International Journal of Latest Engineering Research and Applications (IJLERA) ISSN: 2455-7137

Volume – 08, Issue – 06, June 2023, PP – 22-30

Sustainable Management of Cultural Assets: The Application of Innovative Technologies and the Improvement of Environmental Monitoring Efficiency

Min-ChenYeh.[1*],Yao-Min Fang.[2], Tien-Yin Chou.[2], Chih-HuiYeh.[3], Yu-LinTsai[3]

[1]*Ph.D. Program for Infrastructure Planning and Engineering Feng Chia University, Taichung, Taiwan (R.O.C.)*
[2]*(GIS center, Feng Chia University, Taiwan)*
[3]*Bureau of Cultural Heritage, MOC*

Abstract: Cultural sites are valuable assets with dynamic historical significance. However, they can deteriorate due to various environmental factors. To ensure their sustainable development and conservation, preventive monitoring is essential. Since 2016, Taiwan's Ministry of Culture has implemented preventive monitoring measures to protect cultural sites. Causes of deterioration include temperature, humidity, wind, and light. In order to effectively monitor the cultural relics protection environment, it is necessary to establish and maintain cultural relics meteorological information systems and micro-weather stations. Research involves goal setting, resource allocation, technology building, and monitoring operations. The aim is to provide accurate weather data and support the preservation of cultural assets. The research contributes to strengthening disaster prevention and promoting sustainable development of cultural heritage. It ensures their value is preserved while providing valuable historical data and cultural experience. This study laid the foundation for the establishment and maintenance of cultural heritage meteorological information system and micro-weather station.

Keywords: Cultural Heritage, Preventive Monitoring, Preservation, Meteorological Information System, Micro-Weather Stations

I. Introduction

Since the Republic of China (ROC) in 2016, the Cultural Heritage Bureau has been implementing a preventive monitoring program for nationally designated cultural heritage sites. This initiative is based on the preliminary planning and research conducted during the three-year project titled "Establishment of the Monitoring System for Historic Sites and Historic Buildings Preservation" from 2013 to 2015. The focus of this research is to observe and analyze the long-term deterioration caused by environmental factors on cultural heritage, and to categorize the sources and forms of damages in detail. By examining the specific reactions of structural materials to various damaging factors, individualized preventive monitoring plans are proposed, and the most suitable protective measures are evaluated for combating degradation phenomena.

Temperature and relative humidity are identified as essential monitoring parameters based on international practices and methods in cultural heritage monitoring and preservation. Micro weather stations are installed at 20 cultural heritage sites, including nationally designated historic sites, settlements, and archaeological sites. These micro weather stations collect localized meteorological data such as wind speed, direction, temperature, humidity, precipitation, air pressure, solar radiation, and ultraviolet radiation. The data from these stations are then integrated with the macro-climatic characteristics monitored by the Central Weather Bureau. This integration allows real-time access to on-site meteorological information and regional image data, establishing a regional meteorological database specific to cultural heritage sites. This serves as the fundamental data for disaster prevention monitoring and damage assessment of cultural heritage.

In the fiscal year 2017, the efforts initiated in 2016 were continued. The existing 20 micro weather stations at cultural heritage sites underwent regular inspections, calibration, and replacement, while an additional 20 micro weather stations were installed. Furthermore, indoor micro-environment sensors were installed at selected demonstration sites such as the Chaotian Temple in Beigang and the Confucius Temple in Tainan. These sensors measure parameters such as temperature, relative humidity, and micro-vibration. In terms of the cultural heritage meteorological information system, in addition to ensuring the normal collection of monitoring data from the 20 micro weather stations, enhancements were made to include equipment anomaly alert functions, the delineation of camera alert areas, and warning functions.

The results of these academic research backgrounds demonstrate that the efforts of the Cultural Heritage Bureau in preventive monitoring, along with the research and implementation of the cultural heritage meteorological information system and micro weather stations, contribute to the preservation and maintenance of nationally designated cultural heritage sites.

II. Related Works

2.1Maintenance and Troubleshooting of Cultural Heritage Environmental Monitoring Equipment

This study was devoted to maintaining and operating 122 cultural asset micro-weather station installations, spread across 64 designated cultural heritage areas. Due to the different environmental conditions of each site, the operations will be inspected sequentially, the inspection results will be recorded and the photos of the operations will be saved, and then summarized into an inspection and maintenance record sheet. The following is a detailed introduction to the equipment maintenance and troubleshooting process.

2.1.1Real-Time System Monitoring Mechanism.

Considering that the equipment deployed in this study spans across Taiwan and outlying islands, a maintenance schedule has been established to ensure the system's operation. However, the system needs to maintain continuous and normal operation, and upon detecting any issues, immediate notifications and repairs are conducted. This study aims to achieve real-time monitoring of the system's operational status through an internal control system that enables the real-time detection of instrument equipment operation at each weather station, thereby enhancing the efficiency of on-site instrument maintenance.

The system is capable of continuously monitoring and detecting abnormal observation data. For instance, if the observation data fails to be transmitted successfully, the system proactively reports the data reception status of each station. Daily reports are sent to the platform via email three times a day to keep track of the operational status of instruments at the site, while devices experiencing communication disruptions are marked with different colors.

2.1.2 Equipment Maintenance and Maintenance Plans

This study focuses on the equipment, maintenance, management, and inspection of instrument bodies, communication systems, power supply, information equipment, and various types of circuitry for micro-weather stations deployed by the Cultural Heritage Bureau across Taiwan and the outlying islands.

The equipment maintenance and management plan in this project consists of two approaches: "regular maintenance" and "irregular ad hoc repairs." Regular maintenance primarily involves proper data measurement, interpretation, and recording to ensure the effectiveness of on-site environmental monitoring data. It also includes implementing basic maintenance to reduce equipment failure or degradation rates and performing firmware updates for information equipment.

Irregular ad hoc repairs are conducted when abnormal monitoring data or transmission interruptions are detected at the weather stations. In such cases, the team visits the site to identify the cause of the abnormality, troubleshoot the issue, and document the process through photography. If equipment malfunction, damage, or other factors prevent on-site repairs, spare equipment and supplies are used to restore proper data transmission mechanisms.

Additionally, for non-equipment issues such as insect infestations that affect the operation of the equipment due to nesting activities, regular spraying of insecticides or applying sunflower oil to the poles, as shown in Figure 1, is performed. The frequency of on-site maintenance is adjusted based on the severity of insect infestation.

Figure 1.Illustration of Pest Control Maintenance for Monitoring Station Facilities

2.2 Equipment Calibration and Inspection

In order to enhance the quality of data collection, this research conducted on-site simple calibration for the comprehensive meteorological station established in 2019. The primary focus of this project is to ensure the proper operation of the equipment. Through the inspection and calibration of various instruments, early detection of instrument issues and subsequent calibration or equipment replacement are carried out to improve the quality of data collection.

This study adopted the comparative calibration method for the calibration of meteorological instruments, drawing inspiration from the Instrument Calibration Center of the Central Weather Bureau.

During on-site simple calibration, the same specification instruments were utilized for synchronous comparative testing. This involved bringing a new set of instruments (factory instruments not yet installed on-site) and simultaneously comparing their monitoring values with those of the instruments already installed on-site to determine the proper functioning of the instruments. Depending on the characteristics of the instruments, different testing procedures are employed to verify their functionality.

2.2.1 Environmental comparison

The instruments applicable for environmental consistency assessment include temperature, relative humidity, atmospheric pressure, solar radiation, and ultraviolet radiation. The operational procedures and processes are illustrated in Figure 2 and Figure 3.

Figure 2.Environmental comparison and calibration procedure

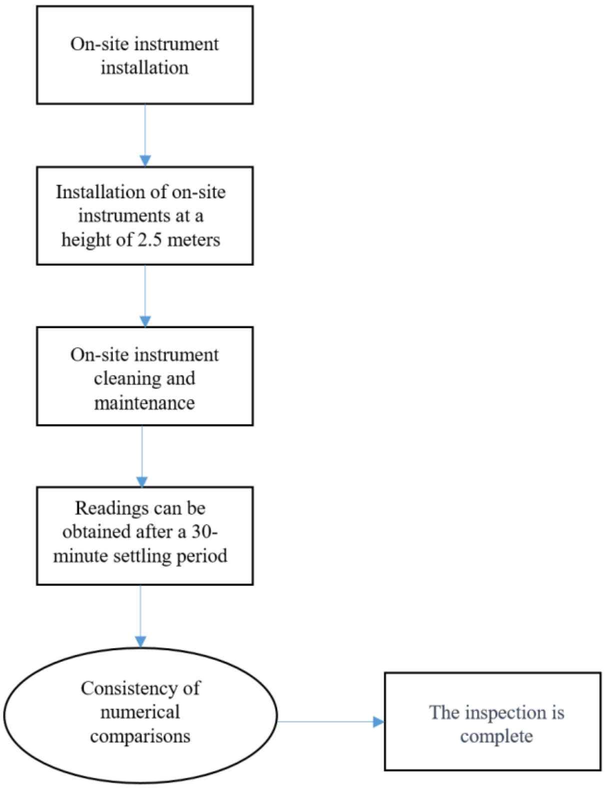

Figure 3. Flowchart of environmental comparison and calibration procedure

2.2.2 Manual comparison

The instruments suitable for manual comparison include the rain gauge, anemometer (wind speed meter), and wind vane. Since the purpose is to create environmental variations manually to confirm the proper functioning of the instruments, the calibration procedures vary for each instrument. The calibration procedures are illustrated in Figures 4 Figures 5and 6.

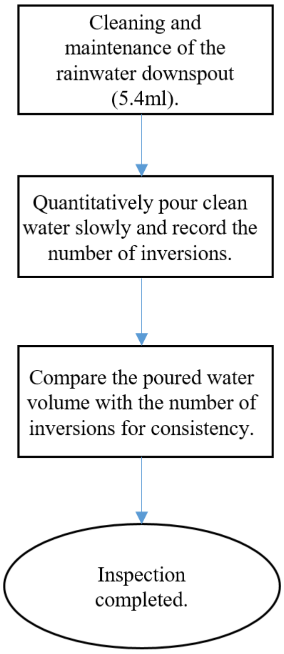

Figure 4. Manual comparison and calibration procedure for rain gauges

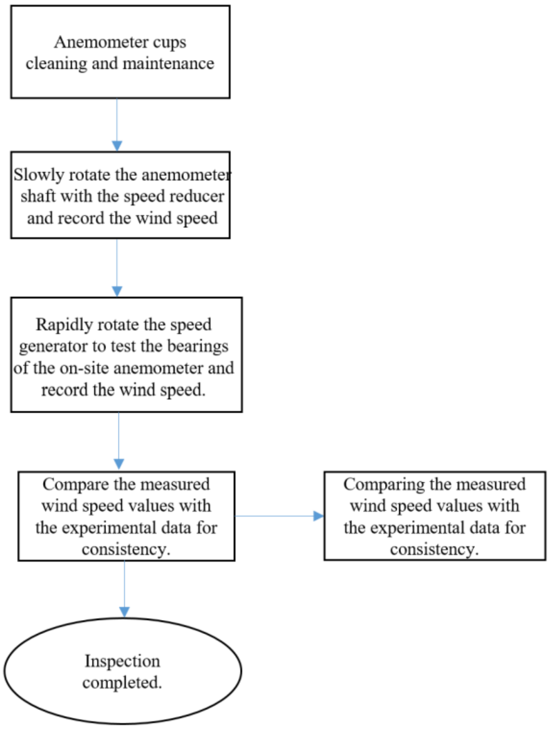

Figure 5. Flowchart of manual comparison and calibration procedure for anemometers

III. Introduction to the Method

For maintaining the normal operation and troubleshooting of the "Cultural Heritage Meteorological Information System," this study will conduct regular server and database inspections and backup procedures. Simultaneously, we will continuously maintain the self-developed data receiving program for the integrated meteorological station and integrate it with the program interface provided by the official website of the integrated meteorological station (as shown in Figure 6). An automated data receiving program will be developed to obtain equipment lists and relevant monitoring data. The research process can be divided into the following main parts:

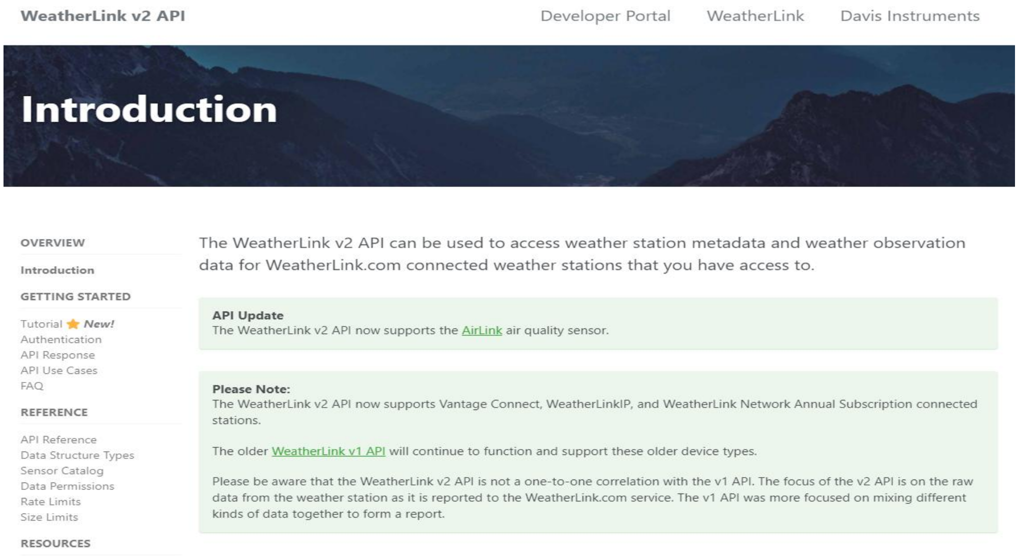

Figure 6. Official API of Integrated Weather Station

(1) System Hardware and Software Maintenance:Conduct monthly inspections of the system's hardware and software functionality and ensure the system's proper operation during the project implementation period. Currently, monitoring data is automatically transmitted from the instrument equipment to the server of the Ministry of Culture. After receiving the data, it will be compared against the set parameters to confirm its validity. Subsequently, the data will be stored in the database and undergo the necessary processing procedures.

(2) Real-time Troubleshooting: Regular system maintenance will be conducted with relevant information recorded for situations where the system cannot function properly, such as the inability to access web pages, error messages, or unidentified intrusions. We provide real-time troubleshooting services that include: (1) Data Reception Interruption: Sequentially verify the proper functioning of the data reception program, ensure sufficient server space and performance, and check the stability of network communication transmission. (2) Inability to Access Web Pages: Remotely check the status of website services, ensure adequate server performance, and verify stable network communication transmission. (3) Error Messages: Remotely examine error logs to identify the causes of abnormalities and address them accordingly, such as verifying the normal operation of database services. (4) Unidentified Intrusions or Other Abnormalities: Check server-related processes and information for any modifications. If restoration or other actions are required, assistance will be sought from the information department of the Ministry of Culture.

(3) Obtaining a list of weather stations: Retrieve the list of all weather stations using the "/stations" endpoint (Figure 7). The data for all integrated weather stations is returned in JSON format, as illustrated in (Figure 8).

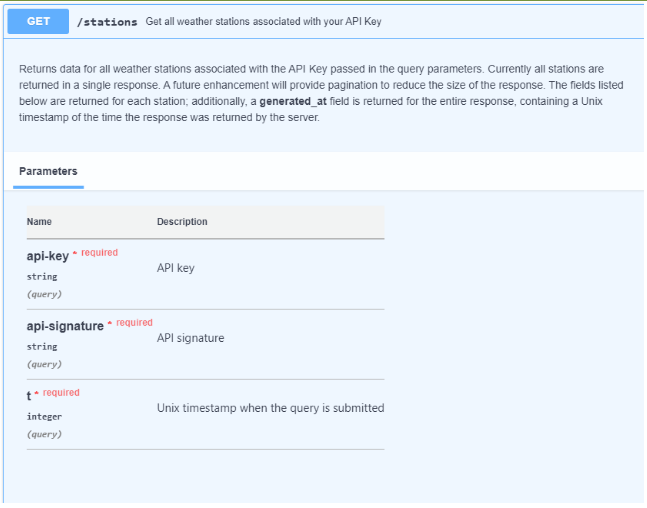

Figure 7. API for retrieving weather station list


```
{
  - stations: [
      - {
            station_id: 53534,
            station_name: "恆春鎮公所",
            gateway_id: 58702,
            gateway_id_hex: "001D0A00E54E",
            product_number: "6555",
            recording_interval: 30,
            firmware_version: "1.1.3",
            registered_date: 1511504173,
            time_zone: "Asia/Taipei",
            region: "taiwan",
            country: "Taiwan",
            latitude: 22.003754,
            longitude: 120.74721
        }
    ],
    generated_at: 1620974816
}
```


Figure 8.Weather station list obtained in JSON format

(4) Obtaining Real-time Monitoring Data: Retrieve the desired weather station ID based on /stations, then use /current/{station-id} to obtain real-time monitoring data (Figure 9).The acquired monitoring data is presented in JSON format, as depicted in Figure 10.

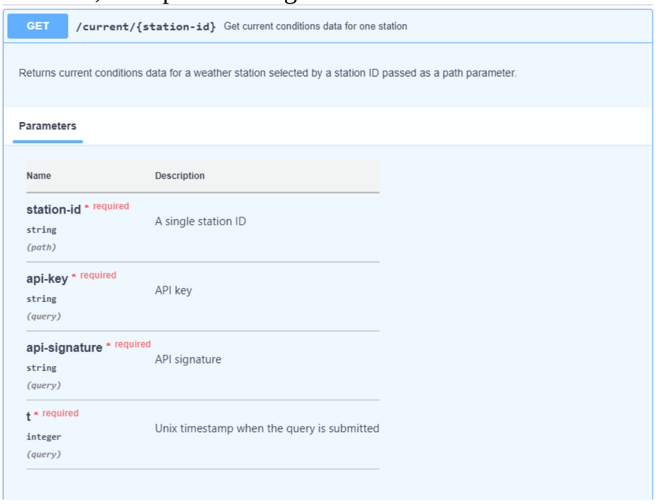

Figure 9. API for Obtaining Real-time Monitoring Data


```
{
    station_id: 53534,
  - sensors: [
      - {
            lsid: 165442,
            sensor_type: 24,
            data_structure_type: 2,
          - data: [
              - {
                    ts: 1639721717,
                    bar: 29.844,
                    temp_in: 83.5,
                    hum_in: 50,
                    temp_out: 77.3,
                    wind_speed: 15,
                    wind_dir: 104,
                    hum_out: 74,
                    uv: 1.8,
                    solar_rad: 536,
                    rain_day_mm: 0.5,
                    dew_point: 68
                }
            ]
        }
    ],
    generated_at: 1639721902
}
```


Figure 10. Obtaining Real-time Monitoring Data in JSON Format

IV. Results and Discussion

The Cultural Heritage Meteorological Information System automates the integration of data from mini weather stations and the Climate Monitoring Data of the Central Meteorological Bureau. It includes parameters such as atmospheric pressure, relative humidity, rainfall, solar radiation, ultraviolet radiation, temperature, wind direction, and wind speed. Additionally, a 3D ultrasonic anemometer is installed to monitor the wind speed, wind direction, elevation angle, sound speed, and temperature in the vicinity of historical sites. This facilitates the assessment of environmental changes and their impact on the cultural heritage.

By conducting data quality checks, the system aims to achieve two objectives: equipment performance analysis and optimization. In terms of equipment performance analysis, quality check rules have been developed based on the inherent characteristics of climate variables to ensure data quality. The verification of the automated check module developed in the previous chapters is also performed. As for equipment optimization, trend comparison with data from nearby reference stations is used as a quality control method to confirm whether the data trends align with the local climate variations. This approach enables the optimization and evaluation of equipment adjustments. These efforts are aimed at enhancing the performance of the environmental monitoring equipment for cultural heritage preservation.

4.1. Analysis and Control of Equipment Performance: Manual Data Verification

Based on the data from the comprehensive meteorological stations and the 3D ultrasonic anemometers installed in 2016, a total of 14 sets of instruments, manual analysis was conducted to assess the integrity and identify any anomalies in the data. Based on this analysis, recommendations for improving the equipment were made to enhance the data completeness and reliability.During the data acquisition, various factors, such as local weather conditions, transmission issues, and instrument malfunctions may lead to data gaps and values outside reasonable ranges. Data verification and quality control measures were implemented to ensure the integrity of the data and increase confidence in its use for subsequent applications. The purpose of data quality control is to confirm the credibility of the data and provide accurate information to users. In this project, data verification was carried out for the comprehensive meteorological stations and 3D ultrasonic anemometers installed in 2016. The data analysis covered the period from the installation of these instruments until August 31, 2022. Table 1 lists the stations included in the data analysis, which consists of 10 cultural heritage monitoring stations, including ten sets of comprehensive meteorological stations and four sets of 3D ultrasonic anemometers.

Table 1 List of Stations and Equipment Categories Installed in 105th Year

Serial Number	station	Integrated weather station	3D Ultrasonic Anemometer
1	Taichung Train Station	1	--
2	Lukang Longshan Temple	1	1
3	MailiaoGongfan Temple	1	--
4	Wang De-lu's Tomb	1	--
5	Tainan Train Station	1	1
6	Chihkan Tower	1	1
7	Former Tainan Prefectural Office & Former Tainan Weather Bureau & Tainan Confucius Temple	1	1
8	Presidential Office & Taipei Guest House	1	--
9	Yuanshan Archaeological	1	--
10	Beinan Site	1	--

4.2 Validation of the Automated Data Verification Module

The comprehensive meteorological station data from "Wang Delu Tomb" and "Former Tainan Prefectural Office" were selected as the validation targets for this study's data automated verification module. The module aims to perform real-time verification of the latest monitoring data and streamline the previously cumbersome manual verification process, thereby reducing time costs.

The data-automated verification module was officially launched on February 1, 2022. The development of this module considered the seasonal variations in monitoring data, such as temperature and atmospheric pressure. Therefore, the verification rules and sampling range were explicitly adjusted from April to August. The relevant parameter settings are presented in Table2.

Table 2 Parameter Settings for Data Automation Verification Rules

check nuclear project	Applicable variable	Related parameter setting	
Continuous Value without change	Relative humidity, air temperature, air pressure, solar radiation, ultraviolet rays, wind speed, wind direction, daily cumulative rainfall	length of time	14 days
value not zeroed	Insolation, UV rays	start time	20:00:00
		End Time	04:00:00
Fault characteristic value	Relative humidity	Eigenvalues	1

4.3 Evaluation of Equipment Optimization Adjustment

Analysis Methods: The Taylor diagram is employed as the analysis method in this study. The Taylor diagram allows for comparing multiple validation data sets with a reference dataset on a single plot, assessing their similarity. Various statistical measures are simultaneously displayed. Assuming the validation and reference data are represented by f_n 、r_n respectively, the Taylor diagram evaluates the similarity using correlation coefficient and root mean square error statistics, visualizing the results.

(1). Correlation coefficient and Standard deviation:

$$R = \frac{\frac{1}{N}\sum_{n=1}^{N}(f_n - \bar{f})(r_n - \bar{r})}{\sigma_f \sigma_r} \text{Formula (1)}$$

Where $\bar{f}$ and $\bar{r}$ represent the means of the validation and reference data:

$$\sigma_f = \frac{1}{N}\sum_{n=1}^{N}(f_n - \bar{f})^2 \text{Formula (2)}$$

$$\sigma_r = \frac{1}{N}\sum_{n=1}^{N}(r_n - \bar{r})^2 \text{Formula (3)}$$

And σ_f and σ_r represent the standard deviations of the validation and reference data, respectively.

V. Conclusions and Recommendations

5.1 Conclusion

(1). Operation and Maintenance of Cultural Heritage Conservation Environment Monitoring Equipment: During the execution of this research project, we conducted maintenance, troubleshooting, calibration, equipment replacement, and optimization adjustments for the existing cultural heritage micro-weather station equipment. A total of 122 sets of equipment were maintained. This equipment is distributed in 64 designated cultural heritage areas to ensure optimal performance of the meteorological instruments and real-time transmission of monitoring data back to the Ministry of Culture's data center.

Regarding maintenance operations, due to variations in environmental conditions at each site, our team collaborated closely with on-site management units to perform inspection tasks while recording inspection results and preserving operation photos. Comprehensive records of inspection and maintenance checks were diligently logged into the Cultural Heritage Meteorological Information System

(2). Operation and Maintenance of Cultural Heritage Meteorological Information System: In terms of software and hardware maintenance, we conducted monthly reviews of system functionality and ensured the normal operation of the system throughout the project's execution. We provided immediate troubleshooting services and documented relevant information.

5.2Recommendations

(1). Enhanced Functionality for System Equipment Record: In this research project, we have improved the existing system equipment history functionality to enhance its capabilities. The previous functionality only included basic equipment information such as equipment ID, coordinates, and calibration time. However, during the project execution, we encountered situations where certain monitoring equipment was temporarily removed or replaced due to long-term station closures or malfunctions, resulting in data interruption. Therefore, we propose to add detailed records of these special circumstances in the future equipment history functionality to facilitate reference for subsequent data analysis.

These enhancements enable the system to comprehensively track changes in equipment and provide more detailed historical records. This ensures data integrity and enables subsequent researchers to analyze and interpret the data more accurately. By augmenting the equipment history functionality, we gain a more comprehensive understanding of equipment operation and can undertake deeper exploration and research of the system's data.

(2). Development of System Audit Function: To enhance system security and prevent image substitution attacks, it is recommended to implement an automatic file integrity check and repair mechanism for static files. This mechanism should perform checks and updates every 10 minutes. Additionally, it is advised to adjust the system's login mechanism to incorporate email-based dynamic verification codes (one-time passwords) for authentication, thus improving security. Furthermore, user traceability should be increased by maintaining logs of user activities, such as system login records, to facilitate auditing in case of incidents.

References

[1]. Hasan Hayat, Thomas Griffiths, Desmond Brennan, Richard P. Lewis, Michael Barclay, Chris Weirman, Bruce Philip and Justin R. Searle The State-of-the-Art of Sensors and Environmental Monitoring Technologies in Buildings., pp. 1-31,2019

[2]. L. Lan, R. Shi, B. Wang, L. Zhang and N. Jiang, A Universal Complex Event Processing Mechanism Based on Edge Computing for Internet of Things Real-Time Monitoring, IEEE Access, vol. 7, pp. 101865-101878, 2019

[3]. Amin Talha Hassan, Dieter Fritsch. Integration of Laser Scanning and Photogrammetry in 3D/4D Cultural Heritage Preservation – A Review., Vol. 9, No. 4, pp. 76-91,2019

[4]. Sandra Fatori´c ID and Erin Seekamp* ID. Securing the Future of Cultural Heritage by Identifying Barriers to and Strategizing Solutions for Preservation under Changing Climate Conditions., pp. 1-20,2017

[5]. Karin Schianetz,Lydia KavanaghSustainability Indicators for Tourism Destinations: A Complex Adaptive Systems Approach Using Systemic Indicator Systems., pp.601-628,2008