

A Three-dimensional Visualization Intelligent Water Conservancy System Based on Digital Twin

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Abstract:

This paper takes the construction of smart water conservancy in the Mount Tai scenic area and the Da Wen River Basin as the starting point. By applying technologies such as digital twin, OPC, GIS, Internet of Things, and cloud computing, a three-dimensional visualization smart water conservancy system based on digital twin is designed. The system consists of three parts: real-time water conservancy monitoring and perception, digital twin simulation and prediction, and remote control intelligent dispatching. Through the analysis of massive data and the establishment of a three-dimensional visualization model, real-time interaction and precise mapping between physical entities and digital virtual entities are achieved, thereby enabling comprehensive simulation and prediction of the water conservancy system. The overall situation of water conservancy can be grasped on one screen, abnormal problems can be warned in a timely manner, and the best solutions can be proposed. Remote control enables dynamic dispatching and fine management of water conservancy, thus building an intelligent, digital, and precise smart water conservancy system.

Keywords:

Smart Water Conservancy, Digital Twin, Three-dimensional Visualization, Simulation and Prediction, GIS, Basin Management

1. Introduction

China has a vast territory and numerous water systems. With the rapid development of the national economy, the role of water conservancy projects in the national economy is becoming increasingly important, and it is closely related to the country's water security, ecological civilization construction, and the dual carbon goals. However, traditional water conservancy projects, due to their lack of foresight, are difficult to adapt to the complex and changing water resource management environment. Problems such as resource waste, ecological damage, and safety accidents are becoming increasingly prominent. Against this background, the concept of smart water conservancy emerged. With the full-scale implementation of smart

water conservancy construction under the “14th Five-Year Plan”, the state has continuously improved and issued policies, and the investment and construction efforts in the water conservancy project industry have been strengthened. The comprehensive digitalization of water conservancy business has become an inevitable trend. Digital twin technology, as an emerging digital and intelligent technology, has brought unprecedented opportunities to smart water conservancy.

2. Project Introduction

The three-dimensional visualization intelligent water conservancy system based on digital twin is realized by monitoring video and sensor monitoring data to achieve real-time monitoring of river and lake water conditions, water quality, water ecology and other information. Then, the data are uniformly aggregated to the data base of the digital twin platform for the fusion and superposition of data visualization charts. Finally, it is presented in the form of three-dimensional models. Through digital models and simulation algorithms, it can promptly issue early warnings of natural disasters and provide the optimal solutions, comprehensively monitor and manage the water conservancy system, and realize digital scenarios, intelligent simulation and precise decision-making. (Figure 1)

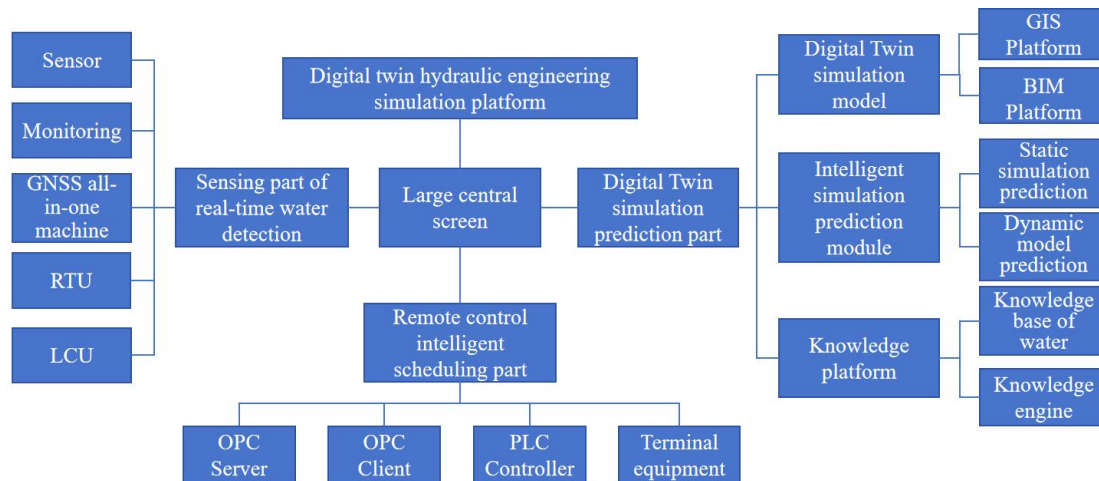


Figure 1. The overall structure diagram of the system.

2.1. Research contents

Through water quality sensors and monitoring equipment, the system online monitors water temperature, water level, water quality, water flow rate, water volume, video images and other information, and transmits them to the database of the central digital twin platform of the system through the WIFI wireless network channel for analysis and processing. The digital twin part uses the integrated coupling of water conservancy professional model, intelligent analysis model and simulation visualization model to construct a digital twin hydraulic engineering simulation platform, which displays various water conservancy and hydrological information on the platform, and displays the specific urban water supply distribution, reservoir location and river and lake conditions with three-dimensional models. The system will compare the current hydrological information index with the data index under normal conditions according to historical data, and automatically issue an early warning if abnormal points are detected, and integrate the optimal solution according to the historical response solutions imported in the database and present it on the central

intelligent large screen, and finally realize automatic management and allocation through remote control. Control the data index to the normal range. (Figure 2)

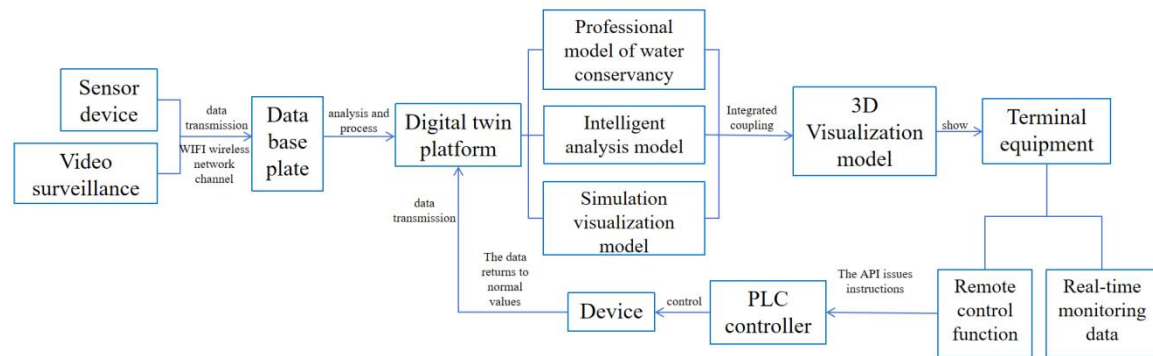


Figure 2. The working flow chart of the system.

2.1.1. Sensing part of real-time water conservancy monitoring

The main function of this part is to connect the field sensors and monitoring equipment through the serial port RS485/RS232 way, using the existing LCU (control and monitoring unit running status), RTU (image monitoring + water data acquisition + wireless communication transmission), GNSS integrated machine (real-time monitoring of rivers, lakes and reservoirs of three-dimensional position, speed and acceleration) equipment, By installing various hydrological sensors in the river and lake area, such as water level monitoring sensors, flow speed monitoring sensors, rainfall monitoring sensors, water quality monitors, etc., the river system is fully covered and real-time hydrological information is monitored and the monitoring data is integrated. The data is transmitted to the computing node of the central digital twin processing platform through the wireless network in real time for storage, data cleaning, conversion and verification. The following sensors and instrument models are mainly used (Table 1):

Table 1. Part of the application devices and models for real-time water conservancy monitoring and perception.

Water level monitoring sensor	SITRANS P DS
Flow velocity monitoring sensor	HFWM-8001
Water temperature monitoring sensor	PT100
Water quality monitor (measuring PH, ORP, conductivity, dissolved oxygen, turbidity, Residual chlorine, ammonia nitrogen)	OSG800
Flow monitoring sensor	FS2012
Rain monitoring sensor	TP02
Industrial router	ZR5000
Industrial computer	General
GNSS all-in-one machine	JD-WY1
LCU	FX100
RTU	S262

In addition to obtaining monitoring data from hardware, the system will also automatically connect to the website of the local hydrological data center or the relevant hydrological data sharing platform to obtain hydrological data, and timely understand the local rain conditions, river flow, water level, reservoir hydrology and other information.

(Note: Collection function: collect water level, rainfall, flow rate, discharge, water quality and other hydrological data, the collection frequency can be set to 1-5 minutes once, 24 hours of uninterrupted acquisition;)

2.1.2. Prediction part of digital twin simulation

(1) Digital twin simulation model construction: In this part, the data acquisition, transmission and storage mechanism should be built inside the system, and the scientific classification, coding format and exchange standard of data should be unified, so as to construct a data set matching the needs of water conservancy engineering. Then, the constructed data set is simulated in the virtual space by using the digital twin modeling technology to construct the digital twin model corresponding to the physical water conservancy project in the real world, so as to realize the real-time synchronization of information. At the same time, the system allows Internet of things devices access, supports a variety of GIS and BIM protocols, and uses GIS+BIM technology to build high-precision 3D terrain and geomorphology models and 3D engineering structure models on GIS and BIM platforms [1], including Digital Elevation Model (DEM), Digital Orthophoto (DOM) and vector data. It can intuitively display the location, scope, status, runoff composition and other element information of rivers, lakes, reservoirs, groundwater and other elements, so that they have accurate mapping with physical entities in information, behavior and rules, and can interact in real time to shape digital scenes. Various mathematical models are constructed on the numerical simulation platform, such as one-dimensional and two-dimensional hydrodynamic models [2] (used to simulate water flow process, predict flood, assess water resources, environmental protection, energy development, etc.), flood season scheduling optimization models (used to reduce flood losses, improve water resources utilization efficiency, optimize water resources management, promote basin governance, provide decision support, etc.), etc. It is fused with the 3D model [3] for parameter calibration and model verification.

(2) Intelligent simulation and prediction module: Based on the 3D terrain and geomorphic model and 3D engineering structure model constructed by the digital twin simulation model, the static simulation prediction and dynamic simulation prediction of various working conditions and scenes of rivers, lakes and reservoirs are carried out [4]. Static simulation prediction is based on the generated structural model, through the interaction with the historical data collected by the real-time water conservancy monitoring part, combined with the simulation engine to carry out offline simulation prediction of the running state of the river, lake and reservoir under different circumstances. For example, when the water resources are scheduled, the system will record the parameters of the historical water resources scheduling, and compare the simulation parameters with the historical parameters in the virtual space. At the same time, the prediction results are visualized in the form of graphs and charts. Dynamic simulation prediction mainly shows the state and change process of river and lake basins and reservoirs under different scenarios, such as normal conditions, extreme weather, flood season scheduling, dry season supply, emergency response, etc. The BP neural network algorithm [5] is used to carry out the intelligent water conservancy dynamic modeling according to the data transmitted from the water conservancy monitoring part, and the three-dimensional dynamic image is visualized. For example, when there is a sudden rainstorm, the system will predict the duration and total rainfall of the rainstorm according to the rain flow in the area monitored by sensor technology and combined with the information of the meteorological

department. The corresponding data will be transmitted to the knowledge platform in time and the emergency plan will be generated, which will be displayed on the central intelligent large screen to realize intelligent simulation. The BP neural network algorithm model is shown in Figure 3 below:

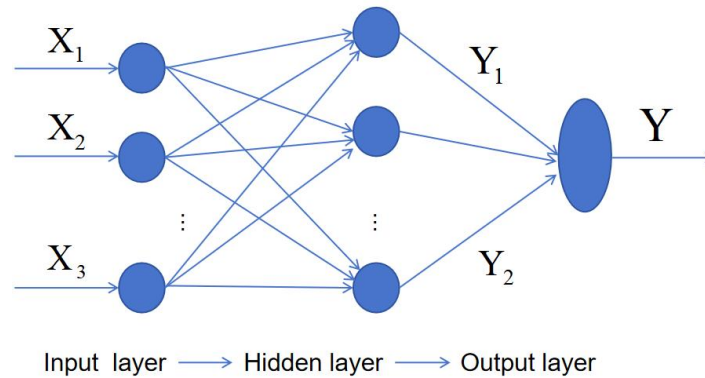


Figure 3. BP neural network algorithm model.

Where, the neural network input pattern is $X = (X_1, X_2, \dots, X_n)^T$, the output mode is $Y = (Y_1, Y_2, \dots, Y_h)^T$, the hidden layer contains h units, the output layer contains m unit, their output is $Z = (Z_1, Z_2, \dots, Z_m)^T$, the target output is $T = (T_1, T_2, \dots, T_m)^T$, and the transfer function from the hidden layer to the output layer is f , the transfer function from the output layer is g .

$$Y_j = f\left(\sum_{i=1}^n \omega_{ij} x_i - \theta\right) = f\left(\sum_{i=0}^n \omega_{ij} x_i\right) \quad (1)$$

$$Z_k = g\left(\sum_{j=0}^h \omega_{kj} y_j\right) \quad (2)$$

Where: Y_j is the output of the j neuron in the hidden layer; ω_{ij} is the connection weight from neuron j to i neuron, when $i = 0$, $\omega_{0j} = \theta$ $X_0 = -1$ θ is a threshold value; Z_k is the output of the k neuron in the output layer, where the error between the actual output and the target output is ε

$$\varepsilon = \frac{1}{2} \sum_{k=1}^m (t_k - z_k)^2 \quad (3)$$

Among them, in order to reduce ε , the weights need to be adjusted

$$\Delta \omega_{pq} = -\eta \frac{\partial \varepsilon}{\partial \omega_{pq}} \quad (4)$$

Where: η is a step size.

The iterative formula of weight adjustment from hidden layer to output layer is

$$\omega_{jk}(t+1) = \omega_{jk}(t) + \eta \delta_k Y_j \quad (5)$$

The iterative formula of weight adjustment from the input layer to the hidden layer is

$$\omega_{ij}(t+1) = \omega_{ij}(t) + \eta \delta_j X_i \quad (6)$$

(3) Knowledge Platform Construction: Taking the 3D scene model of Mount Tai scenic area and Daven River Basin as the main breakthrough point, it integrates the knowledge of water project scheduling business rules, historical flood scenes, expert

forecasting and scheduling experience, and forecasting and scheduling. At the same time, different types of data are structured, textual and knowledge-based. The knowledge base of water conservancy covering business rules, historical scenes, expert experience, forecast scheduling scheme and other content is established. Combined with the knowledge management and application requirements of water resources scheduling and disaster prevention, a knowledge engine [6] is built based on AI algorithm models such as natural language parsing, machine learning and deep learning, including water conservancy knowledge reasoning, intelligent matching of plans, natural language parsing, AI analysis recommendation and external knowledge sharing services. It provides knowledge extraction, knowledge update, knowledge query and other services, realizes the automatic recommendation of emergency rescue and flood control scheduling plans under different early warning conditions, and effectively supports the precise decision-making of emergency rescue and water resources scheduling.

2.1.3. Remote control intelligent scheduling part

This part uses the technology of Internet of things, OPC and PLC [7], and uses OPC Server to connect sensor devices to collect and process standardized data of water resources parameters such as water level, flow rate and water quality. OPC Client establishes connection with OPC Server according to the OPC interface protocol [8]. The data is collected from the OPC Server and transmitted to the PLC controller in real time. PLC controller is built (Siemens CPU224XP is used in this system) to determine the control logic, that is, how to control the parameters. For example, the start and stop of the pump is controlled by adding the reservoir level meter, the water level change is controlled by the deep well dynamic and static liquid level detector, the flow and pressure are controlled by the electric control valve, and the real-time scheduling data information of the central control reaction in water quality detection is controlled. Including water quality, valve opening, flow, flow rate, pressure, temperature, humidity, etc. In the process of remote data transmission, the system uses Siemens CP243-1 (CP243-1 is a communication processor suitable for running in the S7-200 automation system, which is used to connect the S7-200 to the industrial Ethernet). The communication layer is through the DCOM interface, and the OPC protocol is used as the bridge. The data transmission channel between PLC controller and terminal equipment is established by PLC plus Ethernet extension module. With the help of HTML5 WebSocket communication method, the client interface is divided into two parts: Web dynamic pages accessed by the browser and Web API interfaces provided for mobile terminals. Users can control the page through computer WEB or mobile phone APP and other terminal devices to monitor and control the water conservancy system online anytime and anywhere. Call API to send instructions to the device end, so that real-time data is displayed in one screen, remote control is started with one key, and the reliability and operating efficiency of the system are improved. For example, check the current water environment of rivers and lakes and the water and rain monitoring data of upstream and downstream rivers and reservoirs; The floodgate can be automatically opened during the flood to control the flood level. The floodgates can be automatically closed during drought to protect water resources. At the same time, multi-type control functions such as water supply opening time, opening time, immediate closure, and closure after the specified time are opened. Through remote control technology, the precise control and optimized operation of water conservancy engineering facilities can improve the efficiency and

quality of water resources, so as to realize the fine control of water conservancy facilities. (Figure 4)

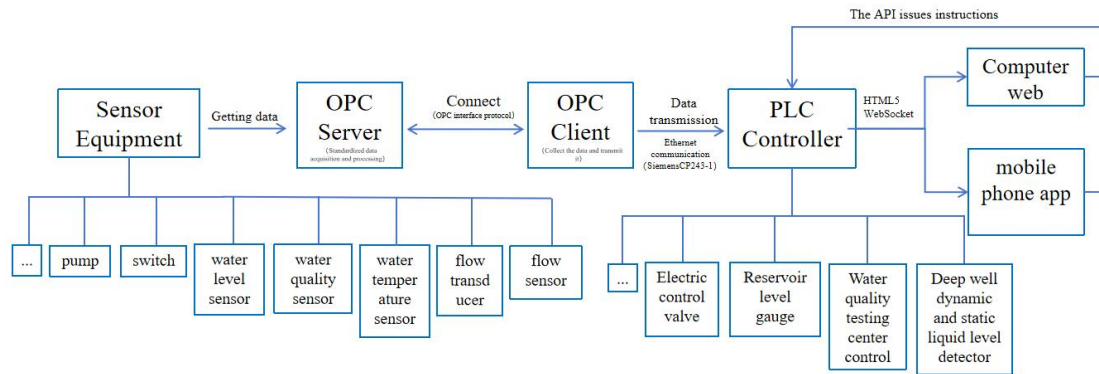


Figure 4. The flow chart of the remote control.

2.2. Research Methods

2.2.1. Construction of data base plate

The Dawen River is located in Shandong Province, China. Its main stream is approximately 250 kilometers long, with a drainage area of 14,486 square kilometers. There are 27 reservoirs in the basin, with a total storage capacity of 115 million cubic meters. Over 140 irrigation projects have been built, covering an area of 733,333 mu. There are 15 hydrological monitoring stations, all of which have achieved automated ground water level observation. A total of 117.9 kilometers of flood control embankments have been planned and constructed, with the completion rate of flood control projects on the main stream and tributaries of the Dawen River reaching 100%. It is one of the important water resource regions in Shandong Province. The comprehensive collection of digital scenes of the Dawen River main stream is an important task for further strengthening the management of rivers within Shandong Province, providing data support for the flood forecasting system of large and medium-sized reservoirs and key rivers in Shandong Province. Therefore, our system builds a data baseplate based on the information of the Dawen River Basin. (Figure 5)

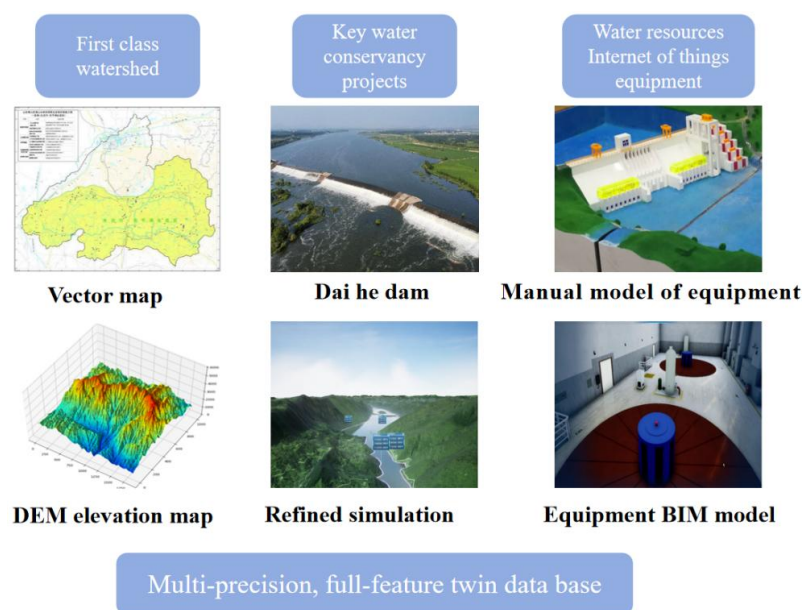


Figure 5. Logical diagram of digital twin water conservancy data floor construction.

As the core and key of smart water conservancy, the construction of a data baseplate is the top priority in the construction of a digital twin river basin [4]. At the macro scale, it focuses on the overall information of the Dawen River Basin, based on the “Water Conservancy One Map”, including vector map data, DEM elevation map data, etc., providing a spatio-temporal data foundation for the macro scene construction of the digital twin river basin. At the meso scale, it mainly focuses on the information of a certain river section where key water conservancy projects are located, including refined real-time data, high-precision DEM data, etc. At the micro scale, it mainly focuses on the specific water conservancy project level, such as water conservancy Internet of Things equipment, reservoir dams, etc., based on GIS+BIM technology, restoring the appearance and internal structure details of the equipment model.

By integrating various technical means such as comprehensive water conservancy sensors, LCU, RTU, GNSS all-in-one machine, numerical simulation, BIM model, etc., and through the collection and processing of water, land, and air data, a multi-temporal, multi-dimensional, and multi-map (DEM, DOM, numerical simulation, etc.) L2-level data baseplate is built, and L3-level BIM models [9] are constructed for reservoirs, irrigation projects, hydrological stations, flood control embankments, bridges, etc. The technical route is as follows:

(1) Collect the existing data models in the main river of the basin. On the one hand, make full use of the government’s public data service platform to realize cross-departmental data sharing of water conservancy and ecological environment, natural resources, agricultural planting, transportation and other data; On the other hand, make full use of the network data, carry out the river basin images, vector data acquisition, the establishment of river basin spatial geographic information model prototype.

(2) Carry out data collection in the river basin, and establish high-precision 3D real scene model [10] by using water sensors, LCU, RTU, GNSS integrated machine, BIM 3D modeling and other technical means.

(3) The powerful platform visualization technology is used to fuse PB level data, integrate the basic digital scene, and realize the automatic fusion between different resolutions, different sizes of data space data and different types of business data, including two dimensions of spatial data fusion and business data fusion.

(4) Based on the three-dimensional digital river scene, combined with spatial analysis, virtual simulation, scene roaming and other technologies, explore new application modes in the flood routing, estuary and river scour and deposition changes, river bed changes, and flood control situation research and judgment, so as to improve the management level of river basin flood control and disaster reduction.

The basic data of water conservancy in the basin, business management data, dynamic monitoring data, geospatial data and cross-industry shared data collected on the existing basis are linked and fused with the data model as the core to form a data base of basic data unification, monitoring data collection, two and three dimensional integration, cross-level and cross-business, and realize the digital mapping of all elements. It integrates with model platform and knowledge platform to standardize business data, and forms a data support system with continuous update ability.

2.2.2. Construction of mathematical model

(1) One-dimensional hydrodynamic-water environment coupling model MIKE 11 [11]: Daven River is a slender river, and the observation year of water quality data is relatively short, and the river reaches are not long. At the same time, the determination of ecological flow control value needs to be considered from the perspective of improving hydrodynamic conditions, ensuring water environmental quality, and avoiding bloom outbreak. In view of this, the system selects two modules of hydrodynamic and water environment in MIKE 11 as the basic modules. Considering the vertical conservation of matter and momentum, based on the one-dimensional unsteady flow Saint-Venant equations and the one-dimensional convection-diffusion model, the MIKE 11 one-dimensional coupling model of hydrodynamics and water environment is constructed, which realizes the comprehensive consideration of river hydrodynamic conditions and water environment conditions, and can reflect the river characteristics more objectively. The constructed model is formulated as follows.

Table 2. Load values of principal components of pollutants in the Tawen River during flood season.

Water environmental indicators	Principal component 1	Principal component 2
COD_{Mn}	0.948	-0.162
BOD	0.699	0.342
$NH_3 - N$	0.302	0.887
COD_{Cr}	0.938	-0.172
TP	0.755	-0.253

Equation of continuity:

$$\frac{\partial S}{\partial t} + \frac{\partial Q}{\partial x} = q \quad (7)$$

Momentum equation:

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left(\alpha \frac{Q^2}{S} \right) + gS \frac{\partial h}{\partial x} + \frac{gQ|Q|}{U^2 SR} = 0 \quad (8)$$

One-dimensional convection-diffusion model:

$$\frac{\partial C}{\partial v} + u \frac{\partial C}{\partial s} = \frac{\partial}{\partial s} \left(E_x \frac{\partial C}{\partial s} \right) - KC \quad (9)$$

Where, Q is the cross section flow rate (m^2/s); S is the section area (m^2); x is the distance change along the flow direction (m); t is the time variable (s) of the point location; q is the side inflow flow (m/s); h is the river level (m); g is the acceleration of gravity (m/s^2); R is the hydraulic radius of the river (m); α, U are momentum correction coefficient and Xie CAI coefficient; C is the index concentration (mg/L); U is the average flow rate of water (m/s); E_x is the longitudinal diffusion coefficient (m^2/s); K is the comprehensive attenuation coefficient (mg/d); s is the spatial coordinate (m); v is the time coordinate (s).

(2) Planar two-dimensional hydrodynamic model MIKE21 [12]: The hydrodynamics module in the MIKE 21 engineering package can simulate the changes of water level and flow due to the action surface of various forces. It uses the hydrostatic pressure assumption and Boussinesq assumption to solve the Stokes

equation numerically, which can be used for the simulation of any two-dimensional free surface flow ignoring stratification, and can greatly reduce the calculation time.

Table 3. Data types and sources.

Data types	Time	Data sources	Parameters
Rainfall	2018—2023	National weather station	Daily rainfall (mm)
Evaporation	2018—2023	National weather station	Daily evaporation (mm)
Measured incoming water from the upper reaches of the Tawen River	2018—2023	Hydrological station	Average monthly flow (m ³ /s)
Area of land	2018—2023	Geospatial Data Cloud	Landsat-8
Elevation of terrain	2018—2023	Geospatial Data Cloud	ASTER GDEM 30M

The two-dimensional system of nonconstant shallow water equations is as follows.

Equation of continuity:

$$\frac{\partial h}{\partial t} + \frac{\partial h\bar{u}}{\partial x} + \frac{\partial h\bar{v}}{\partial y} = hS \quad (10)$$

Momentum equation in x direction:

$$\begin{aligned} \frac{\partial h\bar{u}}{\partial t} + \frac{\partial h\bar{u}^2}{\partial x} + \frac{\partial h\bar{v}}{\partial y} = f_v\bar{h} - gh \frac{\partial \eta}{\partial x} - \frac{h}{\rho_0} \frac{\partial P_a}{\partial x} - \frac{gh^2}{2\rho_0} \frac{\partial \eta}{\partial x} + \frac{\tau_{xx}}{\rho_0} - \frac{\tau_{bx}}{\rho_0} - \\ \frac{1}{\rho_0} \left(\frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{xy}}{\partial y} \right) + \frac{\partial}{\partial x} (hT_{xx}) + \frac{\partial}{\partial y} (hT_{xy}) + hu_x s \end{aligned} \quad (11)$$

Momentum equation in y direction:

$$\begin{aligned} \frac{\partial h\bar{u}}{\partial t} + \frac{\partial h\bar{u}\bar{v}}{\partial x} + \frac{\partial h\bar{v}^2}{\partial y} = f_u\bar{h} - gh \frac{\partial \eta}{\partial y} - \frac{h}{\rho_0} \frac{\partial P_a}{\partial y} - \frac{gh^2}{2\rho_0} \frac{\partial \rho}{\partial y} + \frac{\tau_{xy}}{\rho_0} - \frac{\tau_{by}}{\rho_0} - \\ \frac{1}{\rho_0} \left(\frac{\partial S_{xy}}{\partial x} + \frac{\partial S_{yy}}{\partial y} \right) + \frac{\partial}{\partial x} (hT_{xy}) + \frac{\partial}{\partial y} (hT_{yy}) + hu_y s \end{aligned} \quad (12)$$

Where: t is time (s); x, y is the Cartesian coordinate system; η is the water level (m); h is the stationary water depth (m); u, v are the components of the flow velocity in x and y directions (m/s), respectively; P_a is the local atmospheric pressure (pa); ρ_0 is the water density (L/m³); ρ_0 is the reference water density (L/m³); f_v and f_u is the acceleration caused by the Earth's rotation (m/s²); $S_{xx}, S_{xy}, S_{yx}, S_{yy}$ is the stress component of radiation wave (pa); S is the source and sink term; U_x, V_x is the flow velocity of source and sink (m/s); $T_{xx}, T_{xy}, T_{yx}, T_{yy}$ is the horizontal viscous stress term (pa).

The model is grided in WGS-1984-UTM-Zone-51 coordinates, and the stability of the model is numerically controlled by CFL under two-dimensional conditions, as follows

$$CFL_{HD} = \sqrt{gh} + |u| \frac{\Delta t}{\Delta x} + \sqrt{gh} + |v| \frac{\Delta t}{\Delta y} \quad (13)$$

Where: Δx , Δy control the size of the control grid (m); Δt is the time step (s); g is the gravitational acceleration (m/s^2); the height of the grid point of h (m), and u , v are the components of flow velocity in x and y direction (m/s), respectively.

(3) Two-dimensional hydrodynamic water quality numerical model:

Flow control equation: Two-dimensional unconstant flow in a plane is a viscous incompressible flow following Navier-Stokes Equations (N-S equation), which means that the flow velocity is uniformly distributed along the water depth and only changes along the plane direction. The commonly used equation is:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial Hu}{\partial x} + \frac{\partial Hv}{\partial y} = 0 \quad (14)$$

Momentum equation:

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = fv - g \frac{u\sqrt{u^2 + v^2}}{C^2 H} - g \frac{\partial \zeta}{\partial x} + \varepsilon_x \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) + \frac{C_w \rho_a \omega^2 \cos \theta}{\rho_w H} \quad (15)$$

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} = fu - g \frac{v\sqrt{u^2 + v^2}}{C^2 H} - g \frac{\partial \zeta}{\partial y} + \varepsilon_y \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) + \frac{C_w \rho_a \omega^2 \sin \theta}{\rho_w H} \quad (16)$$

Where: ζ refers to the height (m) of the water surface above the average water surface at the point; f refers to the constant of the Coriolis force, which takes different values depending on the geographical location of the water, $f = 2\Omega \sin \varphi$; Ω refers to the ground rotation velocity; φ is latitude; C refers to the Xie CAI coefficient, usually taken $C = \frac{1}{n} \times H^{\frac{1}{6}}$ (n is the roughness); C_w is the wind stress coefficient of water surface; ρ_a is the density of air (T/m^3); ρ_w is the density of water (T/m^3).

Water quality control equation: Pollutants in urban lakes mainly come from the inflow of surface runoff formed by rainfall, the discharge of domestic sewage and the release of internal pollution. After sewage enters the lake, it will form a diffuse pollution zone.

Two-dimensional lake water quality prediction equation:

$$\frac{\partial C}{\partial t} = E_x \frac{\partial^2 C}{\partial x^2} + E_y \frac{\partial^2 C}{\partial y^2} - u \frac{\partial C}{\partial x} - v \frac{\partial C}{\partial y} - KC \quad (17)$$

Where: C is the concentration of organic matter in lake water; E_x , E_y represent the turbulent diffusion coefficients (m^2/s) in the x and y directions; k represents the degradation coefficient ($\frac{1}{d}$) of organic matter.

The degradation coefficient of organic matter is the value of the coefficient of an idealized model, which indicates the rate of degradation of organic pollutants in the water body over time. The degradation coefficient of organic matter varies with different sewage properties and needs to be determined by experiments. The

following table is the reference of the actual measured values of the diffusion coefficient and pollutant degradation coefficient of the Tawen River:

Table 4. Reference table for the values of water quality equation parameters of the Tawen River.

Parameter names	Numerical value
Diffusion coefficients in x and y directions (m^2/s)	2.0, 2.0
COD pollutant degradation coefficient ($\frac{1}{d}$)	0.06
Degradation coefficient of ammonia nitrogen pollutant ($\frac{1}{d}$)	0.04
Degradation coefficient of total phosphorus pollutant ($\frac{1}{d}$)	0.02
Degradation coefficient of total nitrogen pollutants ($\frac{1}{d}$)	0.04

3. Innovation Points and Project Features

3.1. Digital management of the water conservancy system has been achieved

The system uses digital twin technology to integrate the data and information detected by sensors and monitoring equipment, and builds a three-dimensional visual digital twin model corresponding to the physical entities in the real watershed in the virtual space. This model has an accurate mapping with the physical entity in terms of information, trajectory, and scale, and can interact in real time. By leveraging information processing and analysis, simulation and exercise, it provides scientific decision-making solutions, enabling precise management of the watershed water and promoting the precise management of the water conservancy system. It realizes a closed loop of “status perception - real-time analysis - scientific decision-making - precise execution” based on digital twin technology.

3.2. Highly integrated and unified design.

The system can be applied in multiple aspects such as urban water resource scheduling prediction and control, reservoir scheduling and irrigation, water quality monitoring and pollution early warning, flood and drought disaster early warning and emergency response, water supply network monitoring and fault elimination, effectively expanding the application field of smart water conservancy. By fully utilizing digital twin technology, it integrates four major functions - real-time monitoring, data processing, remote scheduling, and three-dimensional display - into one and presents them on a smart large screen, allowing managers to have a more intuitive understanding of the status of the water conservancy system. The operation situation is presented in all aspects, achieving one-map viewing and one-network management.

3.3. Optimize water resource allocation in the basin and protect the water environment

The digital twin platform, through real-time perception of multi-dimensional information data such as water volume, water quality, and spatio-temporal distribution of water resources within the basin, utilizes intelligent analysis models in the

knowledge platform to analyze massive data and generate intelligent dispatching plans. Combined with PLC controllers, it meets various demands including agricultural water use, industrial water use, urban domestic water use, and water for landscape and ecological purposes, thereby optimizing water resource allocation and enhancing water utilization efficiency. At the same time, it fully considers ecological and environmental protection issues, relying on detection equipment to monitor the water quality status in real time, promptly identify water quality changes and pollution sources, and discover and handle industrial pollution, agricultural non-point source pollution, and domestic pollution around river basins. With a data-driven approach, it realizes the response and processing of water quality information, predicts the movement patterns and diffusion extent of pollutants, and controls and mitigates the impact of pollutants on the water environment, achieving comprehensive, dynamic, and efficient monitoring and control of water resources in the basin.

3.4. Data security is reliably guaranteed

During the system development process, secure communication protocols and data transmission methods were adopted, with encryption protection throughout the data transmission process to ensure data is not tampered with or stolen. A complete firewall and security detection mechanism were established to prevent potential network attacks and virus intrusions, safeguarding the security of sensor data, digital twin models, and decision support systems. Additionally, the system employs load balancing and backup mechanisms. In the event of catastrophic data loss, the system can promptly restore data to ensure data integrity and recoverability, ensuring that even in the event of system failure, it can quickly switch to a backup system, maintaining the continuity of water resource management and achieving higher data security.

4. Conclusions

After nearly a year of in-depth exploration and hard work, the “Haiyanheqing - 3D Visualization Smart Water Conservancy System Based on Digital Twin” project has achieved its expected goals. We innovatively integrated digital twin and 3D visualization technologies and successfully built a fully functional smart water conservancy system. Through practical verification, this system has significantly improved the efficiency of water conservancy data analysis and the accuracy of decision-making, achieving precise real-time monitoring of water conservancy facilities, in-depth data analysis, and intelligent decision-making assistance. It has effectively enhanced the efficiency and scientific nature of water conservancy management, opening up new ideas for flood control and drought relief, water resource allocation, and the scientific management and rational utilization of water conservancy resources. This is a deep exploration of digital innovation in the water conservancy field, truly demonstrating the huge potential and value of digital technology in empowering the traditional water conservancy industry.

During the project execution, we overcame challenges such as real-time data transmission delay, the complexity of multi-source data integration, and the high precision requirements of 3D modeling. Team members were fully involved, from theoretical research to technical breakthroughs, from on-site investigations to system debugging. With the guidance of our teachers, we found solutions and accumulated a wealth of practical experience. Every setback was an opportunity for growth, and every technical breakthrough was the result of the team's wisdom and hard work.

Through this practice, not only did members deepen their understanding of professional knowledge, but they also developed the ability to solve complex problems and a spirit of teamwork. The overall technical level and collaboration ability of the team have significantly improved.

Although the system has achieved initial success in Tai'an City, we are well aware that there is still room for improvement. There are still issues such as the need to strengthen data security protection and further optimize system compatibility. Looking to the future, we will continue to improve the system's functions, enhance its stability and reliability, and actively promote its application in a wider range of water conservancy scenarios. We aim to contribute our youth to the intelligent and modernization of China's water conservancy industry, and strive to build a smarter, safer, and more efficient smart water conservancy system, adding bricks and tiles to the digital transformation of China's water conservancy industry, and bringing the beautiful vision of "Haiyanheqing" to reality.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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