The System of Water-Saving Irrigation based on WSN and MSIF

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Abstract

Confronted by the population mushroomed and the increasing shortage of water around the world today, water-saving irrigation and intensive cultivation are inevitable and viable. In this paper, the auto water-saving irrigation based on wireless sensors networks and multi-source information fusion technology based on entropy is introduced. Using wireless sensors networks which adopts nRF2401 as transfer modual, collecting and fusing multi-source information from crop growing environment at remote monitoring center such as soil moisture and temperature and the CO_2 content, information about intensity of illumination real-time, it is realized to auto water-saving irrigation according to control strategy which is given by expert database about the demand for crops growth. Adopted solar batteries to supplying the current, using multi-level memory management and multi-level energy storage mechanism, it converts the solar into electric and makes the system becoming self-sufficient in energy. Combined with low power consumption and algorithm of multi-sensor planning and management based on entropy, it is significance for energy-saving and consumption reducing, and it is convenient and flexible and precise for automatic saving-water irrigation. The results of practical application verify the reliability and efficiency of the design strategy of system. Also the system can be used in greenhouse and regional farmland and large irrigation area.

Keywords: *Water-Saving Irrigation, Wireless Sensor Network, Multi-Source Information Fusion, Sensor Planning and Management, Fusion.*

1. Introduction

Since the 20th century the world population has been increased by 4 times, and the total industrial production value has been increased by 50 times, but consumption of water has been increased by 100 times. The mode of economic growth lead to an overextension of resources, which lead to world water consumption closed in maximum potential capacity of water resources development and utilization. As main water consumer, the water consumption of agricultural irrigation has been more than 70% world water consumption [1]. The utilizing efficiency of water resource has been more than 70%~80%, but it has just been 40%~50% in China [2] [3]. Confronted by the population mushroomed and the increasing shortage of water, the traditional extensive irrigation technique became outdated as China developed, the auto water-saving irrigation system can not only reduce physical labor, but also increase efficiency. Most of all, it can make better use of limited water resources. The system can be used in greenhouse and regional farmland and large irrigation area.

The auto water-saving irrigation system is introduced in the paper, which is based on wireless sensor network (WSN) and multi-source information fusion (MSIF) using entropy. WSN adopts nRF2401 as transfer modual, which collects soil moisture and temperature and the carbon dioxide content, information about intensity of illumination. Considering crop growth characterization, the system of auto water-saving irrigation is realized by multi-source information fusion technology based on crop growth expert database. In the design the system adopts solar batteries supplying the current. It is convenient and flexible and precise for automatic saving-water irrigation [4] [5].

This paper will be structured as follows. In Section 2 we will expose the structure of system network. In Section 3 we will describe our hardware design of system. In Section 4 we will describe control strategy of system. In Section 5 we will show how applying sensor planning and management for multi-sensor. In Section 6 we will describe software design of system.

2. The Structure of System Network

The system structure shows as Figure 1. There are two types' data need to send. One is environmental data including soil temperature and humidity, air temperature and information about intensity of illumination, and the carbon dioxide content, the time also. The other is the control command. The multi-source information form environment collected by wireless sensor nodes in greenhouse send to main controller through nRF2401wireless channels. Main controller sends the information to remote control center and management center and server using Internet/Intranet, which used as data storage and data processing. The control center sends control command to main controller. The data processing for multi-source information can be handled at remote monitor center and local monitor center.

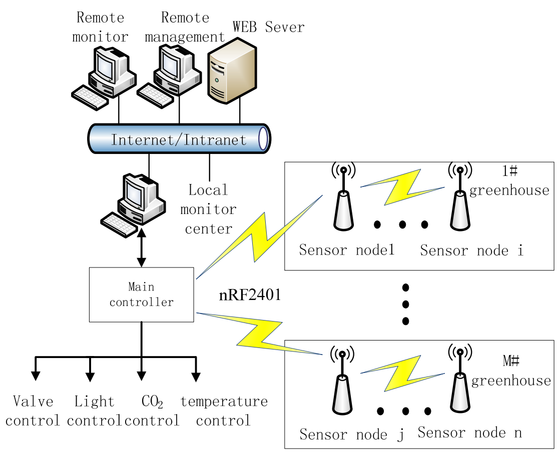

Figure 1 The structure of system network

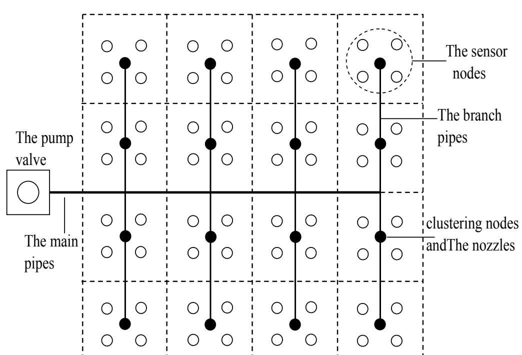

Figure 2 The irrigation areas divided and the sensor nodes assignment

Ideally, the irrigation areas divided and the sensor nodes assignment in greenhouse are shown as Figure 2. Actually, it is not the case in farmland irrigation area. Generally, the shape of regional farmland irrigation areas is irregular. But it is not to affect the sensor node assignment and the controlling effect. In such cases, the sensor node assignment should follow steps. Firstly, we have to determine the influence factors of soil water content. Because the factor is different in different farmland irrigation areas. Secondly, data source selected should be those data source easy to measured and processed which can reflect spatial distribution of the influence factors, such as topographical data likes soil texture and elevation and slope and so on, and soil conductivity. Thirdly, based on the influence factors and data source characteristic, the farmland irrigation should be dividing into sections, by choosing the right soil characteristic. Fourthly, based on polygons, we can determinate the location and number of sensor node for each section. For regular section, it could locate one sensor node, and for irregular section it could locate more than one sensor node which information can be given by various methods such as using the arithmetic average value, weighted arithmetic average value, or the median filter, etc.

3. The Design of System Hardware

3.1 Main Controller and MCU Unit

The design adopts MSP430F1612 as MCU which is ultra-low power consumption. The power consumption of MSP430F1612 can be controlled by control bit of switch state register. It is 160μA current under normal working conditions, and 0.1μA under standby working conditions. It is 1.8~3.6V under working conditions. It has two built-in 16-bit timers, a fast 12-bit A/D converter, dual 12-bit D/A converters, one or two universal serial synchronous/asynchronous communication interfaces (USART), I2C, DMA, and 48 I/O pins. Because of ultra-lower power consumption, it is favorable for lower power consumption system, especially for applications such as batteries and handheld devices.

The digitally controlled oscillator (DCO) allows wake-up from low-power modes to active mode in less than 6Es and may operate up to 8MHz. Typically, the DCO will turn on from sleep mode in 300ns at room temperature. The MSP430F1612 has two built-in 16-bit timers, a fast 12-bit A/D converter, dual 12-bit D/A converters, one or two universal serial synchronous/asynchronous communication interfaces (USART), I2C, DMA, and 48 I/O pins. The core module also has a 4 Mbit flash chip that can be used for storing several firmware images or for logging data.

3.2 The Wireless Data Transfer Modual

The wireless data transfer modual adopts nRF2401, which is 2.4G wireless RF transceiver. Built-in moduals, such as frequency synthesizer and power amplifier and oscillator and modulator makes significant power savings easily realizable. The nRF2401 has 125 channels for choosing, 1.9V~3.6V under working conditions, has some advantages such as high sensitivity receiving and lower transmission power and few buffer circuit and high transmission rate of data, lower power consumption also [6].

3.3 Sensor Node

The sensor node of WSN is different from other sensors, which is intelligent sensor with the function of remote communication. The design fusions information from sensors using MCU, which are moisture and temperature sensor for soil and environmental temperature sensor and sensor for intensity of illumination and sensor for carbon dioxide content. Then data transmits data to wireless gateway by nRF2401. In the end data is transmitted to remote monitoring center. The hardware structure of system sensor node is shown as Figure 3. In regional farmland and large irrigation area, the sensor node need not include the sensor for the environmental temperature and intensity of illumination and CO_2 content, the whole auto-saving irrigation system only need small amount of such sensor node.

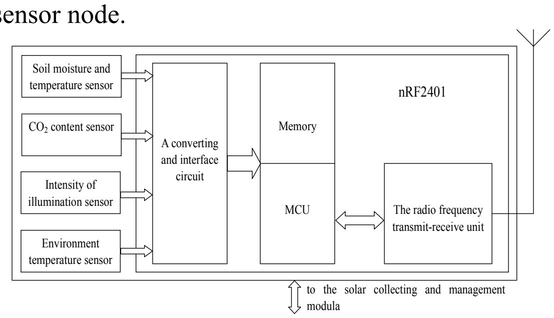

Figure 3 The sensor node modual

The moisture and temperature sensor for soil adopts as TDR-3A. The temperature measuring of TDR-3A is -40°C~+80°C and the precision is $\pm 0.2^{o}C$. The moisture measuring is 0~100% and the precision is $\pm 2\%$ when 0~50%. Output current is 4~20mA. The TDR-3A has many advantages of integration and waterproof and sealing and high precision [7] [8].

The environmental temperature sensor adopts DS18B20 which is lower power consumption digital temperature sensor. The temperature measuring of DS18B20 is -55°C~+125°C, and the precision is 0.0625°C, 9~12 bits A/D. Because of its small size, it can save many lead wires and much logic circuitry.

The sensor for intensity of illumination adopts on9658 which is photo electronics integration sensor. The on9658 is 2.4V~12V and -20°C~75°C under working conditions, 2μs for response time, 520nm for incident wavelength typically. Built-in double sensitive unit receiver, it is sensitive enough to visible region. It's output current changes linearly with the increased intensity of illumination [9].

The carbon dioxide content sensor adopts GMW120 which is made in Vaisalaoy of Finland. The GMW120 outputs 4~20mA or 0~5V and the power is 24VDC or 0~30VAC. The carbon dioxide content measuring of GMW120 is 0~2000ppm and the precision is under ±20ppm+1.5% when content is 20ppm. The repeatability is under ± 20ppm and the thermal zero shift is under 2ppm/°C. The response time of the GMW120 is under 60s and the long-term stability is under 100ppm/5a. The GMW120 is random sampling without directional and measures by single nonfinite infrared light [10].

3.4 The Solar Energy Collecting and Management Modual

As shown in Figure 4, dealing with the sensor node power supply, system adopts power supply subsystem based on solar energy. The subsystem includes solar panels and super capacitors and lithium batteries. The solar panels change the solar tower collected to electric energy, and stores in supercapacitors used as master energy storage which supports electric energy to sensor nodes of WSN. And the subsystem uses lithium batteries as emergency energy standby.

The energy management unit adopts CN3063 which using single lithium battery. Built-in power module, the external circuit of CN3063 doesn't require current detecting and current – limiting diode. The CN3063 has 8 bits A/D converter which is especially convenient to user so as to maximize the use of output current for input power. Modulator circuit can control the temperature of CN3063 within the security range. Built-in CN3063, the constant charging voltage is 4.2V, which can be adjusted by external resistance. Built-in power down mode makes power saving easily realizable and the working current is under 3μA.

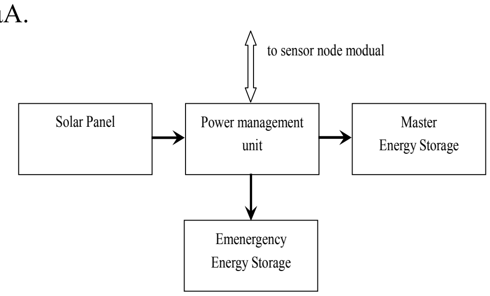

Figure 4 The solar energy collecting and management modual

3.5 Actuators and CO_2 Supplying Subsystem and Other Control Devices

The regulating valve adopts DZK-01 which is wireless electric actuated valve controller. The DZK-01 can control electric actuated valve opening directly and can switch at hand-control and auto control, and it can be displayed by digital and analogy. The DZK-01 outputs 4~20mA and the continuously variable potentiometer is 500Ω~10KΩ, the precision is 0.2%~2%. The irrigation methods adopt spray pumping and drip pumping mainly [11] [12].

The CO_2 supplying subsystem is saving CO_2 in large pressure vessel which includes refrigeration equipment and insulation equipment and air compressor. When CO_2 in air is insufficiency, it starts CO_2 supplying subsystem providing CO_2 for crops.

For increasing illumination system adopts the electric window curtains as device at the daytime and fluorescent as device at night or insufficient light at the daytime.

3.6 Some Problems Involved Hardware Design

(1) About lower power design. For a digital system, power consumption generally meets Equation 1.

$$P = CU^2 f \tag{1}$$

Where, C is the load capacitance, U is the power voltage, and f is operating frequency. Generally speaking, C is uncontrollable, so $P \propto U^2 f$, so when design lower power system, it should be reducing U and f as much as possible without impacting system performance.

The lower power consumption design for sensor node needs lower power consumption design for units and a reasonable security power management strategy. The lower power consumption design for units is chiefly choosing units and putting them into sleep mode through software when it is idle. The reasonable security power management strategy is choosing power supply way to controlling its power supply time for units and controlling devices, which is controlled by MCU.

(2)About selecting hardware. Because data transmission module takes on wireless communication with other nodes and exchanges control information, sends and receives and collects data also, so about two of thirds of the power consumption of node are used for sending and receiving wireless. Then the choosing of radio frequency chip is directly related to the power consumption of nodes. Of course, beside the power consumption it is also important to consider other factors, such as the sensitivity and the wrong frame rate and transmission distance.

(3)About design for anti-interference. The interface rate should be over wireless communication rate. Because of the different parameters of system, sensor data is disturbed by noise during transmission. It is important to strengthen anti-interference ability to ensure that the data transmission is correct.

(4)Others problems involved hardware design. The automatic water-saving irrigation system should be low cost and using flexibly and conveniently, stability and expansibility. For the solenoid valves of irrigation system, not only automatic but manual features are demanded. Even though auto-control is temporary defeat, it is important to guarantee irrigating.

4. Control Strategy of System

The ideal curve of temperature control is shown as Figure 5. Where, T0～T7 are temperature fitting point. T1 and T2 are low and high level of optimum temperature at the daytime respectively. T3 and T4 are low and high limiting temperature respectively. T5 is upper limiting of optimum temperature at the daytime. T6 and T0 are low-level and high-level optimum temperature at night respectively. T7 is high-level temperature leading to respiratory depression at night. Ideally, the curve shouldn't be containing T3 and T4. To achieve high output and steady of crop, we can control crop' temperature by sectionally obeying the curve. Temperature values of some main common crops within a day are shown as Table.1. According to theory and practice, basis on all greenhouse factors interact with each other, it can be realized greenhouse optimum management and high output and steady, which controlled by reference to crop growth temperature curve, adopted temperature change rate as controlled variable. T0～T7 of some common crops are shown in Table.1 which units are ^{0}C. Left columns in Table.1 is the temperature of seeding period, and the right columns in Table.1 is the temperature of growth period [13] [14] [15].

According to the collecting information, system is controlled as described below.

(1)About temperature controlling. Under greenhouse conditions, temperature controlling used as adjusting the temperature during the growth of the crops. The system adopts temperature-varying management including 5 stages temperature-varing controlling such as morning and afternoon and the early night and the after midnight and the early morning.

(2)About humidity controlling. Under greenhouse conditions, it can control dehumidification facilities and prevent crop from seeding diseases.

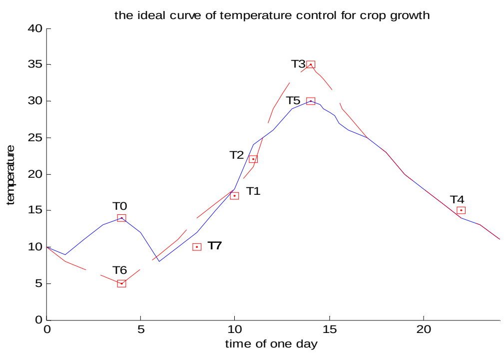

Figure 5 The ideal curve of temperature control for crop growth one day

Table 1: Some Common Crop Temperature Required

	Watermelon		***String beans***		***Peper***	
T0	12	13	15	12	15	18
T1	20	23	20	20	20	20
T2	30	30	22	26	25	30
T3	38	38	32	32	35	35
T4	10	10	10	10	12	12
T5	33	33	30	30	32	32
T6	15	18	20	20	20	20
T7	14	16	17	14	16	19

(3)About light controlling. Under greenhouse conditions, it can control opening and closing of awning shading, and gives crop suitable illumination which prevents crop from over light saturation point and increases photosynthesis. It can control illumination of short sunshine crop for example soja and long sunshine crop and medium sunshine crop.

(4)About CO_2 controlling. Under greenhouse conditions, the system can monitor the CO_2 content real-time. When the CO_2 content is less than certain value, it opens CO_2 generator to increasing air fertilizer.

(5)About soil moisture controlling. It can control water pump keeping soil moisture at 55%～65% optimum.

5. The Algorithm of Multi-Source Planning and Management based on Entropy

The entropy is statistical uncertain information for random variable and system, which is an important mathematical tool for multi-sensor data fusion. The designed system is a multi-sensor system in this paper, which includes four types sensor. Each sensor has fixed probability. If a system has n sensors $S_i(1 \le i \le n)$, which probability is $p_i(x|x_i)$, where $x \in X$ is random variable measured parameter, x_i is the observation sensor i, and $p_i(x|x_i, x_j)$ is the joint probability distribution, x_i and x_j is the observation sensor i and j respectively.

Definition 4.1.

Let $H_i(x_i) = -\sum_{x \in X} p_i(x|x_i) \log p_i(x|x_i)$ as entropy of x_i, which is used to measure of uncertain of x_i. Let $H_{i|j}(x_i) = -\sum_{x \in X} p_{ij}(x|x_i, x_j) \log p_{ij}(x|x_i, x_j)$ as conditional entropy, which is used to measure of uncertain of i about jointed observation (x_i, x_j) under given x_i. Let $H_{ij}(x_i, x_j) = H_{ji}(x_i, x_j) = -\sum_{x \in X} p_{ij}(x|x_i, x_j) \log p_{ij}(x|x_i, x_j)$ as mutual entropy, which is used to measure of uncertain of jointed observation (x_i, x_j).

Based on entropy and mutual entropy, the observation of n sensor can construct entropy matrix by $H = [H_{ij}]$, where $H_{ij} = H_{ji}$, so H is a symmetrical matrix.

The algorithm of multi-sensor planning and management based on entropy is given as follows.

Step 1. Assign the basic probability $p_i(x|x_i)$ and $p_i(x|x_i, x_j)$ according to data collection at t_k sampling time;

Step 2. Calculate the entropy $H_i(x_i)$ and the mutual entropy $H_{ij}(x_i, x_j)$;

Step 3. Let $H_1 \le H_2 \le \cdots \le H_n$, construct the entropy matrix H;

Step 4. Construct relation matrix R described as Equation 2.

$$R_{ij} = \begin{cases} 1, & H_{ij} > H_i \, and H_{ij} > H_j \\ 0, others \end{cases} \quad (2)$$

Step 5. Let

$H_{ij}(x_i, x_j) = H_{ji}(x_i, x_j) = \max\{H_i(x_i), H_j(x_j)\}$, then delete H_{i*} and H_{*i}, reconstruct entropy matrix $H_{m\times m}(m \le n)$, if $\frac{1}{n}\sum_{j=1}^{n} R_{ij} > \frac{1}{3}$ based on the fault tolerance theory, sensor S_i should be shut off or put into hibernation by MCU, go to Step 3; else go to Step 6;

Step 6. If $H_{12} < H_1$, then fuse S_1 and S_2, which relation is redundancy and may be defined as $S_1 \wedge S_2$; else $S_1 \vee S_2$ which relation is complementary. In the state of $S_1 \wedge S_2$, if $H_{13} < H_1$, then $S_1 \wedge S_2 \wedge S_3$, else $S_1 \wedge S_2 \vee S_3$; In the state of $S_1 \vee S_2$, if $H_{13} < H_1$, then $S_1 \vee S_2 \wedge S_3$, else $S_1 \vee S_2 \vee S_3$; and so on.

Step 7. According to the relations type, there are many algorithms to fuse the sensor data. For example, to redundancy relation, the fusion algorithm can be adopted as weighted fuzzy fusion, and to complementary relation, it can be adopted as weighted fusion based on verifiable knowledge principles. Let $k = k + 1$ go to step1.

A calculation and relation for auto water-saving irrigation system sensor is shown as Table 2~Table 5 at 4 sampling time points from t_1 to t_4, where selects temperature and humidity and illumination for S_1 and S_2, probability distribution for 3 parameters are written as p_T and p_H and p_L respectively.

Table 2: Calculation and Relation for t_1 Sampling Time

		S₂	***(S₁, S₂)***	***Relation***
p_T	0.4	0.25	0.2	redundancy
p_H	0.5	0.08	0.3	conflict
p_L	0.35	0.15	0.4	complementary

Table 3: Calculation and Relation for t_2 Sampling Time

	S_1	***S_2***	***(S_1, S_2)***	***Relation***
p_T	0.7	0.15	0.11	redundancy
p_H	0.2	0.3	0.25	conflict
p_L	0.46	0.35	0.15	redundancy

Table 4: Calculation and Relation for t_3 Sampling Time

	S_1	***S_2***	***(S_1, S_2)***	***Relation***
p_T	0.6	0.13	0.15	redundancy
p_H	0.13	0.48	0.12	redundancy
p_L	0.35	0.4	0.2	redundancy

Table 5: Calculation and Relation for t_4 Sampling Time

	S_1	***S_2***	***(S_1, S_2)***	***Relation***
p_T	0.8	0.1	0.2	conflict
p_H	0.3	0.41	0.27	redundancy
p_L	0.5	0.23	0.18	redundancy

6. Design of System Software

In software system, the control process runs as follows. First, system needs to be initialized which includes the hardware such as the MCU and the wireless transfer modual and the sensor node modual and the CN3063. Second, system collects the information of greenhouse. Third, system transfers the information to the MCU through the wireless transfer modual. Fourth, system processes the data. Fifth, system runs interrupt control, which includes four type control such as temperature controlling and humidity controlling and light controlling and CO_2 controlling, and then convert digital signal into analog signal and output it to actuators as control command. In the end, system displays the information and go to second for starting the whole cycle over again.

7. Conclusions

In this paper, it is introduced the system structure and design solutions to auto water-saving irrigation system. Based on wireless sensors networks and multi-source information fusion technology based on entropy, it has realized multi-sensor planning and management and multi-level energy storage mechanism. Through developed and designed for hardware and software, experiments proves it has realized auto water-saving irrigate, which reduces water consumption and system power consumption, and the single hop for communication distance can reaches 350 meters, and can realize 6 hops data transmission. The auto-saving water irrigation system can apply to not only greenhouse but also regional farmland and large irrigation area. Experiment proves it has great application value and promotion value.

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