Establishing an Artificial Intelligence-Infused Early Warning System for Cultural Relics via Intelligent Information Assessment and IoT Monitoring

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Abstract. To track the environment of heritage preservation in real-time, this work combines Internet of Things (IoT) technology with offline monitoring techniques. IoT technology is characterized by minimal intervention, quick response times, labor savings, and an innate ability to understand environmental conditions across a large area. IoT technology outperforms traditional offline monitoring techniques in data comparison, analysis, and ecological regulation services. Strengthening data storage capacity, increasing battery capacity, optimizing sensor configuration and calibration, and streamlining the network are all suggested ways to improve the use of IoT technology in environmental monitoring for heritage preservation. These optimizations can greatly enhance IoT technology's use in cultural relic preservation and ecological monitoring and maximize the information-based pre-control capability of cultural heritage environments.

Keywords: IoT; Dunhuang Cave Cultural Asset; environmental monitoring; Artificial Intelligence
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1 INTRODUCTION

The preservation and protection of cultural artifacts are becoming increasingly critical in the current era of rapid advancements in information technology and the Internet of Things [15]. As a component of cultural heritage, cultural relics serve as a window for future generations to comprehend and carry on the wisdom of their ancestors, in addition to serving as a repository for history and culture. However, the preservation environment of cultural relics is essential for their protection because of their uniqueness and susceptibility. We must use cutting-edge technological tools to monitor cultural artifacts' preservation conditions better and guarantee long-term preservation [2]. This work aims to build an early warning system for cultural relics that integrates intelligent information assessment and Internet of Things (IoT) monitoring. It does this by combining IoT technology with traditional offline monitoring methods.

A vital component of the new wave of information technology, the Internet of Things (IoT), was created and developed at the same time as the third wave, which in turn caused a shift in modern social activities, technological production, and lifestyle changes through the use of modern networks, intelligent perception, automation, and aggregation and integration of technology, the Internet, and connections between things and people to create a smart world in which everything is interconnected [14],[5],[20]. Motivated by this context, advancements in computer simulation, sensing, and 3D imaging technologies have been made possible by the IoT. These technologies enable virtual reality to offer users an "immersive" spatial environment that can be viewed, heard, and interacted with. Additionally, as IoT technology develops, so do the application fields for virtual reality technology. As IoT technology evolves, so do its application fields. A museum is a vital witness to the advancement of a nation's civilization. It serves as a place to exhibit and preserve cultural artifacts. Still, it also has the duty of educating the public about history and culture, which is especially important for China's educational and artistic endeavors. Because of this, it must use cutting-edge scientific and technological methods to improve the effects of science popularization [22].

First and foremost, traditional offline monitoring techniques are indispensable for safeguarding cultural heritage. In offline monitoring techniques, environmental parameters surrounding cultural relics are typically measured regularly or fixedly using sensors and other equipment. This approach can produce comprehensive ecological data and is distinguished by its high precision, stability, and dependability [16],[23],[11]. Nevertheless, it has some limitations in real-time and worldwide due to the point-to-point measurement method and the periodicity of offline monitoring. We implemented IoT technology for routine real-time monitoring of heritage preservation environments to compensate for these shortcomings. With various sensors, embedded devices, and network connections, Internet of Things technology can monitor the preservation environment of cultural artifacts from all angles, offering vital assistance for the prompt protection of cultural relics.

Second, developing Internet of Things (IoT) technology has dramatically benefited heritage preservation's environmental monitoring. Robust connectivity, which enables the networking and intelligence of sensors and devices, is a defining feature of IoT technology. This allows us to obtain changes in environmental parameters at any time and remotely monitor the preservation environment of cultural relics in real time [21]. Moreover, IoT technology can result in more effective data comparison and analysis capabilities. By using deep mining monitoring data, we can better understand how the laws governing the heritage preservation environment change and quickly identify possible risks and issues. As a result, integrating IoT technology and environmental monitoring to preserve cultural artifacts will significantly raise the caliber and effectiveness of this work.

To provide a comprehensive guarantee for the long-term preservation of cultural relics, this study aims to build a more intelligent and effective early warning system by integrating IoT technology and conventional offline monitoring methods. Introducing cutting-edge technological tools will open up entirely new development opportunities for the cause of heritage preservation in this era of digitization and informatization.

2 SYSTEM HARDWARE DESIGN

2.1 Data Acquisition Terminal Design

The primary purpose of this system's data acquisition terminal is to use the main control board to operate the corresponding sensors to gather data on the temperature, humidity, and concentration of gases CO2, H2S, NH3, and C2H6O in the storage environment for cultural relics. Additionally, when the hand-held relay node is linked to the wireless transceiver control, data will be transferred to the hand-held relay node for further processing.

The STM32F103C8T6 microprocessor model, which has high cost-effectiveness, low power consumption, rich and reasonable peripherals, and is based on an ARM Cortex-M core, is used in the main control board of the data acquisition terminal of this system. It is a 32-bit microcontroller with a central frequency of up to 72MHz, a 64KB Flash, a 20K SRAM, and 12-bit analog A/D converters. Additionally, it has three USART interfaces, two SPI interfaces, and other interfaces that can fulfill the system's interface needs.

The temperature and humidity sensor, DHT11, made by Guangzhou Aosong Electronics Co., is used in the data acquisition terminal of this design. The gas sensors are CO2 gas sensing probe MG-811, H2S gas sensing probe MG-136, NH3 gas sensing probe MQ-137, and C2H6O gas sensing probe MQ-3. The hand-held relay node receives the data gathered by the sensors via the nRF24L01 wireless transceiver chip from NORDIC. The acquisition uses the "sleep-wake" method to send data to the outside world to save power. Specifically, it wakes once every five minutes, detects the signal from the hand-held terminal, and sends the data it has collected to the hand-held relay device for the following action, provided a hand-held terminal is nearby. Figure 1 displays the schematic diagram of the warehouse data acquisition terminal.

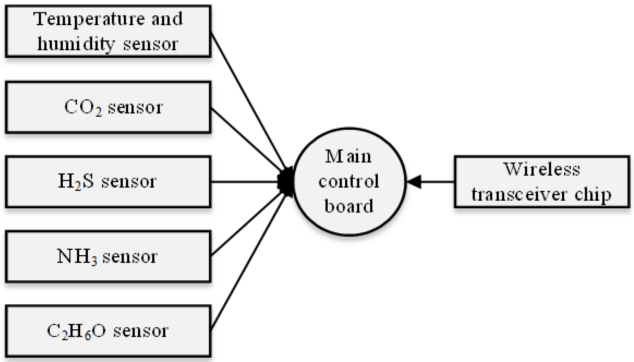


Figure 1: Schematic diagram of data collection principle.

2.2 Hand-held Wireless Repeater Design

The primary function of the hand-held wireless repeater is to activate the nearby collection terminal for data uploading and receiving via the GPRS network. Additionally, the main control board of the microprocessor model STM32F103C8T6 is selected by the main control board [6]. Additionally, the hand-held wireless relay node has an LCD12864 liquid crystal display that supports multiple collection node state switching and shows the operation status of the node that needs to be woken up and the data collected in real-time. In this design, the relay node's nRF24L01 wireless RF chip establishes a connection with the data acquisition terminal, which begins to receive data from the terminal. Simultaneously, it uses GPRS and the Internet as an intermediary for data transmission to facilitate data transmission between the hand-held relay device and the monitoring center. The GPRS data transmission module in this system is the SIM900A module. Figure 2 displays the schematic diagram for the hand-held wireless repeater.

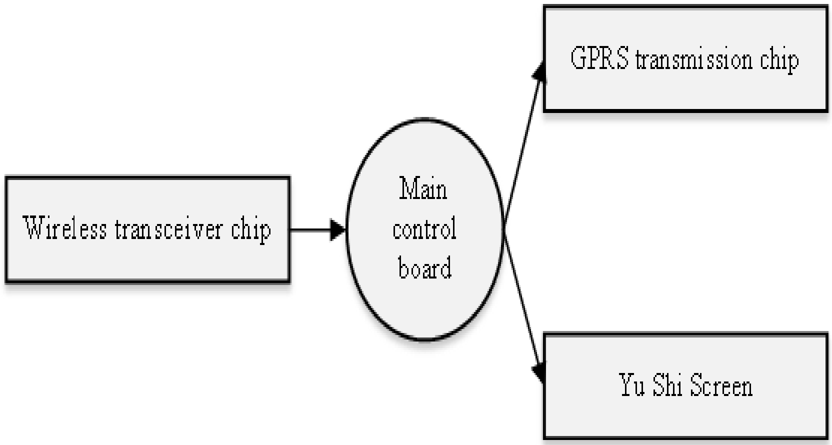


Figure 2: Diagram illustrating the hand-held wireless repeater's essential operation.

3 SYSTEM ALGORITHM RESEARCH AND SOFTWARE DESIGN

3.1 BP Neural Network-Based Artefact Maturity Recognition Algorithm

Artificial neural networks are extensively employed in pattern recognition because of their exceptional nonlinear approximation ability, fault tolerance, self-learning, and self-organization [6],[19]. Error-back propagation neural networks, or BP networks for short, are particularly well-suited for handling imprecise and fuzzy information processing problems that require considering numerous conditions and factors simultaneously due to their nonlinear solid mapping ability, good fault tolerance, and quick processing speed [8]. Before the BP neural network classification recognizer can be recognized and classified, it must first learn from training samples.

Familiarly, by the process of cultural relic maturation, the warehouse data collection terminal collects cultural relics and stores them in an environment with six parameters as the input layer of the BP network. The three categories of "to be ripe," "mature," and "decay" describe how the appearance of cultural relics changes as they mature. The greenish appearance of the artifacts is defined as a "mature" state, as it is all yellow and yellow with more spots as a "mature" state. The term "to be mature" refers to the artifacts' greenish appearance; "mature" refers to all yellow color; and "decay" refers to yellow color with more spots. An analysis and modeling tool is a 3-layer feedback BP artificial neural network, as depicted in Fig. 3. The number of neurons in the network is as follows: Fig. 4 illustrates the specific structure of the input layer, which is 6, the output layer, which is 3, and the intermediate hidden layer, which is 8. The neural network must be repeatedly trained and learned to produce a model that can ultimately identify the maturity level of the artifacts.

Weights connect neurons on different layers to neurons on adjacent layers [12]. The following formula determines a neuron j's output on the hidden and output layers of a BP neural network: Equation 1 determines a neuron j's output on the hidden and output layers of a BP neural network.

$$O_j = f_j(n_j) = \left(\sum_j w_{ji}\, x_i + \theta_j\right) \tag{1}$$

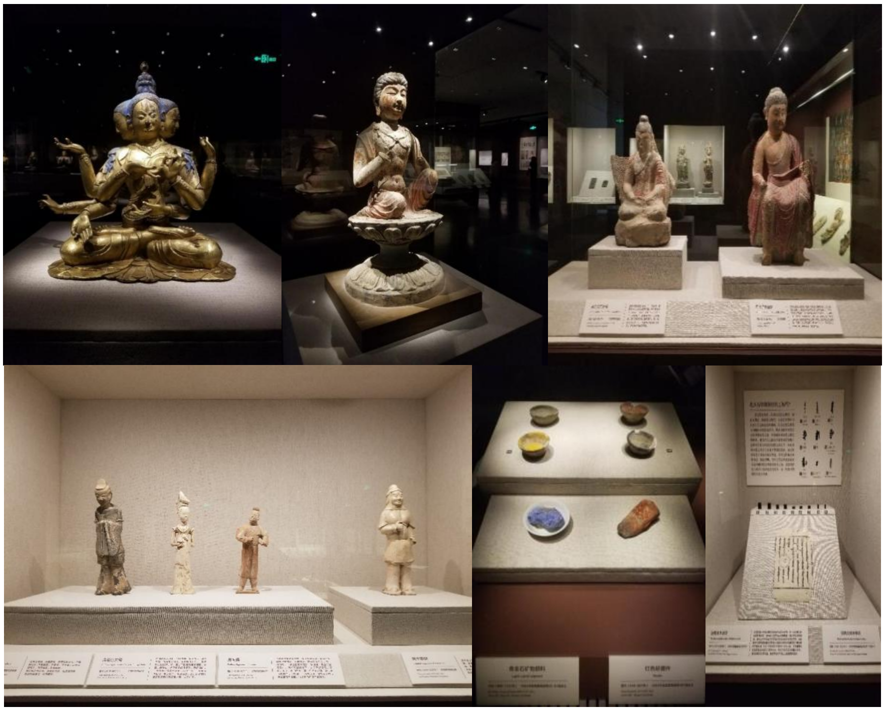


Figure 3: Cultural relics protection.

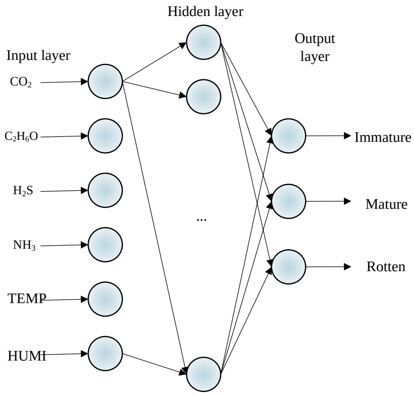


Figure 4: BP neural network structure.

Whereas in the equation above, w_{ji} is the connection weight between neuron j and i, x_i is the input of this neural source, and f_n is the neuron's excitation function；

A continuously differentiable nonlinear Sigmoid function serves as the excitation function：

$$f(x) = \frac{1}{1+e^{-x}} \tag{2}$$

The function's characteristics are as follows: $f(x) = 0.5$ when x = 0, $f(x) = 1$ when x tends to positive infinity, and $f(x)$ tends to 0 when x tends to negative infinity.

3.2 Monitoring Centre Software Design

In this design, the software uses the B/S architecture mode because the hardware of the data processing operation and the system's convenience have high requirements. The data processing link runs on the monitoring center server, and the data processing server receives the hand-held relay device from the data monitoring center for the cultural relics warehousing environment parameters. Real-time storage is achieved by training the cultural relics into the maturity of the classification model of the storage of cultural relics. When monitoring the cultural relics' maturity or mold occurrence, the monitoring center function flow is depicted in Figure 5.

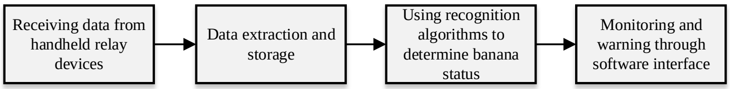


Figure 5: Processing flow of monitoring center.

The primary functional modules of the software system are designed, along with the pertinent database. The data table comprises the following tables: Table 1 (user information), Table 2 (collection terminal information), Table 3 (alarm information), and Table 4 (storage environment information).

Name	*Field name*	*Type*	*Remarks*
User ID	*User ID*	*Int*	*Primary key*
Account	*account*	*varchar*	*Not null*
Password	*password*	*char*	*Not null*

Table 1: User table.

Name	*Name*	*Type*	*Remarks*
Termination ID	*T Id*	*int*	*Primary key*
Terminal number	*number*	*varchar*	*Not null*
Terminal position	*position*	*char*	*Not null*

Table 2: Collecting terminal information.

Name	*Name*	*Type*	*Remarks*
ID	*Aid*	*int*	*Primary key*
Termination ID	*T Id*	*int*	*Foreign key*
Alarm information	*Alarm information*	*char*	*Not null*
Alarm Time	*Alarm Time*	*data time*	*Not null*

Table 3: Alarm information.

Name	*Name*	*Type*	*Remarks*
ID	*Eid*	*int*	*Primary key*
Terminal ID	*T Id*	*int*	*Foreign key*

Temperature	*Temp*	*float*	*Not null*
Humidity	*Humi*	*float*	*Not null*
CO_2 concentration	*CO_2*	*int*	*Not null*
H_2S concentration	*H_2S*	*int*	*Not null*
NH_3 concentration	*NH_3*	*int*	*Not null*
C_2H_6O concentration	*C_2H_6O*	*int*	*Not null*

Table 4: Storage environment information.

4 SYSTEM REALISATION

4.1 Implementation of Pattern Recognition Algorithms

Sample data is first required to train a BP neural network. Sample data is collected using a hardware simulation of a designed cultural relic storage environment. Each maturity of the cultural relic's storage environment is used for three batches of data collection; each batch includes the first handful of cultural relics in the storage box and is sealed for thirty minutes. The data collection terminal sensor is preheated for twenty minutes. Subsequently, as depicted in Figure 6, the terminal will be placed inside the cultural relic's storage box. For the collection of cultural relics data, 6,000 groups were taken, half of which were used as training samples and the other half as test samples. Because there were so many recorded data points, this study only chose a small subset of the data—roughly 100,000 total—for each maturity level of the cultural relic's environment during the 24-hour data collection period, using a frequency of 10s vice-1. Table 5 illustrates how this study only included a small number of data groups with notable variations in the environmental parameters of various maturity states due to the vast volume of recorded data [3],[10].

Figure 6: Heritage data collection.

item / location	*CO mg/m^3*	*NO_2 mg/m^3*	*SO_2 mg/m^3*	*O_3 mg/m^3*	*total suspended particulate matter mg/m^3*
Exhibition center	*2.20*	*0.06*	*0.06*	*0.10*	*0.20*
Tibetan Scripture Cave Exhibition Hall	*2.10*	*0.035*	*0.0*	*0.10*	*0.30*
Academy History Exhibition Hall	*2.20*	*0.045*	*0.05*	*0.10*	*0.40*

Table 5: Dunhuang Academy Cultural Relics Gas pollutant detection.

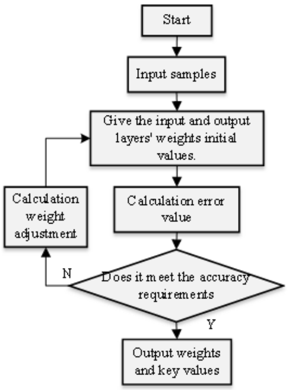


Figure 7: Flow of bp network algorithm.

The data collection terminal in this system experiment gathered six parameters related to the storage environment for cultural relics as the input layer of the BP network and the output layer for placing the cultural relics in the three storage stages: ripe, ripening, and decay.

Fig. 7 depicts the neural network algorithm's flow. The BP neural network toolbox in MATLAB was used to train the network in this study. The neurons in the hidden layer have a transfer function called S-tangent function (tansy), while the neurons in the output layer have a transfer function called S-type logarithmic function (logs); the target is 0.1; the maximum number of cycles is 3,000; and the prepared function is chosen as the training function. The function selected for training is prepared. The Sim function is used to simulate the output of the BP neural network after it has been trained using the Train function, and the neural network model is constructed using the Newff function in the implementation. The neural network training results, as illustrated in Figure 8, when the hidden layer node is 8, according to the experimental results. The training error gradually lowers with increased training times; at 2,500, the training error reaches 0.5, signifying a solid training effect.

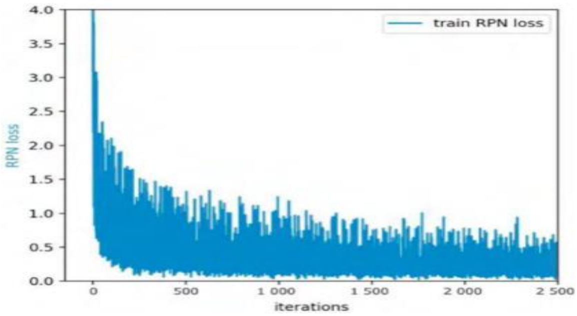


Figure 8: BP network training results.

4.2 IoT Environmental Monitoring System

4.2.1 IoT Environmental Monitoring System at Dunhuang Cave Cultural

Three layers make up the Dunhuang Cave Cultural Asset Reservation Research and Exhibition Center's Internet of Things environmental monitoring system: the application layer, network layer, and perception layer [1],[7],[17]. The network layer comprises the Internet of Things and the Internet fusion network, which use the information gathered from the perception layer for transmission and processing; the application layer is the monitoring system and system management platform in each region. The perception layer is primarily used for temperature, humidity, and other sensors as a monitoring terminal and sensor network to collect various environmental information. The entire system (Fig. 9) uses a variety of sensing devices to gather data on temperature, humidity, light, UV rays, and other elements in the atmospheric environment. The data is then wirelessly transmitted from the sensor location to the monitoring center, enabling automated environmental monitoring.

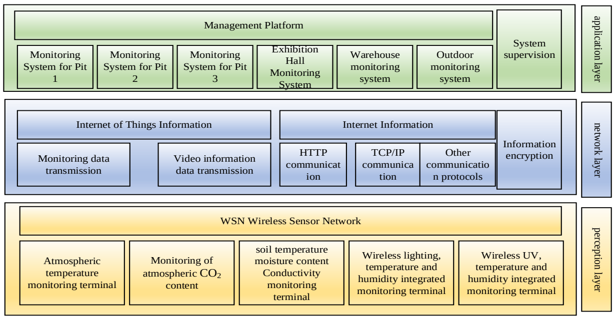


Figure 9: Functional diagram of the structure of the environmental monitoring system.

4.2.2 Dunhuang Cave Cultural IoT Environmental Monitoring System Features

The primary purpose of the environment monitoring sub-system for the preservation of cultural relics is to gather data on environmental elements, including temperature, humidity, carbon dioxide, light intensity, UV intensity, and so forth [4],[18],[13]. To preserve cultural artifacts, environmental settings for real-time presentation, threshold alarm, historical data query, data analysis, and other features can be used in lists, graphics, and other formats. Create reports that the user customizes by combining different kinds of data and facilitating the export of monitoring data.

5 AN EXAMINATION OF THE INTERNET OF THINGS ENVIRONMENTAL MONITORING SYSTEM'S DATA EFFECTIVENESS AND TRANSMISSION CONVENIENCE AT DUNHUANG CAVE CULTURAL

A temperature and humidity wireless monitoring device (MW301GA - HN) and a temperature and humidity logger (Testo175H1, calibrated by the Shaanxi Provincial Bureau of Quality Supervision) with the capability of continuous data storage were placed in an exhibition cabinet in the museum, respectively. A comparison of the temperature and humidity monitoring results was conducted to assess the quality of data acquired and transmitted by IoT in this work (Figure 10). The findings demonstrate that the two devices' overall results trends are consistent (Figure 11), showing the relative validity of the values that each device is tracking. The humidity of the wireless monitoring equipment did, however, slightly drift over the extended period (more than a year) without calibration, indicating the need for routine calibration (either half-yearly or annually, depending on the sensor's accuracy). Furthermore, in addition to standard monitoring equipment, the Internet of Things can also be used to input data into databases for deep data mining. This allows for various approaches to the environmental parameters of historical data presented in multiple ways. This can help the user analyze data, compile information, and assess development trends by summarizing patterns of change in environmental parameters.

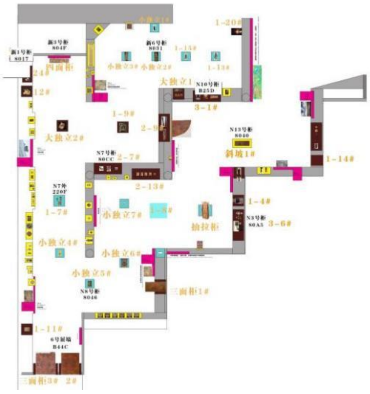
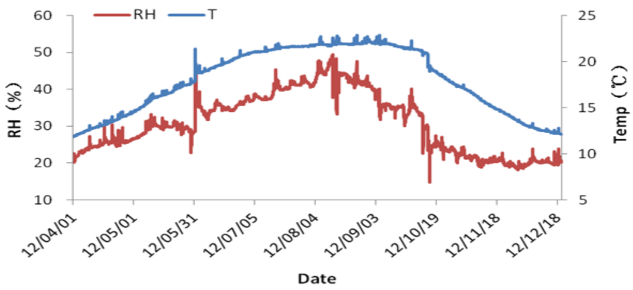
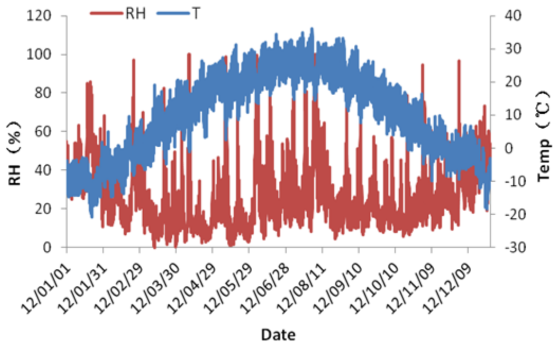


Figure 10: Dunhuang Grottoes exhibition center layout.



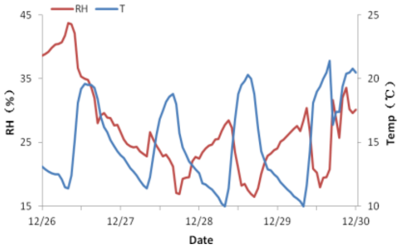
(a) Temperature and humidity curve in the cultural relics warehouse on the first floor



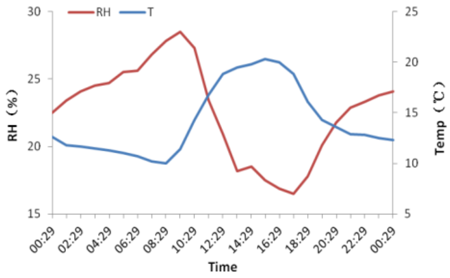
(b) Outdoor temperature and humidity curve chart

Figure 11: Stability monitoring.

The staff can concurrently observe the environmental conditions of various cultural relic preservation areas by using wireless monitoring equipment to visualize each ecological parameter on the software interface as diagrams and numerical values (Fig. 12). Additionally, retrieving the monitoring results from the necessary monitoring points to compare and examine the environmental conditions is feasible; this eliminates the need to visit the location or open display cabinets, etc. to read the data, saving labor intensity and human resources. Furthermore, the distribution and operational state of the monitoring nodes can be seen by showcasing their deployment on the software interface (Fig. 13). Furthermore, the software interface can be configured to remotely set the parameters of single or multiple monitoring nodes (e.g., mean peak acquisition time, data acquisition interval, sensing type precision, and monitoring data formula calculation parameters) to achieve remote control of the working nodes (Fig. 14).



(a) Temperature and humidity curve in the cultural relic's exhibition box



(b) Temperature and humidity curve in the cultural relic's exhibition box on December 28

Figure 12: Temperature monitoring of cultural relics in different areas.

Figure 13: Monitoring (temperature and humidity) navigation interface.

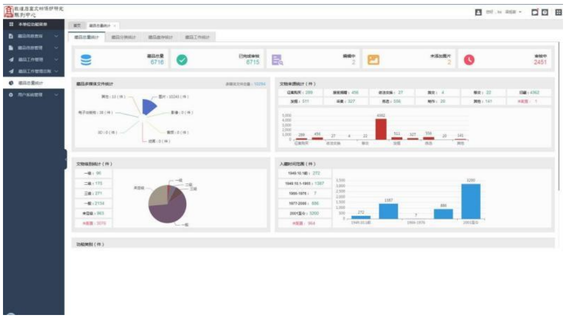


Figure 14: Information statistics interface.

The impact of using IoT technology to monitor the museum environment is minimal. For example, there is no need to regularly open display cabinets or visit the exhibition hall locations to download data, and the results of the target environment monitoring can be viewed directly on office computers. This minimizes interference with the environment used to preserve cultural artifacts and allows for simultaneous access to the environmental conditions of the various monitoring areas to detect issues promptly and issue early warning warnings [9].

6 CONCLUSION

observing the terminal apparatus Small in volume, it can accomplish multiple environmental factors simultaneously with minimal intervention on cultural relics that do not alter their style. It can also respond quickly, collecting, transmitting, recording, and analyzing data in real time, saving labor and facilitating thorough analysis, judgment, and research. Finally, it can synchronously grasp the museum's vast area of various types of environments for cultural relic preservation, high spatial resolution, and rapid environment. As a result, it helps with environmental regulation and is advantageous in data comparison and quick environmental early warning.

Given the features of the Dunhuang Cave Cultural Asset Reservation Research and Exhibition Center's various cultural relic preservation environments, you can significantly increase the popularity of IoT technology in the environmental monitoring of the ruins and the preservation of general cultural relics by combining different networks to smooth the network, prevent data loss, strengthen the data storage capacity, expand the battery capacity, and optimize the configuration and calibration of the sensors. This will increase the information technology of the cultural heritage environment to the greatest extent possible and enhance the ability to pre-control. Creating an artificial-infused early warning system for protecting cultural relics through intelligent information assessment and IoT monitoring presents a pioneering approach to safeguarding our heritage. This system's integration of cutting-edge technology not only aids in preserving invaluable artifacts but also ensures their longevity for future generations.

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