Development and Application of 3D Visualization Platform for Flood Evolution in Le'an River Basin of Wuyuan

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Abstract. With the rapid development of computer network technology, virtual display technology has become a typical representative of modern information technology, which can provide more efficient and intuitive technical means for flood prevention and risk assessment of water conservancy departments, and make more innovations and breakthroughs in the field of 3D simulation. This paper takes the area of Wuyuan County in the upper reaches of Le'an River in Poyang Lake as an example. Based on WebGIS technology, spatial database technology, CTS virtual display technology and combined with TOPMODEL semi-distributed hydrological model and IFMS domestic flood analysis software, it uses computer languages such as C#.NET and Java to carry out secondary development, explore and build a three-dimensional immersive hydrological multi-element virtual reality platform with real-time interactive display function, and realize the dynamics simulation display of three-dimensional data query, water and rain monitoring, flood evolution, submergence analysis, disaster assessment and other scenes under the three-dimensional perspective. It also provides an auxiliary decision-making platform for flood control and disaster reduction in the river basin, and further improves the guarantee level of water safety in the river basin.

1. Introduction

In recent years, affected by the common impact of climate change and human activities, the world has experienced frequent extreme weather, and the flood disasters of small and medium-sized rivers are increasing, which has caused great harm to people’s lives and property and put forward higher requirement for flood control. Wuyuan County is located in the northeastern part of Jiangxi Province, densely surrounded by mountains and ravines. The county seat is located in the south-central part of Wuyuan County, the upper reaches of the Le'an River in Poyang Lake as an example. Based on WebGIS technology, spatial database technology, CTS virtual display technology and combined with TOPMODEL semi-distributed hydrological model and IFMS domestic flood analysis software, it uses computer languages such as C#.NET and Java to carry out secondary development, explore and build a three-dimensional immersive hydrological multi-element virtual reality platform with real-time interactive display function, and realize the dynamics simulation display of three-dimensional data query, water and rain monitoring, flood evolution, submergence analysis, disaster assessment and other scenes under the three-dimensional perspective. It also provides an auxiliary decision-making platform for flood control and disaster reduction in the river basin, and further improves the guarantee level of water safety in the river basin.
of the county seat controls a drainage area of 1863km². Since 2017, two major floods have occurred in the Le'an River Basin, such as "6.24" flood in 2017, the first catastrophic flood in hydrological observation records. The catastrophic rainstorm covers almost the entire basin, the peaking rain is highly concentrated, and the rainstorm trend moves from the upstream to the middle and lower reaches, causing widespread flash floods and urban flooding; in 2020, the "7.9" flood was the second catastrophic flood in record. The flood destroyed the Rainbow Bridge in Song Dynasty in Qinghua Town. The water system diagram of the basin is shown in Figure 1.

Three-dimensional simulation virtual display technology has been more and more applied and recognized in the water conservancy industry with the continuous development of new technologies represented by network information technology. At present, it is the first thing to choose a general three-dimensional display platform to dynamically display professional models or calculation results on the platform to realize 3D visualization and virtual simulation[1-3]. Based on WebGIS technology, spatial database technology, and CTS virtual display technology, this paper explores and builds a three-dimensional virtual display platform for Wuyuan hydrology; by using multi-source hydrometeorological element data in Wuyuan County, calculating hydrological and hydrodynamic model, and adopting color rendering and submerged range diffusion method, the calculation results are dynamically displayed, so as to realize the visual display of the flood evolution, and meanwhile it provides important technical support for the flood control command and decision-making department.

![Figure 1 Schematic diagram of the study area water system](image)

2. Virtual display platform design

2.1. General idea

The overall idea of the three-dimensional virtual display platform (hereinafter referred to as the platform) of Wuyuan hydrology is to establish a data integration platform by assimilating multi-source hydrometeorological elements such as terrain, images, oblique photography, water conservancy projects, river sections, water and rain regime monitoring dynamic data, etc., and build a three-dimensional display platform with secondary development and real-time interactive display function so as to realize the virtual display of flood forecasting and evolution.
2.2. Overall Framework

Based on the actual needs of hydrological applications, flood control management and emergency rescue, a 3-layer frame structure design is adopted on the Wuyuan hydrological three-dimensional virtual display platform, as follows:

(1) Data layer. As the basis of the entire display platform, it mainly includes spatial databases, hydrological monitoring databases, early warning and forecast databases, three-dimensional display databases, and aerial remote sensing data databases. Multi-source data is used to establish unified platform in accordance with the principle of "unified standards, unified data sources, and unified use", so as to provide data support for the system.

(2) Application base layer. It provides an interface and bridge function for the middle layer in the data layer and application layer, and the data base layer and technical application layer. By using WebGIS technology and C/S architecture to build a network platform, and take COM component technology and database operation services as business and database access interfaces, so as to achieve real-time information interaction between the data layer and the application layer.

(3) Application layer. As a platform mainly used for flood prevention and disaster reduction, it is necessary to realize the visual expression of three-dimensional flood simulation that such main functions as data browsing, scene inspection, flood performance and analysis, inundation analysis, and disaster assessment. The human-computer interaction of the platform provides a way of interoperating three-dimensional scenes, and the results are displayed in various ways such as graphics, reports and maps.

3. Main technologies

3.1. Distributed hydrological and hydrodynamic model

On the platform, it builds a distributed hydrology-hydrodynamic coupling model to simulate the water level and flow process of the river above Sandu Station in the upper reaches of Wuyuan, and provide process data for the rendering and analysis of the flood discharge process. Among them, the TOPMODEL model is used to construct the runoff generation and slope convergence models as the basis. The TOPMODEL (Topography based hydrological Model) model is a topography-based semi-distributed watershed hydrological model proposed by Beven and Kirkby in 1979. Its main feature is to use the geomorphic index \( \ln(\alpha + \tan \beta) \) to reflect the hydrological phenomenon of the watershed, especially the distribution law of runoff movement. The model has a simple structure, few optimal parameters, and clear physical concepts[4]. In the soil at any point in the watershed, it assumes that there are three different water-bearing zones: the first is the vegetation root zone, the second is the soil unsaturated zone, and the third is the saturated groundwater zone. Suppose the water flow movement is as follows: after the precipitation meets the interception, the infiltration precipitation first compensates the root zone of the vegetation, and then enters the unsaturated zone of the soil after reaching saturation, and the water stored in this layer is dissipating at a certain rate. The water in the soil is unsaturated layer forms the soil flow \( Q_b \) as a result of the lateral movement of water in the watershed. At the same time, part of the water supplements the soil saturated groundwater area, the groundwater level in some areas rises to the surface to form saturated slope flow \( Q_s \) owning to the vertical drainage, so the sum of soil flow \( Q_b \) and saturated slope surface flow \( Q_s \) forms the total runoff \( Q \) of the basin.

The river flood routing method aims to solve the one-dimensional Saint-Venant equations for calculation by using a one-dimensional hydrodynamic model numerical discretization. The one-dimensional Saint-Venant equations mainly include the continuity equation (formula (1)) and the momentum equation (formula (2)).

\[
\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q 
\]

\[
\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left( \frac{Q^2}{A} \right) + gA \frac{\partial h}{\partial x} + gA(S_b - S_f) = 0
\]

Where: \( Q \) is the flow rate, m³/s; \( A \) is the cross-sectional area of the water, m²; \( q \) is the side inflow, m³/s; \( g \) is the acceleration of gravity, m/s²; \( h \) is the water depth, m; \( S_b \) is the source of the bottom slope; \( S_f \) is
the source of friction.

As for the distribution of water conservancy projects in the upper reaches of Le'an River, a one-dimensional river hydrodynamic model of a tree-like river network can be constructed for different river sections (Sec (1) to (4), as shown in Figure 3). It adopts the discharge process of the reservoir of upper reaches of the basin and the discharge process of the Jiangwan Hydrological Station as the upper boundary conditions, the slope confluence calculated by the TOPMODEL semi-distributed hydrological model as the inflow of each section (water level station) and the water level and discharge relationship of Sandu Station as the lower boundary condition.

3.2. One- and two-dimensional coupling model
Urban storm flood simulation is an important foundation for urban flood control emergency management and risk management. The platform plans to construct a one- and two-dimensional coupled model of Wuyuan urban area to simulate urban river evolution and urban inundation dynamics below Sandu Station. The domestic flood analysis series software IFMS [5-6] (Integrated Flood Modeling System) is used to simulate. Based on the flood risk map project in key areas across the country, IFMS
is a new generation of flood analysis software developed by the China Institute of Water Resources and Hydropower Research in conjunction with Nanjing Institute of Water Resources, Hehai University and Shandong University. It integrates one-dimensional river Network model, two-dimensional surface water dynamics model, urban pipe network model, one- and two-dimensional coupling model, and one- and two-dimensional coupling urban pipe network model. Among them, the one-dimensional river network model can use the Preissmann four-point implicit difference scheme depended on finite difference to discretely solve the Saint-Venant equations, or use the Godunin scheme based on the finite volume method to discretely solve the Saint-Venant equations. The two-dimensional surface hydrodynamic model uses the Godunov scheme based on the finite volume method to discretely solve the two-dimensional shallow water equations. The Riemann problem is calculated by using the Roe scheme approximate solution, and the characteristic hierarchical discretization is used in the bottom slope source term to ensure the conservation of the model. The resistance source term uses implicit discretization to improve the stability of the model. The second-order accuracy uses MUSCL spatial reconstruction and prediction correction method to make the model have second-order accuracy in time and space. All variables are defined in the center of the unit [5]. The one- and two-dimensional coupling model realizes the model connection solution based on the hydraulic connection conditions of the coupling boundary of the lateral connection. The lateral connection uses the most widely used weir formula method to calculate the water flow exchange problem of the lateral connection. The two-dimensional diving equations are as follows:

\[
\frac{\partial U}{\partial t} + \frac{\partial F}{\partial x} + \frac{\partial G}{\partial y} = S
\]

Where: \( U = \begin{bmatrix} h \\ h u \\ h v \end{bmatrix} \), \( F = \begin{bmatrix} hu + \frac{1}{2} gh^2 \\ huv \\ hv + \frac{1}{2} gh^2 \end{bmatrix} \), \( G = \begin{bmatrix} hv \\ huv \\ hv + \frac{1}{2} gh^2 \end{bmatrix} \), \( S = \begin{bmatrix} 0 \\ S_x \\ S_y \end{bmatrix} \).

Where: \( u \) and \( v \) are the flow velocity in direction \( x \) and \( y \), m/s; \( g \) is the acceleration due to gravity, m/s\(^2\); \( h \) is the water depth, m; \( S_x \) and \( S_y \) are the source terms.

\[
S_x = -\frac{h}{\rho} \frac{\partial P_a}{\partial x} - gh \frac{\partial z_b}{\partial x} \frac{\tau_{ax}}{h} + c_x
\]

\[
S_y = -\frac{h}{\rho} \frac{\partial P_a}{\partial y} - gh \frac{\partial z_b}{\partial y} \frac{\tau_{ay}}{h} + c_y
\]

Where: \( P_a \) is the atmospheric pressure, Pa; \( \rho \) is the water density, kg/m\(^3\); \( Z_b \) is the elevation of the bottom of the river bed, m; \( \tau_{ax} \) and \( \tau_{ay} \) are the wind force in the direction \( x \) and \( y \), and \( \tau_{ax} \) and \( \tau_{ay} \) are the River bed resistance in direction \( x \) and \( y \), \( c_x \) and \( c_y \) are the geostrophic Coriolis force in the direction \( x \) and \( y \).

3.3. Three-dimensional virtual simulation technology

CTS, called as CitySpace, is a web-based Web 3D service and digital earth visualization application platform that integrates spatial data processing, storage, editing, exchange, publishing, spatial display, query statistics, and spatial analysis. It provides powerful spatial information technology support for application in diversified industry and supports seamless superposition of various spatial data such as images, terrain, models, vectors, and BS and CS modes at the same time, which share the same plug-in, WMTS services, as well as JS, C#, VB, VC, PB and other development languages. It is used in digital cities, underground spaces, digital public security, digital water conservancy, digital transportation, digital power, digital parks, etc.

4. Platform function and its realization

The platform is developed around five three-dimensional scenes, including: three-dimensional data browsing, water and rain monitoring, flood evolution, inundation analysis, and disaster assessment. The
platform functions are shown in Figure 4.

![Figure 4 Functional interface of Wuyuan 3D virtual display platform](image)

4.1. Three-dimensional data browsing
The data browsing is the most basic function of the 3D virtual simulation system. The platform uses terrain, images, oblique photography, water conservancy projects, administrative areas, roads, river systems, and watersheds as the base map to realize virtual reality immersive browsing of basic data, including maps zooming, panning and dragging, pointing to the north, fast positioning, roaming, collection, etc. At the same time, it has developed the basic measurement of the real 3D model, such as area and length.

4.2. Water and rain monitoring
Three-dimensional virtual simulation is an inevitable trend for the sustainable development of modern water conservancy. It enables hydrology and flood control command and dispatch departments to obtain hydrological data and information more timely and objectively, so as to make more accurate and efficient forecasts and warnings. It has been widely used in flood prevention and disaster reduction, water resources management, and water pollution incident processing. The water and rain monitoring module in the platform is mainly used to realize the display and query statistics of water and rain monitoring information, including rainfall, radar rain measurement, river water conditions, and reservoir water conditions. For the rainfall information, it can realize the real-time rainfall distribution display and the rainfall isoline drawing function of each rainfall station within the Wuyuan area; for the river water condition, it can realize the real-time water level and flow process display of the river observation station; for the reservoir water condition, it can realize the real-time water level of the reservoir in real time display, and each sub-module can also realize the query function of historical data.

4.3. Flood evolution
Based on the image inclination data, the real-time data of upstream inflow and rainfall, the TOPMODEL semi-distributed hydrological forecasting model is used to predict the runoff process of the river channel section which is interpolated into the runoff process of the river surface with a grid as a unit, and then the dynamic process of river water fluctuations can be displayed in 3D earth, and at the same time, the visual display of the vertical and horizontal sections of the one-dimensional river can be realized.

4.4. Submergence analysis
Submergence analysis mainly refers to what kind of submergence range and water depth distribution is caused under a certain flow condition\(^7\). In the past 20 years, with the rapid development of urbanization
in China, the continuous expansion of urban area, the relative gather of regional population and industries, and the overlap of areas threatened by floods and the densely populated and asset-intensive areas, the urban disaster attribute is stronger once the flood disaster occurs, so the study focuses on the submergence dynamics in Wuyuan County [7]. Based on the IFMS software, it uses the distributed hydrological model to calculate the flow process of Sandu Station as the upper boundary condition, the dam water level and flow relationship of the downstream Xingjiang Power Station as the lower boundary condition to establish a one- and two-dimensional coupling model of Wuyuan, and obtain the water level flow process of the grid units, and analyze to obtain the submerged range under the flow process, and adopts the dynamic mode of color rendering and submerged range diffusion to realize the three-dimensional virtual display of flood submergence.

4.5. Disaster assessment
Disaster assessment is a comprehensive qualitative and quantitative assessment of upcoming or existing disasters under the premise of disaster prediction or investigation. And it is an important indicator for assessing the severity of disasters. The flood evolution and inundation analysis results are superimposed and analyzed with socioeconomic layers (population, administrative divisions, key targets), and the population, scope, and key protection units that may be affected by the flood are obtained in this study.

4.6. Contact between modules
The platform integrates the four modules of water and rain monitoring, flood evolution, inundation analysis, and disaster assessment into a whole. The water and rain monitoring module can be used to view real-time water and rain information, and at the same time forecast flood on the hydrological and hydrodynamic model. If the flow of Sandu station is found to be over-alarm, the platform will automatically start one-and two-dimensional coupling model for river flood analysis. When a certain control section is found to be over-alarm, the platform will start the submergence risk analysis and disaster assessment on the two-dimensional plane.

5. Application
This study takes the "6.24" flood in 2017 as an example, and realizes a three-dimensional virtual display of the "6.24" flood based on historical scenarios. Wuyuan was hit by a heavy rainstorm from June 23 to 24, 2017 due to the combination of low- and middle-level shear lines and the warm and humid air currents in the southwest. The rain was heavy, highly concentrated, and lasted for short time. The county’s average rainfall was 201.6mm, especially from 8:00 to 12:00 on June 24, just in total of 4 hours. The county's average rainfall is 89.1mm, and the hourly rainfall exceeds historical records. Due to the short duration, high intensity, and relative concentration of the rainstorm, the river water surged instantly, causing the upper reaches of Tsinghua section and Duanxinx section of the Le’an River also experienced major floods, and the two streams encountered major basin floods at the peak of the river below the confluence. By 16:24 pm on June 24, the highest water level of Sandu Hydrological Station in the county town was 64.54 meters, 6.54 meters higher than super-warning water level, and 4.42 meters higher than the highest water level in 1998, and the maximum peak flow was 5020m³/s (the flow and water level process is shown in Figure 5.), the total amount of secondary floods is 336.7 million m³, which is the first catastrophic flood since hydrological records. The flood caused 60% of the county’s fields to be inundated and 80% of the people were affected to varying degrees according to incomplete statistics. The emergency relocation of 89,000 people, 2870 collapsed houses and 51,000 flooded houses resulted in a direct economic loss of approximately 3.79 billion yuan[8].

Modeling theory, and three-dimensional display technology described above, the extreme floods that occurred in Wuyuan County, the upper reaches of Le’an River in the Poyang Lake system, were tested on 23-24 June, 2017 based on the system framework. The test results showed that the distributed hydrological model has relatively high accuracy of the forecast flow process. The flooding situation calculated by IFMS one- and two-dimensional coupling model is basically consistent with the flooding point distribution of the flood investigation. The water level calculated by the model is basically
consistent with that under the actual situation (as shown in Table 1), and the water level error is between 0.0 m ~ 0.31m, which meets the accuracy requirements. It can be seen that the hydrological and hydrodynamic models and theoretical methods used in this article, as well as the realization of the three-dimensional virtual display technology, are scientific and reliable. Part of the platform interface of "624" flood simulation is shown in Figure 6 and Figure 7.

![Figure 5 Discharge and Water Level Process Diagram of Sandu Hydrological Station in "6.24" Catastrophic Flood](image)

**Table 1 Comparison table of simulated water level in urban area and flood survey water level**

| Flow measurement section of Sandu station | Village house in Xiangtian Village | Sandu Old Station Building | 30m upstream of the left bank of Tianyou Bridge | 30m downstream of the right bank of Tianyou Bridge | The entrance of Wuyuan Scenic Hotel | 30m to the left bank of the downstream of Ximen Bridge |
|------------------------------------------|-----------------------------------|--------------------------|-----------------------------------------------|-----------------------------------------------|--------------------------------|-----------------------------------------------|
| Survey value                             | 75.65                             | 75.35                    | 75.17                                         | 74.80                                         | 74.63                           | 72.95                           | 72.60                           |
| Analog value                             | 75.67                             | 75.52                    | 75.17                                         | 74.65                                         | 74.45                           | 72.64                           | 72.33                           |
| error                                    | 0.02                              | 0.17                     | 0.00                                          | -0.15                                         | -0.18                           | -0.31                           | -0.27                           |

![Figure 6 "624" Extraordinary Flood Rainfall Map](image)

6. Conclusion
Taking the area of Wuyuan County in the upper reaches of Le’an River in the Poyang Lake system as an example, this paper uses computer technology, WebGIS, hydrological models, hydrodynamic models and CTS three-dimensional virtual simulation technology, adopts such multi-source data as spatial...
database, water and rain database, warning and forecast database, three-dimensional display database and aerial remote sensing data database to be assimilated and processed, so as to explore and construct a three-dimensional virtual display platform for Wuyuan hydrology, which realizes the virtual simulation

Figure 7 Three-dimensional dynamic map of Wuyuan urban area inundated by the "624" flood
display of data browsing, water and rain monitoring, flood evolution, inundation analysis, disaster
assessments and other scenes under the three-dimensional perspective, and also provides visual technical
support for flood prevention, mitigation and emergency management of the river basin. The
disadvantage is that the platform is still in the preliminary application stage, and need to be further
studied, such as image recognition technology based on artificial intelligence, and the application of
deep learning algorithms in flood forecasting.

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