Distributed control system for catalysing the formation of artificial rainfall and snow using charged particles

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Abstract. In order to solve the limitations and shortcomings of the traditional artificial rainfall technology, researchers all over the world are actively researching new artificial rainfall technologies. The charged particle catalytic artificial rainfall technology is one of the new artificial rainfall technologies. This method uses a charged particle generator set up in the wild to produce charged particles to catalyse rainfall. It is necessary to control all equipment in the experiment site remotely during the experiment. Thus, a control system needs to be implemented. There are many kinds of controlled equipment in this control system, such as high-voltage power supply, meteorological data acquisition devices, and various experimental auxiliary equipment. In this paper, we design and implement a comprehensive control system based on the characteristics of the charged particle catalysed artificial rainfall field experiment and the controlled equipment in the experiment site. The software interface connected to different types of equipment in the system is developed based on the large-scale experimental control system framework CFET, which can easily add equipment and view measurement data. The system is designed as a distributed system connected through a network, which can meet the needs of centralized control of multiple experimental sites.

1. Introduction
Water is one of the most important resources on the planet. China has abundant atmospheric water resources, but many years of meteorological statistics show that only 16% to 18% of water vapor can form natural precipitation on the ground. In other words, the utilization of atmospheric water resources is seriously insufficient, so it is very necessary to utilize atmospheric water resources by means of artificial precipitation\textsuperscript{[1]}. Nowadays, systematic science and technology of artificial weather modification have been developed\textsuperscript{[2-4]}. However, there are some limitations and shortcomings in the traditional technology of catalysing rainfall by dispersing silver iodide and other catalysts into the clouds. Therefore, many countries are actively researching new artificial rainfall technologies. Charged particle catalytic artificial rainfall technology is one of the new artificial rainfall technologies\textsuperscript{[5-6]}.

This technology uses electrical effects to generate charged particles, which are spread into the air and cause some aerosols in the air to be charged. The electrostatic field of these charged particles has a polarizing effect on other neutral water molecular clusters, thereby generating a non-contact electric...
field cohesive force on the polarized water molecular clusters. This effect promotes an increase in the condensation rate of water molecule clusters and thus the formation of rainfall[7].

So far, our team have used this technology to achieve excellent controllable catalytic precipitation in the cloud room. In order to verify the effectiveness of this technique in catalysing precipitation in real natural environments, a series of field experiments are still needed. The main content of the experiment is to control the high-voltage power supply to supply voltage to the electrodes set up in the rainfall experiment base station, and then generate charged particles to enter the air to promote the formation of rainfall.

In this paper, we propose a comprehensive control system that can meet the needs of charged particle catalysed artificial rainfall experiments.

2. Analysis of demand
The experimental base station contains multiple power systems, data acquisition equipment and other auxiliary equipment. In other words, the system needs to implement integrated management of the above devices, which can greatly improve the efficiency of the experiment.

The main functions of the system are as follows:
⚫ Control multiple high-voltage power supplies used in external field experiments. In the experiment, parameters such as the voltage of the power supply need to be adjusted according to the external environment. At the same time, various parameters of the power supply during the experiment need to be recorded.
⚫ Interact with environmental data acquisition devices. Multiple rain gauges, temperature and humidity sensors and other equipment need to be set around the experimental site to measure changes in environmental parameters during the experiment. These devices are simple sensing devices and do not have the function of storing data, so the sensor data must be obtained and saved.
⚫ Manage video monitoring equipment and other auxiliary devices. In order to ensure the real-time observation of the experimental site during remote experiments, there are a lot of monitoring devices at the experimental site. In addition, in order to maintain the environmental conditions required for the normal operation of the equipment, the experimental site also has some other auxiliary equipment, such as air conditioners and dehumidifiers. These also need a control system to ensure their normal operation.

Considering the various needs mentioned above, the system should have the following characteristics:
⚫ Distributed architecture. Taking into account the existence of multiple experimental sites and changes in the operating scenarios of the experimental staff, the system is split and deployed. Each experimental site can be used as an independent system. The experimenter only needs a client to control the equipment of each experimental site. At the same time, the experimenter is not restricted by the place, and can remotely control the experiment equipment at any place that can access the Internet.
⚫ Compatible device access interface. For different measurement devices using different interfaces and different data transmission protocols, each measurement device is abstracted. At the same time, a unified API for reading measurement device data and a unified measurement device configuration method are designed. Newly added devices need only modify the configuration file to join the system and be managed by the system.
⚫ Dual Internet access based on 4G and cable network. It guarantees that remote control will not be affected when a line fails, and the 4G network also guarantees the availability of remote connections in areas without cable network coverage.
3. System model

An integrated control system is designed based on the various equipment required. Figure 1 shows the overall structure of the system. The system contains the necessary network equipment, host, PLC controller, high-voltage power supply, data acquisition equipment and other auxiliary equipment such as video surveillance equipment.

3.1. Remote control system

The control system can be operated directly on the host of the distributed control subsystem, or it can be remotely operated by using a remote terminal to control the host of the system through Ethernet connection. The remote client software supports more than one operating systems, such as Windows and Android, which allows experiments to be carried out independently of the system environment. Because some experimental sites are in mountainous areas without cable network coverage, the network equipment used 4G and cable network dual-line access routers. This design can ensure the stability of the network connection for communication.
In the control system, in order to achieve complete unattended operation, a remote start-up hardware device is also added. The remote boot device and the control system host are connected to the same local area network. When receiving the boot instruction from the remote terminal, the remote boot device sends a special format network data packet to the target host, and the target host will automatically boot. At the same time, the remote-control service on the host starts automatically.

In this way, it can also be started remotely after the equipment is shut down or accidentally powered down, which is of great significance for the inconvenient field experiments.

3.2. Distributed control subsystem

Figure 2 is a schematic diagram of the connection of various devices in the distributed control subsystem. Because the hardware interfaces of various devices are different, the hardware connection methods for connecting the device to the host of the control system are also different.

High-voltage power supplies are one of the most important devices in the experiment. Their function is to provide a DC voltage of up to 100kV to ionize the air and generate charged particles. The high-voltage power supply supports a remote operation mode. This mode allows a computer to control the high-voltage power supply through an external interface and set the power parameters using an application program interface. In this system, there are mainly two types of high-voltage power supplies. One power supply provides RJ45 hardware interface. This power supply is operated remotely through the local area network. When connecting, you need to configure the relevant network parameters on the power supply and the host. Another power supply provides an RS485 hardware interface. Two connection methods can be seen in Figure 2. The high-voltage power supply based on the network is connected to the same local area network through the switch and the host, and the other is directly connected to the host through a serial cable. The power supply of the high-voltage power supply is controlled by a PLC controller. Using PLC controllers to control various switches in the power distribution cabinet can realize the complex power supply requirements of various equipment in the experiment.

Environmental data acquisition devices such as rain gauges and temperature and humidity sensors need to be arranged in different places on the experimental site. For more flexible deployment, a Zigbee module is used to implement wireless networking communication for these data acquisition devices.

ZigBee is a wireless sensor network technology. Its protocol is a wireless transmission standard based on IEEE802.15.4 technology developed by the ZigBee Alliance. ZigBee technology has the characteristics of low power consumption, low cost, and network self-organization. It is now widely used in industrial fields for automatic data collection [8-11]. ZigBee has multiple networking methods. For the situation of a single control node of multiple data acquisition devices in this system, a star topology is used in the design. The host of the control system is used as the coordination node and the data acquisition device is used as a series of terminal nodes. This topology is simple and efficient.

In addition to monitoring the experimental site by adding monitoring equipment such as a webcam to the system, auxiliary equipment such as air conditioners and dehumidifiers were added to the system in response to the high humidity and extreme temperature that may exist in the experiment site. These devices are to ensure the normal operation of other devices in the system. In this system, the host establishes communication with such auxiliary devices through an infrared module. By uploading the infrared remote-control information of these devices, the air conditioner and dehumidifier can be remotely controlled by software on the host computer.
4. Implementation of distributed control system

Figure 3. The concept of a thing in CFET.

In this control system, the software is partially implemented based on the CFET (Control system Framework for Experimental Devices Toolkit) control framework [12]. The most basic concept in CFET is thing, which is an abstraction of various controllable objects. This controllable object can be an abstract object or a concrete object. Thing has some properties. As shown in figure 3, Status provides the status of the controlled object and is a readable property; Config is the configuration property of the thing and can be modified, and Method provides a method for operating a thing. You can access and manipulate a thing through these interfaces.

Figure 4. Architecture of the CFET.

In this framework, each controlled device is abstracted into a specific thing and managed by the CFET Host. Figure 4 shows the structure of the CFET. The thing in the CFET Hub has a URI (Uniform Resource Identifier), which is the only address representing a thing. When a thing is added to the hub, the resource can be operated on the thing's URI. Specifically, the Get, Set, or Invoke operation is performed on each thing of the thing mentioned above.

For this control system, it is to deploy a CFET Host on the control system host. As for the device to be controlled, adding the device to the control system is actually implementing this device as a CFET thing, and then adding it to the CFET Hub. After this, the device can use the web control through the server service provided in the communication module. Other things that have the device URI can also operate the device, which makes it easy for devices to interoperate.

In summary of the previous introduction, we can see that the basic idea of the entire control system is to implement various controlled devices as CFET things and then add them to the control system.
4.1. Implementation of high-voltage power control system
Manufacturers provide customer software interfaces for the high-voltage power supply used in the system to control the power supply. However, the software interfaces for different types of power supply are different. In other words, you cannot connect to multiple power supplies at the same time through a type of interface. Therefore, in the experiment, when multiple types of power supply are required to work together, a unified interface must be abstracted in the control system to integrate the control of the high-voltage power supply. In this way, the combined control of multiple types of power supply can be realized at the same time.

![Diagram of H-V power supply thing](image)

**Figure 5. Design of H-V power supply thing.**

The thing design of the high-voltage power supply is shown in figure 5. First, read the configuration information of each power supply from the configuration file, such as the serial port address or IP address used to establish a communication connection. Then establish a communication connection with the high-voltage power supply, and then we can call this method of the thing through the CFET Host, such as setting power parameters, controlling power switches, etc. to control multiple power supplies.

In the power supply control system, a variety of power supply operation modes are designed, such as switching the output of the power supply at regular intervals, setting different voltage output waveforms, and gradually increasing the voltage at a certain rate. In addition, we can configure the sequence of switches when multiple power supplies are used in combination. During this period, the voltage and current information of the power supply is updated to the status of this thing in real time, so that the status of the power supply can be displayed in real time through the web, and it can also be used to save the parameters of the power supply during the experiment.

4.2. Software implementation of data acquisition devices
The data transmission methods of sensors such as rain gauges and thermometers are relatively low-level and have different formats. The way of directly connecting various sensors to the control system to achieve communication violates the principle of low coupling. At the same time, it will make program expansion and maintenance more complicated. Therefore, in the software structure of the acquisition device, we use a host module to manage these sensors. The host module here is not the same concept as
the host mentioned above. The host mentioned above is the core computer in the distributed sub-control system, and the host module here is just a software level abstraction. And the host communicates with the control system through a Zigbee communication module. On the control system side, a Zigbee communication module is implemented as a thing, and the system interacts with the data acquisition device through this thing.

![Figure 6. Structure of a data acquisition device.](image)

The structure of the data acquisition device is shown in figure 6. Host implements the driving of various sensors and hides the difference between these sensors to the control system. The control system can obtain the sensor data as long as it knows its channel address.

![Figure 7. State transition logic of host module.](image)

The hardware of a host module is developed based on the ATmega2560 platform, and its program state transition logic is shown in figure 7. When the program starts, it reads the configuration file, obtains the configuration information of each sensor, and then completes the initialization and enters the idle state. In the idle state, the host waits for instructions from the control system. After receiving the instruction, the host parses the received instruction and obtains the operation content. Next, the host configures the sensors or obtains the data collected by the sensors according to the instructions. Finally, the host sends the result of executing the instruction to the control system, and returns the idle state.

5. Conclusion
Experimenterers can conduct experiments through remote control, greatly improving work efficiency. The system was designed with full consideration of various application scenarios, and the system was fully optimized. The distributed system structure guarantees the simplicity of expansion of the field experiment sites. The system has been deployed in the Wushaoling Experimental Site in Gansu and the Liupan Mountain Experimental Site in Ningxia. During the experiment, the system runs stably, which
fully meets the needs of the experiment. In the future we will improve the functions of this control system to improve the convenience of the system.

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