IOT Application System with Crop Growth Models in Facility Agriculture

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***Abstract*—The concept of Internet of Things (IOT) have been put into practice widely. This paper puts forward the idea of embedding crop growth models (CGMs) into the IOT application system in facility agriculture to make the system more intelligent and adaptive. Besides, this paper shares our practical experience and proposes engineering challenges in further practical deployment.**

Keywords-IOT system, Crop growth models, facility agriculture, intelligent system

I. INTRODUCTION

The Internet of Things (IOT) technology has been playing an important role in the modern information technology. Following specific protocols, anything has chances to have access to the Internet and exchange information with the help of such sensor apparatus as radio frequecy identification (RFID), Global Position System (GPS) and SmartSens in order to perform intelligent recognition, tracking, monitoring and management to objects.

The architecture of IOT is normally devided into three parts: sensor layer, network layer and application layer [1]. The sensor layer is mainly composed of all kinds of sensors or sensor gateways such as temperature sensors, humidity sensors and Carbon Dioxide density sensors. The sensor layer functions just like nerve endings in human bodies, recognizing and collecting information. The network layer consists of different building structures of networks or platforms, including private networks, the Internet and cloud computing platforms. The application layer presents flexible interfaces between users and the system at the level of miscellaneous industry requirements.

It is necessary to understand that the feature of an IOT system is often reflected in the particular occasion where it's deployed and applied. Attempts have been made in many social and industrial fields inlcuding agriculture, public security, city management, etc.

When it comes to facility agriculture, there also exists much work to improve. Facility agriculture is a labor-intensive, highly industrial modern agriculture techonology. It enables traditional agriculture to break the tether of nature environment progressively. As research and application on CGMs have been greatly advanced with the rapid development of computer technology and the deeper understanding of physiological and ecological mechanism of crops [2]. Based on physiological and ecological mechanism and relating crops' growth with air, soil, living beings and even humanistic factors, CGMs have been one of the most powerful tools in agricultural research.

This paper focuses on an application system of IOT in facility agriculture. Considering the research on CGMs has made great progress in the past few decades thanks to the increasing computing abilities of computers in the field of agriculture, we suppose it meaningful and significant to embed CGMs into the system to make it distinguishing and more intelligent.

The rest of this paper is organized as follows. Session 2 is the overview of our system functionality. Session 3 presents the typical system architecture. Detailed implementation in hardware is discussed in Session 4, and key information about the use of CGM modules and software implementation are introduced in Session 5. Finally, the paper concludes with a summary to our work and a statement of future work in Session 6.

II. DESCRIPTION TO THE SYSTEM

This IOT system is deployed in a greenhouse environment as a typical example of IOT technology application in agriculture. Essential data including temperature, humidity and light intensity are collected by sensors as the sensor layer. Tags are deployed to function as nodes, connected to sensors, collecting raw binary data and transmitting them to base stations through radio frequency. Data will then be transformed into plaintext and stored into database. Interface is available to database for upper application layer such as CGMs and management system on terminals.

III. THE SYSTEM ARCHITECHTURE

The system structure is made up of three parts corresponding to three layers in the IOT structure: wireless sensor network (WSN), base station/nodes (B/N) network and application platform. WSN acts as the sensor layer of IOT system while the B/N network plays the part of network layer, working in the similar way as the C/S architecture. Application platform and interfaces functions as the application layer. The overall structure can be illustrated in Fig.1.

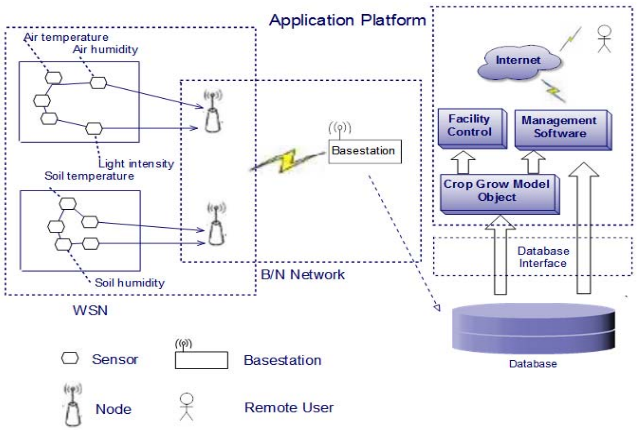

Fig.1 The architecture of the IOT system in facility agriculture

IV. IMPLEMENTATION STRATEGIES IN HARWARE

A. Sensor selection

Robustness, stability and user satisfaction is largely determined by the sensors. Research on sensors has also been a significant subfield in Electronic Engineering.

In our practical implementation. We use SHT10 as our temperature and humidity sensors. Each SHT10 chip integrates both a temperature sensor and a humidity sensor together. The temperature sensor has an operating range from $-40°C$ to $123.8°C$. The humidity one can return the relative humidity values from 0~100% [3].

The light intensity sensor is BH1750FVI. It has a 16 bits register so that it's able to detect light intensity in a wide range from 1 to 65535 Lx [4].

B. Base station/Node network architechture

The B/N network architecture works in the same way as the Client/Server (CS) structure in Computer Networks. CC430 platform combines MSP430, the core MCU, and CC11XX, the radio transceiving module together. The combination cuts both its package size and PCB space by 50% compared to the traditional solution on double chips. Fig.2 shows the structure of CC430. The left chip is the wireless tranceiver CC11XX and the right one is MSP430, containing the processing unit. Each couple of CC11XX and MSP430 can be driven by its USB interface and works as a basestation while another CC11XX is supposed to work alone as a wireless node, a battery supplying its power [5].

The 433MHz frequecy channel is used to transmit wireless signals between basestations and nodes. Under laboratory environment, they can transmit-receive data 70 metres of distance from each other. After receving raw data from sensor chips, the basestation then forwards the data to PC through RS485 or UART (like a USB interface on the right side in Fig.2).

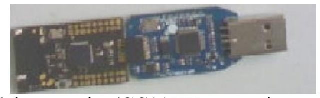

Fig.2 A CC430 base station(CC11XX transceiver on the left and MCU on the right)

C. Energy Consumption

Normally, idle listening occupies the main part of energy consumption in wireless sensor networks. But in our case, the problem can be well resolved by the platform we put into operation. Five low power modes are provided by the CC430 platform. We set the chip to LPM3 mode in our system so that the device will always stay in the low power mode on condition that there is no need to transmit-receive or control. CPU is waken up only when basestation sends commands. Under such circumstance, the working period is much too shorter than the standby mode, greatly prolonging its power endurance.

Besides, the 433Mhz frequency channel our system relies on makes its own contribution to lowering energy consumption as well. 433Mhz channel has its irreplaceable merits compared to other short range wireless communications as Zigbee and GPRS [6].

V. IMPLEMENTATION STRATEGIES IN SOFTWARE

A. Crop growth models (CGMs)

1) Basic ideas

From Fig.1 we have had the idea how the CGM module functions in our information system. Database interface enables the module to have access to all necessary environment data and parameters. After processing those data with relevant algrithoms, the module outputs commands to control facilities and information on the crop growing conditions to management system. The CGM module can be abstracted into a class and operated as an object in actual programming implementation in our system, which can be illustrated in Fig.3.

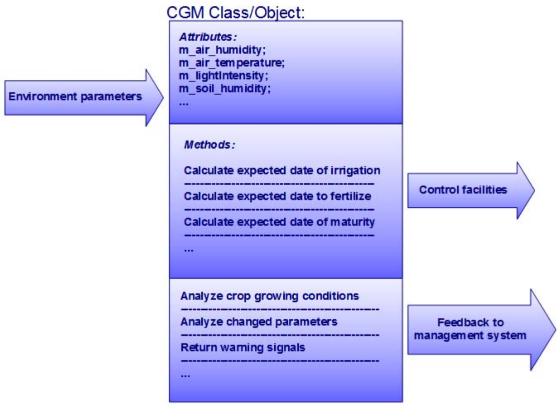

Fig.3 CGM Module functionality

Since almost every ambient environmental factor has effects on the crops' growth and each crop has its distinctive growth model, several models have been set up and proved efficient in the past 30 years, including the Wageningen model from Netherlands, DSSAT and GOSSYM from the USA, CCSODS from China [2]. Most of them work in such scheme that within certain environemental parameters such as air/soil temperature/humidity input, the model is capable of predicting the crop yield and the function between crop composition and time variation. In spite that they focus on different crops, environment parameters or calculations, most of them can be exactly abstracted into the same CGM class module shown in Fig.3. Take GOSSYM as an example.

GOSSYM simulates the growth and development of the entire cotton plant on an organ-by-organ basis: roots, stems, leaves, blooms, squares, and bolls. It also simulates soil processes such as the transfer of water and nutrients through the soil profile. To accomplish this, weather variables are required by GOSSYM, including, on a daily basis, such data as the maximum and minimum temperatures, solar radiatoin, and rainfall [7].

In order to estimate the expected date to apply the next date to irrigate, data should be processed by GOSSYM everyday. GOSSYM returns the date when the crop might face water stress according to the hypothesized weather and environment scenario based on the current data from database. Results from each day will be replaced by the next day calculation within the actual measured weather and soil parameters. As time goes by, the calculated irrigation date will meet the actual date changing some day, and that is exactly the time to apply the irrigation, as is shown in Fig.4.

Time to fertilize and time to maturity can also be estimated in the similar way.

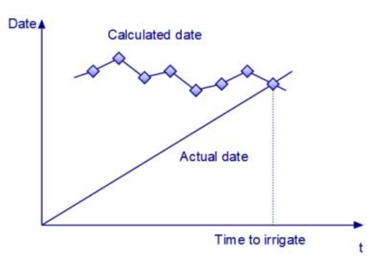

Fig.4 Determine date to irrigate

2) CGM algorithm in the system

In order to demonstrate how the CGM module works and focus on how feedback mechanism is generated from it, we build our own growth models and functions in the current system.

a) Time to irrigate

After each time of irrigation, we have the preliminary total amount of irrigation water. Therefore we can get the primary quantity of water C_0.

As the consumption of water on each day is always a function of daily average temperature, so when it comes to the i_{th} day, the daily waste of water C_i would be :

$$C_i = F(T_i)$$

Sum up all dates recorded in the database, and we can get the general quantity of consumed water:

$$C_c = \sum_i F(T_i)$$

A scenario shall be built to base on when it comes to predicting future consumption of water so that the exact date could be premeditated. In our system, a hypothesized weather scenario is the assumption that the upcoming climate on every day will keep the same as the last actual day stored in the database T_n. Then after x days of such climate scenario, the total using up of water resource would be:

$$C_t = C_c + x \cdot F(T_n) = \sum_i F(T_i) + x \cdot F(T_n)$$

The maximum value of C_t would never be larger than C_0. That is,

$$C_t \leq C_0$$

Make a replacement with the equation above, we get

$$\sum_i F(T_i) + x \cdot F(T_n) \leq C_0,$$

$$x_m \leq \frac{C_0 - \sum_i F(T_i)}{F(T_n)}$$

Now we can get the maximum value of x:

$$x_m = \frac{C_0 - \sum_i F(T_i)}{F(T_n)}$$

Add x_m and the total number of earlier days that have been taken, and the premeditated date – date function would be:

$$D_c = n + x_m = n + \frac{C_0 - \sum_i F(T_i)}{F(T_n)} \quad \ldots\ldots \quad \text{i)}$$

A boundary condition should be taken into consideration that the quantity of consumed water cannot be larger than the original totality C_0:

$$C_0 \geq \sum_i^n F(T_i) \quad \ldots\ldots \quad \text{ii)}$$

$F(T_i)$ is alternative, contingent on different climatic and edaphic scenarios. Suppose daily consumption of water is a linear function of average temperature:

$$F(T_i) = k \cdot \overline{T}$$

So the function of premeditated dates and actual dates will be:

$$D_c = n + \frac{C_0 - k \cdot \sum_i \overline{T_i}}{k \cdot \overline{T_n}}$$

With the boundary condition limiting:

$$C_0 \geq k \cdot \sum_i^n T_i$$

Every day the system analyzes and computes the expected date to irrigate according to current actual data stored in the database and a hypothetical scenario. The result will be updated on the next day because the hypothetical weather for that day is replaced by the actual weather conditions. The emulational diagram to the equation above is shown in Fig.5. Although the anticipated date to irrigate varies every day, they will converge into the spot after all. When that day comes, commands would be sent to facilities, telling them that the crop is in need of water. Then another irrigation will be applied and another loop of daily analyzing begins.

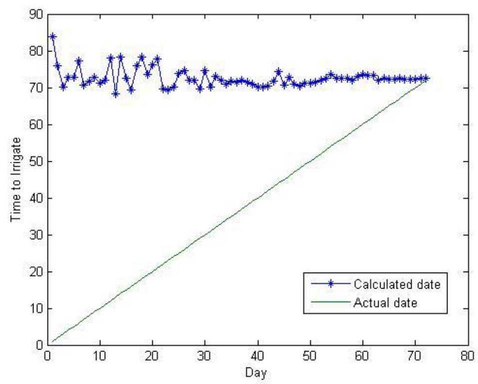

Fig.5. Calculate time to irrigate

b) Time to fertilize

The calculation process is almost the same as described in a). Suppose daily consumption of manure with daily average value of light intensity obeys quadratic law:

$$F(L_i) = k \cdot \overline{L_i}^2$$

Then the calculated date – date function will be:

$$D_c = n + \frac{C_0 - k \cdot \sum_i \overline{L_i}^2}{k \cdot \overline{L_n}^2}$$

Limited by its boundary condition equation:

$$C_0 \geq k \cdot \sum_i \overline{L_i}^2$$

And the result curve would be like Fig.6.

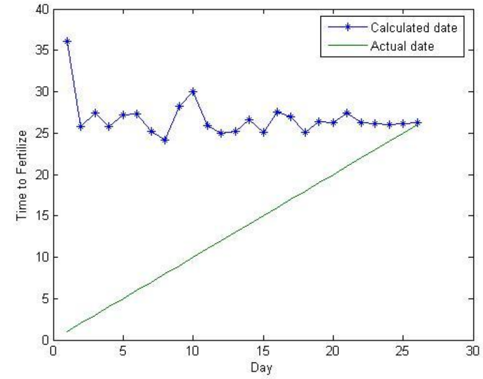

Fig.6. Calculate date to fertilize

Other actions can also be predicted according to other environmental parameters in the similar way of calculation.

The Dc-n function in equation i) and its boundary condition ii) can be regarded as the basic equations of CGM module. We can define it as a container in program designing. With regard to another crop, it has a different growing mechanism $F(T_i)$. Established CGMs such as Wageningen, DSSAT and CCSODS are alternative. When it comes to cotton, the function can be replaced by GOYYSM model.

c) Alarm mechanism

There can be many ways to decide whether the crop has an appropriate environment to grow in. In order to be more intelligent, a more flexible alarming system should be considered. Take temperature alarm strategy as an example. The system sets two temperature threshold values so that the system can feedback warning signals when the temperature is either too high or too low. However, time-tolerance is applied so that no alarm would be reported immediately when there is no need to be urgent. For instance, the system doesn't need to alarm without any hesitation when temperature goes beyond its thresholds but does send out alerts when the abnormality remains for five successive days. In this case, the warning system is evaluated in more dimensions than one. The analytical system is rather more multiple and flexible.

B. Application layer implementation

The management system is developed with Visual Studio 2010 under Windows 7 platform. Microsoft SQL Server 2005 is used as Dbms. User Interface is mainly written with GDI+ (Graphics Device Interface). With the use of modeless dialog boxes [8], the program is able to display all curve graphs and table lists of temperature, humidity, light intensity, etc at the same region on the interface, switched by a list of buttons. In order to focus on block-based design methodology in the system, we only put basic functional modules, including basic CGM modules and essential environment parameter records, into practice. Soil/air humidity/temperature, light intensity are taken into consideration as our own CGM classes are based on, in the same way as have been illustrated in A.2), the CGM works in a routine that the daily consumption of water is in a linear relation with daily temperature and the daily consumption of fertilizer is in a quadratic relation with light intensity thanks to the theory of Photosynthesis. The algorithm is explained and coded as a class. The interface under application layer works as shown in Fig.5.

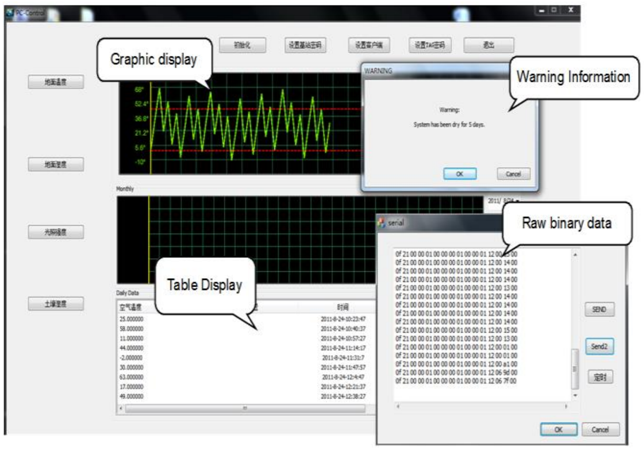

Fig.5 Management system with simulative CGM class

VI. CONCLUSION AND OUTLOOK

This paper discusses an IOT system application in facility agriculture. With CGM modules implanted, the system is much more intelligent and distincts from other industrial IOT application systems.

No two crop growth models have the same growth routines and algorithms [2]. Therefore meticulous CGM modules should be considered before they are employed to meet the factual environmental demands.

Even the latest models in agriculture calculate limited parameters input from outside, which means more considerate and mature CGMs are needed to make the system function better. Besides, when it comes to further practical performance, there are still lots to improve to perfect the system, including the anti-collision algorithm and multihop routing in the WSN and a better multithread mechanism in the application software.

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