Research and design of a digital twin-driven smart river basin platform

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ABSTRACT

River basin management involves many issues including water resources, water ecology, water environment, and water disasters. Digital twins integrated with GIS, BIM and IoT are applied to river basin management, to establish digital twin data and model integration and visual expression methods, study the digital twin operation mechanism, build smart river basin twin, and design a digital twin-driven smart river basin platform. Taking the joint flood dispatching management and control of the reservoir group in the Duhe River Basin as an example. The application has proven that: compared with the problems of incomplete information, insufficient accuracy, lagging feedback and single expression in traditional basin database management or two-dimensional plane management, the digital twin-driven smart basin platform, on the basis of the integration and interaction of GIS data, BIM data and IoT data, and on the basis of data and model two-way drive, can realize simulation, decision making, optimization and visualization in external environment, and the control effect is better than traditional means. The research and practice of the platform can realize real-time monitoring, diagnosis, analysis, decision making and prediction for river basin management, providing a new solution for its intelligent operation, precise control and safe operation and maintenance.

Keywords: digital twin; smart river basin platform; GIS + BIM + IoT; fusion and integration

1. Introduction

The “simultaneous treatment of four rivers” in the basin has far-reaching significance for water resources protection, water ecological treatment, water environment improvement, water disaster prevention and social and economic development. With the change of the focus of water control, higher requirements are put forward for basin management under the new situation. The plan of smart water conservancy of the Ministry of water resources puts forward the objectives of “promoting the modernization of national water governance system and governance capacity”. Applying the new generation of information technology to river basin management will help to improve the level of river basin governance and management.

Digital twin (DT) refers to a digital mapping...
system that makes full use of real data and entity model, integrates multi-disciplinary and multi-professional knowledge, completes “twin image” in digital space and reflects the operation process of the real physical world. Compared with the previous database management or two-dimensional plane management, there are problems such as incomplete information, insufficient accuracy, lagging feedback and single expression. Digital twin makes full use of real-time data, historical data, twin data and entity model to integrate multi-dimensional simulation process and describe and model the whole business process and whole life cycle for human, machine, object, working condition, environment and other elements in the physical space scene in the digital space. Build a digital twin that integrates interaction and efficient collaboration, and finally realize on-demand response, rapid iteration and dynamic optimization of physical space resource allocation and operation[1]. Li[2,3] said that digital twinning is the key way of bidirectional mapping, dynamic interaction and real-time connection between the physical world and the virtual reality of the network world, mapping the attributes, structure, state, performance and function of physical entities and systems to the virtual world with the help of digital twins, the intelligent management of ecological environment and disasters in the Yangtze River basin can be realized. Through the real-time collaborative system, tens of thousands of sensors can be used to collect hundreds of millions of real-time data, so as to obtain all kinds of information, analyze and make decisions in time.

With the help of emerging technologies such as GIS, BIM, IoT and artificial intelligence, this paper uses digital twin technology to faithfully reproduce river basin elements, external conditions, environment and other entities in information space, and constructs the corresponding digital twin driven smart river basin platform through two-way driving of data and model. Through the accurate mapping relationship between digital twins and physical entities in terms of location, geometry, behavior and rules, and based on real-time data, historical data, twin data and professional models, real-time and interactive simulation, decision-making, optimization and visualization are carried out for river basin management, so as to realize data-driven, virtual and real synchronization, dynamic correction and efficient collaboration. Provide a new solution for intelligent operation, accurate management and control and safe operation and maintenance of river basin management.

2. Digital twin fusion and integration

2.1. Data fusion and integration methods

Integrate and exchange BIM data in the micro field with GIS data in the macro field, so that GIS can be deeply applied in many fields from outdoor to indoor, from ground to underground and from macro to micro. At the same time, IOT data itself cannot be associated with the spatial location information and geometric information of building entities. It is necessary to establish macro geographic environment information with GIS and micro building model information with BIM for organic integration to construct digital twin full element information, as shown in Figure 1. Compared with the separate application of GIS, BIM and IoT, the integration and integration of the three have obvious advantages in modeling quality, simulation accuracy, decision-making efficiency, rendering expression and so on[4].

Aiming at large-scale spatial geographic data, BIM model data and Internet of things data, the platform studies the geometric differences and semantic information differences between GIS data and BIM data, analyzes the similarities and differences between their data structures (IFC, CityGML, etc.), realizes the transformation and integration of BIM model and 3D GIS model through the transformation of geometric data, coordinate system and attribute information, and finally realizes the integration and integration of GIS, BIM and IoT (Figure 1).
Independent research and development of three-dimensional GIS platform to support lossless access to mainstream BIM data such as Autodesk, Bentley and CATIA, real-time loading of BIM models of super million components, optimization of BIM performance through instantiation technology, LOD (multi-level of detail) technology, lightweight processing technology and three-dimensional cache technology, so as to solve the problems of resource waste and loading jam of BIM refined models in large scene display; at the same time, WebGL technology is used to realize the visual rendering of 3D scene through the call of GPU at the bottom of the computer, establish the integration method of BIM model and 3DGIS service, and realize the cross platform and cross terminal 3D scene analysis and management service in combination with web and mobile terminal technology.

2.2. Digital twin operation mechanism

The digital twin driven smart river basin platform integrates advanced IoT sensing, big data, cloud computing, wireless communication and automatic control technologies, and establishes the dynamic link and real-time interaction between physical space and information space through full element and multi-dimensional description and modeling of physical entities in terms of location, geometry, behavior and rules in information space, Realize state perception, real-time analysis, scientific decision-making and accurate execution based on two-way driving of data and model, and achieve closed-loop optimization of virtual real integration and synchronous interconnection\(^5\). Its operation mechanism is shown in Figure 2.

![Figure 1. GIS + BIM + IoT data fusion and integration.](image1)

![Figure 2. Digital Twin operating mechanism.](image2)
flood control regulation, flood routing, water ecological carrying capacity, optimal allocation of water resources and pollutant transport, establishes all element mapping and real-time fusion interaction with BIM model in three-dimensional GIS space, simulates and drives the smart river basin under various working conditions, environment and parameters, and generates corresponding river basin management simulation decision-making scheme, Timely conduct consultation and release and provide decision support. Based on the operation mechanism of comprehensive perception, information interaction, in-depth analysis and scientific decision-making of twin system, it can improve the organization and decision-making ability of the whole project, realize the optimal allocation of overall resources and the unified scheduling of various functional modules, and improve the cooperation efficiency of twin platform.

2.3. Visual expression method of digital twins

Spatial geographic data, BIM model data and Internet of things perception data are the digital backplane of digital twin driven smart river basin and the twin reconstruction of various information of physical spatial smart river basin in information space. How to visually express the complex environment, working conditions and evolution of the smart river basin in an all-round, multi perspective and deep-level way in the information space is the key content of digital twin research\(^6,7\).

Aiming at massive multi-source spatio-temporal data, BIM model data and Internet of things monitoring data, the platform has established a variety of visual expression methods, including: a) automatic simplification method of 3D complex model to improve the storage efficiency and loading speed of 3D scene; b) the whole space 3D information visualization method ensures the seamless connection of the model in different scenes; c) scene adaptive visualization method to meet the adaptive loading of models in different user perspectives; d. The physical environment simulation visualization method realizes the high realistic rendering of the real environment in the information space, as shown in Figure 3.

![Figure 3. Visualization method of digital twin.](image)

Independent research and development of 3D GIS platform, establishment of digital twin visual expression method, seamless integration of massive multi-source spatio-temporal data, BIM model data and Internet of things data, establishment of macro, meso and micro integrated management, large-scale 3D scene integrated scheduling and whole space multi-scale and multi-level expression method, so as to realize the digital twin reconstruction of information space.

3. Construction of digital twin of smart river basin

Smart river basin based on digital twin aims to establish a smart river basin digital twin that accurately maps, blends and interacts with physical entities in information space, establish intelligent perception of the whole river basin, all elements and whole life cycle, build a digital model based on GIS + BIM + IOT, and realize the simulation, decision-making, optimization and visualization of river basin operation management through two-way driving of data and model. Each business application scenario in the smart basin should have its corresponding digital twin in the information space to realize real-time monitoring, simulation, prediction, diagnosis and control of the operation status, performance and activities of each business entity in
this paper, the digital twin of smart basin mainly includes the construction of comprehensive supervision twin, water resources management twin, water ecological restoration twin, water environment protection twin, water disaster prevention twin and government and public service twin[8,9].

3.1. Comprehensive supervision twin

(1) Holographic display of information. Quickly collect data for the whole basin, and build a twin that can fully grasp the river basin wading information and realize the intelligent linkage display of information. Relying on the technical basis of model cloud, algorithm base, knowledge base and so on, find problems in time, start relevant business analysis and processing, supervise the implementation, and realize the result tracking, comprehensive comparison, analysis and evaluation of supervision schemes.

(2) Business collaboration. According to the needs of various businesses and regions, build a twin of comprehensive analysis, coordinated disposal and intelligent decision-making according to the relevant businesses involved, so as to realize the collaborative support serving the comprehensive management of the river basin and improve the efficiency of supervision.

3.2. Water resources management twin

(1) Dynamic monitoring and evaluation of water resources. Build the twin of dynamic monitoring and evaluation of water resources to realize real-time monitoring of water resources. Use the water resources evaluation model in the information space to analyze and evaluate the water resources status and development and utilization status of the basin according to different time and spatial scales.

(2) Optimal allocation of water resources. Coordinate the relationship between multi-source water supply and multi-objective water use, and build a twin for optimal allocation of water resources. In view of the serious shortage of water for ecological environment in the basin, on the basis of giving priority to ensuring the basic ecology and domestic water of residents in the basin, comprehensively consider the water demand of all aspects, and jointly allocate multi-source water.

(3) Joint dispatching and management of water resources. Using meteorological forecast and real-time monitoring data, build a twin of water resources joint dispatching management, master runoff changes, predict water inflow, comprehensively consider the dispatching capacity, effect and water demand of various water conservancy projects in the basin, and generate a refined dynamic joint dispatching scheme.

(4) Water intake and water saving management. Based on the twin of water intake and water saving in information space, monitor the water intake in real time, analyze the water consumption according to different scales, and realize abnormal situation alarm, water efficiency and water-saving level analysis in combination with relevant indicators such as total water consumption control index, water intake permit, water use plan and quota.

3.3. Water ecological restoration twin

(1) Water ecological analysis and evaluation. Using remote sensing, video, artificial intelligence identification and other technologies, combined with public opinion, problem reporting, supervision and inspection and other multi-source information, build a closed-loop digital twin working platform covering all links of business, timely grasp the spatial changes of water ecology, and provide auxiliary functions such as patrol management, on-site scheduling, performance evaluation, so as to realize the spatial control of river and lake water shoreline.

(2) Groundwater protection. At the same time, take the groundwater intrusion, groundwater utilization and other factors as the main targets, and build the groundwater protection area, including groundwater intrusion and groundwater recharge, and take into account the changes of
groundwater resources in the shallow groundwater area and deep groundwater utilization area.

(3) Water and soil conservation. Based on the twin of water and soil conservation, the minimum unit of water and soil conservation business management is divided in the information space to realize the intelligent and integrated linkage management of the collection, editing, retrieval and browsing, statistical analysis, output and transfer of business information such as comprehensive management of water and soil loss, prevention and supervision of water and soil conservation, monitoring and management of water and soil conservation.

3.4. Water environment protection twin

(1) Water quality prediction and analysis. Focus on water functional areas, water sources, administrative boundaries, water diversion lines and estuaries to monitor water quality, build water quality analysis and prediction twins around water quality objectives and total pollutant discharge control indicators, strengthen pollution source monitoring, analysis and risk early warning, and realize the analysis and prediction of water quality changes under the influence of different water inflow conditions, water diversion schemes, irrigation modes and pollutant discharge control measures.

(2) Emergency disposal of water pollution. Integrate monitoring, investigation and field data, take risk prevention and control as the goal, build water pollution emergency disposal twins, analyze and predict potential risk sources and prone locations, timely identify and track sudden water pollution events, use water pollution models to realize pollution simulation, risk analysis, deduction and optimization of disposal schemes, and build supporting services such as information services, communication and interaction, process records, information release, effect evaluation, measure analysis, etc.

3.5. Water disaster prevention twin

(1) Flood control and drought relief. Take events as the main line to track the situation of flood and drought in the basin, build the twin of flood control and drought relief in the basin, carry out the simulation, decision-making, optimization and visualization of flood control and drought relief in the basin based on real-time data, historical data, twin data and professional models, and create a whole chain of decision support for multi-dimensional intelligent analysis, joint dispatching of water projects, multi-objective dispatching scenario simulation and scene type full cycle recording.

(2) Project construction and safe operation. Focus on the management of water conservancy projects such as reservoirs, embankments, gates and dams, use three-dimensional model, video, sensing and other technologies to realize the dynamic perception of project risk, build a digital twin of project construction and safe operation, and realize the monitoring, evaluation and risk early warning of project safety status; at the same time, build a digital twin management platform for project safety to realize the safety supervision of the whole cycle of water conservancy project construction and operation.

3.6. Government service twin

Focusing on the administrative affairs such as river basin assets, project planning, finance, poverty alleviation and organ affairs, build a twin of government services by means of information fusion and sharing, process optimization and reengineering, promote the standardization of government services and cross departmental government coordination, and provide the whole process support for supervision and inspection.

3.7. Public service twin

(1) Information service. Provide the public with water related information services required for production, living and entertainment activities, build a twin of information services including disaster event early warning and prediction, water
and water saving guidance and suggestions, and provide information services to relevant management, scientific research, production and operation units.

(2) Transaction service. Based on the twin of transaction services, build an administrative examination and approval processing platform to realize the online processing and information disclosure of administrative examination and approval matters; build a water rights trading platform to provide management tools for water rights trading among regions, industries and water users, and promote the standardized and unified management of water rights trading.

(3) Information exchange. Collect Internet wading information, build an information exchange twin, extract effective information content, screen hot information, predict public opinion development and classify business direction through big data intelligent analysis, so as to provide basis for effective public service work.

4. Overall design of smart river basin platform driven by digital twin

4.1. Overall structure

The overall architecture design of the platform is based on the B/S structure, including five levels: physical layer, data layer, business logic layer, digital twin and user interaction layer, and ensures the standardized, safe and efficient operation of the platform through relevant standard specification system and security guarantee system\[10–12\]. The overall architecture is shown in Figure 4.

4.2. Overall design and implementation

The platform mainly includes five layers: physical layer, data layer, business logic layer, digital twin and user interaction layer\[13–17\].

(1) Physical layer. The physical layer is the basic support of the whole digital twin system, including the space-based integrated sensing equipment and physical entity model, which are responsible for efficient information collection and secure transmission. They jointly support the description and modeling of all elements and life cycle of various entities, environment and information in the information space.

(2) Data layer. The data layer mainly realizes the functions of data exchange, integration, storage, processing and sharing, and integrates big data, cloud computing, virtualization and other technologies to provide basic data support for the whole twin platform including GIS, BIM, IOT and other image model data, real-time data, historical data and twin data of relevant entities in the physical world, with processing performance such as high throughput and high availability.

![Figure 4. Overall platform architecture.](image-url)
(3) Business logic layer. With the help of GIS, BIM and IOT data fusion and integration, artificial intelligence, simulation, decision control and digital twin visualization, the business logic layer constructs the simulation and decision support model of various entities, environments and parameters in the information space through the accurate mapping relationship between twins and physical entities in terms of location, geometry, behavior and rules. Realize the management of water resources, water ecology, water environment and water disasters in the basin under different working conditions and environments.

(4) Digital twin. Digital twins correspond to physical objects one by one, including comprehensive supervision, water resources management, water ecological restoration, water environment protection, water disaster prevention, government affairs and public services that mirror each other with the smart river basin platform under various working conditions, so as to realize information real-time interaction between virtual and real, twin updating, data model driving, simulation decision-making, etc.

(5) User interaction layer. The user interaction layer provides multi scenario business management and interaction interface in the form of web portal terminal, mobile terminal, VR/AR/MR terminal and other terminals.

The platform is based on the self-developed 3D GIS platform framework, integrating spatial geographic data (image, terrain, vector, thematic data, 3D real-world model, etc.), BIM model data, and IoT sensing data, and is built with the mainstream advanced development mode of front-end and back-end separation. Angular and WebGL platform frameworks are used for user interaction and 3D presentation at the front end; C++, JavaEE WEB and Python architecture are used for business logic and algorithm implementation at the back end; MySQL, PostgreSQL and MongoDB are used for database storage and management of spatial data, BIM data and attribute data, thus building The digital twin-driven intelligent river basin platform is built, and the data exchange and business integration of professional models are realized based on the REST web service architecture of HTTP protocol. The overall implementation approach guarantees the scalability, compatibility and advancement of the entire digital twin platform.

5. Application practice of digital twin driven smart river basin platform

There are many twins in the information space of smart River Basin. Taking the flood control joint operation and control system of Duhe River Basin reservoirs in Shiyan City, Hubei Province as an example, the application practice of smart River Basin digital twin platform is carried out. The platform integrates the spatial geographic data of Duhe River Basin, BIM model data, three-dimensional real scene model data, real-time water and rain engineering conditions and other Internet of things data, and integrates professional models such as hydrological prediction, flood routing and flood control operation of basin reservoirs, Through the establishment of digital twins with mutual mapping relationship with the physical world in the information space, multi-scale and multi-level river basin reservoir group monitoring, diagnosis, analysis, decision-making and prediction applications are constructed. The twin construction process is shown in Figure 5, and some function pages of the platform are shown in Figure 6.

The application practice shows that the digital twin driven smart river basin platform integrates massive multi-source heterogeneous data in the information space, integrates various professional models of river basin management, improves the operation efficiency and expression effect of information space simulation, and realizes the simulation decision-making of all elements, multi angles and deep levels; at the same time, with the help of big data, cloud computing, artificial intelligence and other technologies, it has the advantages of fast, efficient, accurate and visual in information retriev-
al, statistical analysis, hydrological forecast, flood control dispatching, scheme deduction and decision comparison, which can provide decision-making basis for river basin management and improve governance level.

Figure 5. Process of Digital Twin for river basin reservoirs group flood dispatching.

6. Conclusion and prospect

6.1. Conclusions

Based on GIS, BIM, IoT, artificial intelligence and other technologies, this paper uses digital twin to describe and model river basin management, external working conditions and physical environment in information space, so as to realize the dynamic link and real-time interaction between physical space and information space, and establish a digital twin driven intelligent river basin platform. Compared with the problems existing in traditional database management or two-dimensional plane management, such as incomplete information, insufficient accuracy, lagging feedback and single expression, the digital twin driven smart river basin platform reconstructs all elements of physical entities in terms of location, geometry, behavior and rules, combines real-time data, historical data, twin data and professional models, and according to the changes of internal and external environment such as the actual situation of the river basin and flood control situation, build a twin system integrating the physical world and information world of the river basin, and realize the simulation, decision-making, optimization and visualization of river basin management in the external environment.
the research and practice of the platform provides effective decision-making to deal with the changes of external complex environment, realizes the management concept of data-driven, virtual and real synchronization, dynamic correction and efficient coordination, and achieves the purpose of virtual control and real control of river basin governance.

6.2. Outlook

Digital twin has initially realized the virtual real interaction and co-evolution in industrial manufacturing, architecture and water conservancy, but there are still questions and disputes in some fields, which are still in the exploratory stage and lack of popularity. With the current advantages of 5G, Bei-dou satellite, blockchain and other technologies in data acquisition and processing, it can further enhance the connection between physical elements, promote the deep integration and interaction of various elements, and enhance the interaction and cooperation between twins, and establish a more perfect and powerful digital twin.

Conflict of interest

The authors declare no conflict of interest.

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