



A Drip Irrigation Remote Control System Using 5G-IoT Technology

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Abstract. Drip irrigation, a type of micro-irrigation system, has been applied in agriculture, forestry, and urban greening. In order to cut down the labor cost and improve agricultural efficiency, modern technology, such as communication methods, or computer science, has been used in drip irrigation for irrigating a wide area. The Internet of Things (IoT) used computing, intelligent mobiles, and mobile app to perform remote monitoring and control tasks. The 5G network is a new generation technology standard that is helpful to massive expand today's IoT technology. This paper proposes a frame structure for a drip irrigation remote control system (DIRCS) using 5G-IoT technology and mobile app. The system can be operated by people who are anywhere in the world using a mobile device. We utilize 5G-IoT technology to realize data storage and sharing in the platform. Moreover, we design layered software architecture to the presented IoT platform as an alternative technique to manage all the systems. Therefore, the drip irrigation system can be controlled remotely to overcome the previous problems like distance problem, range problem. The prototype demonstrates the effectiveness and efficiency of the design in the result.

Keywords: Remote drip irrigation control system · Internet of Things · 5G · Cloud server

1 Introduction

At present, agricultural technology is in an essential stage of transformation from traditional agricultural production management to modernization, and it still faces many challenges in agricultural science and technology to utilize new scientific methods effectively. Drip irrigation, which is a type of micro-irrigation system, has been used in agriculture, forestry, and urban greening. The goal of the irrigation is to place water directly into the root zone and make the minimum evaporation. The technology takes advantage of the potential in water and nutrients conservation by drip slowly into the soil roots. Drip irrigation systems consist of valves, pipes, tubing, and emitters which are used to distribute water.

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Drip irrigation is one of the fastest-growing irrigation technologies with the best water-saving effect in the world, compared with other irrigation systems, such as surface irrigation or sprinkler irrigation [1,2]. India has increased overall water productivity by 42% to 255% by shifting from conventional surface irrigation to drip irrigation, and the crops are banana, cotton, sugar cane and sweet potato [3].

With the requirement of agriculture production, agriculture now requires extensive land to produce. How to manage the environmental quality of soil for planting crop by using drip irrigation quickly and efficiently, researchers hold their huge interests towards the mixture of new technologies in irrigation. Thus, the researches on water usage reduction for drip irrigation based on new technologies have increased over the years [4,5]. The author proposed an innovative approach that estimates irrigation water used at the catchment scale based on satellite soil moisture data [6]. In [7], the author's images captured with a thermal imaging camera mounted on an unmanned aerial vehicle (UAV) were used to evaluate the water status of sugar beet plants in a plot with large spatial variability in terms of soil properties. The author proposed a drip irrigation system that can decide when to irrigate the farm by analyzing the environmental and soil conditions based on a fuzzy logic-based controller [8]. The author designed an irrigation system which use web-based software to remotely access and process the information gathered by all the stations and the irrigation controller [9]. The authors proposed an AREThOU5A platform with an IoT platform that is developed to perform intelligent irrigation practices and policies in water irrigation management of a perennial olive field [10].

As one of the most remarkable technologies of today, the IoT has been significantly indispensable for improving technology in agriculture and industry. About 28 billion intelligent devices by IoT technology are connected all over the world [11]. In the IoT, all interrelated digital devices have the computing capability to generate, consume, and process data with minimal human interaction. The IoT has been applied in many practical application, such as vehicles, transport and logistics, home automation, wearable technology, connected health, and appliances with remote monitoring capabilities [12]. With the increasing coupling and integration of IoT technology, cloud computing, and smart mobile phones, mobile app are increasingly used by people to perform remote monitoring and control tasks. Billions of IoT devices are connected by wireless communication technologies, such as 2G/3G/4G/5G, WiFi, Bluetooth, etc. Among them, 5G networks feature lower latency, higher capacity, and greater bandwidth [13,14]. The 5G networks are helpful to massive expand today's IoT technology, and boost IoT security, privacy, and other network challenges [15–17]. The author proposed the AREThOU5A project that aims to exploit the state-of-the-art technologies in the field of 5G-IoT as a means to promote rational use of water resources in agriculture [18].

In this paper, a novel remote irrigation control system using 5G-IoT technology is introduced. This paper aims to design the prototype which can be operated by people who are anywhere in the world using their smart phone. A novel layered architecture algorithm structure is proposed for remotely watering plants.

Therefore, the drip irrigation system can overcome the problems like distance problem, range problem. The remainder of this paper is organized as follows. Section 2 gives the detailed work about system of hardware structure. Section 3 introduce the work about system of software structure. In Sect. 4, results and discussion are given. Finally, a brief conclusion is presented in Sect. 5.

2 Platform of Remote Irrigation Control System

In this section, we discuss the details of the remote drip irrigation system, including its structure, subsystem, as well as algorithm method applied in MCU. Figure 1 displays a photograph of the DIRCS installed on a farm or field in laboratory environment, and the system is composed of four parts.

The first part is the drip irrigation system which can control by the terminal. All the data, such as the working status of the pump and valves, from sensors around the plants in farm is gathered and transferred by the controller via 5G networks. Moreover, it can evenly distribute water resources to the land-based on its requirement. The second part is cloud servers linking between the customer terminal and drip irrigation system, which help the system obtain data from the environment around the soil. This part utilizes MQTT protocol technology and 5G communication protocol. The third part is the 5G base station which connects other wireless devices to cloud servers. The last part is the terminal which shows the result of analyzing the current land experiment, such as soil moisture, and the user can execute the operation on the screen. All the data come and go through a 5G network, which can support massive irrigation systems management [19].

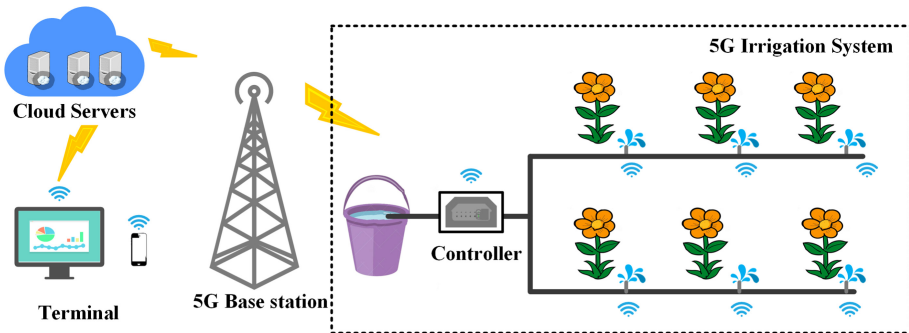


Fig. 1. Platform overview of the remote drip irrigation control system

2.1 Hardware Overview of Drip Irrigation System

The target of the hardware design is to realize the basic function of the drip irrigation system which can monitor and control the states of art by using cloud

server technology efficiently. In the period of the construction for smart irrigation system, it needs to make use of the characteristics of 5G large capacity, realize the management of the large area of land as far as possible combined with IoT technology, so that a system is no longer an independent unit, but an efficient integration as a whole of linkage and information sharing. The design of the system is not only conducive to realize the real-time monitoring of state of farm, efficient management of farmer, environmental state, resource scheduling, real-time navigation and security alert, but also provide convenience for farmer and staff of farm. The drip irrigation platform consists of three parts: the perception module, the communication subsystem, and the user-interface subsystem. The appearance of DIRCS is shown in Fig. 2.

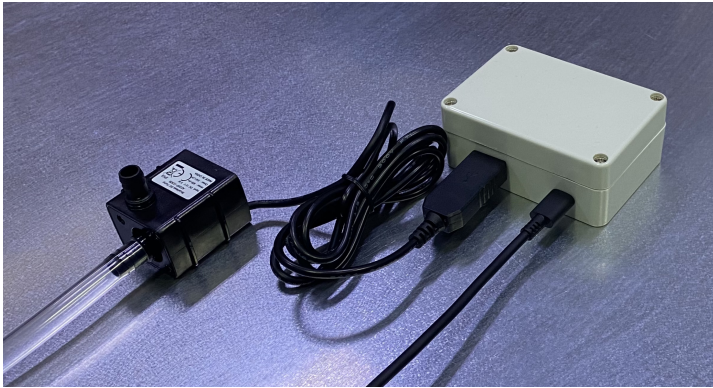


Fig. 2. System appearance of hardware

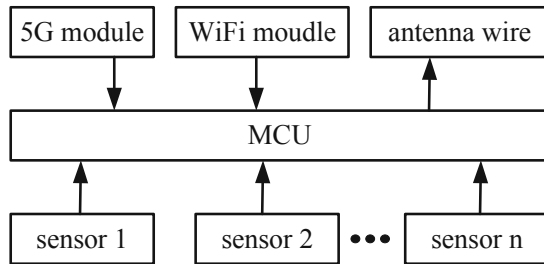


Fig. 3. Hardware structure of perception module

Perception module: The perception module is the essential component of all systems that can bring sensory information with some perception activities. It comprises current, voltage, temperature, and humidity sensors. These sensors

provide helpful information to the controller for analyzing and managing all the plants in the land. In the subsystem, the part obtains the data from the sensor located around the plant. Figure 3 illustrates the hardware structure for the perception module of the proposed IoT platform. It consists of an antenna wire, an 5G module, an WiFi module, and multiple sensors. The module works as a sender of the electromagnetic radiation like 5G signal and WiFi signal which come from converting ambient information by sensors.

Connecting module: In the subsystem, the function of the part is like gateway which obtain the data from the previous module such as perception module, and transfer all the data to the cloud server or local processor by the WiFi network server or 5G network server. The system also can save all the data to the local server for quickly analyzing result. Therefore, the subsystem controls and routes all the information of the DIRCS. Figure 4 depicts the schematic diagram of the proposed communication subsystem circuit. It comprises of ESP8266 WiFi module, 5 V DC power source, and stm32f103c8t6 MCU.

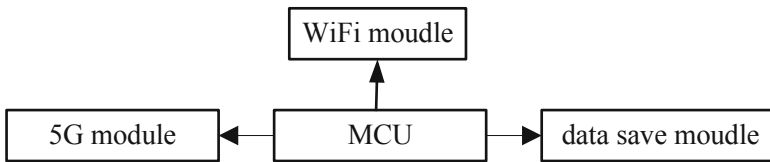


Fig. 4. Hardware structure of connecting subsystem

Actuator module: The actuator module is designed to control the work of field solenoid valves for pump. Figure 5 describes actual structure of actuator module. The subsystem comprise a driver circuit, a driver circuit, and a pump. stm32f103c8t6 single-chip microcomputer is been chosen as the processing unit of the actuator module node. We then select F02X 5G wireless communication module and ESP8266 WiFi module as the communication unit for realizing solenoid valve on/off control and solenoid valve status information feedback. Figure 6 displays a photograph of the actual circuit board for actuator module.

User-interface module: In the subsystem, the part provides the operation function and the alert function for the location user. The hardware of the subsystem is screen or smartphone which show the graphical data. Customers can directly manage the water volume which is used in the plants in farm according to the critical situation or requirement. The subsystem offer a friendly experience by showing all the information in the system by mobile application or web application, and use the MQTT protocol to communicate.

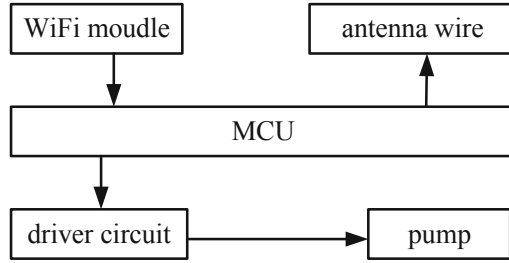


Fig. 5. Hardware structure of actuator module

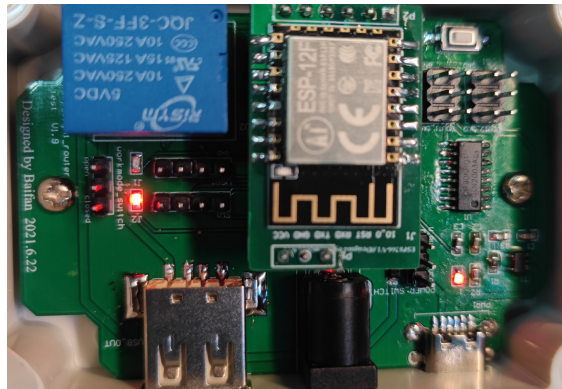


Fig. 6. Actual circuit board of DIRCS

3 Software Layered Architecture Design

In this part, we put forward the software system structure of DIRCS in combination with 5G-IoT technology. The platform for irrigation management involves four-layer architecture, and Fig. 7 shows the structure of the platform software. This software platform is designed by the Java programming language and including web application and phone application.

Physical Layer (L1): Physical layer is the first layer of the software structure where all the physical connectivity of devices work in the hierarchy. Sensors gather and convert the data into binary bits, then transfer to the data link layer.

Data Link Layer (L2): Data link layer is defined as the second layer of the software Model. It converts bits data received from the physical layer, transfers them to the network layer, and stores some important and security data. This module also has permission for a dangerous environment.

Network Layer (L3): The network layer determines the physical path where the data should take, based on network conditions and service priority, and set several protocol functions operated within this layer. The layer also helps to

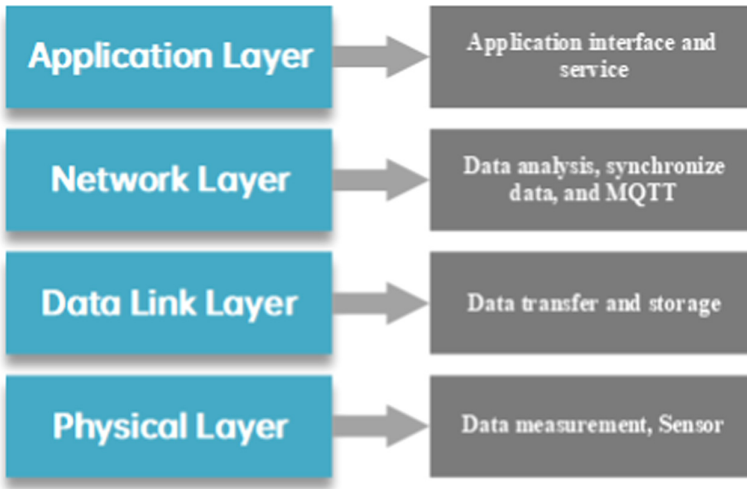


Fig. 7. The structure of DIRCS protocol stack

synchronize data between the user interface and server subsystem and obtain information from the provider. The main protocols involved in this layer are the MQTT and the TCP/IP.

Application Layer (L4): The last layer is the application layer which is directly related to user needs and operation. It provides a method or an interface for the consumer to access information on the network by using an app. It also supports services such as remote control, transfer, and share database.

3.1 Physical Layer Software Algorithms Design

The software algorithm design of the physic layer is designed based on the function of hardware in L1 layer. The design process of software algorithm in the layer is based on the function of the perception module and the actuator module, and the target of the software is mainly control the actuator and provide the information of the perception module. The actuator of the system is the pump which can be controlled automatically, and the driver switch automatically opens and closes to provide power for supporting pump drawing water based on the temperature and humidity sensor. Therefore, the proposed algorithm is shown in Table 1, and it can realize functions about remote controlling and observing the state of DIRCS in the first layer. Table 2 show the device reporting data protocol, and the protocol is applied in communication among modules. The protocol property is defined as the device attribute like ambient temperature. The protocol length is the byte length from the beginning of header to the check in the instruction. Status specifies whether data needs to be transparently transmitted.

Table 1. Monitoring and control algorithm for DIRCS in L1 layer.

Algorithm 1: Monitoring and Control Algorithm for DIRCS in L1 layer

Require: If plants need to water: open the pump and irrigate plants**Ensure:**Real-time monitoring and good surrounding conditions

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1:Define WiFi Access Point Username
2:Define MQTT server
3:MCU.GPOI for Relay board
4:H → Humidity //From DHT-22
5:T → Temperature //From DHT-22
6:T → Temperature Threshold value
7:HL → Humidity minimum Threshold value
8:HM → Humidity maximum Threshold value
9:Initialize IoT //Switching ON system at t=0
10:MCU acquires the data (temperature, humidity)
    for each round do
        Get H and T
        if receive watering command then
            if H < HM then
                Switch ON pump;
                Notify host in L4 layer Irrigation Complete!"
            else if H > HL then
                Switch ON pump;
                Notify host in L4 layer plants need to water!"
            else
                Switch OFF pump
        end for
22:Upload historical data to MQTT Server over WiFi or 5G
23:Update status of sensors/actuators over WiFi or 5G
24:Synchronize data to L4
25:Control actuators remotely via L4 according to command
25:Feedback actuators result to L4
26:Update result in Cloud Server

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3.2 Application Layer Software Algorithm Design

In the application layer, this layer's major feature is to provide specific services to the user and deliver the information from the physical layer. The customer can observe the standard operation data recorded in the MQTT cloud server, such as environmental temperature and state of remote pump through the Internet using the MQTT server. In contrast, the abnormal conditions are conveyed to the parents by triggering an alarm to take appropriate actions. We use stm32f103c8t6 as the central controlling unit, the same as the other development boards available, such as Ti DSP and Raspberry Pi. In these layer, application layer software algorithm is designed in two quick, built-in setting modes for users to realize the quick setting feature is proposed to help users operate this system.

Table 2. Device reporting data protocol

Instruction name	Instruction bytes	Instruction format
Header	1B	0xFF
Length	2B	0xFFFF
Property	2B	0xFFFF
Command	2B	0xFFFF
Flag	1B	0xFF
Action	2B	0xFFFF
Status	2B	0xFFFF
Check	2B	0xFFFF

Smart mode: In this mode, DIRCS will make a tradeoff between the payment and the energy consumption. In these situations, DIRCS will collect weather data from the weather information provider and make the most appropriate number of DIRCS work according to the farm environmental conditions. For example, when it's going to rain soon, the application layer will notify each module in advance to stop all DIRCSs working and then record the length of rain to calculate the next working time smartly. Moreover, the system reports all the things to the consumers, and the consumers can give orders according to the situation, which does not affect the consumer's other command.

Saving mode: In this mode, the highest priority of DIRCS is to save the total energy and water source. During daytime hours, these systems always work in the saving mode, and only several DIRCSs can work to meet the water needs of farm plants. The farm plants have to bear lower irrigation frequency in solar than normal mode. It will result in fewer days watering intervals. Under this mode, these working DIRCSs will participate in the low power mode as much as possible, and some parts of the system will turn off the power during the night.

4 Results and Validation

In the section, the result and validation of DIRCS are presented in detail. The first part is to test the prototype with the delay in downloading or uploading data from the DIRCS to the MQTT server. The process of uploading and downloading the data from the server has about a 1-s delay, but there is no time delay when using 5G connection type. Some results of the testing showed a slight time delay when the network is fluctuating, and it shows the reliability of the DIRCS highly depended on the strength of the connected network. In the second part, the test is conducted to verify the DIRCS from the application. As shown in Fig. 8, the MQTT server and customer interface in the phone app are synchronized and displayed on the screen, the microcontroller update all the data to cloud storage. In the interface, the customer can monitor the 5-days data for drip irrigation. Moreover, users can operate all the devices in the same app to control water

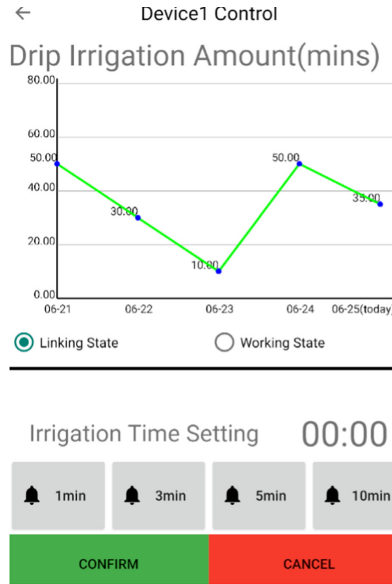


Fig. 8. Mobile application interface

volume precisely by pushing the button. The app provides all the operational data from all the devices for analyzing whether it is working correctly. The result from Fig. 8 shows that the prototype can provide accurate information about the recent water volume for five days to analyze irrigation efficiency.

5 Conclusion

In conclusion, we designed DIRCS prototype and fabricated it with a water pump, an MCU, a WiFi module, and a relay to test the proposed system. Then a new algorithm is proposed and applied in real situations to perform the monitoring and controlling irrigation tasks by MCU. In the process, MQTT technology and 5G-IoT data transmission technology have been utilized to transfer data and commands among the systems. The proposed technique can be widely used in agriculture due to its appealing simplicity and convenience.

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