Design of a radio sensing device for open farmland environmental data collection

Chien-Hung Lai (laisan86@gmail.com)
National Taipei University of Technology https://orcid.org/0000-0003-1391-0639
Kuan-Ting Lai
National Taipei University of Technology
Yuh-Shyan Hwang
National Taipei University of Technology

Research Article

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Design of a radio sensing device for open farmland environmental data collection

Chien-Hung Lai[1*], Kuan-Ting Lai, and Yuh-Shyan Hwang[1]

*Correspondence: ee12245@ntut.edu.tw
[1] Department of Electronic Engineering, National Taipei University of Technology, Taipei, Taiwan.
Full list of author information is available at the end of the article

Abstract

This paper introduces a radio sensing device that is easy to manufacture and maintain, easy to install and relocate, can store solar energy, resistant to typhoon and heavy rains, and has low power consumption. With the radio sensing devices constantly collecting information on environmental changes and sending data back to the backend system designated by the customer, our system can assist the farmers predicting the production period of crops in the area, which allow farmers to plan the different field operations. In this paper, we propose an unified sensor framework and compare our design with various hardware, software and mechanism of sensing devices in the literature. The height of our device is 275mm, the bottom circle radius is 63.3mm, the weight is less than 2kg, the minimum power consumption during radio transmission is only 0.58W, and the end point transmission distance can reach 16 kilometers. Our devices are highly integrated and low power, and have been commercialized and sold worldwide.

Keywords: Radio sensing, open farmland, environmental data, resistant to typhoon, low power consumption

1 Introduction

The topic of smart agriculture is increasing, and sensor data collection devices developed through IoT technology are becoming more and more common. According to the previous work in [1-5], we believes that radio sensing devices should have the following characteristics to be used in open farmland, and propose improvement directions for individual characteristics.

Modern agricultural intelligence is no longer just for agricultural machinery used in open farmland or greenhouse construction. After all, the biological characteristics of different crops can lead to different conditions for planting, fertilizing, irrigation and harvesting. Moreover, the return on investment of crops is actually a factor of consideration. The price of crops such as corn is still suitable for extensive open farmland cultivation, but for fruits with higher unit prices such as strawberries, it is suitable for hydroponic cultivation in greenhouses. For Taiwan, due to the two characteristics of small environmental changes and higher water source stability than many countries, Taiwan still chooses open farmland as its first choice.

At present, in smart agriculture, many studies [1,2] proposed the principle of using the Internet of Things (IoT) technology to monitor the growth environment of designated crops through sensing devices planted to farmland or greenhouses, so that can help farmers understand the current situation. However, the open farmland and greenhouse hydroponic cultivation methods are not the same; the installation of the sensing devices must be able to match different fields for selection. For example, open farmland is mainly soil cultivation, attention should be paid to whether the distribution of soil moisture and nutrients is uneven, while greenhouse hydroponics mainly provides nutrients for crop growth through nutrient solution, so attention must be paid to the pH and temperature of the liquid.

Based on the above description, the sensing device must considerate the requirements of changing different sensing modules according to different crops and planting locations. There are many existing sensing modules; mainly how to use the electrical interface to receive and process the data sensed by the modules, but due to the different manufacturers of each module, the electrical interface provided may not be the same. If a unified electrical interface can be used in the design, in addition to the convenience of software and hardware design, both manufacturing and maintenance work are easier.

As can be seen in the paper of [1-4], the main design is on open farmland, while the content of [5] is mainly for indoor environments. The use of these designs on real farmland may be limited. For example, in order to avoid rapid surface runoff caused by irrigation water, manual or pipeline water transportation measures are adopted to maintain water and soil terraces in layers.

It may be affected by differences in irrigation pipes, fog concentration, and sunshine intensity, which may make the water and soil conditions of each layer of terraces different. This paper has gained inspiration from this, and the sensing device should be easily installed and relocated to be suitable for more farmland.

In view of the fact that the area of open farmland may be different, there are different propositions on the most important power supply in the design of all sensing devices. For example, the method of [1] is mainly using AC power around the farmland, but the literature [2-5] discussed the importance of batteries. At the same time, since this paper advocates that the sensing device should be easy to install and relocate, it may not be possible if the design method of [1,5] is adopted. Besides, to lay a large number of communication and power lines on open farmland, not only construction costs, but also even maintenance is also an expense for farmers. Therefore, the design mentioned in [2-4] is more appropriate.

However, this is also relatively challenging, as [4] also mentioned in the paper, in order to be able to be used in a wide range of applications, batteries will always be an issue. However, the power storage effect of solar panels will vary with the intensity and length of sunlight, and even solar panels may have different power generation due to factors such as shading and aging. If the sensing device is to be installed for long-term sense the environmental changes of farmland, how to save the electricity necessary for periodic testing is very important.

In addition, this paper advocates that the sensing device should be easy to install and relocate, and the internal volume should be expanded as much as possible under the constraints of the same shell material, thickness and height. All components, circuit boards, and batteries are placed in the sensing device to achieve an integrated design, which is convenient for handling in the process.

Taiwan is a country prone to typhoons and heavy rains. Under such geographical restrictions, miniaturized weather sensing devices placed on open farmland are more likely to be damaged than some other countries and regions. Besides, the housing design of the sensing device should also take into account the need for integrated molding to facilitate transportation.

2 Proposed Design

According to the above description in the introduction section, the design scheme of this paper for the radio sensing device is as follows:

2.1 System infrastructure

According to the design principle of the sensing device, its system architecture is shown in Fig. 1. The controller and each sensing module exchange data through an electrical interface, and the sensing modules are responsible for one or more sensing items (such as conductivity, humidity, etc.), according to different crops and locations. The controller sends activation and query signals to each sensing module one by one, and the sensing module transmits the reading value of the sensing item it is responsible for to the controller through the electrical interface.

After the controller collects the reading value of each sensing item, it composes each reading value into a packet according to the regulations of the communication module, and the communication module converts it into a radio signal format and sends it according to the content of the packet. The power module exists independently for the controller, communication module, and each sensing module, and specifically governs solar charging and provides the power required by each part.

Fig. 1 The system block diagram of proposed sensing device

2.2 The unified electrical interface

Many farmland sensing projects are the same as those used by the industry today, and industrial modules and devices are also more suitable for use in many situations where the environment changes drastically. This is the first choice for sensing devices that need to be placed in farmland for a long time. The electrical interfaces commonly used in industrial sensing modules have recommended standard (RS) by the Electronics Industry Alliance (EIA). The common ones are RS-232 and RS485.

The method of RS is to transmit the characters one by one in a sequence of bits. The advantage is that there are fewer transmission lines, simple wiring, and a longer transmission distance. The reading value of the sensing item is expressed as a scalar, so even if the bits are transmitted one by one, there is no concern that this will cause a big time delay. However, for the transmission of logic signals, the RS-232 signal is compared with the ground wire. For the purpose of extending or bending the wire of the sensing items to expand the effective range or fit the field demand. Therefore, the signal transmission interface must not only have high anti-noise ability, but also have the effect of error detection.

When the signal is a low-voltage and is superimposed on a possibly higher voltage compensation (Noise), or the relevant information is expressed as the difference between the two signals, a higher CMRR is very important. In an ideal state, a differential amplifier is shown in Fig. 2. The two input terminals are V+ and V- respectively, and Gd is the differential mode gain. However, the actual differential amplifier is better represented by Eq. (1) with common mode gain: Gcm.

Fig. 2 An ideal differential amplifier

$$\mathrm{Vo} = G_d \times (V_+ - V_-) = \frac{1}{2} G_{cm} \times (V_+ - V_-) \tag{1}$$

The concept of logarithm can be expressed as Eq. (2), Since the G_d is generally much larger than the G_{cm}, the CMRR is a positive number. In this way, we only need to look at the difference between V_+ and V_-. If both include the same amplitude and phase, then Vo is zero. In practical applications, it is often not an absolute ideal operational amplifier. The lower the CMRR, the greater the common-mode signal in the output signal.

$$\mathrm{CMRR} = 10 \times \log\left(\frac{G_d}{G_{cm}}\right)^2 = 20 \times \log\left(\frac{G_d}{G_{cm}}\right) \tag{2}$$

In view of the above reasons, the sensor module in this paper will select RS485 as the unified electrical interface. Regarding the error detection function, Modbus [6] can be used as the communication protocol. Modbus is a communication protocol with a master and slave architecture. There can be multiple nodes on the bus, but there is usually only one node that plays the role of the master node, and the controller generally performs the master node. Others, such as the role of each sensing item, are slave nodes. Like each sensing item in Fig. 1, each slave node has a unique address for identification.

When the master node sends a Modbus command, the command must include the address of the slave node to specify which slave node to process. From the circuit principle, it is actually when the master node sends the command, all slave nodes on the bus will all receive the same command, but only the slave node matching the specified address will execute and respond. Here is a special point: address 0 is an exception! Because at the time of Modbus planning, the purpose of address 0 is for broadcasting. When broadcasting, all slave nodes on the bus will receive and execute commands but do not respond.

All Modbus commands include check codes, so that the correctness of the commands transmitted to the slave node can be affirmed. The check codes are designed using the principle of cyclic redundancy check (CRC), which is represented by 16-bit CRC calculation. The operation of CRC 16 bits can be represented by $x^{16}+x^{15}+x^2+1$, which is actually a polynomial, and the initial value is 65535.

As far as the design of software and hardware is concerned, it is possible to use RS485 as a unified interface and follow the Modbus communication protocol. In addition, this helps easy to manufacture and maintain.

2.3 Mechanism and housing

In the design of the sensing device in this paper, the resistance to damage caused by typhoons must be considered, and the difficulty of flooding caused by heavy rain must also be considered. Thus, the paper proposes that it is more suitable for the environmental sensing device to take a cylindrical shape, and all components and power source can be easily placed in it. The following is a theoretical analysis of why the cylindrical shell is used:

- According to the principle of mechanics, a uniform cylinder with the same cross-sectional area should have the same stress on the cross section when a force is applied at either end. According to the principle of geometry, if the perimeter is the set value, then the circle can be enclosed the largest area. The volume of a cylinder is the area of the circle multiplied by the height of the cylinder. For the same height, if we want to achieve the same volume without a cylinder, we can only increase the circumference. This can be proved by the isoperimetric inequality! Therefore, for the same height, same material and thickness, the cylindrical design can effectively increase the interior space.
- Under a fixed volume, the smaller the force-bearing area, the greater the strength of the structure. According to Eq. (3), F represents the force, and A represents the force-bearing area, and P is the pressure per unit area:

$$\mathrm{P} = \frac{F}{A} \tag{3}$$

  If the A becomes smaller, when the P is a constant value, the F it bears will decrease, so that the shell is less susceptible to bursting due to squeezing by external forces.
- The flow of fluid around the object will be different due to the physical characteristics of the fluid, the shape and size of the object, and the speed of the flow around. Typical is the flow of fluid around a long cylinder. This is why the bows of many ships are usually not straight but arc-shaped, and the main purpose is to fear that the hull will be overturned by the big tide.

Therefore, the sensing device of this paper can encapsulate the circuit board, related components and power supply of each sensing item in the mechanism like [7] did, as shown in Fig. 3. Since all components and power sources can be packaged in the mechanism, flooding caused by torrential rain will not easily cause circuit and power short circuits. Compare with [1], the design is even less susceptible to torrential rain and typhoon, which can lead to failure of normal AC power supply to the sensing device.

Fig. 3 Integration of the circuit board, related components and power supply

The overall design of printed circuit board (PCB) can refer to Fig. 4. With this design method, we have conducted the measurement experiment in the field located in Taiwan as shown in Fig. 5, which has been more than one year.

Fig. 4 The PCB design of proposed sensing device

Fig. 5 The purposed device installed on field in Taiwan

2.4 Power consumption strategy

Regarding saving power consumption, as can be seen from Fig. 1, the power consumption of a sensing device, in addition to the controller itself, each module may have individual power consumption. However, the electricity stored by green energy conversion may be unstable, like shown in Fig. 5. Solar panels will reduce power generation due to shading, aging, surface cracks. Therefore, the controller should always enter the sleep mode, and each module will cut off the power through the transistor switch then. When the next cycle is coming, the controller will be restored first.

After that, the controller will turn on the transistor switches to power each module by the warm-up time, and then actually read sensing data. For example, we read the sensing data once per hour. According to the different warm-up time required by three different modules A, B and C, module A needs 5 minutes, module B needs 2 minutes, and module C needs 3 minutes. The controller will turn on module A at 55 minutes, module C at 57 minutes, and module B at 58 minutes, shown in Fig. 6.

Fig. 6 The timing diagram for powering each module

After reading various sensing data, the controller cuts off the power supply of all sensing modules, and then transmits the sensing data to backend system, enter the sleep mode, waiting for the next cycle at the end.

3 Experiment Results

The sensing module contained in our sensing device is shown in Fig. 7, and the controller, radio transmitter and battery are packaged in a cylindrical mechanism. The part of the bottom of the device facing the ground also forms a funnel shape, so that when moisture condenses in the mechanism, water droplets will fall to the surface due to gravity.

Fig. 7 The sensing modules stack in proposed sensing device

Currently, the most common IoT radio communication services in Taiwan include Narrowband Internet of Things (NB-IoT), Sigfox and Long Range (LoRA) [8]. They all have common demands: low power consumption and long-distance transmission, these two demands. Therefore, this paper individually focuses on the technical characteristics of the above three forms of communication services, conducts experiments and discussions on demanding power and transmission distance. First, judging from the principle of the communication system, any signal can be expressed as Eq. (4):

$$s(t) = A \cdot \cos(2\pi f_c t + \theta) \quad (4)$$

Among them, s represents the signal, A represents the amplitude, fc represents the center frequency, and Θ represents the phase. From the perspective of communication modulation technology, there are three types of modulation methods: amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM). If it is based on the basic principle of electromagnetic waves, the electric and magnetic fields in space are generated by interactive induction, and then energy is transferred in the form of waves; according to Faraday's law of electromagnetic induction, it can be expressed as Eq. (5):

$$\nabla \times E = -\frac{\vartheta B}{\vartheta t} \quad (5)$$

Where E represents the electric field, the unit is how many volts per meter, B represents the magnetic field, the unit is how many volts per square meter multiplied by the second, Eq. (5) shows that the curl of the electric field is related to the change of the magnetic field in time, that is to say: No matter how far the distance is, as long as there is enough energy, the signal can be transmitted by electromagnetic waves. Therefore, it can be understood from this that the demand for long-distance transmission is secondary. The first thing to considerate for sensing device is the power consumption. The comparison result shown in Table 1 for the communication functions tested in Taiwan for this paper.

Table 1 Taiwan marketed IoT radio services test results

	LoRA [8]	Sigfox [8]	NB-IoT [8]
Product name	AcSip S76S [9]	WSSFM10R 4AT [10]	SIM-7000C [11]
Operator	None, private gateway	Unabiz Taiwan	Chunghwa Telecom
Maximum power consumption for transition	2.5W	0.58W	2W for GSM900 1W for DCS1800
Distance : packet length (Bytes)	10km~13:45 16km:31	14km:12	Depends on base stations
Interface for backend	Defined by private gateway	HTTP RESTful API [12]	MQTT [13]

The above IoT radio communication modules are all connected to the controller through serial communication. In order to meet the global market, the above three communication services can be used for the sensing devices proposed in this paper. However, Table 1 shows that individual power consumption is different. Therefore, when the user specifies the communication service to be used, the appropriate battery can be considerate according to Table 1.

At the end, backend system has been successfully set up with Microsoft Azure, provides users with smartphone apps to get push notifications at any time. At this stage, it is accurate enough to assist Taiwan's refined rice production company "SoMiWu" in enterprise resource planning. The following show the actual interfaces currently available for users to operate. Crops' production history tracking and wholesale management functions have also been added. The reading of every sensing items will be recorded and displayed via charts, backend system will plan the field operations automatically with the recorded readings by machine learning regression analysis techniques, and so far, it supports global different languages, shown in Fig. 8 to 11.

Fig. 8 shows how to install the proposed sensing device. As shown in Fig. 7, the appearance of the device is like an upside-down bottle, but it is divided into upper and lower parts that can be rotated and opened. Taking NB-IoT as an example, you can insert the SIM card after it is turned on, and then twist and tighten the upper and lower parts of the device, and then it can be powered on. After power-on, since the device is equipped with GPS, each time the device sends back various sensing data, the GPS coordinates will also be brought into the packet. Therefore, users can install multiple sensing devices in different fields according to their needs, and they are able to freely change the installation position of the devices, manage by backend system that integrated the functions of Google Map service.

Fig. 8 Manage the purposed device on field by back-end system

Although the sensing device continuously transmits various readings back to the background system by radio, the actual growth ratio of different crops will be more or less similar due to many factors such as crop types, environmental changes, irrigation and fertilization plans, etc. Therefore, in the design of the backend system, according to the target crops specified by the user for different sensing devices, it can automatically expand the parameter items that need to be monitored by its knowledge base, and provide various alerts for users to refer to and set by themselves, as shown in Fig. 9.

Fig. 9 The backend system can automatically assist users to manage various values

With the above design of the background system, it is easy to assist the user to automatically plan the field operations for the target crops, as shown in Figure 10. In addition, it is also possible to predict the benefits that can be harvested through the interaction between the degree of implementation of field operations and the factors of environmental change, as shown in Figure 11.

Fig. 10 Help clients plan the field work automatically

Fig. 11 Predict the benefits that can be harvested

There are many methods of regression analysis, among which linear regression is the easiest to use, and at the same time, it can be used in many different fields. All linear regressions can be expressed in (3), where w stands for weight, x stands for independent variable(moisture, pH, soil temperature…etc), m represents the number of independent variables, y stands for dependent variable, and b stands for bias.

$$y = \sum_{n=1}^{m} w_n x_n + b \tag{6}$$

To the characteristics of different crops, the growth period and factors can be obtained according to experiments, so that each growth factor becomes an independent variable after vectorization, and the growth period after vectorization can be formed (6). Repeatedly adjust the weights by the least squares method to gradually reduce the error, and then the adaptive values of the weights can be obtained.

In addition, for the growth model of the regression analysis of each crop, Ridge and Lasso regression analysis methods can be used to find the key factors in the weight, and even sort out a more concise model for later revision when conducting growth experiments on crops.

Ridge regression analysis can be expressed as (7), where β represents the difference between the predicted and actual values, p represents the times of verification comparisons, and λ is the part of the strength adjustment.

$$\lambda \sum_{j=1}^{p} \left(\beta_j\right)^2 \tag{7}$$

Lasso regression analysis can be expressed as (8), where the difference from Ridge regression analysis lies in the calculation of the β.

$$\lambda \sum_{j=1}^{p} \left|\beta_j\right| \tag{8}$$

When there are many independent variables, if we want to remove the unimportant ones, we should choose Lasso regression analysis first. However, if we want to find the important independent variables, we can use Ridge regression analysis to identify them, because the λ will approach but will not really become zero for those unimportant independent variables, so we can use λ to sort and know the independent variables represent the factors are the root causes.

The proposed sensing device can obviously be combined with the backend system to assist the users to easily establish the production and marketing history of crops, to easily maintain the market supply and demand, and at the same time reduce food safety concerns.

Because of this success, with the assistance of the Taiwanese government, the sensing device in this paper has been extended to a wide variety of crops, including sweet potatoes, various leafy vegetables, and tropical fruits [14]. After that, it was also successfully selected as a representative product of Taiwan's smart agriculture and was promoted to many countries in the world to assist local farmers in managing field operations [15].

4 Conclusion

Through the above design and implementation, we have verified that the radio sensing device described in this paper has the characteristics of easy installation and use, low power consumption, resistance to typhoons and heavy rain. Those features make our design suitable for installation in open farmland. In addition, due to the unified use of RS485 and Modbus as the interface, many existing chemical sensing modules on the market can be directly employed, which effectively simplifies the manufacturing process, and at the same time, it is easy to control the cost.

In addition, the end-point transmission effect of the three communication services of LoRA, Sigfox and NB-IoT was actually tested. According to the test data shown in TABLE I, it shows that the minimum power of our radio sensing device is as low as 0.58W, and the longest distance can reach 16 kilometers when transmitting signals.

Abbreviations

IoT: Internet of Things; LoRA: Low power Long Range; NB: Narrow Band; PCB: printed circuit board; AC: Analog Current.

Authors' contributions

Chien-Hung Lai participated in the whole software and hardware design and implementation. Yuh-Shyan Hwang participated in this project as project manager who helped to draft the manuscript. All authors read and approved the final manuscript. All contributors who do not meet the criteria for authorship should be listed in an acknowledgements section. All authors read and approved the final manuscript.

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Availability of data and materials

Data sharing not applicable to this article as no datasets were published during the current study.

Declarations

Competing interests

The authors declare that they have no competing interests in this section.

Author details

[1] Department of Electronic Engineering, National Taipei University of Technology, Taipei, Taiwan.

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Figures

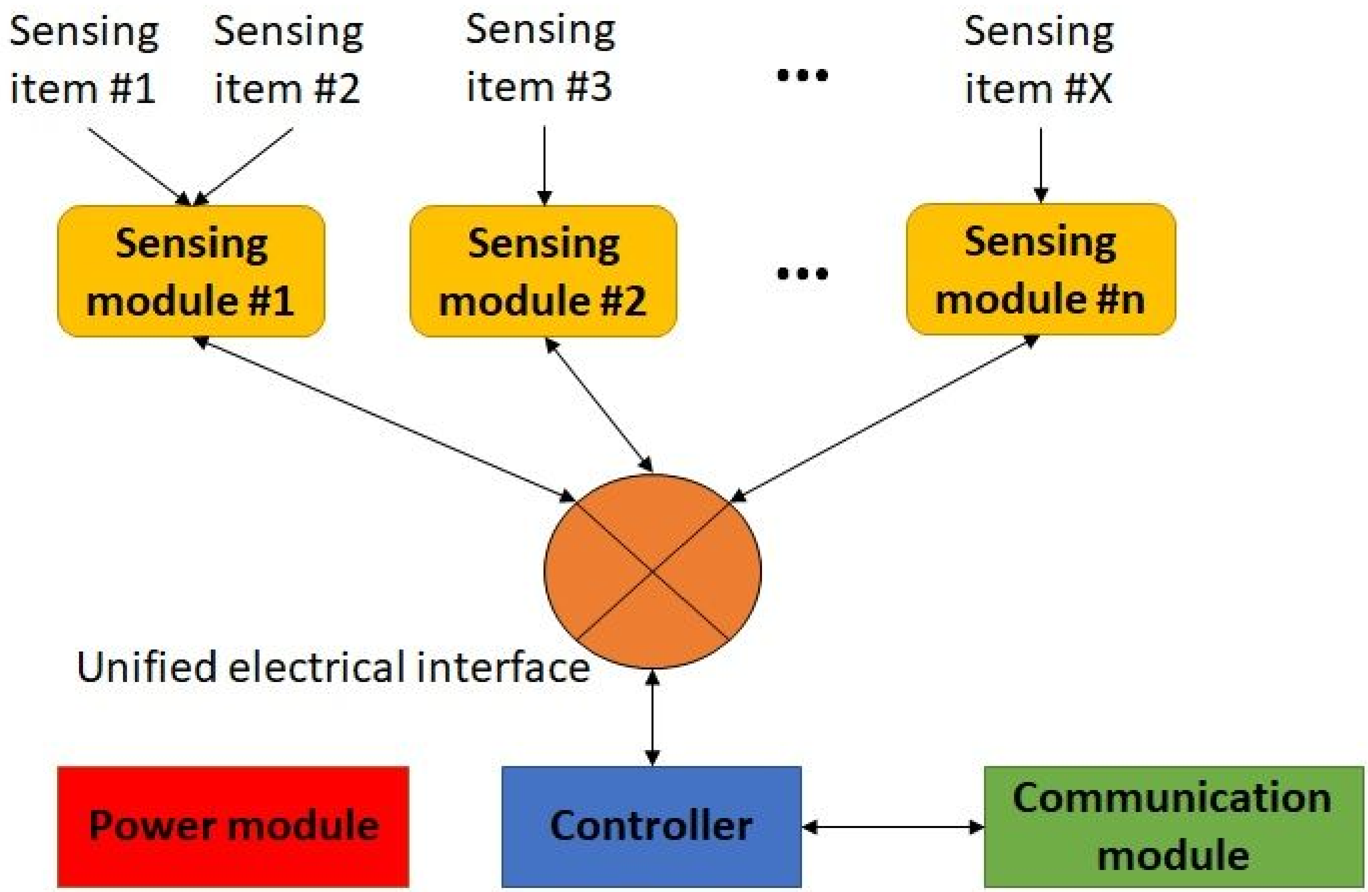

Figure 1

The system block diagram of proposed sensing device

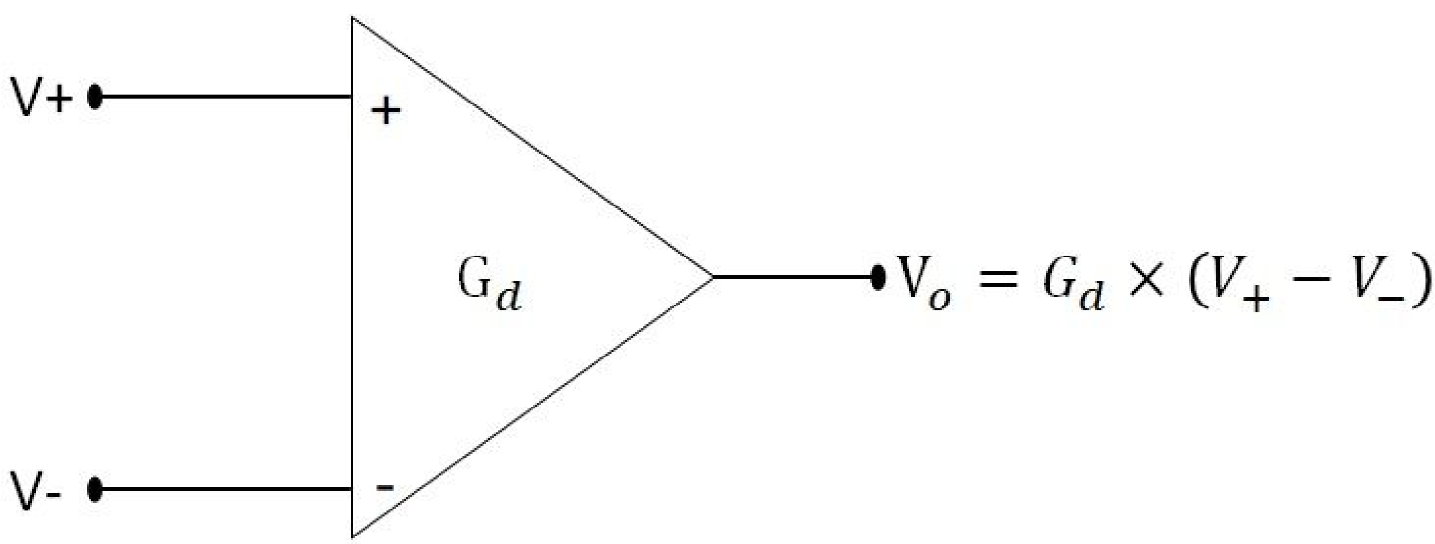

Figure 2

An ideal differential amplifier

Figure 3

Integration of the circuit board, related components and power supply

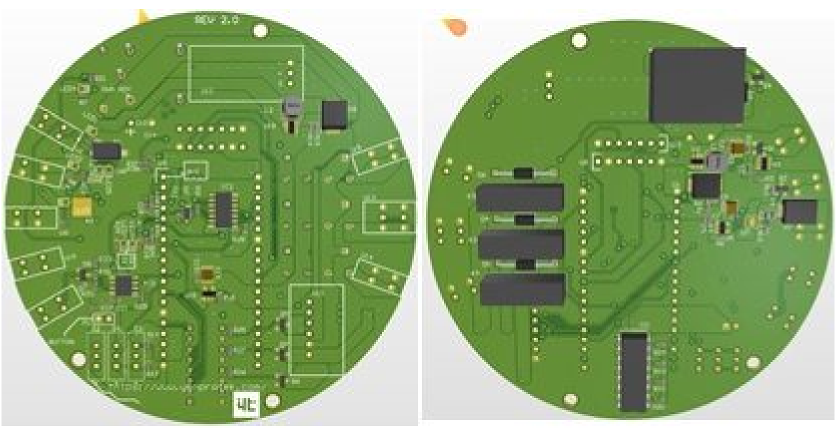

Figure 4

The PCB design of proposed sensing device

Figure 5

The purposed device installed on field in Taiwan

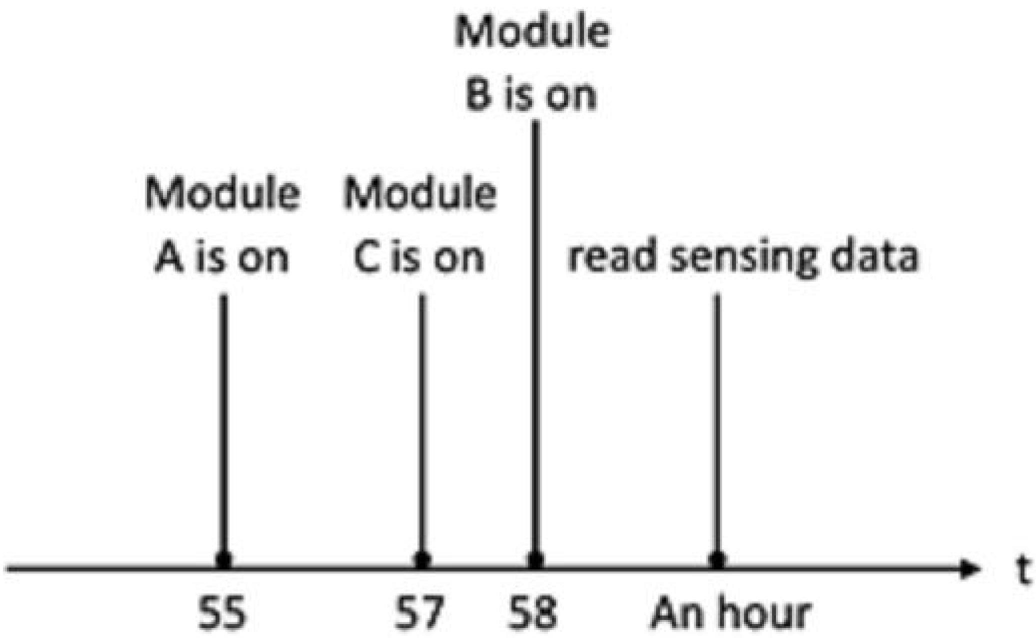

Figure 6

The timing diagram for powering each module

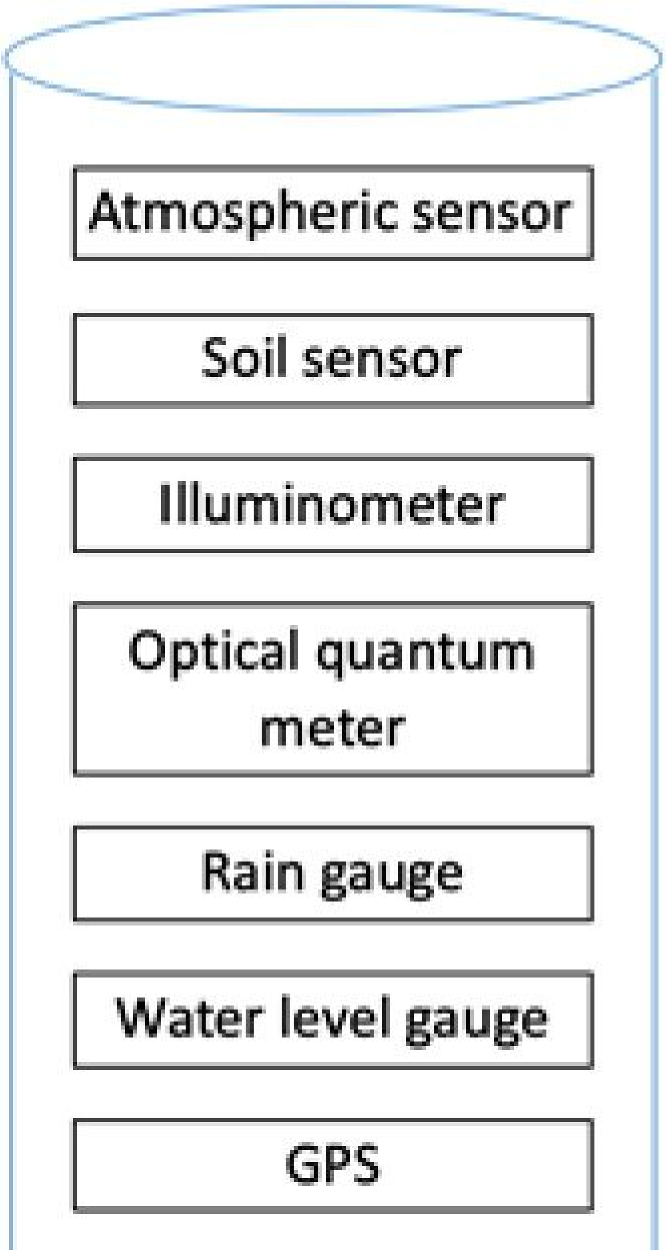

Figure 7

The sensing modules stack in proposed sensing device

Figure 8

Manage the purposed device on field by back-end system

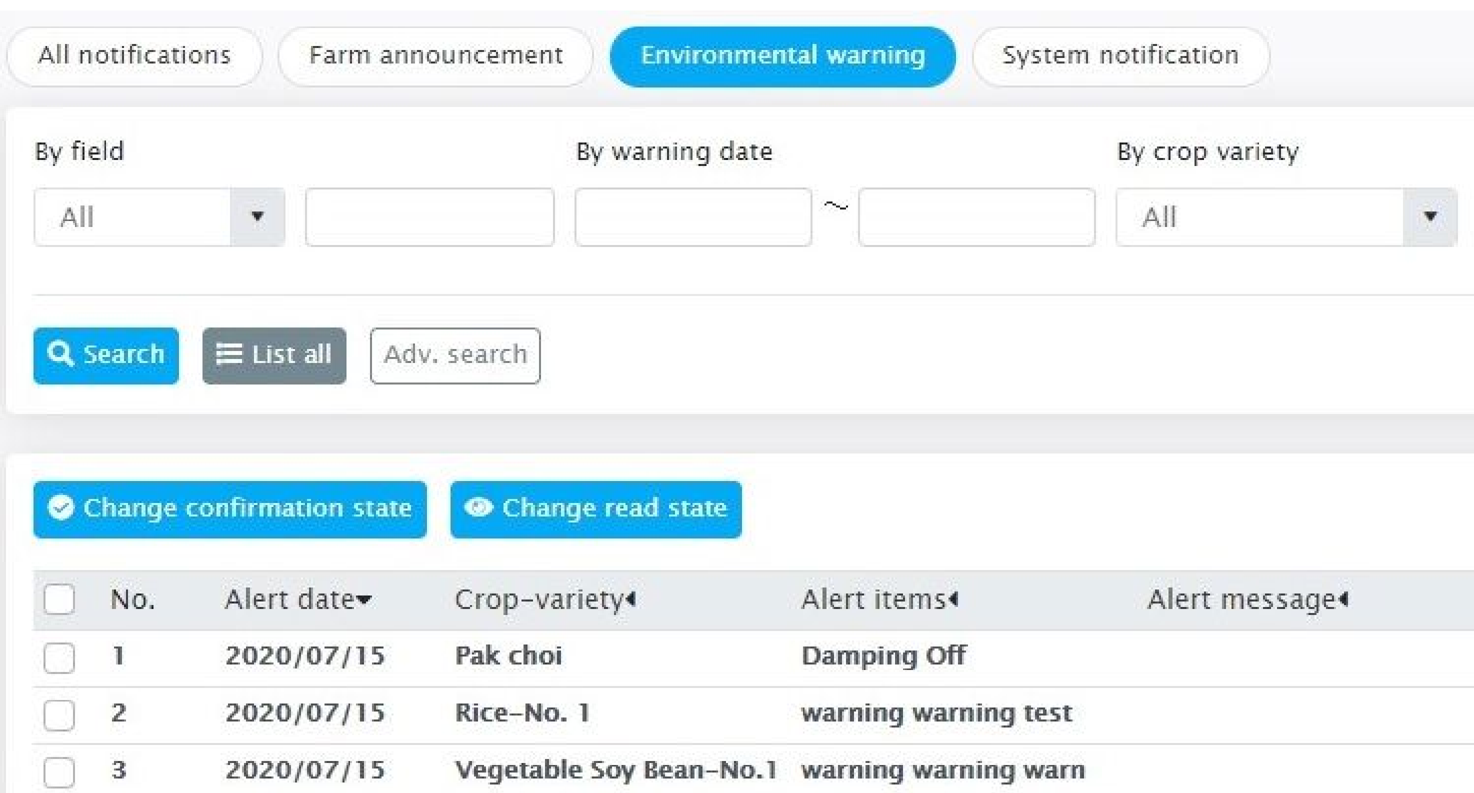

Figure 9

The backend system can automatically assist users to manage various values

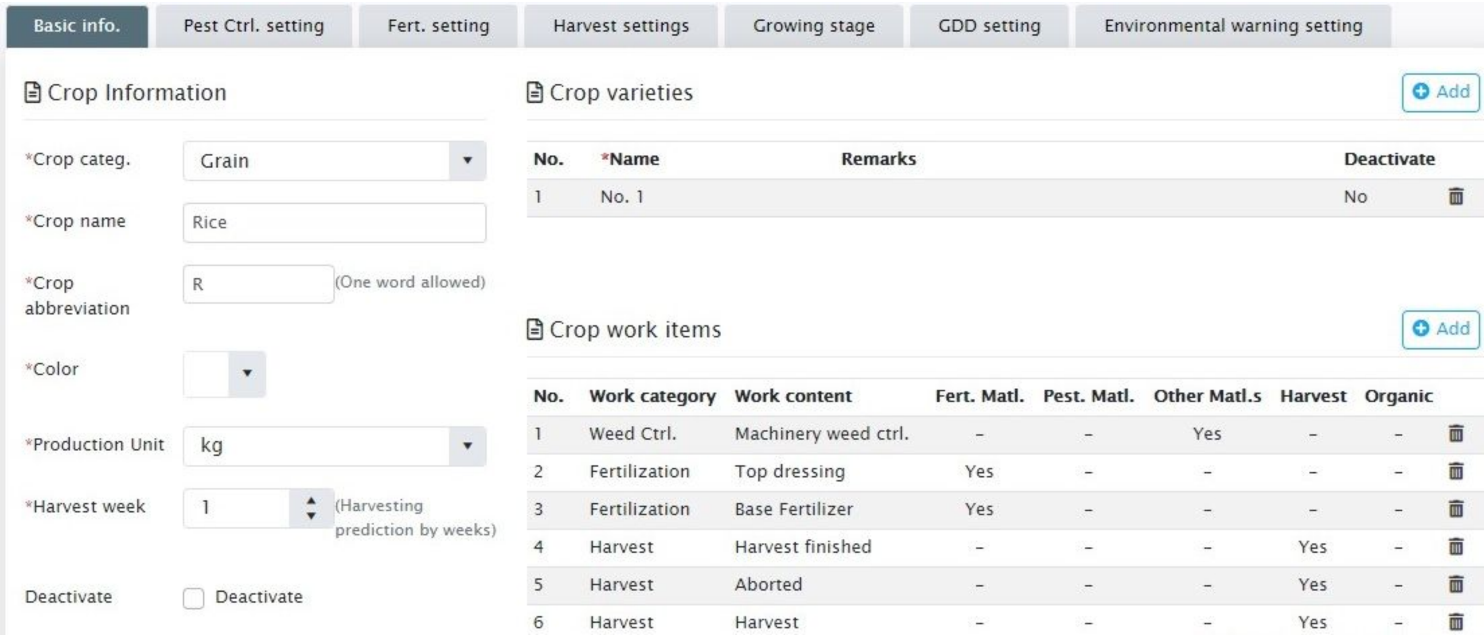

Figure 10

Help clients plan the field work automatically

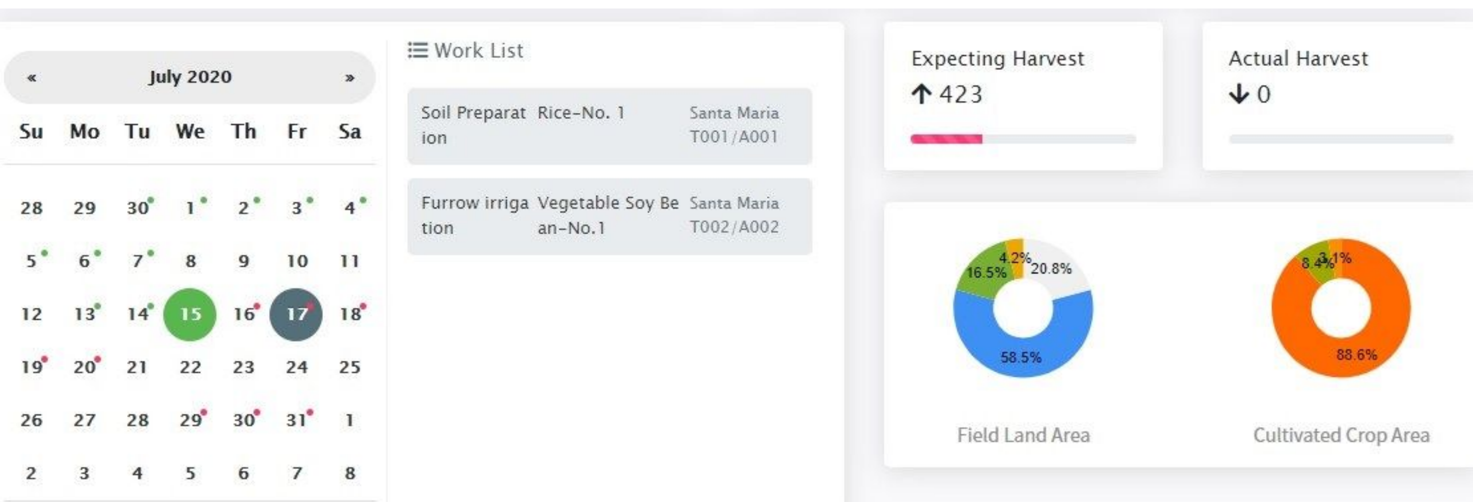

Figure 11

Predict the benefits that can be harvested