A Real and Novel Smart Agriculture Implementation with IoT Technology

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***Abstract*—There's an old saying in Chinese, "food first, ethical niceties second." It tells us how important it is to solve the food crisis. However, for the past decades, because the natural environment changes enormously, pests and disease occur more frequently, and higher and higher manpower costs need to be paid, the traditional agriculture is facing lots of new challenges. In order to address these issues, agricultural technologies with IoT technologies are proposed, but most people consider smart agriculture (smart farming) or called intelligent agriculture as planting crops with different sensors that can give farmers a dashboard to show lots of different numerical information. Some people even call this "Agriculture 4.0."[1] In this paper, we will try to give a more clear definition of "Smart Agriculture" from our point of view. Furthermore, in our work, we tried to implement what we call a complete smart agriculture solution in one shot, especially for the most common hard-working smallholder farmers. In addition, we also implemented the proposed solution named TIAGA in real rural areas. We'll discuss and show the results of one of the successful examples in this paper. We hope that through this paper, we can provide some new directions for the development of smart agriculture and improve the lives of the most hard-working smallholder farmers in traditional rural areas.**

***Keywords*—IoT, Smart Agriculture, Smart Farming, TIAGA, Agriculture 4.0, Extreme Climate**

I. INTRODUCTION

It is widely considered that AIoT plays an important role in what is called "Industry 4.0." Above all of the applications, we focus on the application in agriculture. Most people defines "Smart Agriculture" as installation of IoT devices with different sensors or even just local devices with different sensors which can give some numerical data[1,2]. Maybe some numerical data are useful or readable for farmers but some are not, for example the electrical conductivity (EC) of soil. In fact, most farmers even cannot recognize what it is. As everyone knows, because the agricultural work is very hard, fewer and fewer young people or newcomers are willing to engage in agriculture. These young or new farmers even do NOT know anything of all these numerical data. In fact, this is not very helpful to ordinary smallholder farmers, nor does it provide clear agricultural assistance to the young farmers returning to the countryside or rural area.

In addition to crop planting issues, how to guarantee the food safety to the customers is also a very important topic for agriculture. Different "GAP (Good Agriculture Product)" standards followed GAP of FAO of UN are practiced in the whole world[3]. In Taiwan, the "Taiwan Good Agriculture Practice (TGAP)"[4] even requires extra traceability of agriculture product similar to what GACP (Good Agriculture and Collection Practice)"[5] defined for medicinal plants. However, most research just focuses on only IoT or information technologies but the real issues of "human factor" are often ignored[2]. Perhaps this is because most of the researchers engaged in the development of related technologies are mainly from the field of information and communications technologies. However, standardized planting can not only help ensure food safety, but also ensure the quality of crops and stable yields.

In this paper, we try to redefine what the basic smart agriculture should be through our perspective. At the same time, we also hope to use our own implementation named the TIAGA system as an example to explain what a simple and inexpensive smart agriculture solution that are helpful to general smallholders and consumers should be. The rest of this paper is organized as follows. Section 2 describes what "smart agriculture" should be from our own perspective. In section 3, the proposed smart agriculture solution –TIAGA will be depicted. The implementation result will be discussed in section 4 with one of the real successful examples. Finally, the conclusions will be explained in section 5.

II. SMAR AGRICULTURE

As mentioned before, there are no real clear definition about what a minimum smart agriculture should be. Thus, everyone may claim his or her own system as "smart agriculture" solution. These so-called smart agriculture solutions range from greenhouses or even plant factories controlled by PLC technologies, agricultural record management systems or production and sales traceability systems to the introduction of IoT technologies to provide dashboards to display the data collected by various sensors, and even provide remote control automation facilities. There are also some solutions that provide drone irrigation or management of agricultural products. It can be said that almost all these individual solutions are called smart agriculture[1,2,6,7]. However, almost none of these solutions really start from the perspective of rural or smallholder farmers, and do not consider whether smallholder farmers can afford it. Even the solution meets the needs of ordinary

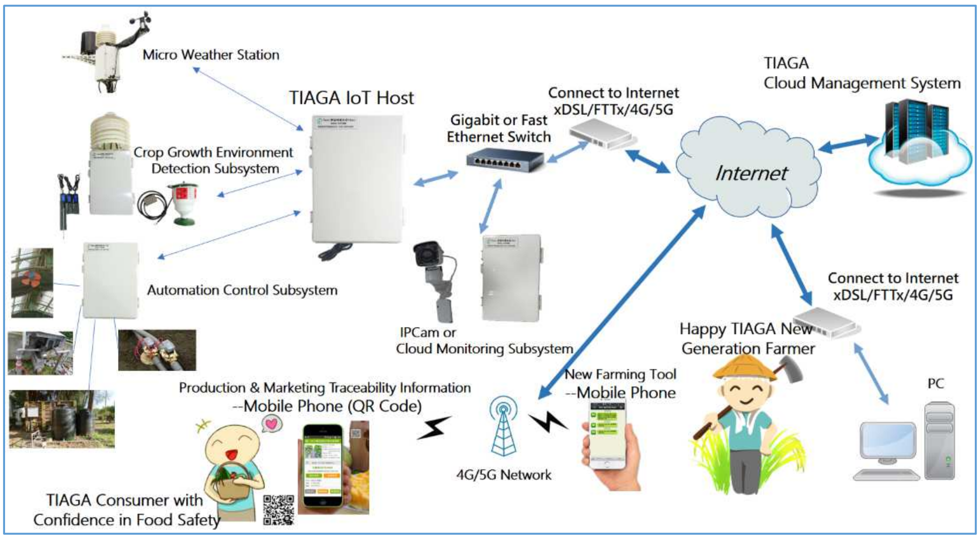

Fig. 1. Overall Architecture of the Proposed TIAGA System

smallholders, it still does not try to build connections between the smallholder farmers and consumers. It means that it doesn't try to establish a bridge for mutual trust between consumers and smallholder farmers.

In the traditional or customary agriculture, the hard-working farmers' lives rely on the climate. Farming is a labor-intensive business that requires a lot of human resources and man-hours. Even with the introduction of "mechanization" and "automation" nowadays, the hard work of farming still makes a lot of young manpower is unwilling to engage in agriculture. In conventional agriculture, farmers may use excessive fertilizers in order to increase yields, and farmers may use excessive pesticides in order to reduce pests. This not only causes harm to the environment, but also increases food safety concerns. Consumers may worry about the safety of the crops they eat. Therefore, "Friendly Farming" engages in agricultural production in a way that is less harmful to the land by reducing the use of pesticides, chemical fertilizers, and basic transformation technologies, while moderately using organic fertilizers and compost. In addition, as the world's population increases and the climate and environment change rapidly, agricultural development is facing even greater challenges.

With the development of the AIoT technologies, "Smart Agriculture (Smart Farming)" or so-called "Agriculture 4.0" takes artificial intelligence (AI) as its core to integrate agriculture, the IoT, big data, cloud computing, edge computing, the Internet, and other information and communication technologies such as 5G and blockchain. The IoT devices integrated with various sensors on the farm side send the real-time farm data collected to the "Decision Support System (DSS)" or "Agricultural Expert System (AES)" in the cloud service through communication or network equipment connected to the Internet. Through artificial intelligence judgments and decisions, the processed decisions can be used to control automation facilities in the farm through IoT-technology-based automation equipment control devices in real time via Internet. If there are no automation facilities or the farmers want to control them manually, they can be notified in real time via mobile phone and they can also remotely operate the automation facilities in the farm by mobile phones. Furthermore, the smart agriculture system has to support a complete growth environment and even growth image collections and recordings. In addition, it also has to support farmer to operate and manage farming records via mobile phones easily. Thus consumers can check the complete production and marketing traceability information including growing environment data, even complete agricultural records of growth images and farmers' agricultural records via scanning QR Codes on agricultural products with mobile phones. We also strongly recommend that third-party fair food safety inspection reports should also be provided. With such agricultural production and marketing traceability system, the relation between the farmers and customers will be closer. Agricultural products are also easier to gain the trust of consumers. We believe that solutions that support the above characteristics can be called smart agriculture.

In addition, we must point out that the essence of smart agriculture is still agriculture, and it means that the smart agriculture solution should be based on the agricultural point of view. As mentioned above, in order to reduce the harm to the environment and land due to traditional or customary, we believe that future agriculture should focus on friendly agriculture or even organic agriculture. In order to achieve this goal, the agricultural expert system and the production and marketing traceability system should play a very important role. The agricultural expert system can naturally adopt the friendly farming method or the organic farming method by providing suggestions to farmers with agricultural materials and agricultural works suitable for friendly farming or even organic farming. The agricultural production and marketing traceability system uses the soil information collected by the IoT equipment and the farmers' farming record to force the farmer to earnestly engage in farming using friendly farming or organic farming methods. Thus, friendly farming or even organic farming can be promoted naturally.

III. Proposed Smart Agriculture Implementation

In section 2, we have defined what smart agriculture should be. In order to carry out our own viewpoint, we implemented our own intelligent agriculture system named the "Tano Intelligent Agriculture GACP Cloud Management System (TIAGA)." As shown in Fig. 1, the whole system is separated into two parts. One is the hardware (IoT devices) part including the TIAGA IoT host (Host), the micro-weather station (M1), the crop growth environment detection subsystem (M2), the IP Camera/cloud monitoring subsystem, and the automation control subsystem (M3). The other part is software part including the IoT cloud management system, the agricultural expert system, and the GACP agricultural product traceability system.

The TIAGA IoT host (Host) collects local weather information, including temperature, humidity, atmospheric pressure, UV intensity, solar illuminance, CO_2 concentration, wind speed, and rainfall, from M1, the actual crop growth environment information, including temperature, humidity, atmospheric pressure, UV intensity, illuminance, CO_2 concentration, soil electrical conductance, soil pH, soil temperature, soil humidity, and number of pests trapped by intelligent pest trap, from M2, sends the collected data to the cloud management system with HTTP protocol via Internet, and the Host also receives automatic control from the cloud management system to M3 to turn on/off the automation equipment, such as automatic watering and fertilizing equipment, exhaust fan, winder, pesticide sprayer, gull wing roof, lights, or other equipment that requires automatic control.

Because the IoT devices would be installed in the real farm environment, the reliability and safety would be the most important criteria. The MCU chips we implemented in each of our MCU board were the simplest ones but with higher reliability. The TEENSY USB 3.3 EVB which is an Arduino compatible board was selected for our Host. The ARM® Cortex® M4-based board could provide reliable operation with enough performance. The MCU used in our M1, M2, M3 MCU board was MEGAWIN MG82FG5B16 which is based on 8-bit 8051 MCU. The IoT host connected to the Internet via fast Ethernet and ISP Internet access device, such as xDSL/FTTx or even 4G/5G routers. The communications among Hosts, M1, M2, and M3 are two-wire RS-485 connections with ModBus protocol as shown in Fig. 2. In addition, the IP Camera/cloud monitoring subsystem also connects to Internet via Ethernet; thus the real time video of crop growth can be provided and also be used as growth records. It must be pointed out that all our IoT hardware devices can be installed in either open fields or greenhouses and the farm automation facilities that can be controlled also depend on the actual status of the farm.

The IoT cloud management system organizes the numerical data collected by the Host, provides real-time numerical data information in dashboard form, and stores the data to the databases for the GACP agricultural product traceability system and future agriculture big data analysis. The agricultural expert system (AES) analyzes the data collected from the IoT management system including the weather and crop growth status including pest information collected from intelligent pest trap box and then gives the famer earlier prediction of agricultural diseases and pests. In addition, the AES can suggest the farmer what and how should do in the current stage or current status faced, including information of agricultural application, fertilizing, and watering. All the information is sent through the popular instant message App LINE to the farmer's mobile phone. Moreover, the system can even automatically control the farm equipment to active to reflect these issues. With these facilities, the new generation farmer can easily and happily manage his/her own farm with his/her own mobile phone or PC running any Web browsers, such as Google Chrome. Finally, the GACP agricultural product traceability system gets the

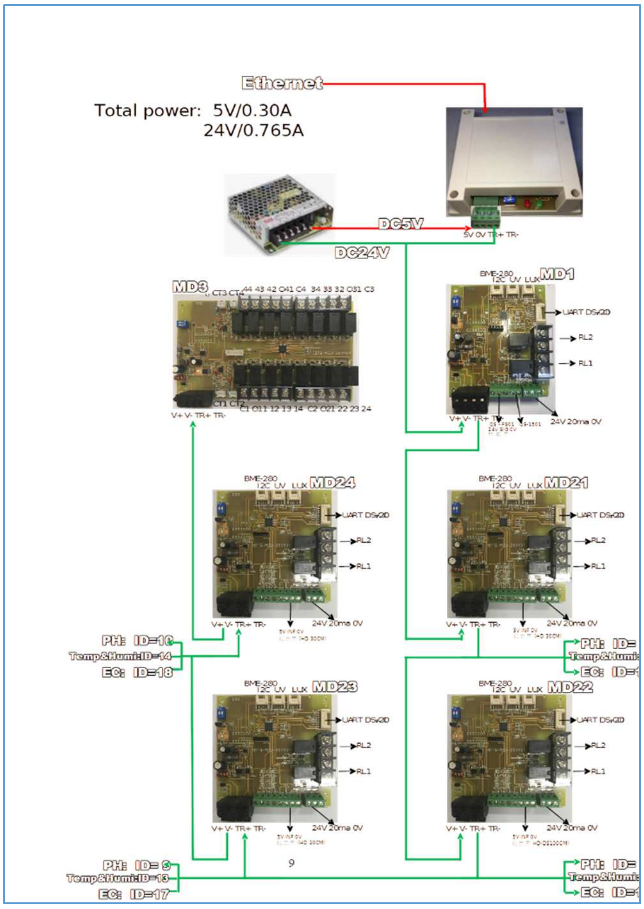

Fig. 2. Proposed IoT devices & the RS-485 Connections

information of the crop growth environment and growth images collected from IoT cloud management system, GACP planting records and agricultural diseases and pests control records inputted by the farmer via mobile phone. It is worth to mention that to make it easier for the farmer to enter the input items the pull-down menu is used. The agricultural materials used for planting are also predefined for selection, so that the farmer can quickly and easily enter the above information. Moreover inspection and analysis reports can also be uploaded. Thus, the system provides information of the agriculture product from seedling to table. The customer can easily scan QR code on the product to see the whole information. Different from other product traceability system, the proposed GACP agricultural product traceability system is just a part of the whole system, and the farmer can easily enter what should be entered manually with mobile phone. In addition, all the growth environment information is collected from the IoT management system automatically without any manual operations.

IV. Real Implementation Results

To verify the proposed intelligent agriculture system, we built a new smart farm with the proposed novel smart agriculture implementation at Yilan Shinnan Farm in Taiwan. It's a greenhouse for growing cantaloupe. This greenhouse originally installed related automation facilities, including fans, watering and fertilizer. In the original design, the smallholder farmer had to go to the greenhouse site to learn about the status of the greenhouse very often and turn on the fan and related facilities through manual switching, especially

Fig. 3. TIAGA IoT devices installed in YiLan Shinnan Farm

TABLE I. COST COMPARISONS

TIAGA Available or Not	Cost Comparisons		
	Manpower	*Water Sprayed*	*Fertilizer Amount*
No IoT Tech	3	1	1
With IoT Tech	1	0.60	0.65

for watering and fertilizer. Before accurate sensor measurement, the farmer relied on the experience to decide whether to turn on or not.

Fig. 3 shows the proposed TIAGA IoT devices installed in this experimental greenhouse. These TIAGA devices including one micro weather station (M1) installed on the roof of greenhouse, one crop growth environment detection subsystem (M2) installed in the middle of the greenhouse, one automation control subsystem (M3) installed near the power distribution box, one TIAGA IoT host installed near M3, and one IP Camera installed on the ceiling near the greenhouse front door. As shown in Table 1, after the proposed TIAGA system was installed in Yilan Shinnan Farm, the total manpower was reduced from 3 to 1, the water needed was reduced to about 60%, and the fertilizer was reduced to about 65% than before. In fact, the manpower for general daily tasks could even be reduced to 0.5. That's because the Yilan Shinnan Farm's owner even doesn't need to come to his greenhouse every day. Before the proposed TIAGA system was installed, he had to wake up as earlier as possible with other two farmers to take care of this greenhouse. After the proposed TIAGA system was installed, he even didn't need to work in his greenhouse. Everything could be done via his mobile phone. What a great improvement it is!

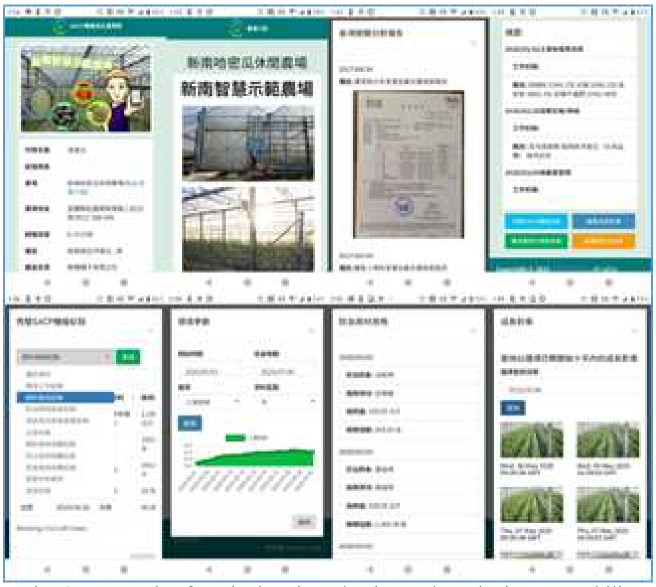

Fig. 4. Example of Agricultural Production and Marketing Traceability Information

Besides all the benefits described above, the TIAGA agricultural production and marketing traceability system can provide consumers with complete cantaloupe production traceability information, which can be easily browsed by consumers via scanning the QR Code on the cantaloupes. It may establish consumers' trust in the cantaloupe produced on the Yilan Shinnan Farm. In fact, every cantaloupe planted at this farm is easily sold out at very good prices. Fig. 4 shows the example of production traceability information from the TIAGA agricultural production and marketing traceability system.

V. CONCLUSIONS

The development of agriculture is related to the most basic food needs of mankind, and its importance is self-evident. The development of agriculture not only has to ensure food security but also food safety. In recent years, due to the impact of extreme climates, the introduction of smart agriculture has become an urgent issue. However, the so-called smart agriculture solutions are numerous and complex, and there is no certain standard. In addition, most of them are not even affordable for ordinary farmers. In this paper, we try to define smart agriculture from our perspective, and we also propose a smart agriculture solution that is affordable and truly practical for ordinary farmers. The system includes our own IoT devices and cloud management system. The most important part of our cloud management system is that our system also includes an agriculture expert system which provides instant message via LINE App, and GACP-based agricultural product traceability system. We try to support the farmer to cultivate crops easier with clear information and suggestions by our AES. We also try to connect the producer of agricultural product, the farmer, to the customer with our GASP-based agricultural product traceability system. Because smart agriculture itself is a very big research topic and the study should be lasted, we will continue our work to improve the current agricultural status. Because some farms are located in places which cannot provide wired Internet service easily, we have already integrated 5G router provided by Compal Electronics Inc. In addition, to recognize the agricultural diseases and pest as earlier as possible, we'll also begin our study on AI-based intelligent pattern recognition to identify the agricultural diseases and pests. We hope that we can also contribute to the development of agriculture.

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