Application of Sensor Networks for Monitoring of Rice Plants: A Case Study

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I. Introduction

Sensor network research [1] has enabled large scale environmental monitoring using small sensors with radio links. The technological advance in wireless communications and microelectronics has enabled the development of small, low-cost sensors. Sensor networks are developed to organize and control these sensor nodes, which have sensing, data processing, communication and control capabilities. Information collected from these sensor nodes is routed to a sink node via diffrent types of wireless communication approaches. The sink node can communicate with remote users through the Internet or satellite network. The research in the sensor networks has focused primarily on the networks issues such as routing, data dissemination [2], [3] and aggregation of co-related data for downstream data delivery [4]. The combination of small size, low cost and wireless networking functionality makes sensor network technology exceptionally scalable.

Agro technology is changing at a fast rate with the application of sensor devices. Diseases encountered in crop fields dramatically affect productivity of a crop. Manual analysis of the causes of diseases in a large crop field is impossible; hence we need a generic and rapid method for the analysis of the causes and timely prevention of those diseases. The timely prevention and monitoring not only enhances the productivity but also aids developing new crops varietiesby observing the adaptation of new breed with different climate conditions. Clearly, Wireless Sensor Network is a promising data mining approach for precision agriculture. Instrumented with wireless sensors, it will become available to monitor plants in real time for air temperature, soil water content, and nutrition stress. The real time information from the fields will provide a solid base for farmers to adjust strategies at any time. As a part of an ongoing research related to developing tools and techniques of connecting Crossbow motes in the form of a network, we are exploring the coverage of the sensing area for plant monitoring. To address this problem, we have been experimented for four months with a localization method of deploying sensor motes in the greenhouse to measure atmospheric parameters such as temperature, barometric pressure, ambient light intensity and humidity to help analyze the effect of these parameters on the growth of rice plants. This paper describes the design and implementation of an integrated network that links several communications platforms, wireless technology and Transfer Control Protocol-Internet Protocol. The main goal is to develop a system that guarantees a low-cost, high performance and flexible distributed monitoring system with an increased functionality. The user interacts with this distributed monitoring system using a transparent and intuitive graphical user interface made available to remote places.

II. Related Work

As an intial effort [5] showed that modern concepts on methods and techniques for the management and control of agricultural systems-such as greenhouse and animal live stocks-claim for the use of computer systems. The method basically focussed on control of the environmental parameters in an economically way, to produce the best crop or animal living conditions. The specific combination of diffrent sensor inputs forms an integrated system that co-ordinates each action for adequate control of various production paramters. The current work at

Iowa State University is called the Development of In-situ Soil Sensor Network for Temporal and Spatial monitoring of Agriculture Fields [6]. The eventual goal of this project is to develop a distributed sensor network to monitor the soil conditions throughout the growing season, with sensors positioned on a 50 m grid over a field. In the process of their work they are attempting to include sensing of soil organic matter, soil nutrients, and other non-agricultural civil and/or military applications.

Another ongoing research [7] at Delft University of Technology focussed on wireless sensor networks in potato field. The main goal of monitoring is to reveal when the crop is at risk of developing the disease and let the farmer treat the field or parts of it with fungicide only when absolutely needed. In [8] a web server based approach is used where sensor nodes are equipped with a web server to be accessed via the internet and make use of wireless LAN to provide a high speed transmission. The use of a web server helps to anaylyze distant agricultural fields over long periods of time whereby the whole dataset is accessible to general public. The Sandia National Laboratory is already running the projects in this area with collaboration of the Mexican government [9] . The present work focussed on using sensing technology in hydroponic greenhouses. The Sandia-placed sensors and computer simulations will tell researchers how to grow crops efficiently. [10] is focused on the investigation of wireless sensor networks in agricultural applications. With a 2.4 GHz wireless sensor node, factors such as coverage area and the agricultural environmental effects (bare soil, soybean, and corn fields as their main target) on the radio were studied. Our research differs from the those mentioned above in that we present a simple design outlining various constraints concerning optimal sensor deployment, data collection and data analysis. Hence, a framework for design and implementation of our system have been presented with detailed analysis of relevant data.

III. Experimental Set-up

The green house is a controlled environmental system for research in the area of food production. Louisiana State University Agcenter has a green house equipped with fans artificial lamps for light intensity control and is isolated from outside environmental conditions. This section discusses the design part of the experiment. The goal of the project is to create a wireless sensor network that will provide 24 hour/ 7 days a week monitoring of environmental greenhouse conditions of lsu greenhouse and its effect on growth of rice plants. Five distinct varieties of rice plants each having four replicas were placed in the LSU greenhouse and studied for four months. The plants are placed in a random block experiment design throughout.

A. System Design

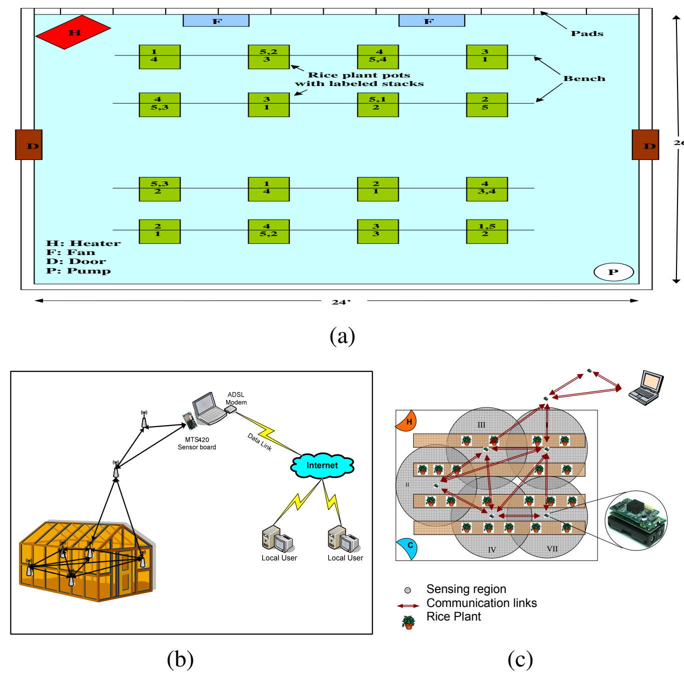


Fig. 1. (a).Greenhouse floor plan and Randomized block diagram, (b). LSU Agcenter greenhouse design of distributed sensor network for studying the rice plants and (c). Placement of sensors according to the sensing regions and optimal coverage of all the rice plants

In figure 1(b) the LSU agcenter design of sensor network is presented. Data is gathered from sensor nodes by hop-by-hop communication in the database server running on the PC that acts as a sink node with the help of MTS420 sensor board[1]. The webserver interacts with database server running on the sink, with the help of ADSL link to enable the remote access of the interesting data. Furthermore, data are analysed remotely by researchers. Data are collected by using the sensor board and stored in a postgres sql data base. Further, analysis is run on the data using Matlab version 7 [2] and Statistics tool. Further analysed data are plotted for clear understanding using graphics tools like microsoft excel.

B. Sensor Nodes

Sensor nodes are setup in a wireless network to collect various environmental readings. These nodes are a common mix between the ability to sense real time data with the ability to instantaneously communicate the data findings. The sensors are usually set up in an

[1] All the sensor boards are from crossbow, www.xbow.com
[2] www.mathworks.com/products/matlab/

ad hoc environment, and the battery operated sensors are referred to as motes. There are three very essential components of the sensor networks namely sensing, communications, and computation to have a successful deployment. These mentioned factors are the equivalent of obtaining the correct and necessary hardware, software, and algorithms. A wireless sensor mote is programmed to monitor various conditions. The possible conditions that can be monitored are light, humidity, temperature, as well as GPS readings. These readings are routed to the system and the data is converted for human interpretation.

The Cross bow Mica2 wireless sensor network devices were utilized with the environmental board 420i. The Mica2 nodes have the following characteristics:

- Program Flash Memory: 128k bytes
- Battery: 2x AA batteries
- User Interface: 3 LEDs
- Size(in): 2.25 x 1.25 x 0.25
- Weight(oz): 0.7
- Multi-Channel Tranceiver: 315, 433, or 868/916 MHz

The Mica2 sensors were outfitted with the MTS420 sensor board. The sensor nodes fascilitates measuring of Barometric Pressure, Ambient Light, Relative Humidity, Temperature. The GPS hardware has been removed as its not needed here. It also has EEPROM which could be programmed as per user requirement. Each sensor has to be programmed with a unique ID to uniquely identify it in the network.

C. *Rice Background*

The LSU Agcenter and the United States Department of Agriculture(USDA) researchers has spent several decades in the understanding and cultivation of rice to maximize production and yield quantity under varied environmental conditions. The growth structure of rice can be classified into three(3) basic phases: vegetative, reproductive, and ripening, respectively. Traditionally, rice being a tropical plant has a reproductive phase of 25 days anad the ripening phase is approximately 30 days. A very interesting property that can be inferred in the rice plants is that the differences in the growth duration [11] are categorized by changes in the length of the vegetative phase. The following rice varieties are used in the current experiment:

- Variety 1 = Cypress, LA variety first released in 1992 known for its high grain milling quality.
- Variety 2 = Rosemont, TX long-grain variety, very susceptible to fungus
- Variety 3 = Pecos, TX variety, tolerant to fungus
- Variety 4 = Cocodrie, LA variety, known for high yield, but susceptible to fungus
- Variety 5 = IR64, popular variety grown in Asia, susceptible to fungus

There are four replicas of each variety of rice plants studied for the effect of spatial distribution of environmental conditions on plant growth.

IV. Implementation

Implementation issues of the current work is discussed in this section.

A. *Greenhouse Randomized block design*

Floor plan of green house is shown in Figure 1(a). The LSU Agcenter greenhouse is 26' long and 24' wide with two 24" fan. Plant varieties are labeled with the corresponding variety number and placed on four equidistant benches. Location of heater, fan and pump have been shown. Clearly, floor plan and randomized block design of the experiment affect the growth rates of plants. We further comment on this in section V and VI.

B. *Wireless sensor network design*

A group of sensors (in our case five sensors are distributed in field and one outside) are distributed inside and outside of the greenhouse to form a sensor network. The sensor nodes are placed in the greenhouse in such a way that different variety of plants come in the sensing range of every node.

The placement of the sensors is based on the following constraints:

- Each rice plant is in the coverage region of at least one sensor
- The overlap between the sensing regions has to be minimized (thus minimizing the number of sensors)
- Multiple communication paths exist between the sensors and the base station (laptop). This provides reliability in case of temporary failures of the sensors.

In the current scenario, there are five sensors sensing and forwarding the data to the base station. Each sensor coverage region is labeled as shown in Figure 1(c). Thus each rice plant falls into one of the regions I(covering plant variety 5,4 and 1), II(covering plant varieties 5, 3, 1 and 2), III (4 and 3), IV(1, 2, 4 and 5), and VII(Covering plant varieties 1,2,3 and 4. Sensors IV and VI are for forwarding purposes.

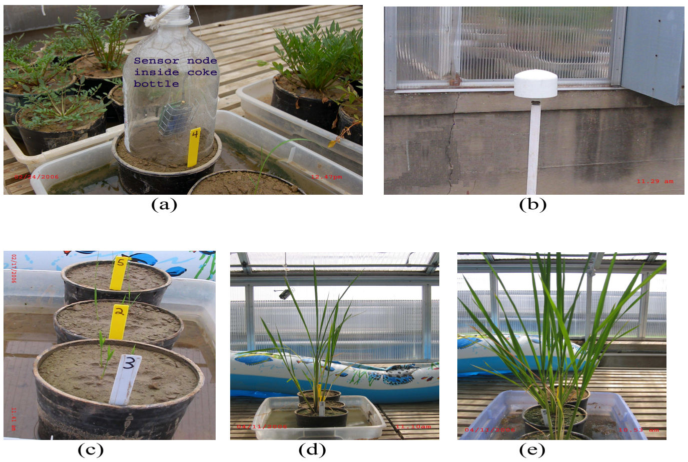


Fig. 2. (a). Sensor placement in a coke bottle (b). Routing sensor outside the green house (c)Plant varieties in the clay pot(germination phase) and (d,e). Reproductive and Ripening phase respectively of rice plants and placement of sensors

The sensor motes implemented in the greenhouse forms a self-organizing robust mesh network, with IEEE 802.11 as shown in figure 1(b). The architecture is divided into three main layers. Layer 1 is the mote layer or sensor mesh network layer. This layer is programmed with TinyOS firmware as platform. The interface, called MOTE-VIEW interface, is application oriented and programmed to do specific tasks like weather monitoring, target detection and tracking. Layer 2 is the Server layer which is responsible for data collection and logging and other database related services. The sensor readings are stored on a server when they arrive at the base station and the server layer takes care of all procedures involved. Layer 3 is the client layer which provides software for users for visualization, data monitoring and data analysis tools to display, calibrate and interpret sensor data.

C. *OS/Software Application*

MOTE-VIEW [12] interface in our sensors supports the MICA2 platform, based on TinyOS[3] framework. In addition to this, it supports certain other features like security/intrusion detection system which is based on MSP. Further, we have used the XMesh Application available in MOTE-VIEW to program our MTS420 sensors. XMesh is Crossbow.s multi-hop mesh networking protocol and it has features like low-power listening, time synchronization, scheduling sleep modes, any-to-base and base-to-any routing. Thus, the XMesh application has helped our sensor motes to form a mesh within the greenhouse, by forwarding data to the base station and finally to the server for storage. Our MOTE-VIEW interface runs on Windows XP Professional platform with remote viewing facility.

[3]TinyOS: A Component-Based OS for the Networked Sensor Regime, http://webs.cs.berkeley.edu/tos/

D. *Sensor Placement*

During the germination phase, a sensor has been placed in the coke bottle as in figure 2(a) to measure diffrent environmental factors such as humidity, light, temperature etc. Special care has been taken to place the sensor near the top of the plants. Further, the sensor has been moved to the top of the plant to measure the environmental parameters such as temperature, humidity, pressure and light as suggested by agriculture researchers as in Figure 2(d,e). In the same figure(2(c)) plant varities were placed in a small pots. Additional sensors for the hop to hop communication have been placed outside of the greenhouse. Outside sensor has been placed in a small container with a hole in a base to save it from rain and other environmental disturbances that may affect integrity of sensor network operation.

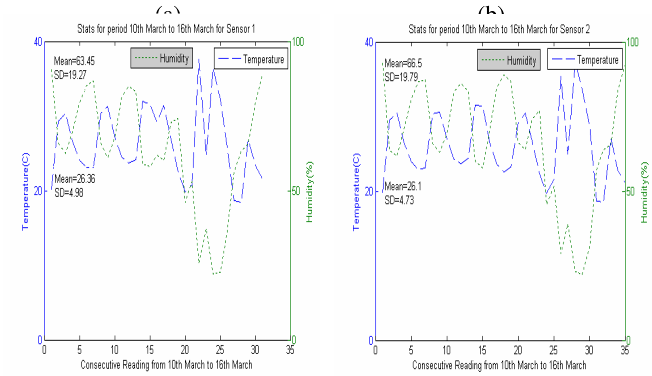
V. Experimental-Result

The placement of sensors accounts for the different growth variation for different plant varieties and replicas as spacing and fixing the sensors are important as it sensed the regions around it. We assumed that sensors have circular sensing region and likewise we recorded the reading for different plants. Sensors collectively transfer the data to forwarding sensors which finally reach to the sink. Temperature, humidity, light intensity are considered important factors for the growth of the plant. This section contains data collection and analysis part. Because of space limitation, all the results can not be presented here. Our main focus of this section is to explain the usefulness of the data of interest, which are useful for agriculture researchers.

A. *Weekly Statistics*

The current project is real time monitoring of the growth of the plants with different environmental parameters. The weekly statistics for temperature and humidity variation is shown in Table **??** for the period of 10th March to 16th March, 2006. As we can see from the table, standard deviation and mean variation of the parameter for interest has been calculated and also given the variation. As we can see in the green house, the variation is not the same for all the nodes and it solely depends on the design of the greenhouse like heater placement, fan plancement etc. and that variation will

TABLE I
WEEKLY STATISTICS FOR ENVIRONMENTAL PARAMETER VARIATION SENSED SENSOR NODE REGION 1 (A) AND NODE REGION 2 (B)IN THE GREEN HOUSE



account for different growth rate for different plants. As it is already mentioned that we covered all the regions of interest using the sensor node,s hence for each sensor nodes we have different variation as mentioned earlier.

B. Node-Region wise Growth Variation

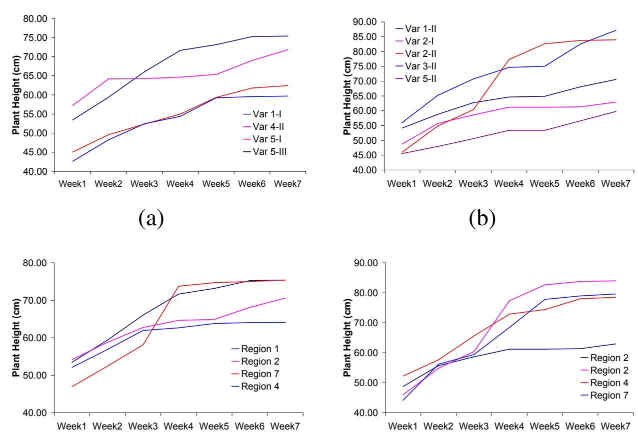


Fig. 3. (a). Growth variation of rice plants of different varieties in node region 1, (b). Growth variation of rice plants of different varieties in node region 2, (c). Variation of rice variety 1 as observed in different sensing regions and (d). Variation of rice variety 2 as observed in different sensing regions.

As shown in the Figure 3(a) and Figure 3(b), the growth variation of different plant varieties have been shown in different node regions. As we can see different varieties has different growth rates as expected. For example the 3rd replica of variety 4 grew longer as compared to other plant varieties which accounts for the environmental parameters that are more favorable for this variety and among other varieties, this gives good performance. As we can see in the Figure 3(c) and Figure 3(d), one particular plant varieties gives different growth rate in different regions which is due to the fact that environmental paramters are not same for each region. Hence, It gives valuable information about the placement of the plants in the greenhouse.

C. ANOVA Analysis

ANOVA[4]. test has been run on multiple variables to see the effect of diffrent variables on other variables, hence it provides an important statistics result. Hence, Table II shows the effect of temperature and humidity effect on variety 1 plants. Since, diffrent varieties have diffrent growth patterns, ANOVA analysis has been performed and shown in the Table III. In the table, HRep1, HRep2, HRep3, and HRe4 correspond to replicas 1, 2, 3, and 4 of varity 1. The favorable factor for the growth of variety 1 and replica 1 governs good growth environment having a little higher temperature and lower humidity. Growth differences between different varieties helps us choosing the variety of the plant corresponding to favorable environmental conditions and depending on the environmental factor we should choose plant variety for maximum growth. The data helps us in different domains first choosing the variety and favorable conditions for that variety as we have differences between growth of different replicas.

TABLE II
ANOVA ANALYSIS SHOWING THE EFFECT OF HUMIDITY AND TEMPERATURE ON PLANT VARIETY 1

Variety 1 - Height TemperatureF Humidity

The CORR Procedure

3 Variables: Height TemperatureF Humidity

CSSCP Matrix

	Height	TemperatureF	Humidity
Height	1837.166696	387.396281	-153.607619
TemperatureF	387.396281	222.526505	-68.563283
Humidity	-153.607619	-68.563283	1068.828026

Covariance Matrix, DF = 27

	Height	TemperatureF	Humidity
Height	68.04321098	14.34801041	-5.68917106
TemperatureF	14.34801041	8.24172242	-2.53938086
Humidity	-5.68917106	-2.53938086	39.58622317

Simple Statistics

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum	Label
Height	28	64.29464	8.24883	1800	46.95000	75.40000	Height
TemperatureF	28	79.55383	2.87084	2228	72.73183	84.02783	TemperatureF
Humidity	28	62.33421	6.29176	1745	52.76140	73.04312	Humidity

Pearson Correlation Coefficients, N = 28
Prob > |r| under H0: Rho=0

	Height	TemperatureF	Humidity
Height	1.00000	0.60589 0.0006	-0.10962 0.5787
TemperatureF	0.60589 0.0006	1.00000	-0.14059 0.4755
Humidity	-0.10962 0.5787	-0.14059 0.4755	1.00000

[4]ANOVA analysis is preformed using SAS tool, www.sas.com

TABLE III
ANOVA ANALYSIS SHOWING PERFORMANCE RELATION AMONG DIFFRENT REPLICAS OF PLANT VARIETY 1

Variety 1 - Height Only

4 Variables: HRep1 HRep2 HRep3 HRep4

CSSCP Matrix

		HRep1	HRep2	HRep3	HRep4
HRep1	HRep1	436.2435714	275.0928571	615.5975000	228.0557143
HRep2	HRep2	275.0928571	184.8842857	376.4825000	143.5160714
HRep3	HRep3	615.5975000	376.4825000	908.7600000	310.2200000
HRep4	HRep4	228.0557143	143.5160714	310.2200000	126.0971429

Covariance Matrix, DF = 6

		HRep1	HRep2	HRep3	HRep4
HRep1	HRep1	72.7072619	45.8488095	102.5995833	38.0092857
HRep2	HRep2	45.8488095	30.8140476	62.7470833	23.9193452
HRep3	HRep3	102.5995833	62.7470833	151.4600000	51.7033333
HRep4	HRep4	38.0092857	23.9193452	51.7033333	21.0161905

Simple Statistics

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum	Label
HRep1	7	67.76429	8.52686	474.35000	53.45000	75.40000	HRep1
HRep2	7	63.42143	5.55104	443.95000	54.15000	70.60000	HRep2
HRep3	7	65.20000	12.30691	456.40000	46.95000	75.40000	HRep3
HRep4	7	60.79286	4.58434	425.55000	52.10000	64.10000	HRep4

Pearson Correlation Coefficients, N = 7
Prob > |r| under H0: Rho=0

	HRep1	HRep2	HRep3	HRep4
HRep1	1.00000	0.96865	0.97770	0.97235
HRep1		0.0003	0.0001	0.0002
HRep2	0.96865	1.00000	0.91848	0.93994
HRep2	0.0003		0.0035	0.0016
HRep3	0.97770	0.91848	1.00000	0.91642
HRep3	0.0001	0.0035		0.0037
HRep4	0.97235	0.93994	0.91642	1.00000
HRep4	0.0002	0.0016	0.0037	

VI. Conclusion and Discussion

The present paper outlines the method through which the measurement data are available from the greenhouse to analyse and predict the various environmental factors affecting the plants in various manners. In the agricultural research adaptance of engineering system to the condition of severe environment, open system, and long-term operation makes it easy to adapt and control the agricultural field. Furthermore, it will help in a lab-based measurement in the actual field. However, the following design constraint must be considered while designing a robust sensor network:

Robustness: The overall robustness of a sensor network depends on many factors: the ability of network protocols to recover from errors, the quality of radio transmissions, the quality of the gateway link, how well the nodes withstand harsh outdoor conditions and misadventure from wildlife or humans, the accuracy of the sensors and software used for measurment of humidity, temperature, light intensity and lifetime of battery power sources. Hence, if the network does not perform reliably in any one of these areas, then it may fail to deliver data from the field. In the present case we did not observe any data loss and the sensor-network deployed in the greenhouse has been monitored through the remote connection once a week. Since the greenhouse environemnt is a controlled environment, no-loss case may seem obvious but in the case of real time monitoring of crop field loss of data communication is expected due to outside interference in the communication.

Accuracy: We want to know how feed grows from changes in temperature and location and time of watering. That will help us modify the design and operation of the greenhouses. In the present work, sensor nodes are located at diffrent location and the placement of temperature and light controlling devices will give a diffrent reading at diffrent location. Hence, the plant growth expected to be diffrent in diffrent geographical locations inside the greenhouse. The accuracy of data corresponds to such diffrences.

Lifetime of the sensor network: For the long time measurement battery life should be sufficient so that we have lowest number of battery replacements. We ran the experiment for four months and recorded data for every 4 hours as suggested by agriculture researcher. Due to low frequency of data collection, we only had to replace battery once during the whole duration of experiment. To employ the optimization of battery power, the nodes have been programmed to go to sleep mode when not sensing.

It is difficult to perform a fine judgment by automatic sensor, and there is understandable anxiety about sensor error because of the possible consequences to living things. In our proposed system, the sensor-nodes are constructed, not with the artificial intelligence to judge for themselves, but managed by manual operating using the field users judgment. This system can also construct a man-machine system in which the field user himself can check and operate the peripheral equipment with a sense of security in the case of an important subject. With regard to future work, sensor network with embedded intelligent should be explored for the automatic control and adaptability to the various environmental conditions without manual interference of field users. Intelligent sensors surely revolutionise the environmental research. The proposed design and implementation described in this paper is effective and can be a guideline for further research in this area.

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