Building Operation and Maintenance Management based on Digital Twin

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Abstract

By performing lightweight processing on the digital models of buildings and the building operation data, the digital twin models of buildings are constructed. The static data and dynamic data of building operation are integrated. The characterization data of physical equipment is collected, processed, stored, and analyzed, thereby obtaining the corresponding relationship between the equipment status and the equipment response, realizing the information binding of real and virtual equipment, and enhancing the equipment management level and management efficiency.

Keywords

Digital Twin, Static Data, Dynamic Data, Virtual Reality.

1. Introduction

Digital twins are essentially mapping models of the physical world in the virtual space. By constructing digital twin models of buildings and supported by technologies such as the Internet of Things, dynamic simulation, and augmented reality, digital twin technology can continuously adapt to environmental changes, achieve scheduling optimization, intelligent control, energy consumption management, health management, etc., and optimize the whole life cycle management of buildings. By integrating the static data and dynamic data of building operation, collecting, processing, storing, and analyzing the characterization data of physical equipment, and then obtaining the corresponding relationship between the equipment status and the equipment response, it helps managers make wiser decisions, optimize resource allocation, and improve the overall performance and efficiency of buildings [1]. However, digital twin technology has encountered several technical challenges during the implementation process, such as the complexity of multi-domain modeling and integration, the need for large-scale data processing, the challenges of real-time requirements, and the guarantee of precision and accuracy. This paper conducts research on the application of digital twin technology in the field of architecture from two aspects: building operation data processing and model processing.

2. Digital Twin and Building Operations and Maintenance

The application of digital twins in the field of building operation and maintenance is in a stage of rapid development and continuous innovation. In today's field of building operation and maintenance, digital twin technology has become a crucial means to improve management efficiency and quality. By creating digital models that are highly similar to actual buildings, comprehensive and real-time monitoring and analysis of physical entities have been achieved [2-3].From the perspective of the operation and maintenance management of equipment and facilities, digital twins enable maintenance personnel to clearly understand the operating conditions of various types of equipment. For example, the temperature adjustment of the air-conditioning system, the air volume control of ventilation equipment, and the monitoring of building energy consumption can all be accurately reflected in the digital twin model. With the real-time data collected by sensors and combined with data processing and analysis algorithms, not only can potential faults of equipment be detected in a timely manner, but also maintenance work can be planned in advance, effectively prolonging the service life of equipment and reducing maintenance costs.

Meanwhile, in terms of energy conservation and carbon reduction in buildings, digital twins have also demonstrated huge advantages. By comprehensively considering factors such as the structural characteristics, use functions, personnel flow, and external environment of the building, precise simulation and prediction of energy consumption are carried out. By comparing the actual energy consumption with the predicted energy consumption in real time, the equipment control strategies within the building are optimized to achieve energy conservation in the building [4]. For example, according to the activity patterns of personnel in different areas, the turning on and off of lighting and air-conditioning systems are intelligently controlled.

However, the wide application of digital twins in the field of building operation and maintenance also faces some challenges. The complexity of the technology is one of the key factors restricting its popular application. Firstly, to construct a high-precision digital twin platform, a large number of sensors and Internet of Things devices need to be installed in the building, and massive amounts of data within the building need to be collected, processed, and analyzed. Meanwhile, high-precision models need to be lightweighted to run on the server; otherwise, the model will experience display lags due to its excessive size and cannot be used normally. Secondly, the accuracy and integrity of data are of crucial importance. However, in actual applications, there may be errors or omissions in data collection, which will affect the reliability of the digital twin model.

3. Data Processing and Model Lightweighting

3.1. Data Acquisition and Processing

Currently, the amount of data generated by intelligent buildings is extremely large, and the growth rate of data also shows an increasing trend. The data dimensions stored in intelligent buildings are rather complex, including not only building-related data (such as building materials and building structures), but also the operation data of intelligent systems (such as power monitoring systems, energy consumption monitoring systems, and lighting control systems), and the multi-dimensional data further leads to the increase in the amount of data [5]. There are many problems in the process of collecting, storing, retrieving, analyzing, and visualizing the data of various information systems in current intelligent buildings, which are mainly manifested in two aspects: a large number of dimensions and an enormous amount of data; a wide variety of data types and the existence of a large amount of heterogeneous data [6]. Therefore, this paper focuses on the classification and interface types of intelligent systems within the building to perform data de-heterogenization processing, complete the construction of the data middle platform, and achieve the collection of massive data layers. Meanwhile, a variety of data compression processing algorithms are adopted. By analyzing the characteristics of different types of equipment, a large amount of structured data generated by the equipment is processed and compressed to ensure the stability of data storage and retrieval.

The architecture of the data collection middle platform for each intelligent system within the building consists of the device layer, the control layer, and the network layer. The device layer is composed of various terminal devices of each intelligent subsystem. The control layer is the private control network or bus link within each intelligent subsystem. The network layer is that the network controllers or gateways of each intelligent subsystem convert the private communication protocols within each subsystem into the standard TCP/IP network protocol and then access the device IP management network access switch. Relying on the switches at all levels of the device IP management network, the monitoring instructions and data streams of each subsystem are uploaded and transmitted to the data middle platform. The physical architecture of the system is shown in the figure. The common system composed of each intelligent subsystem and the device IP management network adopts the universal TCP/IP network protocol. The device IP management network conducts data transmission for the network devices of each subsystem that support the TCP/IP protocol by dividing different virtual transmission subnets (VLANs). Each network segment isolates each system and ensures the independence of the speed and bandwidth within each network segment, thus ensuring the reliability of the overall system.

Due to the large variety of equipment types and different interface protocols in the front-end device layer, the data middle platform needs to monitor, query, and control the information of intelligent systems and equipment according to the current equipment types, interface protocols, etc. Meanwhile, it should collect, process, and analyze data based on the information of each subsystem to achieve information sharing and coordinated control among the subsystems. The interface protocols of each intelligent subsystem are shown in Table 1.

Table 1. Interface protocols of each intelligent subsystem

Subsystem	**communication protocol**
Computer Network System	SNMP
Building equipment monitoring system	OPC, BACnet, ModBus
Intrusion alarm system	Web Service, SDK, API, OPC
Video security monitoring system	SDK, API
Entrance and Exit Control System	OPC, Web Service, SDK, API
guard tour system	WebService, SDK, API, OPC
Passenger flow analysis system	OPC, Web Service, SDK, ODBC
Parking garage management system	OPC, Web Service, SDK, API
Information guidance and publishing system	OPC, SDK
Intelligent lighting system	OPC, BACnet, Modbus
Elevator operation monitoring system	OPC, ModBus, BACNet
Building Energy Efficiency Supervision System	OPC, ModBus
Power and environmental monitoring system	OPC, BACnet, ModBus

After completing the data collection of the equipment, it is necessary to process the abnormal data. The preprocessing of the abnormal data in the collected data includes three parts: abnormal data detection, abnormal data processing, and missing value processing.

(1)Abnormal data detection

There are mainly five major categories of commonly used abnormal data detection methods: detection based on statistical-based methods, detection based on distance-based methods, detection based on deviation-based methods, detection based on density-based methods, and detection based on clustering methods. The basic idea of each type of abnormal detection method is to adopt different abnormal detection methods according to the respective characteristics of variables. Since the characteristics of different subsystems in intelligent buildings are not the same, the characteristics and regularities of their data also vary greatly. Therefore, starting from the basic ideas of different abnormal detection methods, this paper discards complex mathematical theory derivations and selects different abnormal detection methods respectively according to the characteristics of variables in each system. In view of the different characteristics of the above-mentioned abnormal data detection algorithms, the abnormal data detection algorithms for the data of each subsystem in the building are summarized to form the abnormal data detection methods for the intelligent subsystems. The specific data detection algorithms applicable to each variable are shown in Table 2.

Table 2. Scope of Application of Abnormal Data Detection Algorithm

Outlier detection algorithm	**Scope of application**
Cook distance detection method based on deletion model	1. Heat exchange well temperature of ground source heat pump system, 2. Temperature measurement well temperature of ground source heat pump system, 3. Photovoltaic power generation, current, irradiance
Statistical anomaly data detection method based on 3σ principle with moving window	1. Temperature difference of air conditioning system, 2. Pressure difference of air conditioning system
Density based LOF anomaly detection algorithm	1. Air conditioning system user side and ground source side flow rate, 2. CO2 concentration value
Threshold method	1. Voltage, 2. Frequency, 3. Power factor
Isolation Forest iForest Algorithm Based on Machine Learning	1. Power, 2. SPD remaining life
Trend anomaly detection method	1. Operation status, voltage, current, power, etc. of the pump, 2. Operation status, voltage, current, power, etc. of the generator
Monotonic sequence logic detection method	1. Forward electrical energy, 2. Reverse electrical energy, 3. Photovoltaic power generation, 4. Water volume, 5. Cooling and heating, etc
DBSCAN algorithm based on clustering idea	Real time power of electrical equipment such as elevators, lighting sockets, and fresh air units

(2) Abnormal data processing

After abnormal data detection, the abnormal values need to be processed. The commonly - used abnormal value - processing methods are shown in Table 3.

Table 3. Outlier Handling Methods

Outlier handling methods	**Method description**
Delete records containing outliers	Directly delete records containing outliers
Mean correction	Correct the outlier by taking the average of the two observed values before and after
Considered as a missing value	Treat outliers as missing values and use missing value processing methods to handle them
Not processed	Directly mining and modeling on datasets with outliers

(3)Missing value handling

Missing values refer to the clustering, grouping, censoring, or truncation of data in rough data due to the lack of information. It means that the values of one or some attributes in the existing data set are incomplete. Missing data is a common phenomenon. In order to conduct a detailed analysis of the data of each system based on the currently available data, it is necessary to appropriately process the missing data. In this paper, the main methods for processing missing data are as follows: deletion method, mean imputation method, hot deck imputation method, regression imputation method, and k-nearest neighbors method.

Since the characteristics of different subsystems in buildings are not the same, the characteristics and regularities of their data also differ greatly. For example, for monotonically non-decreasing data such as electric energy, water volume, and cooling and heating energy, which change relatively little in a short period of time, the mean method can be used to supplement the missing values. Therefore, starting from the basic ideas of different data interpolation methods and the situation of data loss, different interpolation methods are selected respectively. In view of the different characteristics of the above interpolation algorithms, the data interpolation algorithms of each subsystem in intelligent buildings are summarized. The specific missing value algorithms applicable to each variable are shown in Table 4.

Table 4. Missing Value Algorithm

Interpolation algorithm	**Scope of application**
Delete method	1. Short data interval and minimal data loss
Mean imputation method	1. Electricity, 2. Water volume, 3. Heating and cooling, 4. Voltage
Hot card filling method	1. Power factor, 2. Current, 3. Power, 4. CO2 concentration, 5. Irradiance
Regression filling method	1. Electricity, 2. Water volume, 3. Heating and cooling, 4. SPD remaining life, 5. Pressure
K-nearest neighbor method	1. Power, 2. Current, 3. Temperature, 4. Flow rate

3.2. Model Lightweighting

BIM model lightweighting refers to reducing the file size of the BIM model, lowering the demand for computing resources, and enhancing the processing and interaction efficiency of the model through a series of techniques and methods without significantly losing the key information and precision of the model [7-8]. Digital twin systems need to process and analyze a large amount of data in real time, including real-time information from sensors, intelligent devices, etc. [9]. If the BIM model is too large and complex, it will seriously affect the response speed and performance of the system, leading to data processing delays and failing to meet the high real-time requirements of digital twins.

Secondly, in order to achieve the widespread application of building digital twins, especially in mobile devices and cloud deployments, lightweight models can be uploaded, downloaded, and shared among different platforms more easily, improving the scalability and compatibility of the system. Moreover, in digital twins, frequent interactive operations and simulation analyses need to be performed on the building model. Lightweight BIM models can reduce the consumption of computing resources, enabling more efficient complex analyses and simulations and providing more timely support for decision-making.

The main techniques and methods for realizing the lightweighting of building models include:Geometric Simplification [10]: Algorithms such as vertex merging, edge collapsing, and face simplification are employed to reduce the number of vertices, edges, and faces of the model while maintaining its approximate shape and characteristics.

Texture Compression: By compressing the size of texture images, for example, by using compression formats like JPEG and PNG, the amount of texture data is reduced without significantly degrading the visual quality.

Level of Detail (LOD) Technique: Based on the distance of the model from the observer or its importance, different versions of the model with various levels of detail are generated. Low-detail models are used in long-distance or non-critical scenarios to reduce the amount of data.

Model Format Conversion: The BIM model is converted into a more efficient and compact format. Some formats specifically designed for lightweighting have advantages in terms of storage and processing.

Removal of Redundant Data: Elements and data in the model that are unimportant or repetitive for practical applications are deleted, and only the key information is retained.

4. Practical Application

Based on the newly-built business premises of Tianjin Architectural Design Institute, this paper carried out the construction of a digital twin platform. The running effect is shown in the figure. Combining the building model, project static data, dynamic data, BIM data, and relevant operation evaluation indicators, real-time dynamic analysis, evaluation, and display of the building operation situation were conducted. Through the adjustment of control parameters and control strategies, the dynamic adjustment of the building operation performance was achieved, as well as the demonstration of the achievements of the building's intelligent construction. The platform effect is shown in the figure 1.

Figure 1. Platform rendering

Through the digital twin technology in a three-dimensional display form, it can be presented and managed on the unified large-screen interface of the intelligent equipment room in a more vivid and intuitive manner. It provides a visual display for leaders, operation managers, etc., enabling them to understand the overall operation situation of the building in real time, intuitively, and conveniently, and thus offering auxiliary support for comprehensive decision-making and emergency command. The three-dimensional digital twin management application is based on three-dimensional visualization technology, integrating the operation information of various intelligent subsystems and equipment within the building to achieve the integrated operation management of "space + facilities + people".

(1) It has the function of global feature display, including: building models, project static data, dynamic data, and meteorological environment information, etc. Through dragging, zooming in, or clicking operations, one can enter the three-dimensional model of a single building, and perform floor cutting as well as view the equipment and facilities in key rooms. The control and status monitoring of intelligent devices can also be carried out within the three-dimensional model.

(2) It has the scene interaction and roaming functions that combine virtual and real elements. Based on cloud computing and video streaming, the rendering is completed in the cloud. Using

video streaming technology, the ultimate 3D rendered images are transmitted to users in real time, and can achieve the same rendering quality and precision as the client side, providing technical guarantee for the presentation of large-scale scene rendering on lightweight terminals. The roaming supports a smooth animation and lens switching interactive experience, with a multi-linked and friendly interaction form and a multi-angle and multi-lens display method.

(3) It has the function of comprehensive situation display. The comprehensive situation display integrates key information such as security monitoring, equipment and facility management, green energy management, and environmental space into one, with the basic purpose of convenient interaction, enabling a global overview and mastery of various key information.

(4) It has the functions of key data analysis, processing, and display. Through the processing and analysis of the operation data of intelligent buildings, the dynamic data display of the building operation performance can be achieved.

5. Conclusion

The application of digital twin technology in building operation and maintenance (O&M) management offers significant advantages and holds substantial potential. By constructing a virtual mapping of physical buildings, digital twins enable real-time monitoring, predictive maintenance, and intelligent decision-making. This enhances O&M efficiency, reduces costs, and extends the building lifecycle. In the future, as IoT, big data, and AI technologies advance further, digital twins will play an increasingly vital role in building O&M. They will drive the advancement of the construction industry towards greater digitalization and intelligence.

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