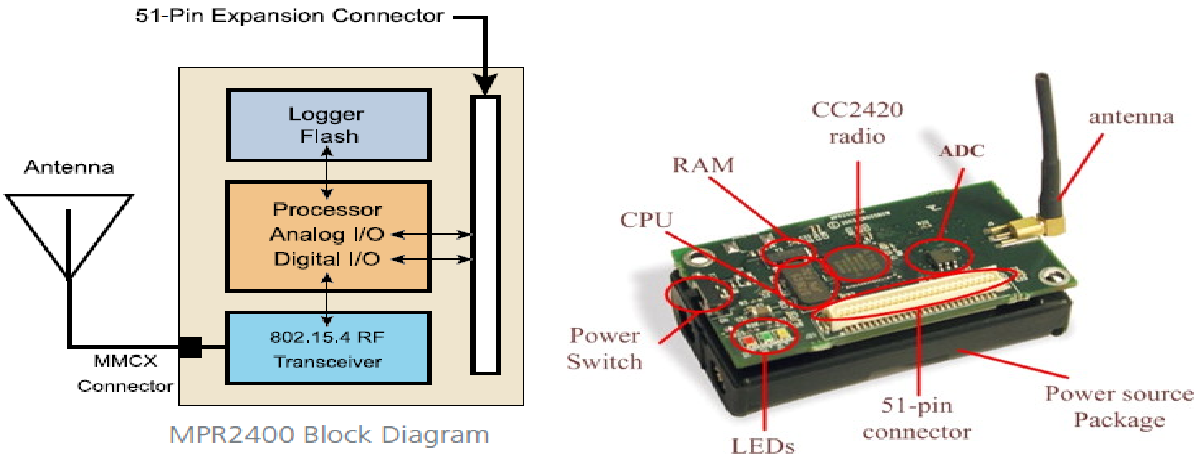


Fig.1 Block diagram of Sensor Mote (source: www.openautomation .net)

As shown in Fig.1 It has ATmega128L which is a low-power micro controller Processor and Radio Platform The 51-pin expansion connector supports Analog Inputs, Digital I/O, I2C, SPI and UART interfaces. These interfaces make it easy to connect to a wide variety of external peripherals. The MicaZ (MPR2400) IEEE 802.15.4 radio offers both high speed (250 kbps) and hardware security (AES-128). It has a program flash of 128K to store sensor based applications, Measurement flash of 512K to store the sensed data before it is passed to sink or other node, EEPROM of 4K to store the footprint of OS, 10bit ADC with 8 channels and 0-3V input. It draws 10mA current in active and < 15 µA in sleep mode.

RF Transceiver : It is mounted on the Mote board and works on 2400 MHz to 2483.5 MHz ISM band, programmable in 1 MHz steps, Transmit (TX) - data rate 250 kbps, RF power -24 dBm to 0 dBm , Receive Sensitivity -90 dBm (min), -94 dBm (type) , Adjacent channel rejection 47 dB + 5 MHz, channel spacing 38 dB - 5 MHz channel spacing ,Outdoor Range 75 m to 100 m 1/2 wave dipole antenna, LOS Indoor Range 20 m to 30 m 1/2 wave dipole antenna , Current Draw 19.7 mA - Receive mode , 11 mA - TX, -10 dB ., 14 mA -TX, -5 dB , 17.4 mA - TX, 0 dB , 20 µA - Idle mode with voltage regulator on, 1 µA in sleep mode with voltage regulator off.

Data Acquisition Sensor Board

MDA series are actual data acquisition board having empty slots for interfacing external sensors. They are the experimental boards having only temperature and humidity sensors.

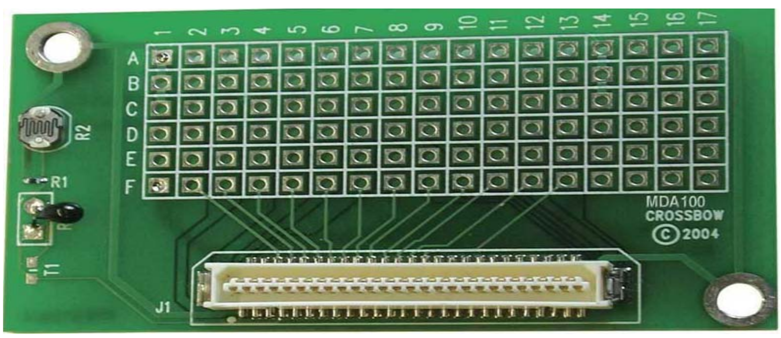


Fig 2. MDA 100 Sensor Module (courtesy www.memsic.com)

The sensor boards having sensors for various physical and environmental parameters sense the data from their respective medium and send the digital data to mote on which they are bread boarded. The Applications residing in 128K of flash are going to deal with the data. Every sensor has a specific application attached to it with respect to the configuration of the sensor board. These applications become active when the data from the particular sensor board reaches the motes. The running TinyOS will pick up sensor board configuration and will forward the digital data to that application. The board and sensor specific application will deal with the data and do the operations it is programmed for. Finally the data is packaged into tinyos specific data format and is diverted either UART or radio link. The whole assembly is shown in Fig.3

SENSOR BOAD (MDA 100)	SENSORS (Sense data)	MoteWorksDriver (2K)
BREAD BOARDING INTERFACE		
MOTE AND RADIO BOARD (ATmega128L)	Sensor Board Specific Applications like Temperature, humidity in (128 K)	Sensed Data Buffer (512 K)
	TINYOS 2.x (4 K)	
UART or RADIO LINK		

Fig 3 Schematic Representation of Sensor-Mote-OS-Radio relationship

B. Working Of Soil Moisture Sensor

In this research a Soil Moisture Meter from Irrometer with a trade name of Water Mark Soil Moisture Sensor is supposed to be interfaced with MicaZ sensors of Memsic. To perform the assembly we must understand the complete working of moisture sensor as well as electronic radio mote boards and sensor boards.

1. OPERATING PRINCIPLE OF SENSOR:

Fig 4 shows soil moisture sensor. WATERMARK sensor is a resistive device that responds to changes in soil moisture. Once planted in the soil, it exchanges water with the surrounding soil thus staying in equilibrium with it. Soil water is an electrical conductor thereby providing a relative indication of the soil moisture status. As the soil dries, water is removed from the sensor and the resistance measurement increases. Conversely, when the soil is rewetted, the resistance lowers. The WATERMARK sensor is unique in that it takes its resistive measurement within a defined and consistent internal matrix material, rather than using the surrounding soil as the measurement medium. This unique feature allows the sensor to have a stable and consistent calibration that does not need to be established for every installation. The relationship of ohm of resistance to centibars (cb) or kilopascals (kPa) of soil water tension is constant and built into the reading devices that are used to interrogate the sensor. The sensor is calibrated to report soil water tension, or metric potential, which is the best reference of how readily available soil water is to a plant. The WATERMARK sensor (Model 200SS-V) consists of stainless steel electrodes embedded in a defined and consistent internal granular matrix material that acts like a soil in the way it moves water. This matrix is encased in a hydrophilic material that establishes good hydraulic conductivity with the surrounding soil and is held in place by a durable stainless steel perforated shell with plastic end caps.

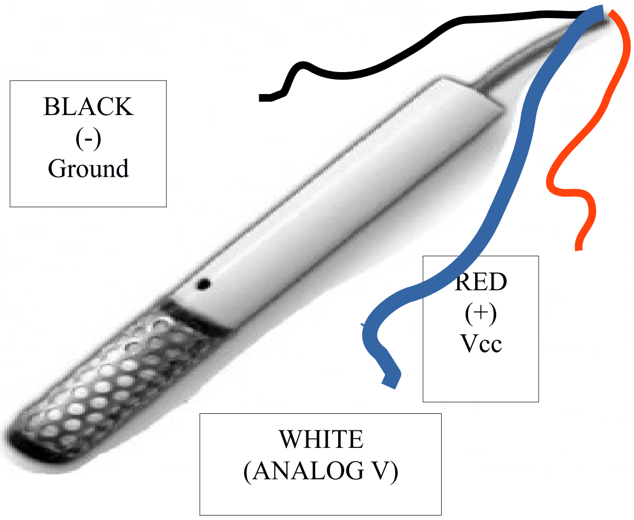


Fig 4 Water Mark Soil Moisture Sensor

2. Specification Information:

The soil moisture measurement device, or sensor, shall represent soil moisture status in units of soil water tension or metric potential, registering in centibars (cb) or kilopascals (kPa) when read with a compatible reading device. Its construction shall be of the Granular Matrix Sensor (GMS) type and require no on-site calibration or routine maintenance.

3. Electrical Properties:

This sensor operates on 3.2- 30 volt (2 AA) Batteries, 1.5 mA input, polarity protected / 0-2.8 volt output, linear / 0-239 cb (kPa) = 0 to 2.8 volts linear. The Sensor comes with three colored wires RED, WHITE AND BLACK (As shown in Fig 4). The RED is the + ve end, BLACK is – ve and WHITE is SIGNAL which give Analog Voltage Signal. The RED is used to excitation by powering the sensor while resistance varies between BLACK and WHITE wires with varying moisture content. The variability of resistance affects the voltage given by the SIGNAL cable. This voltage value will be the indicator of moisture stress in Kpa or Moisture content in the soil.

IV. The WSN Mote and Soil Moisture Meter Interfacing

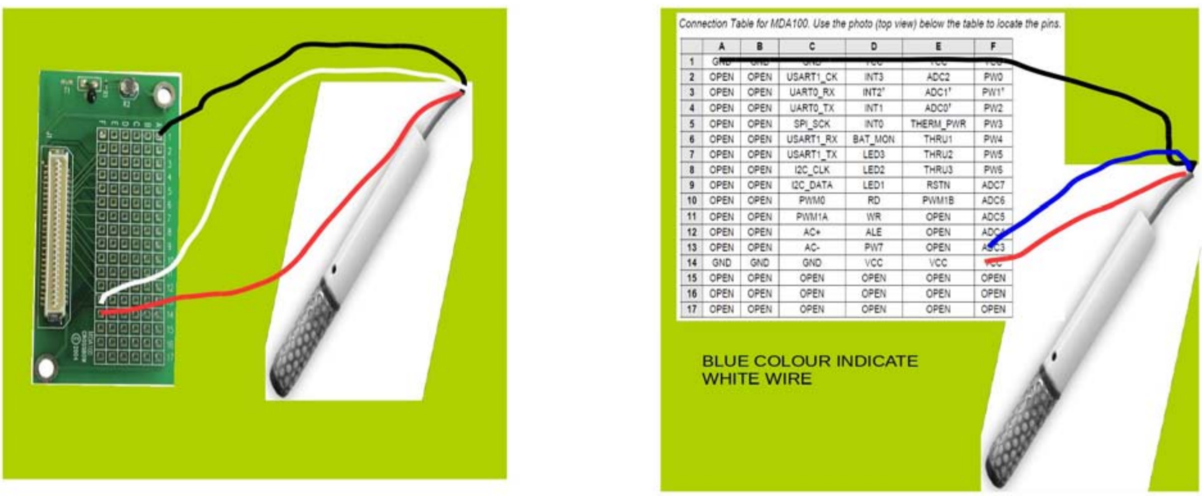
The goal of this section is to Interface our WATERMARK Soil Moisture Meter with MDA Sensor Board and thereby

- Get the data on sink node and then to computer
- Calibrate the Moisture Sensor
- Do Needful Changes in the sensor specific application and re-deploy it on mote board.
- Get the real moisture data on sink and then to computer.

This type of board is already discussed above. We studied the specific MDA 100 sensor board specifically to interface it with soil moisture meter. For this purpose we need to study the PIN diagram of sensor and understand its electric circuitry. From Fig 4.10 We can see that MDA 100 contains 102 pin arranged in 6 columns and 17 rows. This sensor board has only two sensors viz. Temperature and light. The sensor is connected to the analog-digital converter channel number 1 (ADC1) through a basic resistor divider circuit. In order to use the thermistor, the sensor must be enabled by setting digital control line INT2 high.

B) Connectivity of Soil Moisture Meter with MDA Sensor Board

Our soil moisture meter is having three cable ends of colour red, black and white. Red is positive used for purpose of giving power to excite the watermark soil moisture sensor. The Black is negative used to connect to the GND Pin to have the potential difference due to the resistance posed by the granular soil moisture medium. The White one is the Analog end and should be attached to an empty ADC pin as shown in Fig. 5



	A	B	C	D	E	F
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	OPEN	OPEN	USART1_CK	INT3	ADC2	PW0
3	OPEN	OPEN	UART0_RX	INT2'	ADC1'	PW1'
4	OPEN	OPEN	UART0_TX	INT1	ADC0'	PW2
5	OPEN	OPEN	SPI_SCK	INT0	THERM_PWR	PW3
6	OPEN	OPEN	USART1_RX	BAT_MON	THRU1	PW4
7	OPEN	OPEN	USART1_TX	LED3	THRU2	PW5
8	OPEN	OPEN	I2C_CLK	LED2	THRU3	PW6
9	OPEN	OPEN	I2C_DATA	LED1	RSTN	ADC7
10	OPEN	OPEN	PWM0	RD	PWM1B	ADC6
11	OPEN	OPEN	PWM1A	WR	OPEN	ADC5
12	OPEN	OPEN	AC+	ALE	OPEN	[illegible]
13	OPEN	OPEN	AC-	PW7	OPEN	[illegible]
14	GND	GND	GND	VCC	VCC	[illegible]
15	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
16	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
17	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN

Fig 5.Watermark Soil Moisture Meter with MDA 100 Sensor board (real and with Pin diagram)

V. Calibration of WSN Node and Soil Moisture Meter Assembly

The calibration of Soil Moisture Meter is required sampling of soil moisture content with respect to Vcc received from ADC3 to the sink and captured by serial forwarder. Various researchers have calibrated watermark soil moisture sensors 200SS (in our case) in their research Berrada, Abdelfettah [130] have done extensive work on calibration of watermark soil moisture meter and watermark dielectric sensors on different types and with different depth of the soil. They came out with a calibration of suction potential and resistance imposed by sensor granular material.

$$S = - (4.093 + 3.213\ R)/ (l\text{-}0.009733\ R\text{-}\ 0.01316\ T)$$

(n=729, =0.945)

Where S is soil water potential in kPa, R is electrical resistance in kQ, and T is soil temperature in 'C.Colin S. Campbell [13] has tested the echo soil moisture by crossbow which works on dielectric sensors and plotted the volumetric soil moisture content with the voltage received from sensors. In this research the outcome of the sensor reading from the ADC pin was the voltage which is received at certain moisture values. At every voltage value the gravimetric analysis was done for finding the percentage weight of the soil i.e. percentage soil moisture content.

Fig. 6 : Taking soil samples using auger equipment

Fig 7. Installation of soil moisture sensor

A soil mass was taken using auger hole technique with a fixed dimension from 0.5 m depth of the soil.

The watermark soil moisture meter was inserted into the soil mass and sensor readings were taken at regular intervals. The readings taken were the received voltage from the MDA sensor board and the % age volumetric content of soil by weight

$$M\ (\text{in}\ \%) = (Mo - Mdry) * 100 / Mo$$

Where M is percentage weight of moisture

Mo = Mass of soil observed

Mdry = Mass of the dry soil with no moisture

(This was found by keeping the soil in oven for an over on 75 degree Centigrade. The soil was wetted after this and assembly of soil moisture meter with sensors was used to take the readings at certain time duration. The moisture content was also compared with the suction pressure, an indicator of soil moisture potential. This was done from the trusted literature and the work of researchers [130]. The relationship of Suction Pressure and voltage was also understood in order to confirm the calibration.

VI. Results and Analysis

The results obtained by observing the voltage at sensor Pin and %age Moisture in the soil samples is given in Table 1. The values in the table 1 are plotted as graph in Fig. 8. A regression analysis was performed on the graph developing mathematical relation between Voltage and moisture.

Table 1 Observed value of sensed voltage and moisture content

Voltage	Moisture
0.088	23.3
0.117	21.8
0.234	20.3
0.351	19.1
0.468	18.1
0.586	17.3
0.703	16.6
0.82	16.1
0.937	15.6
1.054	15.1
1.172	14.7
1.346	14.4
1.406	14.1
1.523	13.8
1.64	13.5
1.756	13.3
1.874	13
1.991	12.8
2.108	12.6
2.226	12.4
2.343	12.3
2.46	12.2
2.577	12.15
2.694	12.1
2.812	12.05

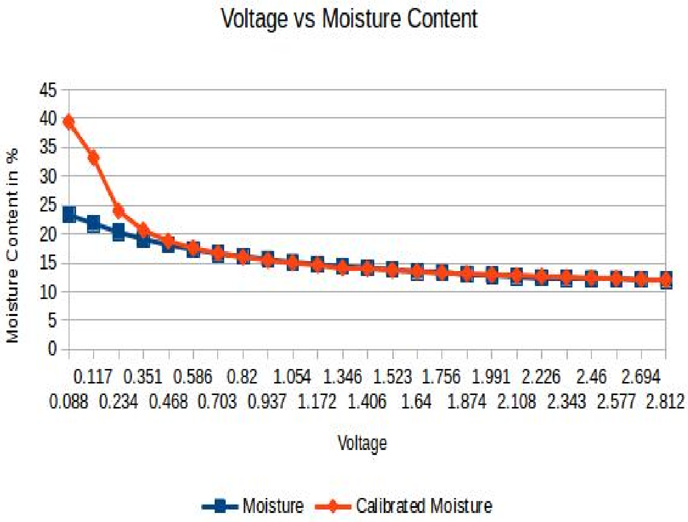


Fig. 4.17 Plot of observed and calibrated values of voltage vs % soil moisture

The observed readings were used to do a regression analysis and with reverse exponential curve fit. The regression analysis gave a relationship of a fitting curve

General equation : $y = a * e^{b/x}$

The resultant equation fitting the curve is

$$\mathbf{V = 0.0192 \quad X \quad e^{60/M}}$$

The equation derived for percentage soil moisture from the above equation is

$$\mathbf{M\ \% = 60 / (In\ V / 0.0192)}$$

Table 4.2 Observed value and regression value of fitting curve of sensed voltage and moisture content

Voltage	kpa	Computed pressure
0	0	-0.21
0.117	10	9.78
0.234	20	19.77
0.351	30	29.76
0.468	40	39.75
0.586	50	49.83
0.703	60	59.81
0.82	70	69.80
0.937	80	79.79
1.054	90	89.78
1.172	100	99.86
1.346	110	114.71
1.406	120	119.84
1.523	130	129.83
1.64	140	139.82
1.756	150	149.72
1.874	160	159.79
1.991	170	169.78
2.108	180	179.77
2.226	190	189.85
2.343	200	199.84

2.46	210	209.83
2.577	220	219.82
2.694	230	229.81
2.812	240	239.88

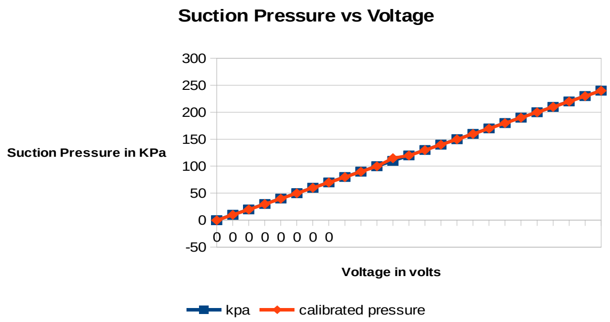


Fig 4.18: Plot of actual measurement and fitting curve from regression for suction pressure and voltage

The relationship of suction Pressure and voltage is given as under The regression equation for suction pressure vs voltage is worked out as

P = - 0.2076 + 85.38 V

Where P = suction pressure in Kpa

And V = voltage in volts

Fig 4.19 : Observed and computed value of Moisture content from voltage

$P = 1.61143 \quad X \quad e^{60/M}$

Where P = soil moisture suction in Kpa

And M = %age Moisture Content

All calibrations and regression analysis done in this section was be used for developing a sensor application on the MDA 100 sensor board. At present the voltage we get is just the digital voltage converted by ADC3 pin which was interfaced with the MDA sensor mote. To develop the application we need study TinyOS and NesC, the importance of which is already discussed earlier.

To write the application layer we need to some modification in the modules which are already written in the motes. In nesC modules of MDA 100 the modifications were done in SensorBoardApp.h by declaring a new data type Uint16_t moisture for ADC3 Pin. In XSensorMDA100.nc interface ADC3 was declared as moisture. Following event was added for ADC3.

```
async event result_t moisture.dataReady(uint16_t data) {

//modification for soil moisture

pack->xData.datap1.moisture = 60/(ln10 (data)/ 0.0192)

    call ADC4.getData();

    return SUCCESS;      }
```

The values of moisture packet were send through radio as well on UART.

VII. Conclusion

A successful model was developed for the new researchers to interface the data acquisition boards and electronic wireless motes with the domain specific sensor. The assembly of MTS400 mote, MDA 100 sensor boards and Water Mark Soil Moisture Sensor now works as per expectation. The Soil Sensor Senses the moisture Stress and passes this stress as voltage to Data board. The nesC application sitting on mote is executed by TinyOS environment. Our calibration equations are used in nesC application so that the outcome of sensor is the %age moisture content directly. This data can be propagated using the radio transceivers placed on mote and can be obtained at the sink. The value obtained can help to decide the quantity and timing of water to applied to the crops in order to release the moisture stress. This can help in saving water and save plants from wilting or water logging.

References

1. Akyildiz, Ian F., et al. "A survey on sensor networks." Communications magazine, IEEE 40.8 (2002): 102-114.
2. Basha, Elizabeth A., Sai Ravela, and Daniela Rus. "Model-based monitoring for early warning flood detection." Proceedings of the 6th ACM conference on Embedded network sensor systems. ACM, 2008. pp 298-304
3. G. Tolle, J. Polastre, R. Szewczyk, D. Culler, N. Turner, K. Tu, S. Burgess, T. Dawson, P. Buonadonna, D. Gay, W. Hong, A macroscope in the redwoods, in: Proceedings of the Third International Conference on Embedded Networked Sensor Systems (Sensys), San Diego, CA, 2005. pp – 51-63
4. Martinez, K. et al. Environmental Sensor Networks. IEEE Computer, Vol. 37, No. 8, pp. 50-56, 2004.
5. Burrell, J. et al. Vineyard Computing: Sensor Networks in Agricultural Production. IEEE Pervasive Computing, Vol.3, No.1, pp. 38-45, 2004.
6. Wang, Ning, Naiqian Zhang, and Maohua Wang. "Wireless sensors in agriculture and food industry—Recent development and future perspective." Computers and electronics in agriculture 50.1 (2006): 1-14.
7. Hanson, B.; Peters, D.; Orloff, S. Effectiveness of Tensiometers and Electric Resistance Sensors Varies with Soil Conditions. Calif. Agric. 2000, 54, 47-50.
8. Balendonck, J., Hemming, J., Van Tuijl, B. A. J., Incrocci, L., Pardossi, A., & Marzialetti, Sensors and wireless sensor networks for irrigation management under deficit conditions (FLOW-AID). In Proceedings of the International Conference on Agricultural Engineering (AgEng 2008) (Vol. 3 pp. 452-2).
9. Robert Evans, D. K. Cassel, R. E. Sneed, Measuring soil water for irrigation scheduling: monitoring methods and devices Published by: North Carolina Cooperative Extension Service Publication Number: AG 452-2 URL: http://www.bae.ncsu.edu/programs/extension/evans/ag452-2.html
10. Ling, P. A review of soil moisture sensors. Assn. Flor. Prof. Bull. 2004, 886, 22-23.
11. Cardell-Oliver, R.; Smettem, K.; Kranz, M.; Mayer, K. A reactive soil moisture sensor network: Design and field evaluation. Int. J. Distrib. Sens. Netw. 2005, 1, 149-162.
12. Shete Dilip Trimbak, Kamlendu Kumar Pandey "Computer Aided Methodology for Design of Paired Laterals for Drip Irrigation." Workshop, micro irrigation & sprinkler irrigation systems, 28-30 April 1998, New Delhi: proceedings. Central Board of Irrigation and Power, 1998 pp-125-131.
13. Bandyopadhyay, K.K. and Pradhan, S. (Editors) Assessment of Soil-Plant-Atmosphere System for Improving Resource Use Efficiency in Agriculture, Training Manual, TB-ICN: 95/2012, Division of Agricultural Physics, Indian Agricultural Research Institute, New Delhi- 110012, India. pp. 1-176.
14. Cardell-Oliver, R., Smettem, K., Kranz, M., & Mayer, K. (2004, December). Field testing a wireless sensor network for reactive environmental monitoring [soil moisture measurement]. In Intelligent Sensors, Sensor Networks and Information Processing Conference, 2004. Proceedings of the 2004 (pp. 7-12). IEEE.
15. Dong, X., & Vuran, M. C. (2010, June). Spatio-temporal soil moisture measurement with wireless underground sensor networks. In Ad Hoc Networking Workshop (Med-Hoc-Net), 2010 the 9th IFIP Annual Mediterranean (pp. 1-8). IEEE.
16. Musaloiu-e, Razvan, et al. "Life under your feet: A wireless soil ecology sensor network." Proc. 3rd Workshop on Embedded Networked Sensors (EmNets 2006). 2006.
17. Levis, Philip, et al. "TinyOS: An operating system for sensor networks." Ambient intelligence. Springer Berlin Heidelberg, 2005. 115-148.
18. www.tinyos.net, web site of Tiny OS supported by University of Berkley.
19. Hill, Jason, et al. "System architecture directions for networked sensors." ACM SIGOPS operating systems review. Vol. 34. No. 5. ACM, 2000.
20. Levis, Philip, et al. "The Emergence of Networking Abstractions and Techniques in TinyOS." NSDI. Vol. 4. 2004 pp 1-1.
21. Gay, David, et al. "The nesC language: A holistic approach to networked embedded systems." Acm Sigplan Notices. Vol. 38. No. 5. ACM, 2003 pp- 1-11.
22. Gay, David, et al. "nesc 1.3 language reference manual." (2009) url : http://www.tinyos.net/dist-2.0.0/tinyos-2.0.0beta1/doc/nesc/ref.pdf
23. Electrical Interface for Watermark™ or Gypsum Block Sensors EME Systems, 2229 Fifth St., Berkeley CA 94710 url: www.emesystems.com/pdfs/SMX.pdf
24. Bertolino, A. V. F. A., et al. "Comparison of the soil matrix potential using tensiometers and Watermark sensors." url: http://www.irrometer.com/pdf/research/Comparison_soil_matrix_potential_using_tensiometers_and_Watermark_sensors-Brazil_soil_erosion_paper.pdf.

AUTHOR(S) PROFILE

Dr. Kamlendu Kumar Pandey, is Assistant Professor in Dept. Of Information and Communication Technology at Veer Narmad South Gujarat University, Surat, Gujarat in India. The interest areas are Wireless Sensor Networks, Cloud Computing, and Service Oriented Architecture. He is having 18 years of rich experience in academics and industry in the various fields of Computer Science.