Design and Development of a Three-Dimensional Intelligent Contract System for Five Responsible Parties

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Abstract: Against the backdrop of increasing complexity in construction projects and the diversification of participants, traditional paper contracts and two-dimensional electronic contracts are gradually revealing limitations in multi-party collaborative performance and responsibility tracing. This paper focuses on a three-dimensional intelligent contract system for five responsible parties, expounding on its overall architecture design, key technology implementation — including blockchain technology, artificial intelligence algorithms, and multi-dimensional data synchronization technology — and the development path of core functional modules. It aims to provide technical support for the digital upgrade of contract governance in the engineering construction field.
***Keywords*:** Five Parties; Responsible Parties; Three-Dimensional Intelligent; Contract System

1. Introduction

With the escalating complexity of engineering construction projects, the traditional contract system shows a significant lag in areas such as collaborative performance by multiple responsible parties and progress control. In engineering practice scenarios involving the five responsible parties—the construction unit, design unit, construction unit, supervision unit, and operation unit—static text contracts struggle to meet the demands of modern engineering management. There is an urgent need for a new form of digital contract that integrates visual expression and clear mapping of responsibility chains. The three-dimensional intelligent contract system emerges in this context. By integrating mechanisms such as blockchain trusted storage and artificial intelligence semantic recognition algorithms, it constructs a performance contract network driven by digital models. This achieves precise binding between contract clauses and the engineering semantic model, breaking down the information barriers between traditional contract management and the actual engineering process.

2. Overall Architecture Design of the Three-Dimensional Intelligent Contract System

In the architecture design, based on the vertical linkage of the underlying data perception layer, the middle logic operation layer, and the upper application interaction layer, real-time binding of performance behaviors and node states, as well as permission associations and rule linkages among the five responsible parties, are completed. The system drives contract execution through models, performing semantic mapping between Building Information Model component attributes and contract clause elements. Utilizing a semantic recognition engine, it classifies key trigger conditions within the contract content, which are then input into the smart contract execution framework for automated performance judgment. The logic operation layer embeds a rule engine and data decision unit, which dynamically decides clause activation or triggers penalty mechanisms based on performance status and on-site feedback. The underlying blockchain structure is used to store various performance behavior data, ensuring data immutability and full-process traceability during contract execution. At the system application layer, responsibility allocation management is integrated. Based on the 3D interface interaction mechanism, it enables the five responsible parties to have synchronous perception and asynchronous collaboration regarding the same contract model, effectively supporting collaborative performance, dynamic supervision, and responsibility traceability throughout the entire contract lifecycle[1]. The system also integrates a multi-dimensional visual analysis module at the application layer, which can display the performance status of each node and key progress nodes in real-time, supporting responsible parties in quickly locating problematic components and links through the 3D model, thereby enhancing the transparency and controllability of contract execution. To improve collaboration efficiency, the system introduces a message push mechanism and a hierarchical permission strategy. Different responsible parties receive performance reminders, node warnings, and data feedback within their authorized scope, achieving precise management and task closure. Addressing the multi-source heterogeneous nature of on-site data, the system integrates sensor data through IoT interfaces, enabling real-time collection and intelligent parsing of information such as the construction site environment, equipment status, and personnel behavior, further enhancing the judgment accuracy and response speed of the data decision unit.

3. Key Technology Implementation

3.1 Blockchain Technology

In the three-dimensional intelligent contract system for the five responsible parties, blockchain technology serves as the foundational support for building a trusted performance environment and ensuring multi-party collaborative data consistency. It possesses core capabilities such as immutability and full-process traceability. Within the system architecture, it is primarily embedded in the form of a consortium chain, using the Hyperledger Fabric framework to build a modular architecture. Based on this modular architecture, different responsible parties can configure different access and operation permissions according to the contract agreement, thereby achieving dynamic governance during the execution of the 3D intelligent contract. The system combines Fabric's chaincode mechanism and multi-channel mechanism to automatically invoke corresponding smart contracts for performance logic judgment at different behavior trigger nodes, and writes interaction data to the ledger. During smart contract execution, the AES symmetric encryption process shown in Figure 1 is used for data encryption assurance, achieving confidentiality control of ciphertext during storage and transmission, further enhancing the anti-tampering and verifiable capabilities of core data among various subjects in the 3D intelligent contract system. Based on dynamic binding with the 3D model, the blockchain ledger can record the contract behaviors triggered by each component node and their corresponding operators, realizing a full-chain accountability mechanism at the behavioral dimension[2].

To further enhance the application efficiency of the blockchain system in the 3D intelligent contract scenario, the platform introduces an on-chain/off-chain collaborative storage mechanism. It classifies and processes key performance data and large-capacity 3D model data in the intelligent contract: lightweight data is stored directly in the blockchain ledger, while heavy data is linked via hash digests, with the original data saved in a trusted distributed file system such as IPFS, achieving an organic unity of data integrity verification and storage efficiency. Additionally, the system constructs a cross-chain collaboration module, supporting interaction with external business chains such as those of construction units, supervision units, and financial institutions, enabling mutual recognition of performance credentials and status synchronization between different business chains, and promoting the application integration of intelligent contracts in a broader scope. Addressing the complex and variable execution environment of project sites, the system also combines a blockchain event listening mechanism to capture state change behaviors matching contract clauses in real-time and trigger chaincode response logic, making the performance process more automated and precise. In terms of chaincode governance, a multi-organization endorsement mechanism and consensus algorithm configuration are adopted to ensure fair and transparent governance rights for all parties in contract execution and dispute resolution, fundamentally enhancing the system's ability to guarantee the authenticity, timeliness, and security of contract execution in complex engineering scenarios.

3.2 Artificial Intelligence Algorithms

The introduction of the BERT deep semantic modeling mechanism effectively addresses key issues such as unclear attribution of rights and responsibilities and inconsistency in performance behaviors. In the system's semantic perception module, the BERT model is used to perform deep contextual modeling of the clause content in engineering contracts. Based on the multi-layer bidirectional Transformer encoder, word embedding vectors are mapped to a high-dimensional semantic space, achieving the extraction of semantic dependencies among internal elements of clauses and the reconstruction of dynamic logical relationships between entity roles. To achieve real-time matching of responsible party performance behaviors and triggering of semantic rules, the system introduces a residual attention fusion mechanism to build a semantic deviation detection model[3]. Assuming the contract text representation is and the responsible entity behavior sequence representation is , the attention-weighted semantic mapping function is as follows:

$$\alpha_{ij} = \frac{exp(BERT(t_i)^T \cdot BERT(e_j))}{\sum_{k=1}^{m} exp(BERT(t_i)^T \cdot BERT(e_k))} \tag{1}$$

$$S_i = \sum_{j=1}^{m} \alpha_{ij} \cdot BERT(e_j) \tag{2}$$

Here, α_{ij} represents the semantic matching weight between t_i contract clause and e_i responsible behavior , and S_i is the behavior vector aggregation result of the contract semantic node. This formula is used in the system's intelligent performance recognition module to calculate the matching degree between clauses and performance behaviors, supporting performance status assessment and default behavior warning[4].

Building upon the aforementioned semantic matching mechanism, the system further introduces a multi-task joint learning strategy, integrating three tasks—clause classification, behavior discrimination, and default prediction—for combined training. By sharing the underlying semantic encoding layer, the model's generalization ability for multi-objective tasks in performance scenarios is enhanced. Specifically, with the main task being default risk prediction, the model is supplemented with clause categorization and behavior extraction tasks, achieving overall optimization through the dynamic weighted combination of loss functions, thereby effectively improving the accuracy of performance behavior recognition under complex semantics. To enhance the model's ability to model performance evolution over time, the system embeds a Transformer-XL structure, introducing a recurrent memory mechanism to capture long-term dependencies, thus enabling trend analysis and early warning of delays, deviations, and potential risks during the performance process.

4. System Functional Modules and Development Implementation

Based on the model-driven approach, the contract management module is embedded to complete clause element parsing, task assignment path generation, and responsibility binding form creation. The performance monitoring module integrates a multi-source data synchronization mechanism, Kafka message middleware, and IoT perception nodes to achieve multi-dimensional behavior data collection, execution status tracking, and node event backtracking. The dispute resolution module, based on intelligent semantic discrimination algorithms, automatically identifies ambiguities in contract statements and pushes intelligent prompts and neutral suggestions. System development adopts a microservices architecture, dividing it into multiple business subsystems, supporting multi-terminal heterogeneous access and concurrent scheduling of task flows. During the development and deployment process, the performance of core modules was tested and evaluated. The test results verify that each functional module of the system exhibits high consistency under complex responsibility collaboration conditions, providing technical feasibility support for the engineering practice of the 3D intelligent contract system among the five responsible parties[5].

5. Conclusion

In summary, against the background of continuously increasing complexity in engineering construction collaboration, the three-dimensional intelligent contract system provides a new solution for the digitalization of contract structures for the five responsible parties. By integrating BIM models, blockchain storage, AI semantic parsing, and Kafka data synchronization mechanisms, it achieves precise binding between contract clauses and component status, as well as dynamic tracking of the performance process, constructing a strongly closed-loop intelligent performance system. This effectively enhances the transparency and collaborative efficiency of contract management, providing an innovative path for digital governance in engineering.

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