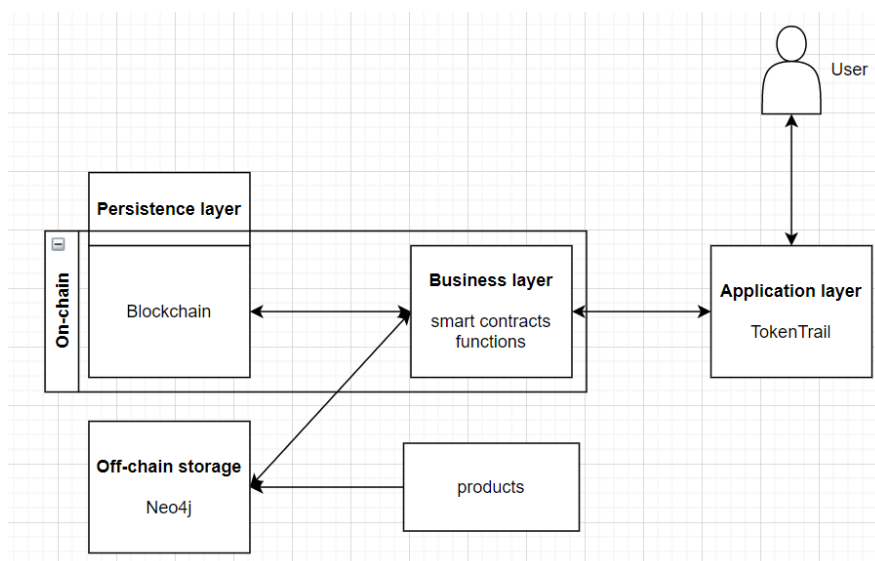


1.

- With the development of the world, product manufacturing involves more and more fields and regions. Therefore, it becomes more and more difficult to guarantee the traceability of the product completely and truly and obtain the information of the product at any time and place. Although there are some schemes, their universal applicability is poor. The authors aim to solve the lack of reliable tracking application.
- Requirements:
 - Functional requirements:
 - ◆ The system should generate unique data histories for each product.
 - ◆ The system should be able to input and merge information in different fields and convert it into digital information in a unified format.
 - ◆ Each unit should be continuously monitored, including position information, controller data and data related to other parts.
 - Non-functional requirements:
 - ◆ Interoperability.
 - ◆ data integration and exchange.
 - ◆ Scalability.
- In discrete manufacturing, multi-party is necessary and there is no trusted authority. Tracking history is not a centralized operation. To trace data and transaction histories, immutability is needed. High performance is not required since we use blockchain to track product history. Besides ideas such as store data in both on-chain and off-chain can improve performance. Obviously, data transparency is needed to guarantee the authentication and integrity of data. Thus, blockchain is suitable.

2.

- The user sends a request of data to an api, known as application layer. Then the api will pass it to business layer. specifically, smart contracts and functions will do request to database. Neo4j database collect data from outside and send it back to on-chain.



- On-chain components include business layer, smart contracts, ERC1155 Interface, functions and blockchain in persistence layer. Off-chain components include application layer, Neo4j database. A permissioned blockchain is used. In the paper, blockchain platform is Ethereum because Ethereum is widely used and matured. A permissioned platform can avoid data leak from the system while parties inside the system can access to transparent data. PoA is the most suitable consensus mechanism for the case mentioned in the paper. To achieve it, the researchers use Geth client to implement Clique algorithm. For business layer, the logic of tracking system is achieved by the smart contract ATM. In terms of token, ERC1155 use fungible and non-fungible tokens. The api, known as TokenTrail, grab data from both on-chain and off-chain database and present it with user readable format.

3.

- The solution is evaluated by case study, where the case is assembly of car's electrical and electronic system. Car assembly includes great quantities of components from various fields and regions. Besides, some car factories customize components for special vehicles, which can test applicability of the solution. Therefore, this case is complex with different kinds of challenges to trace units and suitable to test functionality and performance of the design.
- The evaluation showed that the TokenTrail performed well. It is easy to input IDs and product information, including material amount, order placement and so on. While tracking status, the UI can clearly present tracked data in a complex assembly structure. TokenTrail converted information and events to a user-friendly format, which made it easy to use. In performance test, the researchers evaluated the performance of blockchain processing transactions by evaluating consumed gas. Though gas consumption was within expected range, it could perform better with a more reasonable lifetime distribution of products. Additionally, the simulation showed the throughput of order reached to a satisfied extent. The system was able to complete orders in a high-volume environment. Besides, the performance would improve with stronger computational power. Overall, it is good enough for nowadays tracking requirements to multi-assembly product.

4

- The solution solved the problem to a certain extent, while some potential issue still exists. One of the good sides is the implementation of blockchain, which ensure a high transparency and immutability in a decentralized environment, reducing cost and the risk of data leak. Besides, the use of fungible token and non-fungible token made it more applicable and manageable. Moreover, the universal applicability is better than conventional solution. On the other hand, the performance of blockchain can be improved to increase throughput of orders. Apart from that, the confidentiality of products and information is low because of the introduction

of blockchain, while some product information should be private. The deployment of smart contract may cause issue as well since smart contract is immutable once deployed on blockchain. Thus, confirming the correctness of smart contracts before deployment is significant. The evaluation will convince potential users to adopt the design. Because it generally solved the problem to track history in product manufacturing.

- To improve the solution, encrypting On-chain data pattern can be apply to increase confidentiality of the data. For private data that need to be stored on blockchain, this design pattern can protect it from other party.