Thoughts and Practices on Data Quality Inspection for 3D Real Scene Construction

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Key words: 3D Real Scene; new fundamental surveying and mapping; data products; quality inspection; development trends

SUMMARY

3D Real Scene, which provides a true, three-dimensional, and temporally sequential reflection of human production, living, and ecological spaces, serves as a significant new type national infrastructure. It achieves real-time correlation and interconnection between digital space and the physical world through "human-machine compatibility, IoT sensing, and ubiquitous services." As a unified spatiotemporal positioning framework and analytical foundation for Digital China, it represents a crucial strategic data resource and production factor for digital government and the digital economy. This paper first introduces the current situation and challenges in data quality inspection for 3D Real Scene construction. Secondly, it explores key technologies for quality inspection, focusing on standard systems, inspection workflows, and technical methods. Thirdly, through typical case studies, it analyses the effectiveness of quality inspection practices. Finally, it outlines future development trends in data quality inspection for 3D Real Scene construction, providing insights and references for related work.

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1. INTRODUCTION

The 3D Real Scene construction is a significant initiative proposed by the Ministry of Natural Resources (MNR) of the People's Republic of China to implement the Digital China strategy. It aims to create spatiotemporal information that authentically, three-dimensionally, and sequentially reflects human production, living, and ecological spaces, characterized by "entity-oriented modeling, semantic enrichment, temporal sequencing, and integrated representation." Since its deployment in 2019, the construction has progressed through three phases: pilot exploration, regional construction and application, and comprehensive deployment and advancement. Through collaborative efforts at the national, provincial, municipal, and county levels, preliminary achievements have been made in 3D Real Scene construction. It is expected that by the end of the 14th Five-Year Plan period (2025) , phased results will be achieved. Multi-precision, multi-resolution terrain-level 3D Real Scene data will cover all terrestrial land and major islands, and city-level 3D Real Scene data will initially cover all prefecture-level cities and above.

Compared to traditional surveying and mapping products, 3D Real Scene data not only contains geometric information but also integrates multidimensional information such as textures, semantics, and even temporal changes. The amount of elements and information contained per unit area increases multiplicatively compared to traditional basic-scale topographic maps, bringing entirely new challenges to the quality inspection of 3D Real Scene data. Currently, preliminary quality inspection standard systems have been established, and some key technologies breakthroughs have been achieved. However, the existing quality inspection standards cannot fully adapt to the new characteristics of 3D Real Scene data and struggle to meet the quality inspection requirements for 3D Real Scene data under the new foundational surveying and mapping paradigm. Faced with the transformation and upgrading of surveying and mapping, the continuous emergence of products like basic geographic entities, 3D Real Scene models, and geographic scenes, the workload for quality acceptance and verification is immense, and inspection capabilities still need continuous strengthening. Therefore, in order to response to the updates and iterations of supporting technologies, quality inspection for 3D Real Scene products should aim towards intelligentization (smart direction).To strengthen theoretical research, technological development, and system construction, fostering innovation in inspection theories, technologies, standards, supporting environments, and management tools, so as to achieve intelligentization across the entire quality inspection business process and form efficient inspection capabilities that guarantee the quality of geographic information and services.

2. KEY TECHNOLOGIES FOR QUALITY INSPECTION OF 3D Real Scene DATA PRODUCTS

2.1 Systematized Inspection Standard System

The data products of the 3D Real Scene China are based on a unified spatiotemporal benchmark. It consists of 4D products, geographic entity data products, geographic scene data products, and geographic real-scene data products. This system effectively describes the terrain fluctuations, natural elements, artificial facilities, and management units of the real world, along with their dynamic changes, within a 3D Real Scene digital space.

In accordance with current surveying and mapping product quality inspection standards, and considering the characteristics, production methods, and output types of fundamental geo-entity data, National Quality Inspection and Testing Center for Surveying and Mapping Products (QICS) have comprehensively considered factors such as the comprehensiveness of output quality requirements and the criticality of quality inspections. It also balanced the scientific validity, rationality, and operational feasibility of the output quality evaluation standards to construct a technical system for quality inspection and acceptance of fundamental geo-entity data outputs. It encompasses basic specifications, sampling inspection procedures, quality evaluation methods, as well as quality elements and error classification for unit outputs pertaining to three categories of fundamental geo-entity data: converted production entity data, collected production entity data, and rapidly constructed outputs of urban 3D models (Level of Detail 1.3, LOD1.3). Through nationwide solicitation of opinions, experimental verification, and multiple rounds of review, the technical system has been further refined, resulting in the formation of a technical document suitable for the quality inspection and acceptance of fundamental geo-entity data outputs. This provides a solid foundation for formulating industry standards for the quality inspection and acceptance of such data outputs.

2.2 Standardized Quality Inspection Process

The 3D Real Scene Construction Project implements a **Two-level Check and One-level Acceptance System**. The products must sequentially pass the process inspection conducted by the surveying and mapping unit's operational department, the final inspection by the quality management department, and then undergo acceptance inspection entrusted to a provincial-level quality inspection agency. Furthermore, at the national level, national quality verification is organized for data gathered from provincial levels to the national level and for data constructed at the national level, further ensuring the quality of construction outcomes at all levels. All levels of inspection work should be conducted independently and should not be omitted, replaced, or have their sequence altered, as illustrated in Figure 1 (shown in Figure 1).

The Two-level Check and One-level Acceptance System is a standardized quality management framework, which includes process inspection, final inspection and acceptance inspection. **Process inspection** targets various operational workflows, processes, and production stages, focusing on identifying and resolving quality issues during production. **Final inspection** serves as a comprehensive evaluation of the production unit's overall technical capability and management proficiency, requiring a clear pass/fail determination based on compliance with design and specification requirements. **Acceptance inspection** reflects a third-party supervision mechanism, ensuring the objectivity and impartiality of the outcomes. These three interconnected processes collectively form a whole-process, multi-layered quality assurance chain. **National-level quality verification** is a critical step in ensuring the accuracy, reliability, consistency, and usability of 3D Real Scene data as a key national new infrastructure. It facilitates coordinated national management and application, enhances data application efficiency and public trust, and drives technological innovation and industrial upgrading.

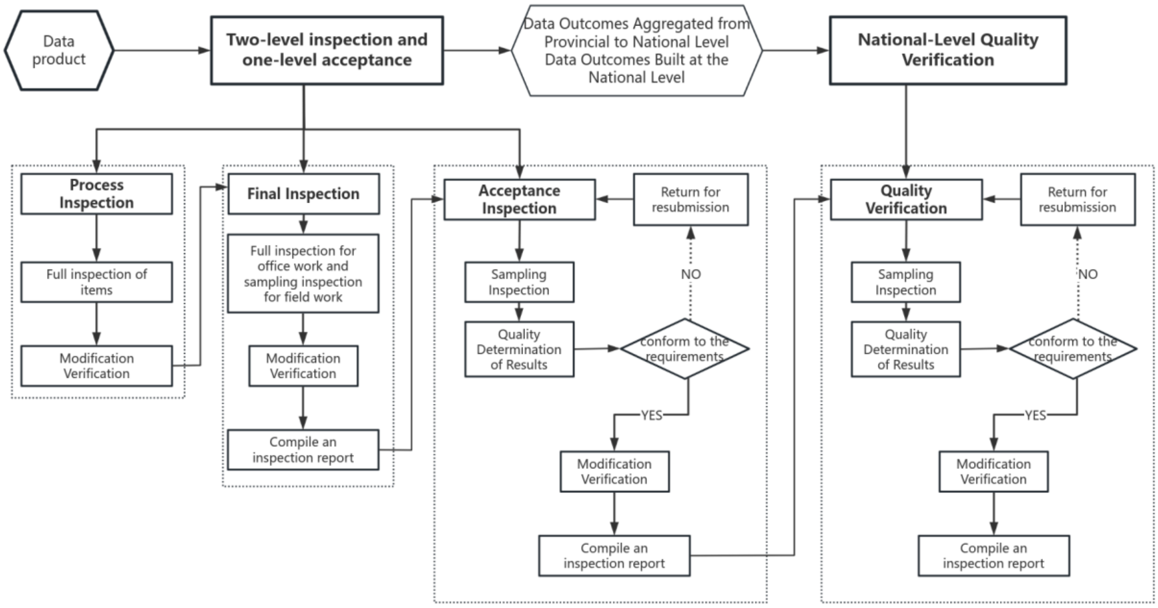

Figure 1: Outcomes Quality Inspection and Acceptance Process

2.3 Intelligent Quality Inspection Technology

2.3.1 Quality Inspection Technical Method

Compared to traditional manual inspection methods, current cutting-edge technical approaches include: automated defect detection based on computer vision to identify common model flaws such as floating objects, holes, and adhesion; employing image quality assessment algorithms to quantitatively evaluate texture clarity, consistency, and color balance; and checking the alignment between geometric models and semantic annotations to uncover issues like semantic segmentation errors or incomplete labeling. Common quality issues and corresponding inspection technical methods for fundamental geo-entity data outputs are summarized in Table 1.

Table 1: Common Quality Issues and Inspection Technical Methods for Fundamental Geo-entity Data Outputs

Inspection Items	**Common Quality Issues**	**Traditional Quality Inspection Methods**	**Intelligent Quality Inspection Directions**
Geometric Defects	Floating Objects, Holes, Adhesion, Distortion	Manual Visual Inspection	Computer Vision Recognition, 3D Morphological Analysis
Texture Defects	Missing Textures, Mapping Errors, Color Shift	Manual Comparison, Color Analysis	Image Quality Assessment, Texture Feature Analysis
Accuracy	Planar Position Deviation, Elevation Error	Field Survey Verification, Aerial Triangulation Check	Point Cloud Registration Analysis, Multi-source Data Comparison
Logica	Data Format Errors, Missing Files, Naming Non-compliance	Manual Verification, Script Checking	Automated Metadata Validation, Rule Engine Checking
Semantics	Relationship Errors, Misclassification, Missing Attributes	Manual Sampling Verification	Knowledge Graph Reasoning, Multi-modal Data Fusion Analysis

Automated Quality Inspection (AQI) Technology can significantly enhance inspection efficiency and reduce labor costs. However, it requires a large number of annotated samples for model training and places high demands on hardware computing capabilities. Integrating the product models and key technologies of the 3D Real Scene system, and building upon quality inspection models from surveying and mapping geographic information, it accounts for the quality characteristics and application requirements of 3D Real Scene outcomes. By applying cutting-edged information technologies such as cloud computing, big data, and artificial intelligence, it breakthroughs the computational challenges associated with large-scale spatiotemporal data, innovates the technical framework for quality inspection of 3D Real Scene outcomes, and establishes an information-based technical system for inspecting the quality of 3D Real Scene outcomes.

2.3.2 Quality Inspection Model

In the aspect of quality inspection models, the inspection of 3D Real Scene products now is facing the chanllenges with more spatial covers, shorter processing period, more complex inspecting items, and therefore quality inspection and verification of surveying and mapping products have also expanded from acquiring geometric information based on traditional measuring instruments to dynamic perception supported by ubiquitous smart sensors such as drones and laser scanners. With the increasing demand for spatial and attribute inspection of 3D Real Scene products, quality inspection has transitioned from data processing primarily relying on models and algorithms to a hybrid intelligent computing paradigm guided by knowledge and based on algorithms.

2.3.3 Quality Inspection Platform

In terms of quality inspection software, there is a need to explore and develop high-quality, high-efficiency intelligent inspection software for 3D Real Scene products. This involves building an intelligent quality inspection platform that aligns with the characteristics of intelligent surveying and mapping production and 3D Real Scene quality inspection, thereby enhancing the efficiency and accuracy of quality inspection for 3D Real Scene outcomes. Currently, the inspection technology for 3D Real Scene construction products primarily combines manual checks and programmatic inspections and some breakthroughs have been made in key quality inspection technologies for 3D models and fundamental geo-entities. In recent years, QICS have developed "ZhiJian Master" — a quality inspection software for rapidly constructed outcomes of fundamental geo-entities and urban 3D models (LOD1.3), which has improved the inspection efficiency of new outcomes and has been applied domestically.

3. PRACTICAL CASES OF 3D REAL SCENE DATA QUALITY INSPECTION

In recent years, with the comprehensive advancement of 3D Real Scene construction, QICS has undertaken quality verification tasks for national-level, provincial-level, city-level terrain-based fundamental geo-entity data. This has allowed QICS to accumulate extensive practical experience in quality control and inspection. From a quality inspection technology perspective, focusing on the core characteristics of data outputs-"real," "scene," and "three-dimensional"-innovative technologies have been proposed to efficiently and accurately verify the consistency between data and the objective world. Particular attention is paid to the coordination and realism of the overall scene, as well as the structural integrity of models and the correctness of semantic information. In terms of implementation effectiveness, national-level quality verification adopts a strategy combining standardization and differentiation, ensuring both the uniformity of basic data across the country and addressing the specific needs of key areas, thereby providing systematic assurance for the data quality of 3D Real Scene construction. This article reviews and analyzes three aspects: the construction of data products at different levels, the content of quality verification, and typical cases of quality issues, aiming to provide reference and insights for data quality inspection in 3D Real Scene construction.

3.1 National-Level Terrain-Based Fundamental Geo-entity Data Quality Inspection

National-Level Terrain-Based Fundamental Geo-entity Data is produced through the conversion of 1:50,000 fundamental geographic information element data. It primarily focuses on achieving digital mapping of ecological spaces, and includes key features such as topography and landforms, major mountain ranges, principal water systems, high-class transportation networks, and administrative divisions. This data is mainly used for 3D visualization and spatial measurement, supporting macro-level planning and ecological restoration initiatives.

Focusing on the characteristics of the products and application requirements, quality verification content includes nine quality elements: spatiotemporal benchmark, temporal accuracy, geometric accuracy, completeness, representation quality, attribute accuracy, semantic relationships, logical consistency, and accessory quality. The main quality issues identified during inspection typically are as follows: (1) Incomplete construction of combined entities, e.g., provincial highway combined entities are not continuous. (2) Errors in spatial identification codes for entities, inconsistent attributes between combined entities and minimum-granularity entities, incorrect attribute values, redundant entries, or omissions. (3) Redundant or omitted entity relationships, or relationships that exceed the scope defined in the technical design. (4) Errors in topological relationships of entities, such as self-intersections present in paddy fields or surface rivers.

3.2 Provincial-Level Terrain-Based Fundamental Geo-entity Data Quality Inspection

Provincial-Level Terrain-Based Fundamental Geo-entity Data is primarily derived from the conversion of 1:10,000 and 1:5,000 fundamental geographic information element data, supplemented by newly collected terrain-based fundamental geo-entity data. It serves as the foundational carrier for city-level and component-level 3D Real Scene construction.

The content of outcome quality verification are as same as the nine quality elements as illustrated above. The main quality issues identified during inspection typically are as follows: (1) Incorrect assignment of spatial identity codes for entities, such as inconsistencies in the last digit of location codes or non-uniform formats of entity identity codes. (2) Omission, redundancy, or type errors in entity conversion. (3) Insufficient editing of converted entity data, leading to discontinuous road/water networks and logical chaos. (4) Errors in constructing semantic relationships, such as misrepresenting the composition relationship between road segments and roads as an ownership relationship, redundantly establishing composition relationships between unrelated rivers, or incorrectly defining the composition relationship between river segments and rivers.

3.3 City-Level Fundamental Geo-entity Data Quality Inspection

City-Level Fundamental Geo-entity Data is produced through the conversion of 1:500, 1:1,000, and 1:2,000 fundamental geographic information element data, supplemented by newly collected city-level fundamental geo-entity data and urban 3D model (LOD1.3 level) data. It primarily focuses on achieving digital mapping of production and living spaces, and includes key features such as buildings, structures, transportation networks, water systems, and pipelines. This data is mainly used for detailed visualization and spatial statistical analysis, supporting refined urban management, as illustrated in Figure 2.

(a) stereoscopic model (b) polygon model (c) point model

Figure 2: Example of City-Level Fundamental Geo-entity Data

Taking the data outcomes of city-level 3D models (LOD1.3) as an example, quality verification content includes eight quality elements: spatiotemporal reference, temporal accuracy, geometric accuracy, stereoscopic features, scene effect, attribute accuracy, logical consistency, and accessory quality. The main quality issues identified are manifested as follows: (1) Non-compliance of attribute definitions and data organization with technical requirements; exceeding limits of geometric accuracy, such as areal models exceeding planar accuracy tolerances. (2) Stereoscopic features not meeting requirements, such as widespread inconsistencies between the geometric structural features of models and the actual site. (3) Widespread attribute assignment errors, such as mandatory attribute fields being entirely unpopulated. (4) Non-compliant topological representation in models, such as pervasive redundant nodes and extremely small faces.

4. FUTURE DEVELOPMENT OF 3D REAL SCENE QUALITY INSPECTION

With the acceleration of 3D Real Scene construction tasks and the increasing demand for massive data aggregation and immediate application of outcomes, new challenges have emerged in rapid quality inspection and scientific quality evaluation. In response to the current shortcomings in inspection capabilities and the need for transformation in intelligent quality inspection capabilities, the following suggestions and measures are proposed.

4.1 Establishing a Quality Inspection Standard System that Balances Standardization and Personalization

To address the practical needs of the diversified development of 3D Real Scene construction, it is essential to establish a nationally unified 3D Real Scene quality inspection standard system, providing clear guidelines for data production and quality control. In 2023, the Ministry of Natural Resources (MNR) issued the *"3D Real Scene Construction Outcomes Quality Verification Plan (2023-2025)"*, which established a quality control mechanism for 3D Real Scene construction outcomes. In 2024, the MNR further released the technical document *"Quality Inspection and Acceptance of Fundamental Geo-entity Data Outcomes"*, forming reference inspection standards for fundamental geo-entity data and urban 3D models (LOD1.3 level). Additionally, to meet the specific requirements of different regions and application scenarios, there is a need to further develop personalized quality inspection solutions within a unified standard framework. This aims to construct a 3D Real Scene quality inspection standard system characterized by "standard unification and application flexibility", refining and perfecting the standards of 3D Real Scene construction, and extracting quality inspection models that are referenceable, replicable, and promotable.

4.2 Exploring a Whole-Process and Dynamic Quality Monitoring Mechanism

Traditional quality inspection often relies on static, post-event checks. With the continuous advancement of 3D Real Scene construction, data update mechanisms have become increasingly critical, necessitating a shift in quality monitoring towards a whole-process and dynamic approach. By deeply integrating with the data production workflow, the focus can transition from "result-based inspection" to "process-oriented inspection". This enables the timely detection and correction of quality issues during production, thereby reducing quality risks, improving production efficiency, and supporting the scalable enhancement of data quality in 3D Real Scene construction.

4.3 Research on Full-Chain Self-Controlled Quality Inspection Technologies for 3D Real Scene Outcomes

To address the issues of inconsistency in manual inspections and the substantial workload associated with field operations, research on full-chain self-controllable quality inspection technologies for 3D Real Scene products will be carried out. The focus will be on constructing a big data support repository for 3D Real Scene quality inspection, encompassing various types of reference data, samples, and inspection knowledge, to enhance data utilization and the uniformity of evaluation metrics. Emphasis will be placed on building independent innovation capabilities, breaking through key core technologies for 3D Real Scene quality inspection, and supporting the development, application, and promotion of 3D Real Scene quality inspection software. By integrating new technologies such as artificial intelligence, big data, and cloud computing with traditional surveying and mapping inspection techniques, a new paradigm for quality inspection will be pioneered.

5. SUMMARY AND OUTLOOK

Three-dimensional spatial data, with geospatial information at its core, serves as a critical foundation for enabling digital transformation. It accelerates the integration, sharing, and application of 3D spatial geographic data resources, facilitating the convergence of decision-making, execution, and operational flows through data streams, thereby driving process reengineering, rule reshaping, and institutional restructuring across various sectors. Quality inspection of 3D Real Scene construction products is based on transitioning from a "production-service orientation" to a "scientific-production orientation," and from "data and information-based services" to "knowledge-based services." This shift aims to construct intelligent quality inspection application scenarios for 3D Real Scene environments, providing robust assurance for advancing the high-quality development of 3D Real Scene initiatives.

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BIOGRAPHICAL NOTES

Junyu CHEN is currently the Deputy Director of the National Quality Inspection and Testing Center for Surveying and Mapping Products. With a long-term engagement in the management of the surveying and mapping industry, she has organized the formulation and introduction of major industry management policies such as the Measures for the Management of Surveying and Mapping Qualifications and the Classification and Grading Standards for Surveying and Mapping Qualifications by the Ministry of Natural Resources. She has presided over quality inspection work for major projects including the national Real-scene 3D Construction and the construction and maintenance of global geographic information resources. Additionally, she has organized national surveying and mapping quality supervision and spot check activities. Her main research interests focus on quality control and assurance of new basic surveying and mapping products.

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