Improvement Hydraulic Ram Pump Water Resources Management Analysis System Based on the Wide-area Internet of Things

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ABSTRACT

The intelligent hydraulic ram pump monitoring and early warning system based on the wide-area Internet of Things aims to monitor the working status of Hydraulic Ram Pumps in real time through the Internet of Things, big data, monitoring, automatic control and other technical means, and form early warnings through data centralized analysis and judgment. To realize monitoring of the equipment which is called Hydraulic Ram Pump, it can manage and analyze the water resources information. It can ensure the safe operating environment of the equipment and facilitate real-time grasp of water resources information on the working area of the equipment.

CCS CONCEPTS

• **Hardware**; • **Communication hardware, interfaces and storage**; • **Sensors and actuators**;

KEYWORDS

Internet of things, Automatic control, Big data, Monitoring system

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1 INTRODUCTION

Due to the geomorphic characteristics of China, in some areas where are sparsely populated, draught and irrigation have always been the most troublesome issues for local residents and the government [1]. Although China's economic infrastructure is gradually improving, and most areas are generally connected to tap water to solve the drinking water problem, there is still big problem with farmers' irrigation. Due to the large demand for agricultural water [2], farmers currently use two methods to solve the problem. On the one hand, they apply electric pumps, oil pumps or other devices for water. On the other hand, storing water is also an excellent way. They are processed by using natural water and groundwater. However, the electric pumps, oil pumps and other devices on the market can only pump water alone, and the information integration for water resources collection is not high enough. Although some equipment has simple data collection devices, there is no set of equipped systems to collect information. Analysis cannot guarantee the safe operating environment of the equipment. Therefore, there is an urgent need for a water resources management analysis system that can target the bottom-end water lifting equipment market [3].

2 SYSTEM STRUCTURE

The system establishes a separate Internet of Things environment. Then the system collects information on various modules through an embedded microcontroller. Through the 4G network, the data can be uploaded to the cloud server which performs simple processing to deal and analyze the data onto the water resources management service system further. As a terminal, a smartphone can learn about the working conditions of the device in real time.

Note: This product is based on the energy-saving shocked pump of Wuhan Huitai New Energy Company (Model: HT-ZZ-50)

The embedded microcontroller in the intelligent controller is based on STM32F103C8T6 [4], which is mainly used to collect the data onto each sensor and upload it to the server through the Internet of Things module and control the closing of the electronically controlled opening valve; the flow sensor is mainly used for collection the flow rate information on the water outlet; the Hall sensor is used to collect the number of times the connecting rod jumps per unit time; the electronically controlled opening valve is used to open/close the equipment to change the operating status of the equipment; the turbidity sensor is used to collect the water quality information on the water inlet . Photovoltaic power supply components are used to power smart controllers and IoT modules.

3 FUNCTION DISTRIBUTION

3.1 Flow Calculation

In Figure 1, the output signal of ①the flowed velocity sensor is collected by the embedded microcontroller in ④the intelligent controller. And the current cross-sectional flow (time in seconds) is calculated according to the diameter of the outlet pipe. Next the minute flow rate, hourly flow rate, and daily water supply are calculated from the cross-sectional flow rate (second).

Cross-section flowed calculation: The output of the flow sensor is a pulse signal, and different flow rates correspond to different

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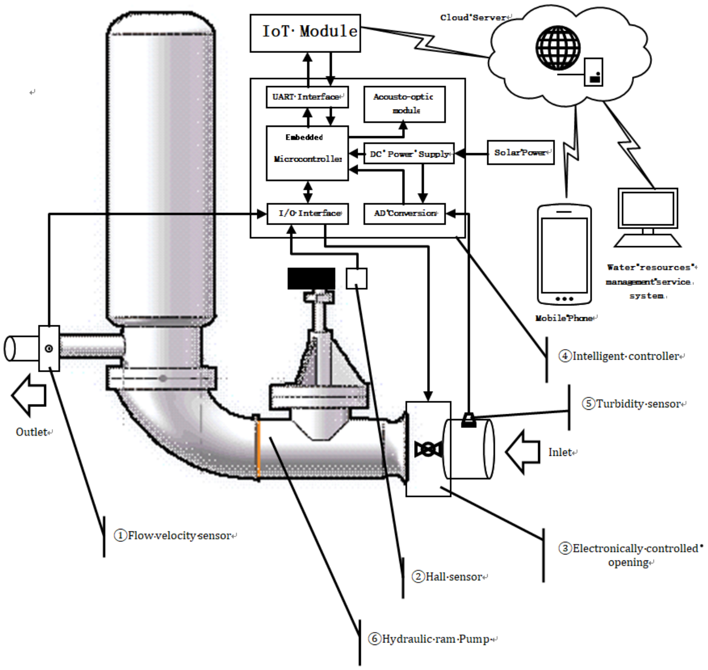


Figure 1: System Composition and Topology Diagram.

square wave pulse frequencies. Due to the working characteristics of the Hydraulic Ram Pump, the flow rate of the pumped water is constantly changing. At the same time, the flow rate of the pumped water flow will also change from the impact on the water flow at the inlet end. Therefore, in order to accurately measure the cross-sectional flow, the embedded microcontroller collects and calculates the current sensor output frequency every Δt (Δt is a fixed amount of time less than 1S, such as 0.1S), which is recorded as f1 and converted to flow rate S1. In this way, the flow velocity at n points (n=1S/Δt) can be measured continuously and denoted as S1 to Sn. The inner diameter of the outlet pipe is represented by Φ, and the cross-sectional flow Qs is

$$Qs = \Sigma_{(i=1)}^{n} Si \times \Pi(\frac{\Phi}{2})^2 \times \Delta t \tag{1}$$

In order to simplify the calculation, the average flow velocity can also be used for calculation, as shown in the following formula

$$Qs = \frac{\sum_{i=1}^{n} Si}{n} \times \Pi\left(\frac{\Phi}{2}\right)^2 \tag{2}$$

Cumulative flow calculation: Since the flow rate of the water outlet is always changing, the cumulative flow Qt in a certain period of time is calculated by cumulative addition. Supposing the time period has m seconds, then Qt is:

$$Qt = \sum_{i=1}^{m} Qs\,(i) \tag{3}$$

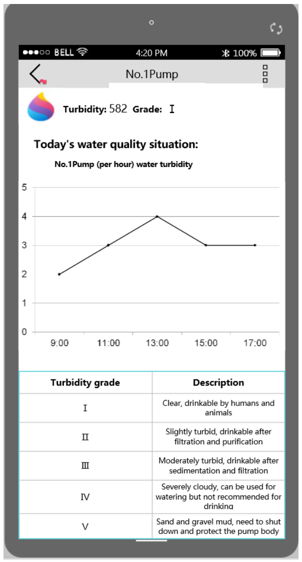
Optimization scheme: ① the flow rated sensor in the figure can also be set at the end of the water user's pipeline at the same time (that is, a flow rate sensor is set at the outlet end of the Hydraulic Ram Pump and the end of the water pipeline), and the end flowed rate sensor uploads the flow rate data through the wireless Internet of Things to cloud server. The cloud server analyzes whether there is water leakage or "water theft" in the water pipeline according to the "water flowed rate of the pump body" and the "end watered to flow rate". Specifically:

- If "Pump Outlet Flow" ≈ "End Outlet Flow", there is no leakage or stolen water in the pipeline.
- If "Pump Outlet Flow"> "End Outlet Flow", there is water leakage or stolen water in the pipeline.
- If "Pump Outlet Flow" <"End Outlet Flow", the sensor may be faulty.

3.2 Water Quality Testing

As shown in Figure 1 ⑤ turbidity sensor is installed at the water inlet, at the front end of ③ electronically controlled opening valve. Since the common factors affecting water quality (such as sediment, water microorganisms, industrial and domestic emissions, human and animal activities) will cause changes in water turbidity. As shown in Figure 2, the mobile phone will display the water quality information in real time. This system uses a low-cost turbidity sensor as a water quality monitoring method. It can reduce the cost and adapt it to the capacity of water scarce or underdeveloped areas.

The output of the turbidity sensor is a voltage signal, and different turbidity corresponds to different output voltages. This signal is collected and converted into a digital quantity by the analog-to-digital conversion component (independent component or embedded micro-controller) in ④the intelligent controller of the figure,



Turbidity: 582 Grade: I

Today's water quality situation:

No.1Pump (per hour) water turbidity

Turbidity grade	Description
I	Clear, drinkable by humans and animals
II	Slightly turbid, drinkable after filtration and purification
III	Moderately turbid, drinkable after sedimentation and filtration
IV	Severely cloudy, can be used for watering but not recommended for drinking
V	Sand and gravel mud, need to shut down and protect the pump body

Figure 2: Mobile Phone Interface Figure ①.

and obtained by the embedded micro-controller to obtain the turbidity level. The following Table 1

3.3 Self-Diagnosis (Including Power Supply System)

In the Figure 1, ②the Hall sensor is installed near the connecting rod of the pump water valve of the pump body, and a permanent magnet is installed on the connecting rod of the pump water valve. When the water pump works normally, the pump valve connecting rod and the permanent magnet fixed on it does longitudinal reciprocating motion. When the magnetic pole of the magnet sweeps ②the Hall sensor, the sensor outputs a level jump signal. ④The embedded microcontroller in the intelligent controller detects the level jump and counts, and calculates the number of actions of the pump valve connecting rod in a unit time. Combining ③ the opening ratio of the electronically controlled opening valve and ① the data onto the flow sensor to get the current working state of the pump (normal, fault). The diagnosis strategy is as shown in Table 2

3.4 Water Safety Control (Including Flow Control)

3.4.1 Water Quality Control. As mentioned in Figure 2 water quality inspections, ④the intelligent controller uploads the water quality level data onto the cloud server through the "Internet of Things module", and the users can check the current water quality level at any time through the smart phone and obtain recommendations of use.

If the water quality reaches Grade V, ④the intelligent controller will automatically close the ③electronically controlled opening valve to cut off the pumping water and continue to monitor the water quality. If the turbidity of the water drops from grade V to grade IV or lower, it will automatically open the ③electronically controlled opening valve to resume pumping.

3.4.2 Anti-Impact Control. As described in Table 2 flow calculation, ④ the intelligent controller calculates the current pump water flow Qt. If Qt exceeds the maximum permissible flow rate per unit times, it indicates that the water flow rate of the inlet is too high (such as encountering mountain torrents, etc.). At this time, ④the intelligent controller controls ③the electronically controlled opening valve to reduce the opening and reduce the inlet water flow, so that the pump water flow Qt is reduced to the allowable range. So as to realize the anti-impact protection for the pump body and prolong the service life.

3.4.3 Network Management and Control. As mentioned above, when the above-mentioned various abnormal situations occurs, ④the intelligent controller reports the abnormal situation to the cloud server through the "Internet of Things Module", and the manager makes decisions and handles. Managers can use the "Water Resources Management Service System" in the picture to issue management and control instructions in the intelligent Hydraulic Ram Pump equipment under their jurisdiction or required for management, control and protection. Control instructions include: adjusting (increase or decrease) the opening of the inlet valve, stop or resume pumping, etc.

4 DATA STORAGE AND UPLOAD

4.1 Local Storage of Data

In the Figure 1, ④the embedded microcontroller in the intelligent controller stores the calculated flow rate, water quality, and equipment working status (referred to as working conditions) data in the FLASH area of the microcontroller in the form of "time stamp + data body". Data will not be lost after power failure. To save storage space, the following rules are adopted

<1> Daily starting point record: Based on 0:00:00 every day, record the starting point of the time stamp, which occupies 4 bytes.

Table 1: Turbidity Rating Table

Serial number	AD conversion value	Turbidity grade	Description
1	0 ~ 800	I	Clear, drinkable by humans and animals
2	800 ~ 1600	II	Slightly turbid, drinkable after filtration and purification
3	1600 ~ 2400	III	Moderately turbid, drinkable after sedimentation and filtration
4	2400 ~ 3200	IV	Severely cloudy, can be used for watering but not recommended for drinking
5	3200 ~4095	V	Sand and gravel mud, need to shut down and protect the pump body

Table 2: Diagnostic Strategy Table

Serial number	Diagnosis strategy
1	Flow Judgment Method Principle: Each time the pump valve of the Hydraulic Ram Pump beats, the pump output is basically fixed, and this flow value is recorded as Qr(constant). The actual flow rate of the water outlet during each beating cycle of the detection valve is recorded as Qt. If: Qr×(1-p) ≤Qt≤Qr×(1+p))P is the allowable error percentage), the pump body is considered to be working normally; If: Qt<Qr×(1-p) It is considered that there is a water leakage problem of the water outlet of the pump body; If: Qt>Qr×(1+p) It is considered that the Hall sensor is abnormal, and the adjustment rod signal is missed; If: Qt>0, But Qr=0 means that the Hall sensor is invalid or the magnet is invalid;
2	Judgement method of connecting rod bounces frequency Principle: When the Hydraulic Ram Pump is working, the reciprocating frequency of the pump valve and its connecting rod is basically stable, denoted as fs. If the embedded microcontroller detects that the connecting rod frequency fs is unstable, there are large jumps and frequent changes, it is considered that the pump valve connecting rod is loose or the Hall sensor is abnormal.
3	Horizontal ratio Principle: Compare historical data in the same period horizontally. If the average value of the historical period flow at a certain time are Qm, the current flow of water are Qt. If Qt <Qm×(1-p) (p is the allowable error percentage), it is considered that there is a problem of siltation or runoff shortage at the inlet end.
4	Power supply diagnosis In the picture ④ The AD conversion component in the intelligent controller converts the output voltage of the "photovoltaic power supply component", the embedded microcontroller obtains the conversion result, and calculates its output voltage value V If V>the upper limits of the safety threshold, it is considered that the output voltage of the power supply component is too high, and problems such as battery overcharging and photovoltaic panel specification inconsistency may occur. If V<the lower limit of the safety threshold; it is considered that the battery of the power supply component is over-discharged or the photovoltaic panel is poorly illuminated (such as falling leaves or dust covering the surface of the photovoltaic panel, etc.). When this occurs, the embedded microcontroller will switch to a low power consumption mode and Regularly monitor the voltage V value, and if the V value returns to normal, it will resume its normal working state.

Timestamp	Cumulative flow	Water quality I~V grade	Equipment working condition code
4 bytes	4 bytes	High 4bit	Low 4bit

Sub-number	Minute flow	Water quality I~V grade	Equipment working condition code
2 bytes	1 byte	High 4bit	Low 4bit

The cumulative flow is recorded in minute granularity, flow data occupies 4 bytes; water quality data and equipment working status share 1 byte. 9 bytes in total

<2> Daily data record: record the current flow data onto one minute in minutes, a total of 4 bytes.

If the current flow data, water quality data, and equipment working condition code are the same as before and there is no change in the current one minute, no record will be made; otherwise, record will be made.

The minute serial number is the serial number of minutes from the beginning of the day to the end of the day. That is, the serial number of 0:01:00 every day is 1, and the serial number of 0:2:00:00 is 2.

According to the maximum amount, the total data generated per day is 4 bytes/minute × 1439 minutes + 9 bytes = 5765 bytes. If an embedded microcontroller with an internal FLASH capacity of 256K bytes is used and 200K bytes are reserved for data storage space, the number of days that can be stored is (200×1024) bytes ÷ 5765 bytes/day = 35.52 days. It means that one month of offline data can be stored locally when offline. It is sufficient to meet the needs of use, and there is no need to configure a non-volatile memory, further reducing equipment costs.

4.2 Data Upload

After ④the intelligent controller is successfully connected to the cloud server through the Internet of Things module, it submits the data described in 3.1.1 to the cloud server. The submitted data

Table 3: Failure Tips-Maintenance Method

Serial number	Fault name	Prompt mode	Maintenance method
1	Blocked water inlet	Buzzer keeps beeping	Manual dredging and removal of debris at the water inlet
2	Leaking water outlet	The buzzer sounds shortly	Plugging or replacing pipe parts
3	Sensor failure	The buzzer sounds briefly and the LED tube flashes	Directly replace the low-cost sensor and plug in the correct plug-in

storage area can be overwrittened to accommodate new storage data. The data to be uploaded is divided and encapsulated in data packets of every 64 byte, and uploaded to the server one by one.

5 MAINTENANCE AND INSPECTION TIPS

5.1 Device Location Reminder

In the Figure 1, the "acousto-optic module" in ④the intelligent controller is a buzzer and an LED light-emitting tube. When maintenance personnel or users need to determine the target device, they can issue a location instruction in the Internet of Things module through the smartphone application software. The location map of the target device can be displayed on the smartphone, and the target device will automatically turn on after receiving the location instruction. The acousto-optic module emits sounds and flashes, which is convenient for finding and positioning [5]. This function is especially useful for the location of smart Hydraulic Ram Pumps that are densely arranged in groups of the same place. Since it is difficult to distinguish the devices densely arranged in groups of the electronic map, there will be problems such as handwriting corrosion and abrasion when making nameplates on the devices. Nevertheless, set the display screen of the device cannot adapt to the long-term field high. Low temperature and high humidity application environment will increase the cost and failure rate of the equipment. Therefore, the system uses a buzzer and an LED light-emitting tube combined with a sound flash prompt is the most appropriate method.

5.2 Fault Prompt

Different from the existing solutions, for common and simple faults that ordinary water users can handle by themselves, the system gives an intuitive prompt mode through the "acousto-optic module" in ④the intelligent controller in the Figure 1. Water users can maintain themselves according to the sound and light prompts during daily inspections, without the need for professional maintenance personnel to go to the site for maintenance and repair. As shown in Table 3 below. This reduces operation and maintenance costs. This also eliminates the "fault-report" processes and shortens maintenance time to improve equipment availability.

At the same time, water users and maintenance personnel can view the detailed status information on the equipment at any time through the smart phone application software and understand detailed fault information, which can maintenance methods and procedures.

5.3 Reminder of Inspection Results

When the maintenance or repair is completed, the self-diagnosis function of this system will automatically update the equipment status information. The water user and maintenance personnel can intuitively understand the maintenance results in the smart phone and know whether the equipment is back to normal.

6 MANAGEMENT AND ANALYSIS OF WATER RESOURCES

When multiple equipment is installed in an area, a pump group is formed. Each device uploads the collected information on the server to build a local database, so that you can understand the distribution of water resources in the area and the distribution of pollution levels of water sources. The future water resources can be inferred based on historical data, so that local residents can reasonably and effectively use local water resources for production and development.

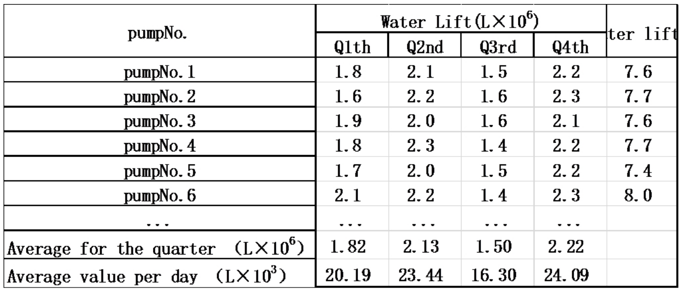
6.1 Analysis of Water Resources Distribution

The collection of the flow rate of the water outlet through the flow sensor will be displayed on the mobile phone terminal in the form of a line graph. By selecting the date range, you can learn about the historical information on the device. As shown in Figure 3

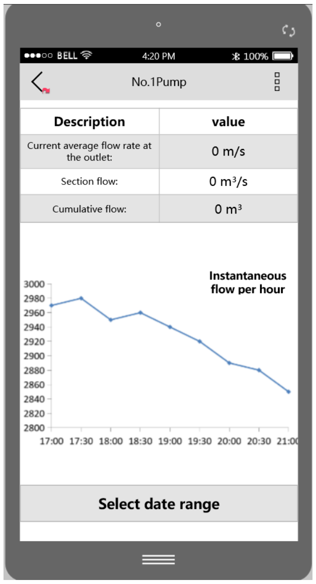
A group of pumps constructed by multiple devices will pass through a circular range on the map to roughly indicate the amount of water lifted by each device (the amount of water lifted is more than the amount of water lifted by the device in one day as a reference for comparison). As shown in Figure 4:

When there is enough data, it can be analyzed the water resources situation of the year based on historical data.

First, the system will divide the pumping volume of each pump in one year according to the quarter. Then it can be summarized in the server and build an EXCLE table, as shown in the figure:



pumpNo.	Water Lift($L\times10^6$)				ter lift
	Q1th	Q2nd	Q3rd	Q4th	
pumpNo.1	1.8	2.1	1.5	2.2	7.6
pumpNo.2	1.6	2.2	1.6	2.3	7.7
pumpNo.3	1.9	2.0	1.6	2.1	7.6
pumpNo.4	1.8	2.3	1.4	2.2	7.7
pumpNo.5	1.7	2.0	1.5	2.2	7.4
pumpNo.6	2.1	2.2	1.4	2.3	8.0
...	...	...	...	...	
Average for the quarter ($L\times10^6$)	1.82	2.13	1.50	2.22	
Average value per day ($L\times10^3$)	20.19	23.44	16.30	24.09	



Description	value
Current average flow rate at the outlet:	0 m/s
Section flow:	0 m³/s
Cumulative flow:	0 m³

Figure 3: Mobile Phone Interface Figure ②.

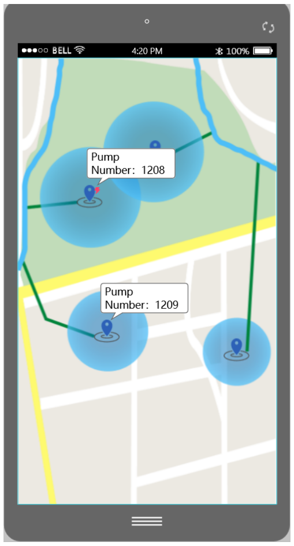
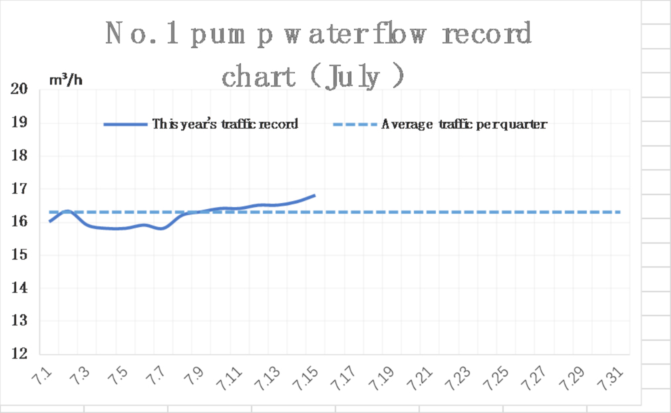


Figure 4: Mobile Phone Interface Figure ③.

As shown in the above table, the average daily water withdrawal for each quarter in 2020 is summarized and analyzed (note $\bar{v}$2020i, 20 means year, i means quarter, which can be taken as 0, 1, 2, 3). Based on the average daily water withdrawal in the current quarter in the past five years, it can be estimated the average daily water withdrawal (denoted by $\bar{V}c$) in the quarter of the next year as:

$$\bar{V}c = \frac{1}{5}\sum\nolimits_{n-4}^{n} \text{vni}$$

Present the result of $\bar{V}c$ in the real-time water lifting to flow record chart, as shown below:



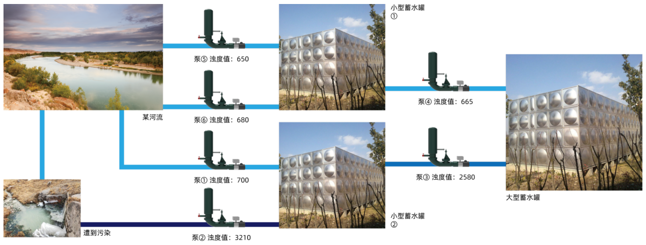
The solid line represent the water flow detected in real time this year, and the dotted line represents the average flow (V̄c) in the third quarter based on the analysis of the past five years.

As long as the local topography have not changed much and the collected data is sufficient, the average flow can be used as a reference to the current quarter's water resources.

6.2 Analysis of the Distribution of Pollution Degree of Water Sources

Since a single device is lost in the process of water delivery, individuals often use multiple equipment graded water delivery methods to ensure sufficient water resources in the case of long-distance water delivery. However, due to the establishment of multiple devices, the risk of contamination is increased. Therefore, it can be analyzed the location of the pollution source by collecting the turbidity of the water inlet of each level of equipment to reduce the time for investigation.

Therefore, a model is constructed to facilitate everyone's understanding.



7 CONCLUSION

This system is dedicated to the monitoring of equipment operation and the collection and analysis of some basic information. It is necessary to lower the threshold of management equipment and timely discover problems to prevent equipment from continuing to work which are caused by failures or water source pollution, etc. Because the system is automated and informatized, the equipment can work uninterrupted 7×24 hours, which improve the efficiency of water delivery. The system is also can be monitored in real time to ensure the normal operation of the equipment. If the equipment is damaged, the equipment information can be analyzed to eliminate the fault and save manpower and material resources. Owing to the underlying hardware of this system belongs to low-power operation, normal sunlight is sufficient to meet daily needs, so there is no need for complicated human management after the system is built, only regular maintenance is required. Due to the advantages of simple construction and clean energy of this system, it can meet the needs of some small and medium-sized water transmission equipment's that need monitoring data.

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