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Design Issues for Wireless Sensor Networks and Smart Humidity Sensors for Precision Agriculture: A Review

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Abstract- Precision agriculture is a process in which information and technology is used for collection of high resolution spatio-temporal data regarding atmospheric and soil conditions from farm land. With the help of farm land data and an appropriate crop-growth model, a decision support system regulates the agricultural needs precisely in order to gain maximum benefits for farmer. Application of Wireless Sensor Networks (WSN) provides a low cost and easy to implement solution for automatic data collection from farmlands. Various design issues for WSN in context of precision agriculture have been reviewed in this paper. Humidity (RH) sensors play a crucial role for WSN for precision agriculture applications. This paper also reviews various requirements of Humidity sensors characteristics in context of WSN application for precision agriculture. In the later section of the paper, in depth comparative review of recent research work done in field of design and performance modeling of humidity sensor has been given.

Keyword- Precision Agriculture, Capacitive Humidity Sensor, Resistive Humidity Sensor, Relative Humidity.

I INTRODUCTION

Even after spending a lot of money and human resources by central and state governments for the agricultural growth like subsidies on fertilizers, low interest agricultural loans, setting up rural branches of national banks, a shortage of soil testing labs is observed in most of the states of the country. [1] Due to which farmers do not have a tendency to test their soil in order to increase crop yields. As a result, farmers remain unaware of atmospheric conditions like Relative Humidity (RH) of the air, Temperature and soil characteristics like soil type, soil porosity and pesticide levels etc. [2] Due to which they apply more or less irrigation/fertilization as compared to the required precise quantities for a particular crop under given soil and environment conditions. If fertilization is applied in less quantity, it severely affect crop yield leading to financial loss of farmers. Over fertilization contaminates ground water leading to the problem of mass cancer as being faced by many regions of Punjab state. [3] If soil samples are taken to a Lab testing facility by some farmers, this sample cannot represent soil of large farm lands of hundreds of hectare field. Also the soil properties change from time to time. Thus soil data experimentally taken at one time do not remain valid for large crop seasons. For precise application of agricultural inputs, accurate spatial-temporal data from farm lands regarding soil and atmospheric conditions is required at regular intervals. [4] Based on such information, required crop inputs like irrigation of pesticides can be applied in precise quantity. The process of using information and technology for precise regulation of agricultural needs in order to gain maximum benefits for farmer has been termed as precision agriculture.

Remote sensing may be a solution for the problem being discussed but it is not an economical way and moreover information obtained relates to large geographical region and do not represent local conditions precisely. [5]Several research works have been recently reported on the application of Wireless Sensor Networks (WSN) in Precision Agriculture (Discussed in later sections).

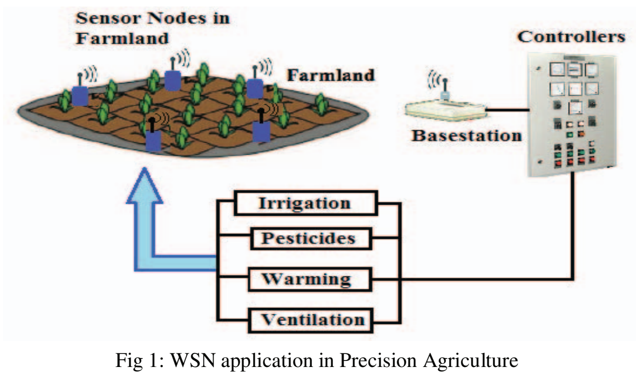

Fig 1: WSN application in Precision Agriculture

II. WIRELESS SENSOR NETWORKS FOR PRECISION AGRICULTURE

Due to rapid advancements in VLSI fabrication technologies, microcontrollers with better computational capabilities (Table 1) and transducers/sensors are easily available in market in low cost and miniaturized sizes.

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Moreover wireless RF communication solutions like Zigbee and Bluetooth are available to provide high data rates with in limited coverage area at very low cost [6,7,8]. Being such devices in reach, miniature sensor nodes for monitoring the data regarding atmospheric and soil conditions can easily be made by using limited resources and finance.[9] Such sensors can be installed at the farm-land in large numbers (10-100 or as per requirement) and a wireless sensor network can be formed to serve as a platform for automated data collection regarding atmospheric and soil conditions. Fig. 1 shows a conceptual block diagram showing application of WSN in precision agriculture.

Soil and atmosphere related data is collected at Base Station (BS) by WSN where it is analyzed and applied to Crop Growth Model (CGM) [10] by a program known as Decision Support System (DSS). Based on the results, DSS controls the inputs to Agriculture like irrigation and fertilization. [10,11] Fig. 2 shows block diagram of DSS.

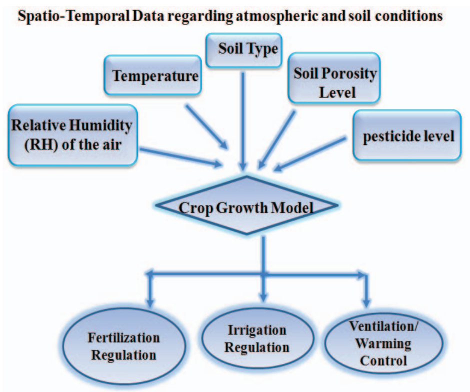

Fig. 2: Decision Support system Block Diagram

Table 1: Microcontroller Comparison

MCU Family	**Word Size**	**ROM**	**RAM**	**Clk. Freq**	**Others**
Intel 8051 [12]	8bit	8KB	128/256 Byte	Upto 12 MHz	4 Bidirectional I/O ports of 8 bit each
Microchip PIC 16C5X/XX [13]	8bit	512 Bytes to 2KB	25 to 73 Byte	40 MHz	8 bit real time counter, watchdog timer & sleep mode
Free-scale 68HC11[14]	8bit	0, 12, 20 KB	Upto 768Byte	Upto 3MHz	Embedded 8 bit ADCs

Thus usage of WSN in Precision Agriculture is a low cost and reliable solution for automatic farm land data collection at fine resolution and regular intervals. It also reduces the human interaction to growing crop and financial losses.[2,4]

III. REVIEW OF WIRELESS SENSOR NODE ARCHITECTURE

A WSN node is made-up of six basic sub-units: (i) sensor unit, (ii) amplifier unit, (iii) analog to digital converter (ADC), (iv) processor unit, (v) transceiver and (vi) power unit. Fig. 3 shows a general block diagram of a wireless sensor node. Sensor is basically a transducer which converts the physical quantity to be measured like humidity or temperature to an equivalent analog electrical signal. Transducer output may not be appropriate to fanout ADC, so it is amplified to proper level and digitally converted by ADC. Processor unit is generally a microcontroller which manages local processing operations on sensed data like calibration, unit conversion, detection of increment/decrement in sensed signal etc. Beside local processing, controller is also programmed to carryout different communication protocols for transmission of locally sensed data to neighborhood node (in case of Multihop communication) or coordinator node (in case of Star topology network). For Multihop communication, controller is also responsible to relay the data sensed by a different node to the next node in the direction of coordinator node. Transceiver unit is responsible for communication among WSN nodes. Use of corner-cube retro-reflector (CCR-an optical communication device) [7,15], RF devices like Blue tooth [16] ,Zigbee [17] , WiFi [4] etc. have been reported. Mostly sensor node are run using limited power resources like a battery. Latest research work is being carried out on the integration of sensor nodes with never ending energy resources like solar energy harvesting [18] and self powered sensors using soil energy cells.[19] Some of applications like chemical threat detection may require the location of sensor nodes. So a location finding system can be an additional unit of a sensor node. Table 2 contains the details of sensor node units from different wireless sensor networks.

Table 2: Details of Sensor Node units from different Wireless Sensor Networks

WSN	Processor Unit			Transceiver Unit
	Processor Type	**Flash mem.**	**RAM/ EEP-ROM**	
Smart dust mote [20]	Atmel AVR8535 4MHz Clock	8 KB instruction	512 Bytes/ 512 Byte	Corner-cube retro-reflector (CCR)-active optical device
µ-AMPS WSN (MIT) [16,21]	Strong-ARM SA-1110 59-206 MHz Clk	512 Mbyte for static memory devices (ROM, SRAM, and Flash memory)		Bluetooth compatible (2.4 GHz) RF unit

IV. HUMIDITY SENSORS IN PRECISION AGRICULTURE

Humidity is the amount of water vapour in air. Relative Humidity (RH %) is the most common measure for air humidity which is ratio of partial water vapour pressure to saturation vapour pressure. Relative humidity depends on temperature and the pressure of the system of interest. [22] Humidity indicates the likelihood of precipitation, dew, fog and rain. The health of most of the crops are highly sensitive to these climatic conditions, so accurate and highly sensitive relative humidity (RH) sensors are very important for precision agriculture. Other important application areas for humidity sensors is modern industry like pharmaceutical industry, paper packaging, and printing industry, museums and cold chain, green houses applications etc. [23, 24, 25, 26]

Most of the researchers have included humidity (RH) sensors in their research work on precision agriculture. [27] Various design issues for WSN for precision agriculture application are discussed in Table 3. Each design issue has been accompanied with the relevant requirement from humidity sensor.

Table 3: Design Issues for WSN for Precision Agriculture

Design Issues for WSN for Precision Agriculture	Requirements from Relative Humidity Sensor
High resolution spatio-temporal data from farm lands [4] DSS applies the collected data to Crop Growth Model (CGM) and controls the inputs to Agriculture. For accurate prediction from Crop Growth Model, High resolution spatio-temporal data is required from farm lands	• High sensitivity to humidity variations ($\leq$ 1% RH) [28] • Less response time (<10 Sec) [29] • High RH measurement range (10-90%). [28,30,31] • High speed microcontrollers (>16 MHz) • High resolution ADC ($\geq$ 8 bit)
Energy efficient sensor nodes. Batteries of sensor nodes must last for large crop periods. It has been observed that the sensor battery drains quickly due to high sampling rate in Precision agriculture. [2,32] Moreover this problem become severe in case of sink sensor nodes even duty cycle is not 100%.	• Humidity Sensor designed to consume low sensing power. • Sporadic sensing consume lesser power than constant event monitoring • low power on board controllers and other components [24,33] • Alternative solutions like solar panel energy harvesting [18] and using soil energy cell [19]
High packet loss rates & high latencies WSN designed for precision agriculture works in outdoor environments with ever changing channel response. [33] has experimentally shown that the probability of successful packet reception get reduced to 77% in open air as compared to 90% of indoor. In outdoor environment packet loss rates are high. Moreover limited channel bandwidth with requirement of high sampling frequencies leads to the problem of high latencies.	• Storage capability to store sensed data for retransmission in case of packet loss. • **Cooperative effort of sensor nodes [32,34] :** Local Data processing to carry out simple computations and transmit only the required and partially processed data

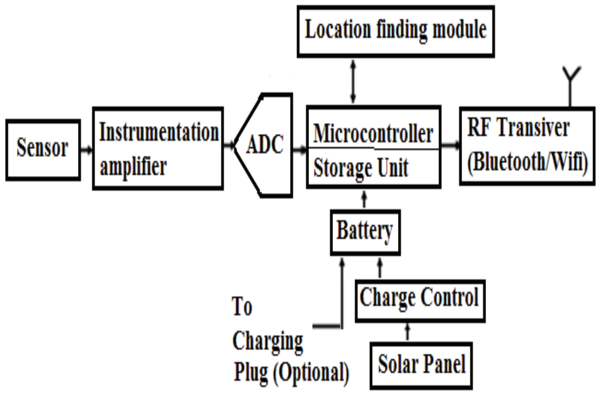

FIG. 3: A GENERAL BLOCK DIAGRAM OF A WIRELESS SENSOR NODE

V. REVIEW OF HUMIDITY SENSOR DESIGNS, MODELLING & INTERFACING TECHNIQUES

Based on their sensing techniques, electric HUMIDITY sensors can be classified into three categories. (i) Thermo conductivity based humidity sensors (ii) Resistive humidity sensors (iii) Capacitive humidity sensors.

Thermo conductivity based humidity sensors utilize two metallic resistors, one exposed to the environment and other sealed from the environment. The resistors are heated by applying same electrical biasing. (Fig. 4) Exposed resistor cool down to a lower temperature due humidity of environment and has thermal conductivity as a function of humidity. The difference between the thermal conductivity of two metal resistors is utilized as a signature to sense humidity [35].

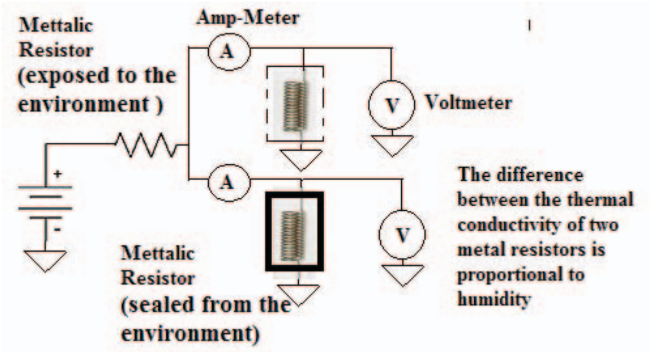

Fig. 4: Thermo conductivity based humidity sensors (Conceptual Fig.)

Resistive humidity sensors utilize thick/thin film conductors coated with polymers such as polyvinyl alcohol and nafion in which number of movable ions depends upon atmospheric humidity. (Fig. 5-A) Thus their impedance changes with relative humidity (RH) [36, 37].

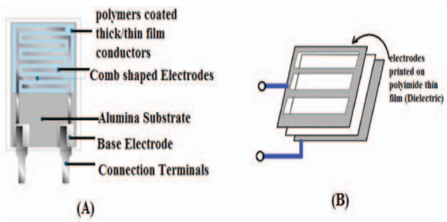

Fig. 5: Basic structure of (a) Resistive humidity sensor (b) Capacitive humidity sensor developed with polyester substrates-Melinex (DuPont 5033) over ST726 [22]

Capacitive humidity sensors are basically capacitors where electrodes are printed on polyimide thin films.(Fig. 5-B) lectric constant of polyimide thin films gets changed with humidity. [22]

Performances of Resistive and Capacitive humidity sensors are limited by nonlinear transfer characteristics. [22,36] This requires to design analog front end circuit and subsequent signal processing circuit in order to compensate for nonlinear terms. [38] Recently Artificial Neural Networks have been used to linearize the characteristics of sensors. [22] Thermo humidity sensors show linear response, low hysteresis, and long term stability. But they are not power efficient as metal resistors needs to be heated up to required temperature. [35]

Capacitive humidity sensors are efficient in terms of sensitivity, response time, and power consumption. However their linearity is adversely affected by the change in ambient temperature. [22,38,39]

Due to available high end state of art VLSI fabrication techniques, it has become possible to implement CMOS compatible humidity sensors which are low power and lost cost.[38] Thermo based sensors and resistive sensors lacks in terms of CMOS compatibility.[35] However polyimide film dielectric based capacitive humidity sensors have been implemented together with integrated circuits. [40] [39] used Cyclotene 4024-40 (Divinyl siloxane Benzocyclobutene, DVS-BCB) polymer film as dielectric to design a fast response double layer Capacitive Humidity Sensor using (Fig. 6-A). Proposed CHS was fabricated for various dielectric polymer film thicknesses (1-3.5 µm) and comb shaped electrode dimensions (Line width µm/ line space µm = 15/25, 20/20, 10/50, 50/10 & 4/6). An optimized Model of proposed sensor was made based on electrostatic and molecular diffusion calculations was made and used to simulate the response of the sensor under specific conditions. Results are summarized in Table 4.

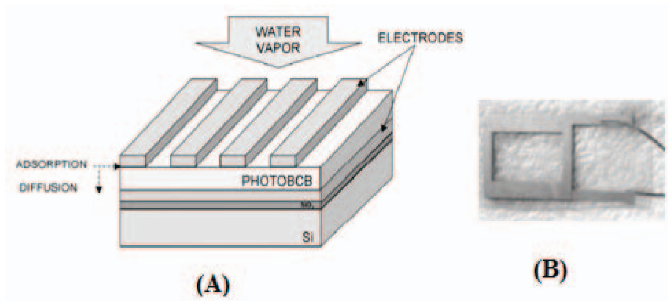

Fig. 6: (A) Capacitive Humidity sensor proposed by [39] (B) Capacitive Humidity sensor of [22] developed with polyester substrates-Melinex (DuPont 5033) over ST726

[35] presented a thermo humidity sensor design which uses two P-N junction diodes in place of metallic resistors. (Fig. 7) One diode is exposed to the humid environment and other one is sealed. By applying same bias, exposed diode heats up to a lower temperature as compared to sealed one and provides different diode turn-on voltages. Comparison of two turn on voltages works as a signature to determine the humidity level.

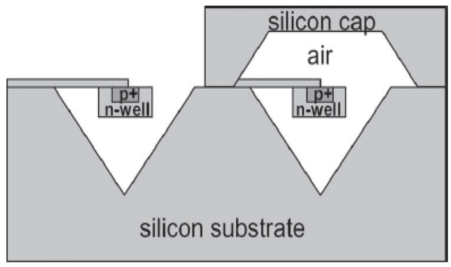

Fig. 7: Cross Section view of thermo humidity sensor proposed by [35]

Diodes are suspended to achieve thermal isolation from the substrate so they can be heated to elevated temperatures with less power, provide high sensitivity and make the design compatible for CMOS fabrication. The readout circuit can be integrated with the sensor on single chip providing low cost, compact size and better noise. The humidity sensor implemented with this approach also provides a linear response and low hysteresis. A fabricated prototype have been tested by [35] and Results are summarized in Table 4.

[38] presented the design of a novel CMOS compatible capacitive humidity sensor with a current-mode analog front end interfacing circuit using a fully differential OTA followed by a wide-swing current source having high-output impedance. Using a single clock phase, AFE can produce a differential output from a single-ended sensor. The proposed technique features a linear transfer function at a lesser nonlinearity error relative to full-scale swing. However circuit shows nonlinearity for single-ended sensors. The circuit consumes less power. Prototype has been fabricated and tested in a commercially available 0.8-μm CMOS process. However the approach has sensitivity to stray capacitances. Results are summarized in Table 4.

[22] presented an RFID based capacitive Humidity sensor, developed on two types of polyester substrates [Melinex (DuPont) and CG3460 (3M)] by using thick-film print technology (Fig.-6-B). Proposed CHS is compatible to be integrated with RFID labels. Authors also implemented a microcontroller based RH measurement system using the proposed CHS. Proposed CHS showed nonlinear transfer response for at 20 ◦C and 50% RH at 10% estimated nonlinearity error relative to full-scale swing. Authors suggested the use of an ANN based algorithm implemented in microcontroller in order to compensate for nonlinear response. Results are summarized in Table 4.

[40] presented a CMOS compatible inter-digital capacitive humidity sensor where both the comb shaped capacitor electrodes are printed on same side of grapheme oxide substrate (Fig.-8). Proposed CHS is attached to a patch inductor etched on FR-4 substrate to form an inductor–capacitor (LC) tank circuit. Thus resonant frequency of tank circuit becomes humidity dependent. Proposed design is highly sensitive over a range of 15%–95% RH. Results are summarized in Table 4.

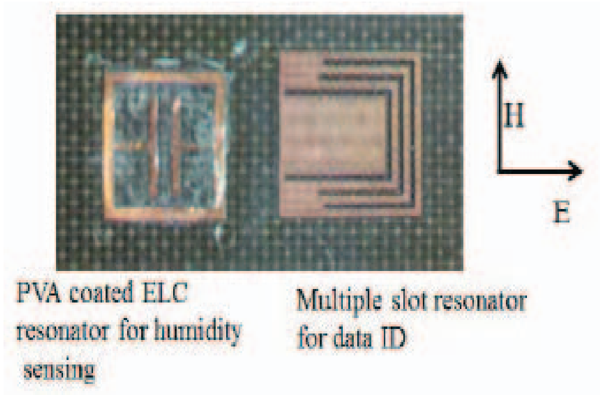

Fig. 8: CMOS compatible inter-digital capacitive humidity sensor Proposed by [40]

Humidity sensor proposed by [41] utilizes the property of poly vinyl idene fluoride (**HEC/PVDF)** coated on plastic optical fiber (POF) by the virtue of which the refractive index changes atmosphere humidity. Such humidity sensors have shown a sensitivity of 0.0231 mV/% for 50 to 85% RH range and 0.35% non-linearity. Results are summarized in Table 4.

III CONCLUSION

Various design issues for WSN in context of precision agriculture were reviewed along with different requirements of Humidity sensors characteristics in context of WSN application for precision agriculture. In later part of paper, different research works done in the filed of design/performance modeling of various types of humidity sensors are studied and compared on the basis of RH measurement Range, Humidity Sensitivity, Nonlinearity (relative to full-scale swing) and Power Consumption. Capacitive humidity sensor, developed on two types of polyester substrates by using thick-film print technology provides better (10-100%) RH measurement range but this design lacks in terms of linearity. ANN based linearization technique have been used for compensating this disadvantage. On the other hand CMOS Thermo humidity sensor, CMOS capacitive humidity sensor with a current-mode AFE and Humidity sensor made of POF coated with HEC/PVDF gives better performance in terms of linearity. Moreover CMOS Humidity sensors works well in terms of power consumption. Although sensitivities and power consumption are given in different units based on the design of a particular sensor, but all of the sensors have been designed to achieve best of these parameters.

Table 4: Summary of results from different papers

	[39]	[35]	[38]	[22]	[40]	[41]
Humidity Sensor Type	Double layer CHS with Cyclotene 4024-40 polymer film dielectric	CMOS Thermo humidity sensor Fabricated using 0.6 µm CMOS process.	CMOS compatible capacitive humidity sensor with a current-mode AFE Fabricated using 0.8µm CMOS process.	Capacitive humidity sensor, developed on polyester substrates [Melinex and CG3460] by using thick-film print technology	Comb shaped capacitor electrodes are printed on same side of grapheme oxide substrate	Humidity sensor made of tapered plastic optical fiber (POF) coated with polyvinylidenefluoride (HEC/PVDF)
RH Range	10-90%	20-90%	--	**10-100%**	15%–95%	50-85%
Humidity Sensitivity	0.08 -0.22 pF/%RH	14.3 for or 20 ◦C	--	0.17 pF/%RH CG3460-based sensor	13.33 MHz/%RH	0.0231 mV/%RH
Nonlinearity (full-scale swing)	Not Evaluated	**less than 0.3%**	**0.2%**	**12.2% CG3460-based sensor**	--	**0.35%**
Power Consumption	Not Evaluated	1.38-mW	0.725mW	Low Power design	1dB for 35% to 85% RH	--
Other	Response Time = 0.184 Sec to 0.732 Sec	Hysteresis less than 1%.	Output full scale range= 136.4mV Capa. range =0.75pF	--	--	--

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