Research on Intelligent Maintenance Management Techniques for Ecological Protection of Beautiful Expressway Slopes

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Abstract. This paper employs an Internet of Things (IoT) automatic control scheme to achieve unmanned maintenance of vegetation on high slopes. Through timed irrigation and interval-based irrigation control methods, the irrigated area becomes an optimal environment for plant growth. The entire system can cooperate and allow management personnel to remotely control the growth of plants in the entire area, saving manpower and resources. The system's operational effectiveness has been verified, but further reinforcement of monitoring and control is required, particularly for remote feedback from key equipment. This technique is suitable for areas with severe mountains, complex terrains, high manpower and irrigation costs. It is necessary to ensure conditions such as water sources, power supplies, fertilizers, and to pay attention to issues such as the use of water retention agents and the maximum and minimum water requirements under deficit irrigation. Through the research and demonstration of the technology, the level of green construction and operational management of highways has been significantly improved, expanding the recognition in the field of creating green highways in Yunnan and even nationwide. At the same time, it has enhanced the scientific nature of landscape planning and design, protecting and showcasing the unique characteristics of the local natural and cultural environment.

Keywords: Expressway slope; Automatic control; Plant detection; Water requirements

1. Introduction

Intelligent highway maintenance is an innovative technology based on an Internet of Things (IoT) automatic control scheme, where data collection and analysis play a critical role [1]. To better achieve automated control and remote monitoring, it is necessary to collect a large amount of data and make scientific decisions through analyzing these data. Therefore, the application of artificial intelligence technology in intelligent highway maintenance is becoming more widespread. For instance, using deep learning algorithms to analyze collected data on vegetation growth, soil moisture, and other factors can yield more accurate maintenance plans [2]. At the same time, real-time monitoring data can be compared and analyzed with historical data to detect anomalies and handle them promptly. Furthermore, in terms of data collection, IoT technology plays a significant role. By installing sensors and monitoring equipment, real-time

IDEE 2023, November 24-26, Zhengzhou, People's Republic of China

DOI 10.4108/eai.24-11-2023.2343479

monitoring of parameters such as highway vegetation growth, water levels, temperature, and others can be achieved, and data can be promptly uploaded to cloud servers [3]. This also provides an important basis for subsequent data analysis and decision-making. In summary, the application of artificial intelligence and IoT technology has broad prospects in intelligent highway maintenance. Through continuous innovation and improvement of technical means, we believe that we can more efficiently achieve intelligent maintenance of highways, providing more convenient and comfortable guarantees for people's travel [4].

According to the topography of this project, in order to reduce manpower and irrigation costs, the planting of plants and irrigation methods adopt the Internet of Things automatic control scheme, with "timed irrigation, interval-based irrigation" as the main control method [5]. At the same time, "irrigation based on soil moisture, irrigation according to other external control instructions" are reserved as backup irrigation control methods.

The design area of the unmanned intelligent control project for green irrigation on the high slopes of Matai service area is 3200 square meters, divided into two rotation irrigation areas, all of which are imported pressure-compensated drippers; PE pipelines are all placed on the ground, and the drip pipes need to be fixed on the hanging net; unmanned, pumps, filters, etc. are all placed in the pump room. The first-level anchor rod frame beam slope protection, slope ratio 1:1, single anchor rod length 8 meters, 149 rods total 1192 meters, single anchor rod length 8 meters, 22 rods total 176 meters (rapid groove); the second-level anchor cable frame beam slope protection, slope ratio 1:0.75, single anchor cable length 28 meters, 97 bundles total 2716 meters, single anchor rod length 8 meters, 25 rods total 200 meters (rapid groove); the third-level anchor cable frame beam slope protection, slope ratio 1:1, single anchor cable length 28 meters, 45 bundles total 1260 meters, single anchor rod length 8 meters, 7 rods total 56 meters (rapid groove) [6].

In this system, important equipment includes pressure-compensated drippers, automatic backwash filters, and unmanned systems. Pressure-compensated drippers not only have a long lifespan, but also labyrinth flow channel pressure-compensated irrigators have good irrigation uniformity and good anti-blocking performance [7]. Pressure-compensated drippers have anti-siphon characteristics to prevent external debris from being sucked into the dripper. Its pressure compensation capability makes it suitable for uneven ground and long-distance drip tape laying needs [8]. Non-drainage: Once the water supply is shut off, the non-drainage function prevents the dripper from draining. This helps to provide a precise amount of water for each plant. If the greenhouse's drip tape is installed above the plants, this becomes more evident; without the non-drainage feature, the water in the pipeline would completely drain out. A mesh filter is a key device used to clean dirt in the water and is an important link to ensure the normal operation of the micro-irrigation system. This study examines the characteristics of filter mesh surfaces and the interception of material by the filter cake layer, summarizing the interception efficiency. In addition, the research also considers the flow rate and interception rate to identify optimized structural characteristics. Furthermore, the study investigates the inlet location of the mesh filter, and explores the impact of changing the size, shape, and quantity of the flow guide plates on the characteristics of water flow within the filter element and the distribution of particle movement. The paper also investigates the structural size of the particle carrying capacity at the clogged end, and the structural optimization design for thorough flushing of particles during the flushing process. Mesh filters have a huge market demand and the need for applications in many fields [9]. The filtering performance of mesh filters is of great significance for the development of modern micro-irrigation systems. The unmanned system monitors the growth of high-slope plants through high-definition cameras, which can be operated in real-time on a computer or mobile phone, and can monitor the growth of high-slope plants in real-time through the PAD management platform. Meteorological information data is collected by the automatic control environment monitoring system to ensure a reasonable arrangement of the plant growth environment.

2. Unmanned System Research

The automated control system can also compare results based on environmental variables and data, allowing the system to choose the optimal path to manage relevant equipment in the irrigation area, making it the optimal environment for plant growth [10]. With the collaborative operation of the entire system, a single person can control the growth of high embankment plants in the entire area, saving manpower and material resources, and realizing the intelligent management of high embankment plant growth.

2.1. Composition of Unmanned Programs

The unmanned program is divided into four parts: the main program part; the device driver part; the CRC check part; the RS485 communication part.

Program function description:

① Main program part: The main program is responsible for mobilizing the other three programs, executing serial port monitoring, and serial port driving.

② Device driver part: The device driver drives the humidity probe to collect the external humidity value.

③ CRC check part: The principle of CRC check is actually to append an r-bit binary check code (sequence) after a p-bit binary data sequence to form a binary sequence with a total length of $n = p + r$ bits. The check code added after the data sequence has a certain specific relationship with the content of the data sequence. If due to interference, one or some bits in the data sequence make mistakes, this specific relationship will be destroyed. Therefore, by checking this relationship, the correctness of the data can be verified. When the receiver receives the data, it uses the received data to do modulo 2 division on P (pre-agreed), if the remainder is 0, it is considered that the data transmission is error-free; if the remainder is not 0, it is considered that the data transmission has errors. Since it is unknown where the error occurred, it cannot be automatically corrected, and the general practice is to discard the received data. Please note the following three points: a. CRC check is a commonly used error-checking code and cannot be used for automatic error correction. b. As long as it is rigorously selected and a divisor P with enough bits is used, the probability of undetectable errors is very small. c. Only using cyclic redundancy check CRC error detection technology can achieve error-free acceptance (just very approximately considered to be error-free), and it is not necessarily reliable transmission.

④ RS485 communication part: Read serial port data, configure serial port parameters, define RS485 direction parameter pins, define Modbus register group, address, function code, call serial port driver function and CRC check function.

The Deep Dive number can achieve soil temperature and humidity collection. The difference is that the domestic agricultural field generally uses 433MHZ signal transmission, and we use ultra-low power LORA data transmission. Under the condition of solar panel power supply and battery power supply combination, the Deep Dive number can collect data every minute, and the Deep Dive can work continuously for 3-5 years, which is an absolute leading advantage in the industry. We abandon the traditional solar power supply mode, and through design and process optimization, not only reduce the cost of the equipment, but also improve the environmental applicability of the equipment.

2.2. Main Components of the Unmanned IoT Automatic Control System

The IoT automatic control system mainly consists of three parts: the IoT data collection system; the IoT control center and network communication system; and the remote management platform of PC and mobile application software. The main functions of the IoT automatic control and environmental monitoring system are: (1) Meteorological Information Collection in the Irrigation Area: Real-time collection, monitoring, and recording of meteorological information around the base. (2) IoT Centralized Control: Advanced distributed system design principles are used for centralized management and independent control by region. (3) Optimal Strategy Intelligent Control: Based on the administrator's experience data or the comparison results of environmental parameters and experience data, the administrator sets or the system automatically selects the optimal path, performs intelligent management and control of related equipment in the irrigation area, and finally adjusts the environmental parameters to the best growth environment for plants. (4) Remote Cloud Management: Through the IoT big data remote management platform and mobile management platform, the mobile APP software platform or PC computer software platform can remotely view the relevant data information of the base and perform remote management and control of the equipment as needed [11]. (5) Data Cloud Storage and Analysis: The system stores the real-time data collected in the cloud. By logging into the cloud platform through a mobile phone or computer, environmental parameters and other data can be saved and printed in the form of curves for research and analysis.

2.3. Unmanned Soil Moisture Sensor Design Flowchart

The soil moisture sensor is a standard modbus protocol device. The soil moisture probe collects soil moisture in real time and stores it in the microcontroller's memory (as shown in the collection process in Figure 2b). When the microcontroller sends a request to read the moisture value, the soil moisture probe responds. If the request sent by the microcontroller is correct after verification, the probe responds and promptly feeds back the data to the microcontroller. The microcontroller completes a soil data collection cycle (the specific process is shown in Figure 2a). For external devices, the entire system composed of the microcontroller and the soil moisture probe is a complete sensor. This sensor stores the soil moisture data inside the microcontroller. When the host computer sends a request to the microcontroller, if the verification is correct, the correct response occurs, that is, the soil data is sent back to the host computer through the serial port. The host computer and the sensor complete a cycle of data interaction (the interaction process is as shown in Figure 2a). The overall system architecture is shown in Figure 1.

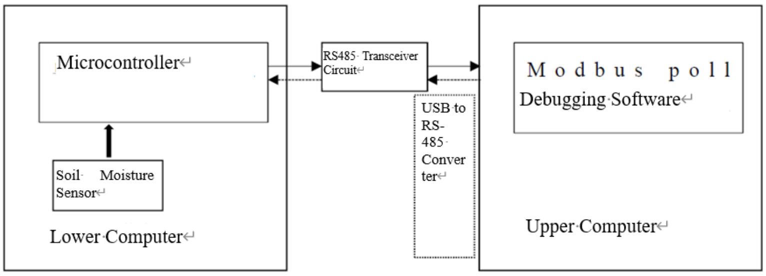

Figure 1. Overall System Framework Diagram

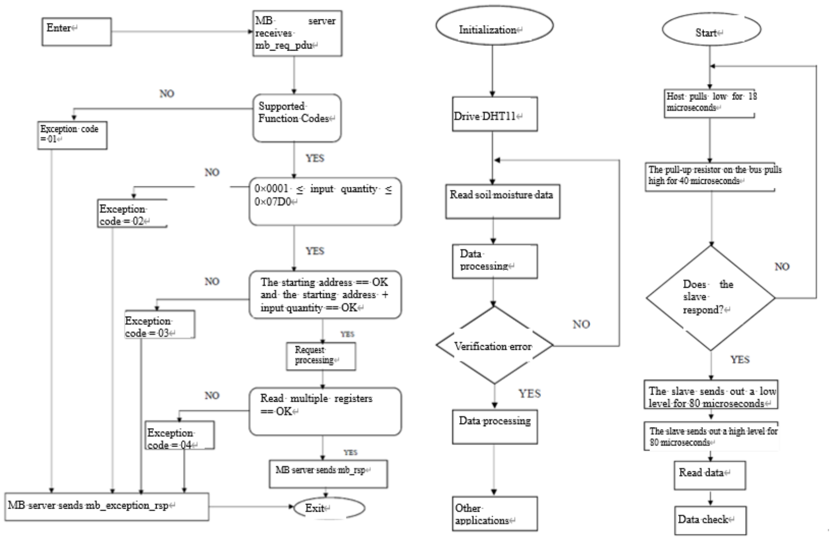

Figure 2. a, b, c State diagram of reading holding registers; Flowchart of soil moisture collection program; Flowchart of soil moisture acquisition subroutine

3. Implementation of the Intelligent Maintenance Management System for Slope

The implementation of this intelligent maintenance management system project relies on three core technologies, namely the implementation of an unmanned system, the efficient filtering capability of filter equipment, and the excellent anti-blocking performance and service life of a pressure-compensated dripper.

3.1. IoT Automatic Irrigation Controller

Due to the large elevation differences in mountainous areas, signals can be blocked during communication. Therefore, a LoRa relay communicator (XZXT-LoRa-4G-Link) will be installed in places with large elevation differences to ensure normal communication.

Figure 3. Control Equipment

The communication connection method between the controller and the control point (solenoid valve) is as follows:

Each set of controllers communicates with the ultra-low power wireless decoder (XZXT-LoRa-Li-Valve) in the irrigation area it controls via LoRa wireless communication. The ultra-low power wireless decoder (XZXT-LoRa-Li-Valve) and the solenoid valve it controls (up to two) are all wired connections.

When the distance from the solenoid valve to the solenoid valve controller is ≤30m, the connecting line uses RVVP--2×1.5mm2 shielded cable; when the distance from the solenoid valve to the solenoid valve controller is within the range of 30m--100m, the connecting line uses RVVP--2×2.5mm2 shielded cable. When laying the shielded cable, a φ16 low-density LDPE tube should be used for physical protection.

3.2. PAD Management Platform

Just like operating a tablet computer, this platform has an intuitive and visualized operation interface, which greatly facilitates the actual operation by users.

Through continuous optimization of the product, the usual practice of only supporting android in the industry has been abandoned. Instead, we have developed operation software that supports android, ios, and linux operating systems. This allows agricultural production to be truly carried out at your fingertips, enabling users of different platform mobile phones to operate without any barriers. Through authorization management, a mobile phone can operate all devices that have been authorized. At the same time, hierarchical account management is used to ensure that all operations are carried out within the framework of management. The platform keeps a complete record of operation usage, making enterprise management more relaxed and controllable, and facilitating the management of formulas and the control of environmental factors. Furthermore, the visualized platform allows users to see the real-time actions of each device during operation, giving them more confidence in using the system.

3.3. Video Surveillance System

In this design, an IoT video surveillance system is configured as follows figure 4:

Figure 4. Construction Record and Camera

This system uses the latest cloud processing technology to transmit the audio and video digital signals from the front-end digital camera to the Ezviz Cloud via the 4G network and the internet. It can be displayed uniformly in the APP, and pictures are intermittently captured to record the growth process. The APP can access the internet for remote real-time video viewing.

Two digital high-definition cameras (DS--2DC4220IW-D--360 degrees) are configured, powered by solar panels and battery packs. The camera comes with a storage card that can be uploaded to the Ezviz Cloud platform.

The basic parameters of the digital high-definition camera are: 360-degree rotation photography, 2 million pixels, 20 times optical zoom, and 20W power.

The digital high-definition camera installation locations are: one is configured at a high position in the middle, and one is configured at a low position to prevent the view from being blocked due to the height difference. This setup provides a detailed reflection of the slope growth situation and the surrounding environment.

3.4. Implementation Process of Unmanned Technology

The unmanned system monitors the growth of high-slope plants through high-definition cameras, which can be operated in real-time on a computer or mobile phone, and can monitor the growth of high-slope plants in real-time through the PAD management platform. The automatic control environment monitoring system can effectively collect meteorological information data, ensuring a reasonable arrangement of the plant growth environment. The automatic control system can also manage and control the related devices in the irrigation area along the optimal path chosen by the system based on comparisons of environmental variables and data. This ensures the creation of the best environment for plant growth. Unmanned technology can be managed and controlled on the Internet through the IoT big data management platform. As long as the system detects unfavorable conditions for plant growth, it will notify you. You can then control and adjust remotely to create an environment suitable for plant growth, ensuring that plants can grow under the most suitable conditions. The plant growth conditions detected by the system will also be uploaded to the cloud data platform for storage. This information can be additionally saved and printed for analysis, providing a better understanding of the plant growth situation.

With the coordinated cooperation of the entire system, one person can manage and control the growth of plants on the high slopes over a large area. This saves manpower and resources and ensures intelligent management of the growth of plants on high slopes.

3.4.1. Pond. The pond uses an assembled installation method, with a size of 29 cubic meters. It includes a rainwater collection system to fully meet the water requirements for drip irrigation in the high slope demonstration area.

3.4.2. Drip Irrigation. The project uses an imported pressure-compensated drip tape with a flow rate of 1.5L/h. It is laid out throughout the entire high slope demonstration area, requiring a total length of 7000 m, with a distance of 0.4 m between each.

3.4.3. Filter. The filter is installed after the pond, using its efficient filtering ability to ensure water quality before the pond water enters the drip irrigation system, ensuring the normal operation of the drip irrigation system.

3.4.4. Others. The pipeline installation uses a total allocation method to ensure consistent pressure in the demonstration area. The pipeline is buried deep underground to prevent direct sunlight. The water pump uses 380 volts and has a power of 10 kilowatts. Its pump room is connected to the edge of the pond.

4. Results and Analysis

(1) Verification Results of Technical Demonstrations

Since the operation of the intelligent unmanned system for high slope maintenance on December 3, 2021, it has been working normally for nearly 80 days. It promptly replenished the soil layer's moisture on the stone high slope, and the areas with vegetation basically grew vigorously, validating the overall operation effect.

(2) Deficiencies or Remaining Issues

The monitoring and supervision of the system operation need to be further strengthened, especially the remote feedback of key equipment such as water pumps, filters, and valves. This part is also under research.

(3) Value of Promotion and Application

Unmanned maintenance of high slope vegetation is managed and controlled by an automatic control system based on environmental variables and data comparison. It allows the system to choose the optimal path to manage and control related equipment in the irrigation area, making the irrigation area the best environment for plant growth. With the coordinated cooperation of the entire system, managers can remotely control the growth of plants in the entire area, saving manpower and resources, achieving intelligent management, and generating significant socio-ecological benefits for expressway greening maintenance.

(4) Conditions or Notes for Promotion and Application

Water Source. Despite the drip irrigation system raising water utilization efficiency to over 97% with small water usage, water shortage still exists in arid and semi-arid areas. Therefore, ensuring water quantity and quality is key to the entire system.

Power Supply. Some projects can secure basic power supply in service areas, but for field projects far from the power grid, power needs to be extracted from solar energy.

Fertilizer. For places with particularly poor natural conditions, consider applying some nutrients.

Others. The application of water retention agents, the maximum and minimum water requirements under deficit irrigation, etc.

5. Conclusion

This project utilizes unmanned technology to achieve "heaven and earth integration" environmental supervision during highway construction, forming a mature set of environmental supervision techniques. After comprehensively analyzing the current status and multi-functional requirements of granite slopes along the Molin expressway, we have proposed an optimized design technique for ecological protection of these granite slopes. We have developed tunnel lighting fixtures with brightness and color temperature adjustment capabilities, as well as lighting controllers with brightness, color temperature, and indoor luminance index monitoring and feedback functions at the tunnel entrance. These innovations allow for a transition in light color between the artificial lighting environment inside the tunnel and the external lighting, enhancing driving safety and visual comfort. We have also proposed a new technique for treating wastewater in expressway service areas using a biodegradation process based on purple clay waste rock materials. Compared to traditional wastewater treatment technologies, this process simplifies the wastewater treatment process, shortens retention time, reduces operational costs, and enhances wastewater treatment capacity within the same land area.

Through the research and demonstration of the results of this project, we have significantly enhanced the level of green construction and operation management of the Molin expressway, as well as expanded the awareness of the Molin expressway in creating green highways in Yunnan and even nationwide. At the same time, it has improved the scientific nature of landscape planning and design of the Molin expressway, effectively protecting and demonstrating the unique natural and cultural environmental features of the region, allowing for a perfect fusion of the landscape and cultural landscape. It has transformed the Molin expressway into a typical demonstration project of an eco-friendly, green, and low-carbon green highway, thereby increasing the influence of Yunnan Province's green construction technology level for expressways.

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