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An Irrigation Control System Based On An FPGA

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***Abstract*—Automation of irrigation is an effective way to increase production. However, as an agricultural country, China is still in the initial stage of agriculture modernization. So it is significant to combine information technology with the agricultural irrigation and to develop an intelligent irrigation system which is suitable for the development situation of the agriculture. In the paper, an irrigation control system based on an FPGA is presented. Using RS-232 interface to communicate with a host computer, the system receives irrigation commands from the decision making system and controls automatically the irrigation of 16 greenhouses or pieces of field. A control panel is designed in the system to make it easier for users to manage and intervene the irrigating. There are 16 LEDs indicating the status of water shortage. A small keyboard is used for users to input commands and 12 Seven-segment displays are used for displaying the date and time or user inputs. With many I/O pins, flexibility, easy debugging and all the control logic supported, the control system based on an FPGA represents a new trend in hardware application design.**

Keywords-irrigation control system; FPGA; control panel; manual control command

I. INTRODUCTION

Irrigation is a very important aspect of the agricultural infrastructure and has an important effect on production yield. With the limit of water resources and ecological environment, irrigation systems must be intelligent and efficient. And with the use of information technology, researchers around the world have developed a series of water-saving irrigation systems which are of great help to agriculture production such as: Fuzzy irrigation greenhouse control system based on an FPGA [1], Remote Monitoring and Control System with Automatic Irrigation System using GSM-Bluetooth [2] and so on.

Compared with the research of irrigation in advanced countries, the development of our irrigation controllers is still in its infancy. Most of the existing irrigation control systems are applied to small scale. Their functions and scope of application are limited. Or others may be too expensive and difficult for wide adoption. So new irrigation systems suitable for the current situation of our agriculture are necessary.

An irrigation control system based on an FPGA, which we came up with, is discussed in the paper. The paper is organized as follows: Section 2 is devoted to function and structure of the system. Section 3 presents design and implementation of its controller. And section 4 gives a conclusion.

II. FUNCTION AND STRUCTURE OF THE SYSTEM

A. Intelligent Irrigation System

An intelligent irrigation system may include a data acquisition system, a decision making system and an irrigation control system. Temperature, humidity and other information of greenhouse or a piece of agricultural field are collected through the data acquisition system and transmitted by means of the cable, GPRS or wire line network, to the decision making system, which determines if there exists water shortage and how much irrigation volume is needed. A command will be issued if irrigation is needed. The irrigation control system will automatically to open and close the pump and solenoid valve for irrigating.

An irrigation control system can be developed based on a micro-controller unit (MCU) or an FPGA. An irrigation control system has already been done with STC89C52, a kind of MCU. But due to the limitation of the pins of STC89C52, the irrigation controller can only control the irrigation of a single greenhouse or a single piece of field. In order to support more requirements, some other peripheral circuits had to be added and more complex solution structure and debugging is resulted in in an irrigation control system based on a MCU.

In comparison, an FPGA has more I/O pins and is able to control irrigation of several greenhouses without external interface circuits. It is powerful, flexible and convenient to complete all the control logic by means of VHDL or Verilog HDL. The irrigation control system based on an FPGA is fast in speed, small in size and easy to debug. It is low in cost and presents new approach of the hardware development for irrigation control in the near future.

B. Irrigation Control System

The irrigation control system based on an FPGA consists of a control panel (Figure 1), a controller and driver circuit (Figure 2).

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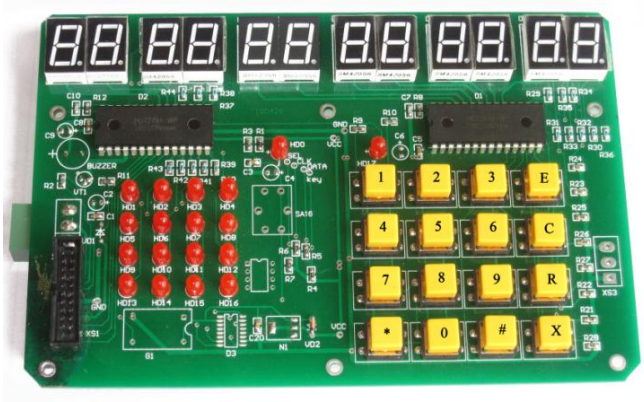

Figure1. Control panel

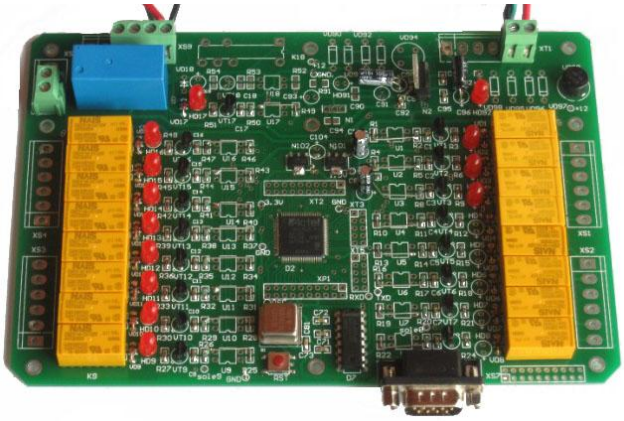

Figure2. Control and Drive circuits

The control panel is made up of 12 Seven-segment displays, 4*4 LED, a 4*4 small keyboard and a buzzer. It offers an effective way for users to input a command through the keyboard. The LEDs indicate the irrigation staes as follows: long bright light means water shortage and flashing light expresses irrigating. The Seven-segment displays display date and time or the input of the keyboard. And the buzzer is used to prompt input errors or warn personnel accidents.

The Controller consists of an FPGA and is the core of the entire irrigation control system. Receiving a command from the decision making system through RS-232, the controller opens the pump and solenoid valves after 4 hours and starts the irrigating in accordance with the requirements. Administrators can delay or cancel the irrigation by means of the control panel. To ensure the safety of operations, only the administrator who has been authenticated can input a command and carry out an intervention. Administrators can also set more sophisticated patterns of irrigation and the timing. More details will be told in the following.

The drive circuit is used to amplify the control signal and drive the pump and solenoid valves.

C. *Manual Control Commands*

To allow the users to change the irrigation settings and operations through the control panel, a series of user commands were designed.

For convenience to describe, users are divided into two categories – operators and administrators. An administrator can use all commands including management of operators, such as increasing or deleting an operator. But an operator cannot use management commands. And the irrigation control system has only one administrator.

When a user uses the keyboard to operate, he or she should press key “E” (enter) first, then input his or her user code (2 digits) and password (3-12 digits). The user code and password should be authenticated. Otherwise, he or she would not be able to input any command. When the authentication fails, the buzzer rings to alert for potential illegal operations. “X” (exit) button can be pressed to stop the buzzer, but it may ring continuously for 3 seconds at least to catch the attention of the administrators.

A user can input one or more commands and its or their parameters after he or she is authenticated. Different commands have different parameters and the definition of each command is shown as follows: (*command code*: command name)

1) 11: setting time. Its parameters are year, month, day, hour, minute and second. Each of them is represented in 2 digits. 12 digitals are inputted continuously to set or adjust the date and time.

2) 22: delaying irrigation. Its parameter is area code (2 digits). The irrigation of the specified area is delayed. The decision making system sends a message to the administrator simultaneously when it sends an irrigation command to the irrigation control system through RS232. The administrator can determine according to the situation that the irrigation will be carried out in time in advance or later. He or she can even cancel the irrigation.

3) 23: canceling irrigation. Its parameter is area code. The irrigation of the specified area will be canceled.

4) 24: setting number of plots to control. Its parameter is the number of plots which the irrigation control systemis configured to manage. The system can control 16 plots at most. And the administrator can set the quantity of fields according to real situation.

5) 33: setting time of irrigation. Its parameters are area code and starting time of irrigation. It should be used with the command irrigation delaying.

6) 44: inputting pump flow capacity. Its parameter is pump flow. The irrigation control system can calculate irrigating time by means of the required water quantity and the pump flow capacity and controls the closure of the pump and solenoid valve.

7) 45: using flowmeter. There is not any parameter in the command. The flowmeter instead of pump flow is used to control the closure of the pump and solenoid valves.

8) 46: canceling flowmeter. There is not any parameter in the command. The flowmeter is no longer used to control the closure of the pump and solenoid valves. Instead pump flow is used to control the closure of the pump and solenoid valves.

9) 55: modifying password. Its parameters are the original password, new password, the new password. A user can modify his or her password by using the command.

Administrator command (the following command can only be used by an administrator)

10) 66: create a user. Its parameters are user code and password. A new user with the user code and the password can operate the system from now.

11) 67: delete a user. Its parameter is user code. And the user cannot operate the system from now.

12) 99: change the administrator. Its parameter is user code. The original administrator is no longer the administrator in the system. And the operator whose user code is inputted as the parameter of the command becomes the administrator from now. (The initial administrator code is 99 and the password is 123456789000 when turned on.)

III. DESIGN AND IMPLEMENTATION OF THE CONTROLLER

The controller is designed and realized by means of Verilog HDL and an FPGA. It is the core of the system and in charge of receiving commands and sensory information, analyzing them and generation control signals and responses. The controller is consisted of serial communication, command receiving and log uploading, panel control, keyboard command receiving, keyboard command processing, field management, time management, user management and Seven-segment displays displaying module.. The relationship among the modules is shown in Figure 3.

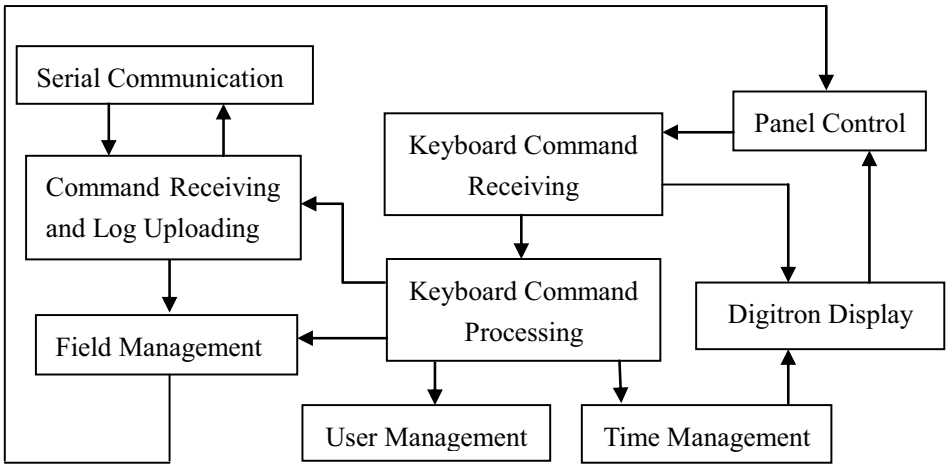

Figure3. The composition of the controller

A. Serial Communication Module

The module is used to realize the communication between the decision making system (running on a PC) and the FPGA through RS232. It receives and sends data from and to the decision making system. The transform rate of the serial port is 9600bps. And each frame is made up of 10 bits which includes one start bit, 8 data bits and 1 stop bit. The data received are transmitting to command receiving and log uploading module. And the data sent come from the command receiving and log uploading module.

B. Command Receiving and Log Uploading Module

The module is used to receive irrigation commands and to send upload log files by means of the serial communication module from and to the decision making system. The controller controls the irrigation of a specified field after receiving an irrigation command. So the area code of the field and the required irrigation quantity should be told. And the irrigation command is made up of as follows:

The first byte: command code 0x01.

The second byte: area code.

The third to sixth bytes: irrigation quantity (32 bits in binary).

In order to guarantee the correctness of the command received, the controller will send the entire command back to the decision making system. When the decision making system receive the command, it compares the received command with the original one. If they are matched, a confirm command is sent to the controller immediately. The controller begins to execute the irritation when it receives the confirm command.

The confirm command is made up of only one byte 0x02.

But if the received command is not matched with the original one, the decision making system will retransmit the irrigation command and repeat the above procedure until the received command matches with the original one.

Every time when the controller receives a command (including commands from the keyboard) or carries out an operation, the command received or the operation done will be sent to the decision making system by means of the serial communication module, which is called uploading log. The log uploading command is made up of as follows:

The first byte: command code 0x08.

The second byte: the length of the log m (number of bytes).

Bytes from the third to the (m+2)th: the content of the log (the command or the operation).

Such an irrigation command must be confirmed that a log uploading command must be confirmed the same way. The decision making system will record the log when it receives the log uploading command and the confirm command.

C. Panel Control Module

The module is responsible for reading the key value of the pressed key from the control panel and controlling the display of the LEDs and the Seven-segment displays on the control panel. The shortage of water is displayed by means of the LED array and the current time or input is shown by means of the Seven-segment displays.

The LED array and the Seven-segment displays are controlled and driven by two pieces of HD7279A. A HD7279A can drive 8 bits common cathode digital tube or 64 independent LED. It can also access an 8*8 keyboard and scan to identify keys simultaneously. A serial interface is included to communicate with the controller, receive control commands or report the identified key's value.

When a key is pressed, the signal named key of the HD7279A goes high. The controller reads this signal and sends command to read the key value and to display the key value on the Seven-segment displays. If there is no key pressed, the digital tubes will display the current time and the 4*4 LED array will stand for the status of fields.

D. Keyboard Command Receiving Module

The module receives the key value from the keyboard. According to the function keys (enter button, command button and return button) and command type (such as the number of parameters), this module validates the input operation and assembles them into a complete command. The administrator can control the irrigation system by the means of the keyboard. Firstly, an administrator needs to press the key "E" (enter) and inputs his or her user code and password. Secondly, only after the user code and password are verified can the administrator do other operations. Otherwise the buzzer sounds to alert for failed authentication. The control commands can be typed in after authentication. If the command has any parameters, the operator needs to input various parameters in turn. After each input, an "R" (return) button should be pressed. Users can quit with "X" (exit) button at any time. If the input period times out or ran into any error, the system will start the buzzer and exit the input state. Multiple commands can be entered after one authentication.

E. Keyboard Command Processing Module

The module determines whether the command is valid, which is based on receiving the keyboard command and its parameters. If the command is correct, it will be carried out or be transferred to specialized modules. Otherwise, the command will be ignored and nothing would be done.

F. Fields Management Module

The module is responsible for analyzing and executing the commands received from the decision making system or the keyboard input. This module controls the irrigation by the means of regulating the pump and solenoid valve with the inputted control signal. And there is a state memory recording the status of each field in the controller. The status of each area is represented by 3 double words (12 bytes), the recording format is as follows: The 31st bit of the 0th DWORD (double words) means water shortage, the 23rd bit means irrigation delaying, the 19th bit implies irrigating now, and the 0-15th bits indicates year and month of the irrigation time; the 1st DWORD indicates day, hour, minute, second of the irrigation time; the 2nd DWORD saves the irrigation quantity. The controller saves the irrigation water in the 2nd DWORD of the specified area, sets the 31st bit to indicate "water shortage" and set the start time to the specified plus 4 hours.

Human intervention can delay irrigating, set the irrigation time or cancel irrigating. The controller sets the 23rd bit of the 0th DWORD into high as soon as an irrigation delaying command is received, to delay the irrigation. When the irrigation time command is received, it will set the irrigation time accordingly and clear (set to low) the "delaying irrigation" bit. If this module receives the irrigation canceling command, the 31st bit of the 0th DWORD will set into low to indicate "no water shortage".

The module queries the record of the irrigation status continuously. If any area is in shortage of water, no irrigation delaying is set and the irrigation time is no longer than current time, it will start irrigating. It opens the solenoid valve of the specified areas before starting the pump. If the flow meter is used, it reads the current flow meter reading, adding the specified irrigation quantity to get the reading for stopping irrigation. The flow meter is read every second and irrigation will finish when the current reading is greater or equal to the calculated "stopping" reading. If flow meter is not used the irrigating time which is calculated by dividing the irrigation quantity by the pump flow rate without the flow meter. When the current time minus the starting time is greater than the irrigation time, the irrigation will be completed. Then, the state of shortage of water will be cleared.

The LEDs array on the control panel is controlled by the panel control panel module according to the status of fields. The value of the 31st bit and the 19th bit of the 0th DWORD will change the state of the light (dark, bright, flashing).

G. Time Management Module

The module is responsible for managing the time of the irrigation system. The time is represented by 12 digitals in

chronological order. And time data is stored in the system as BCD code which can display on digital tubes directly. Time is calculated as follows: First, timing to 1 second based on the clock cycle. If the second counter comes to 60, it will carry to minutes counter; if minutes counter comes to 60, it will carry to hours counter; and if hours counter comes to 24, it will carry to days counter. The days counter will carry to months counter according to different month when it comes to 30, 31, 28 or 29. If months counter comes to 12, it will carry to years counter. With too many compute, the time management is very complicated.

The controller receives the command of time setting to achieve the goals of time resetting.

H. Seven-segment displays Display Module

The module is used for displaying the date and time or user inputs. The Seven-segment displays usually show the date and time until a user starts keyboard operation. After "E" (enter) button was pressed, the Seven-segment displays display what the user press. And they will show the time again if "X" (exit) button is pressed.

Time is stored as BCD code. The display module just sends it to the panel control module to displaying on the digital tubes.

When the keyboard operations start, the first digital tube of this control module will blink to remind of the position where the next key value displays. If the input value is the password, it will be replaced by "-" on the Seven-segment displays. With a finished key value displaying, the flashing position moves to the next position.

When the function key "C" (command) or "E" (enter) is pressed, the leftmost digital tube will blink and wait for another input. However, if key "X" (exit) is pressed, the Seven-segment displays will show the current time. And if 12 digits are all inputted already, the flashing position will move to the leftmost digital tube again.

I. User Management Module

The module allows addition/deletion of users and changing user passwords. The system can have three users at most (two operators and one administrator). An administrator can use all the commands provided by the system. He can not only add or delete a user, but also change the administrator. System has only one administrator at its first power-up. The initial user code is 99 and the password is 123456789000. Users can modify their own passwords.

A user management table which has recorded all user codes and passwords is stored in the controller. Users can be verified in this table before they input commands and control this system. When adding a user, the user code and password must be written in this table.

IV. CONCLUSION

The direction for the development of control systems is towards intelligence and miniaturization. In this paper, an intelligent irrigation control system utilizing the powerful processing ability and the highly integrated features of FPGA has been introduced. This system can receive and execute irrigating commands from a decision making system, and it also has an independent keyboard and display built in for direct user inputs. Therefore both fully automatic irrigation control and manual intervention to account for local situation are supported in this system. The irrigation control system based on an FPGA is cheap, small, powerful and easy to operate. So it is suitable for China's current agricultural situation with greenhouses and fields development.

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