Three-dimensional Visualization of Expansive Soil Channel Slope Monitoring in the Middle Route of South-to-North Water Diversion Project

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Abstract. The deformation of expansive soil canal slope in the middle route of South-to-North Water Transfer Project is obvious under the action of dry-wet cycles such as atmospheric rainfall and evaporation. By means of three-dimensional visualization, the deformation trend and characteristics of canal slope in three-dimensional on-line can provide more intuitive and clear basis for the stability evaluation and rapid disposal of canal slope. Based on the self-developed three-dimensional geographic information platform -3D GIS-Ark, this paper studies the three-dimensional visualization expression method of channel and safety monitoring information in the middle route of South-to-North Water Transfer Project, and realizes the three-dimensional model of Nanyang Expansive Soil Canal section, the visualization expression and early warning of monitoring equipment management and section monitoring information. The three-dimensional visualization results studied in this paper can provide visual decision support for engineering safety analysis, intelligent evaluation and early warning, and have significant application value in the field of engineering safety monitoring.

1. Introduction
The Nanyang section for middle route of South-to-North Water Transfer Project is located at the south foot of Funiu Mountain and the north edge of Nanyang basin. The strata involved are mainly upper tertiary (N) fluvial and lacustrine sedimentary clay rocks, sandy clay rocks, sandstone, and conglomerate rocks, quaternary Middle Pleistocene alluvial silty clay, clay, and quaternary slope silty clay. For the expansive soil slope section of Nanyang section, on the one hand, the upper part of the canal slope is in contact with the external environment, and the water content in expansive soil may be changed by meteoric precipitation and evaporation; on the other hand, after the main canal of the middle line is connected with water, the foundation and the first-grade slope of the canal will be inevitably affected by "common problems" such as groundwater or seepage water in channels for their location is below the water-extending line. The expansive soil also has the following characteristics.1) The expansive soil has a wide distribution range, the total length of Nanyang channel is 36.8km, of which about 29.5km is located in the expansive soil (rock) region. 2) The expansive soil is of many types as well as the strata distribution, there are strong, medium and weak expansive soils...
within the region, and locally there are expansive rocks. 3) The ground water level for part of the canal section is high. 4) During the construction, more than 20 landslides of which have a length of up to 200 meters large landslides and other independent characteristics took place.

It is difficult to analyze the deformation and stability of the expansive soil slope due to the deformation for slope of expansive soil canal by the interaction of strips and blocks in the soil and the coupling of water bodies in the soil, expansion of expansive soil with water and contraction with water loss, multi-fissure and uneven deformation for expansive soil, and the factors of seepage and stress distribution of expansive soil [1-2].

One-dimensional text, displacement table, two-dimensional single point process line and picture analysis model are used in traditional canal slope analysis. The correlation degree between measuring points and between measuring points and geological conditions of canal slope is not enough, the degree of 3d visualization is not high enough to comprehensively and intuitively present the overall working state of the monitored object and the change trend of the monitored physical quantity, and it is difficult to reflect the deformation trend, evolution law and stable state of canal slope. At the same time, it lacks spatial analysis ability, and relies on the professional ability, knowledge level and experience level of data analysts [3-7].

With the development of computer graphics technology, the research on the two-dimensional world is becoming more and more mature, and begins to expand to the three-dimensional field. Three-dimensional visualization technology starts from computer science and has penetrated into various disciplines currently. In terms of safety monitoring of water conservancy and hydropower projects, 3d visualization of monitoring system has become an important research topic for the development of safety monitoring due to the demand of real-time acquisition, automatic processing, intelligent analysis and network service of engineering monitoring data [8-12].

In combination with the national "12th five-year plan" scientific research project and the field practice, the Xichuan section of the middle route of south-to-north water diversion project is selected as the experimental project object to develop a 3d visualization system for safety monitoring of channel engineering. Through the connection with the channel security monitoring database, the indicators of the monitoring objects (temperature, stress, strain, displacement, etc.) can be obtained in real time by full automation, and combined with the scene around the channel, channel structure, 3d laser scanning point cloud data, etc., the monitoring information is displayed in a real-time, dynamic and intuitive manner in various ways, such as images, texts and tables, and the development trend of deformation state in a certain period of time is given. The development trend of channel safety monitoring information digitalization and visualization enables the decision-making management personnel to more convenient and timely grasp channels running and in a timely manner to accidents in the bud.

2. Development of three-dimensional visualization system

2.1. System architecture

Three-dimensional Visualization is a theory, method and technology that utilizes computer graphics and image processing technology to transform data into graphics or images for display on screen and interactive processing, a completely new way to describe and understand objects and an another representation form of data body with a lot of advantages. Three-dimensional Visualization can not only scientifically explain the simulation results, but also clearly express the simulation results. It can integrate a large amount of data, check the continuity, relevance and interactivity of the data, provide a strong guarantee for the analysis, evaluation and derivation of data, and play a bonding role in the communication and cooperation of multiple information.

The 3d visualization system adopts the three-tier architecture (Figure 1), namely the data resource layer, the basic platform layer and the visualization application layer.
2.1.1. Data resource layer. The data resource layer includes basic geographic data, 3d model data, laser point cloud data, security monitoring data and relevant management data etc. The professional safety monitoring data include the monitoring and recording information, attribute information and spatial position data of more than ten kinds of instruments, such as osmometer, steel bar meter, fixed inclinometer sensor, moisture content meter group, horizontal two-way meter and thermometer.

2.1.2. Basic platform layer. The basic platform layer (functional business support layer) is the 3d geographic information visualization platform, and 3DGIS-Ark of the Changjiang Institute of Survey, Planning, Design and Research is selected. It can well realize three-D topography and landform data integration, thematic information, three-D display of laser point cloud data, spatial three-D analysis and other functional services, and also provide security monitoring required results information query, analysis, simulation display and other services.

2.1.3. Visualization application layer. Visualization application layer mainly completes the visualization of security monitoring. The functional modules are mainly designed from several aspects, including 3d model integration and visualization, monitoring instrument visualization, monitoring data query, point cloud data integration and visualization, point cloud feature point visualization and analysis, triangle network visualization and analysis, real-time dynamic demonstration of monitoring information. The scene roaming and operation, data query and analysis and the channel security monitoring and early warning can be realized in the three-dimensional environment through the business development on the basic platform and the connection with the channel security real-time monitoring database.

2.2. System functions

- Three-dimensional symbolic expression of monitoring instruments and equipment. For the weak identification of each sensor of the monitoring instrument in the three-dimensional environment, by abstracting the functions of each instrument and equipment, a three-dimensional model or symbolic expression can be formed, which enables users to more quickly query and manage the corresponding instrument and equipment.

- Configuration of monitoring equipment. For the difficulty in reflecting the corresponding correlation in the data table of the instruments and equipment involved in the monitoring process and the corresponding monitoring results, by combining the spatial position of the monitoring

![Three-D visualization system architecture](image-url)
instrument and the results of the monitoring timing sequence in the way of automatic correlation, the access of the spatial-temporal information and the quick browsing query of the instrument and equipment can be realized.

- Roaming and management of indoor and outdoor integration in 3d environment. Monitoring instruments and equipment are mostly located in underground and indoor areas. In order to efficiently and intuitively browse and query the engineering area and surrounding areas where these instruments and equipment are located, the integrated roaming of aboveground, underground and indoor and outdoor can be used for seamless free browsing and query management in various space areas.

- Three-D visualization analysis of monitoring data results. Monitoring data results are stored in the database in the form of records, which is difficult to directly reflect the monitoring results. Through proper exaggeration in a 3d environment by setting the monitoring body color, height, texture changes to intuitively reflect the sequential monitoring results, reflect the status and trend of the monitoring process.

- The deformation of canal slope has three dimensional visualization expressions of measuring point and section deformation.

- Digital simulation function. The dynamic digital simulation of the process of measuring point, measuring line and section deformation is completed by multi-period monitoring data and time axis.

- The relationship between cause and effect of 3 d visualization: to complete 3d visualization and simulation of the correlation between causal quantities (water level, rainfall, etc.) and effect quantities (deformation, seepage and osmotic pressure, stress and strain, etc.).

- Visual expression of early warning: combined with early warning threshold, visual expression of safety monitoring and early warning is completed by means of display color, transparency and exaggerated amplification ratio of spatial distance.

3. Key technologies of the system

3.1. Seamless integration of terrain and channel models
The topographic model is derived from digital orthophoto map (DOM) and digital elevation model (DEM). The 3d model of the channel was generated by the modeling staff according to the point cloud data and relevant drawing data, terrain models is often difficult to be effectively combined with architectural models accurately due to the DEM and DOM data acquisition and real-time data accuracy. For the above reasons, with the help of the functional service of Ark platform 3DGIS-Ark, the automatic nesting of multi-level topography and landform is completed in real time based on the base of the 3d model of the channel in the test section studied in this project and the data precision of digital elevation model and digital orthophoto, so as to realize seamless nesting of channel model and topography and landform model (Figure 2).

![Figure 2. Seamless integration of terrain and channel models.](image)

3.2. Three-dimensional deformation expression based on section
The osmometer, inclinometer and other instruments recorded in the safety monitoring database are usually embedded with the channel section as the reference. Therefore, the three-dimensional
deformation study can be carried out by taking the section as the logical unit to study the benefits of seepage, seepage pressure and deformation monitoring of canal slope.

3.2.1. Three-dimensional deformation expression of a single instrument. Firstly, the system obtains space position of the instrument embedding

\[ \text{vecPos}(x, y, z) \]

(1)

Secondly, it obtains monitoring value of the instrument at different elevation points:

\[ f(h) = (x_h, y_h, z_h) \]

(2)

Where, \( h \) is the elevation relative to the embedded position of the instrument.

Thirdly, when a certain height offset \( oz \), height magnification \( r_h \) and horizontal magnification \( r_{xy} \) are determined, the monitoring values of the instrument at different elevations can be abstractly expressed as three-dimensional points:

\[ p_h = (0,0,0z) + \text{vecPos}(x, y, z) + (0,0,z_h) \times r_h + (x_h, y_h,0) \times r_{xy} \]

(3)

Lastly, three dimensional lines or cylinders of a certain width are formed by successively connecting three dimensional points at different elevations. Then, the monitoring situation of a single instrument at a given time can be expressed by the three-dimensional line or cylinder in three-dimensional space.

3.2.2. Three-dimensional deformation expression of multiple instruments. Firstly, selecting multiple monitoring instruments on study sections.

Secondly, according to the method (1), the abstract three-dimensional expression of the monitoring value for the \( n \)th monitoring instrument at different elevations can be obtained:

\[ p_{nh} = (0,0,0z) + \text{vecPos}(x_{nh}, y_{nh}, z_{nh}) + (0,0,z_{nh}) \times r_h + (x_{nh}, y_{nh},0) \times r_{xy} \]

(4)

Thirdly, it connects the three-dimensional points on elevation \( h \) in turn to form a three-dimensional line in space:

\[ L_h(P_{1h}, P_{2h}, \ldots, P_{nh}) \]

(5)

Lastly, according to the monitoring values of different time points and different elevations, one or more three-dimensional lines can be formed in the three-dimensional space to express the monitoring situation of the section.

3.3. Three-dimensional expression based on the correlation between causal quantity and effect quantity

Effect quantity generally refers to the monitoring value acquired by monitoring instrument in a period of time, while cause quantity refers to external factors that guide the change of effect quantity, such as water level, water depth, temperature, humidity, etc.

3.3.1. Three-dimensional expression of the effect quantity. The monitoring value (effect quantity) can be described in 3d space by using the expression method of single instrument in 3d deformation expression of section.

3.3.2. Three-dimensional expression of the cause quantity. In the three-dimensional geographical environment, the water level, water depth, temperature, humidity and other causes can be abstractly simulated by means of graph, text and three-dimensional symbols, as shown in figure 3 and figure 4.
The system obtains the magnitude of the effect quantity and the cause quantity at the specified time point, and then uses the above method to express the change value of both at the same time in the three-dimensional space by abstract means, so as to reflect the correlation between the effect quantity and the cause quantity change.

3.4. Real-time dynamic expression based on deformation
The value obtained by the monitoring instrument is the monitoring value at a certain point in time. Therefore, according to the monitoring values at different time points, the real-time dynamic expression of monitoring deformation can be realized in the three-dimensional environment.

3.4.1. Dynamic deformation expression based on section. Firstly, the system designates the monitoring instruments for the study section and set the order of instruments according to the spatial relationship.
Secondly, it obtains or interpolates the instrument's monitoring value at time t:

\[ h_i = f(t) \]  

(6)

Thirdly, it draws the equivalent or exaggerated cylinder on the spatial position of the instrument, then the geographic coordinate for the top of the cylinder can be expressed as follows:

\[ f_i(x, y, z, t) = P_i(x, y, z) + k \times vec(0, 0, h_i) \]  

(7)

Where, \( k \) is the exaggeration coefficient.
Fourthly, it connects the top of the cylinder in turn to form a three-dimensional line:

\[ L(t) = (f_1(x, y, z, t), f_2(x, y, z, t), \ldots, f_n(x, y, z, t)) \]  

(8)

Lastly, with the dynamic adjustment of the time point t, the change of the height for the cylinder will be affected by the change of the monitored value \( h \), and each node of the 3d line will also change, achieving the effect of real-time dynamic expression.

3.4.2. The dynamic expression based on causal quantity and effect quantity. Firstly, the system determines the external (environmental) factors and monitoring instrument types corresponding to the studied cause quantity and effect quantity.
Secondly, it obtains or interpolates the instrument's monitoring value at time t:

\[ h_i = f(t) \]  

(9)

Thirdly, it determines the magnitude of the external (environmental) factor of time t:

\[ Z_i = f(t) \]  

(10)

Fourthly, it determines the three-dimensional symbol expression of the monitoring value, such as linear symbol, planar symbol, etc. and the three-dimensional expression of external (environmental) factors, such as depth and height of water.
Lastly, with the dynamic adjustment of time point t, the change of monitoring value h will cause the change of 3d symbols and the deformation of 3d expression of external (environmental) factors. The real-time dynamic expression of cause quantity and effect quantity in a certain sense are reflected because both of them change at the same time.

3.5. Three-dimensional expression and warning based on point cloud

3.5.1. Warning based on point cloud data. Assign warning value in advance for the characteristic points, characteristic lines, characteristic surface and triangular network of any block, and mark the range beyond the warning value in red by comparing the measured value with the warning value.

3.5.2. Warning based on monitoring sections. By selecting the measured value of multi-type instrument with the same section, the early warning identification was carried out through the internal correlation degree of the measured value.

3.5.3. Warning based on cause quantity and effect quantity. Three dimensional expression and early warning analysis (Figure 5) were conducted by selecting the types of associated causal and effect quantities.

![Figure 5. Deformation early warning analysis based on point cloud data.](image)

4. Applied research

4.1. Construction of 3d model of Nanyang Expansive Soil Canal section

Three-D solid model is established by means of laser spot scanning, field photography, channel design drawings and other methods, which has real geospatial location information and can be integrated with the 3d geographic information platform. In order to facilitate the smooth roaming and rendering of model data, with the help of 3DGis-Ark platform, the tree-like scene diagram is adopted to better solve the organization and rendering problem of 3d model dat.

Firstly, the scene is abstracted into a repeatable partition space according to the relationship between its renderable objects and each renderable object corresponds to a piece of space. Each space is governed by SceneNode, which handles the movement, rotation, scaling, and spatially related behavior of the space, and finally links objects to be rendered to the space corresponding to SceneNode. Each SceneNode corresponds to a node in the tree structure, and holds the relative position of the parent node and the pointer to the child node. Based on tree scene organization, channel safety monitoring visualization platform is obtained after secondary development on Ark platform, and generates virtual reality scene based on real image maps in accordance with the division, and also provides roaming in the virtual three-dimensional simulation system (including virtual through), to establish a model of regional observation of arbitrary Angle of view, as shown in figure 6.
4.2. Management and inquiry of monitoring instruments and equipment

Combining with the related information of monitoring instruments and equipment in Nanyang expansive soil canal section, establishing and managing deformation monitoring instruments such as inclinometer and sedimentometer, monitoring instruments for seepage and seepage pressure such as pressure tube, osmometer and moisture content meter, and stress-strain monitoring instruments such as strain gauge, earth pressure gauge, steel bar gauge. There are more than ten kinds of instruments and hundreds of thousands of monitoring records. Automatic placement of monitoring instruments can be realized in the visualization platform according to its category and spatial location.

Monitoring index information and attribute information of each instrument can be inquired in real time in the management list of instruments and three-dimensional virtual environment.

The process line displays the dynamic relationship between the two variables in a two-dimensional intuitive way. Based on the safety monitoring data, the monitoring visualization system draws the process diagram of various instruments and equipment on the platform in real time (Figure 7).

The 3d visualization system platform can also display the recorded information monitored by the instrument by tabular way, provide metadata information such as the project, type, elevation, pile number, section and embedding time of the inquiry description instrument and equipment, establish a quick link between the monitoring instrument and external files, and realize the quick call of documents, pictures and other data, provide follow-up maintenance and management of various monitoring instruments and equipment, such as adding, deleting, editing, etc.

4.3. Visual expression and early warning of channel cross section monitoring information

4.3.1. Osmometer head value. Edit the color, warning threshold, size and other parameters that describe the three-dimensional expression of the osmometer, and adjust the order. According to the spatial position of the osmometer and the water head value at a certain time point, a 3d cylinder with equivalent or exaggerated magnification is drawn on the 3d space, and then the top of the cylinder is successively connected to form a 3d polyline. The time span of dynamic demonstration was set, and
the percolation head value was obtained by querying the monitoring database in real time, so as to achieve the effect of dynamically adjusting the height of the cylinder in real time under the three-dimensional environment, and realize the dynamic three-dimensional expression and early warning.

![Osmotic head value](image1.jpg) ![Deviation of inclinometer](image2.jpg)

Figure 8. Visualization of displacement values of osmotic head and inclinometer.

4.3.2. The depth horizontal displacement of the inclinometer. Edit and describe the color, warning threshold, size, left and right bank and other parameters expressed by the inclinometer in 3d, and adjust the order. Based on the spatial position of the inclinometer and the displacement of each hole depth, the translational nodes were drawn on the corresponding elevation points of each inclinometer, and the nodes were connected from top to bottom to form a blue line representing the horizontal displacement of the hole depth. When the displacement value exceeds the warning value, the corresponding node becomes red for warning. According to the order of the inclinometer, connect the nodes of the same hole depth in turn to form green curves (Figure 8). When the displacement value exceeds the warning value, the corresponding node on the curve turns red for warning.

5. Conclusion

Based on the self-developed 3d geographic information platform 3DGIS-Ark, the 3d safety monitoring visualization system of expansive soil channel is developed, and innovatively solves the technical problems of seamless integration of terrain and channel model, automatic space placement of monitoring instruments, real-time query, three-dimensional expression of monitoring results and early warning. However, it is relatively weak in three-dimensional space analysis. The research and development of more comprehensive spatial analysis capability combined with artificial intelligence are the development direction of three-dimensional security monitoring visualization in the future.

In the way of 3d visualization, the scene, structure and safety monitoring information of channel engineering in Nanyang expansive soil canal section are presented in a real-time, dynamic and intuitive manner, and the digitalization and 3d visualization of channel structure and safety information are realized. And the 3d visualization platform also visualizes the abstract monitoring data, providing convenient decision support for decision makers.

The 3d visualization system has a wide application range such as all kinds of water resources and hydropower engineering, underground tunnel, high-rise strucution monitoring, large-scale bridge structural health monitoring, etc., greatly improves the production efficiency of related industries, effectively reduces the related industries in the construction and operation in the process of economic, social, and environmental damage, and promotes the progress of the related industrial technologies.

Acknowledgments

This study is supported by The National Key Research and Development Program of China, No.2017YFC0405002.

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