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Blockchain-based data management for digital twin of product

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ABSTRACT

The concept of digital twin was originally proposed to assist product lifecycle management through the high-fidelity virtual product. In product lifecycle, there are many participators constructing a complicated network with enormous product lifecycle data. It is difficult to manage data of digital twin efficiently and securely from the perspectives of data storage, data access, data sharing, and data authenticity among the complicated network. Moreover, the virtual product is always updated to the latest state of the physical product by overwriting the history virtual product that records the development process of digital twin. To address abovementioned data management problems simultaneously, a data management method for digital twin of product based on blockchain technology is proposed in this paper. A peer-to-peer network is constructed to enhance data sharing efficiency among participators. The basic structure of blockchain is introduced, including block, chain, and transaction. The blockchain is used for data storage through cryptography that ensuring only eligible participators can access the corresponding data. The change sensitive characteristic of blockchain can ensure data authenticity as well. In addition, the concept of smart contract can be used to execute some actions automatically to increase data sharing efficiency. A case study is presented to demonstrate the effectiveness of the proposed data management method. The results show that the proposed method can solve the abovementioned data management problems simultaneously.

1. Introduction

Product lifecycle management is about “managing products across their lifecycles” from the very first idea for a product all the way through the lifecycle, until it is retired and disposed of [1–5]. With the development of digitalization, many computer-aided technologies emerged in PLM, such as computer-aided design (CAD) [6], computer-aided engineering (CAE) [7], computer-aided manufacturing (CAM) [8], computer simulation [9] and enterprise resource planning (ERP) [10]. These enhance product design and manufacture efficiency. The emergence of digital twin [11] pushes the digitalization of product lifecycle management to a higher level, which aims at monitoring and optimizing all processes of the entire product lifecycle. Digital twin is a key enabling technology for smart manufacturing [12–14].

The concept of digital twin was first proposed by Professor Grieves [11] in 2003 for managing the product lifecycle in the virtual space, which was defined as three parts including the physical product in real space, the virtual product in virtual space and the data transmission between these two spaces. The development of the digital twin met with barriers from limitations of digital technologies for a long time, until in 2010, when NASA constructed the first digital twin of spacecraft [15]. The digital twin made a significant contribution to the project, and it was proven powerful. Afterward, the investigation of the digital twin gradually became a hot trend in the aerospace field. Then, more progress was made. For example, Glaessgen and Stargel [16] discussed the necessity of an ultra-high fidelity digital twin to mirror the life of its flying twin. A digital twin of aircraft wing was constructed to monitor its health using a dynamic Bayesian network [17]. Tuegel [18] investigated the challenges and realization of the airframe digital twin. This trend later extended the digital twin to generic products [19,20], which inspired other researchers to apply the digital twin to other research fields [21–24], especially in the manufacturing system field [25–29]. Tao et al. [30] reviewed state-of-the-art digital twins in the industry. Qi et al. [31] summarized the enabling technologies and tools for digital twin.

The development of information technologies (Internet of Things (IoT) [32], sensor technology, etc.) supports the efficient operation of a digital twin of product, especially the seamless data transmission between physical product and virtual product. The data generating during product lifecycle is the foundation of digital twin. Cai et al. [33] proposed an IoT-based configurable information service platform for PLM. Li et al. [34] summarized the application of “Big Data” in PLM.

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Uhlemann et al. [35] investigated the data acquisition problem of digital twin. A data modeling and exchange method of digital twin was proposed by Schroeder et al. [36]. However, there is rarely study concerning the data management of digital twin of product, including data storage, data access, data sharing, and data authenticity, which should be executed securely and efficiently. In addition, to monitor the real-time state of physical product, the corresponding virtual product is always updated to the latest state of the physical product. That means the virtual product is overwritten all the time. The history data of virtual product will be lost after being overwritten. Actually, the history data of virtual product records the evolution details of digital twin of product. It is crucial for performance optimization and design improvement. But, not enough attention is paid to the value of the history data. So, an effective solution should be proposed to solve the overwritten problem. It is difficult and complex to solve the abovementioned problems in the same time. The blockchain technology [37–40] provides a complete solution for data storage, data access, data sharing, and data authenticity, where any overwritten action will be captured and recorded. Therefore, a data management method is proposed based on blockchain technology for digital twin of product to solve the abovementioned data management problems simultaneously.

The remaining part of this paper is structured as follows: Section 2 introduces digital twin of product and blockchain technology. Section 3 elaborates the proposed data management method using blockchain technology for digital twin of product. Section 4 provides a case study to implement the proposed method. Section 5 concludes this paper.

2. Digital twin of product and blockchain technology

In this section, the digital twin of product for lifecycle management is analyzed to show the advantages of digital twin. In addition, the concept of blockchain technology is introduced, which the relationships between data management of product lifecycle and blockchain technology are discussed.

2.1. Digital twin for product lifecycle management

The general definition of digital twin recognized and used by most researchers up to date is that digital twin is an integrated multi-physics, multi-scale, probabilistic simulation of a complex product or system to mirror the life of its corresponding twin [23]. The digital twin of product consists of three components: physical product, virtual product, and the data transmission between physical product and virtual product, as shown in Fig. 1. The interaction between physical product and virtual product is crucial for maintaining the vitality of digital twin. In other words, the data transmission from physical product to virtual product updates the virtual product to the latest states of physical product, which can be used to monitor the performance of the physical product. The data transmission from virtual product to physical product can be used to support the performance optimization, maintenance scheduling, and others of the physical product.

The product lifecycle includes product design, manufacturing, maintenance, etc., where enormously diversified product data are generated, named as product lifecycle data. It is a complicated process, which sophisticated details should be concerned in each period. For examples, market preference, function requirements, design constraints, and others should be analyzed in depth by product designer; production planning, process planning, production scheduling, and others are the main works of product manufacturer; the order proceeding, product usage, and others should be concerned by the customer; etc. Therefore, the product lifecycle management is necessary to ensure that all the processes within product lifecycle are under control. The emergence of digital twin provides an approach to monitor all activities of product within the entire lifecycle and optimize the performance of the product based on the simulation results of digital twin, as shown in Fig. 2.

2.2. Blockchain technology

A blockchain is a growing list of blocks that are linked using cryptography. Each block contains a cryptographic hash of the previous block, a timestamp, and transaction data (represented as a Merkle tree). It is a decentralized, distributed and public digital ledger that any involved record cannot be altered retroactively, without the alteration of all subsequent blocks. Blockchain was invented by Nakamoto [37] to serve as the public transaction ledger of the cryptocurrency bitcoin in 2008. Lischke and Fabian [41] analyzed the network of Bitcoin. The cost-saving benefits in the banking industry were discussed by Cocco et al. [42]. Apart from cryptocurrency, there are numerous applications, such as privacy preservation [43,44], next generation reputation systems [38], institution of property [45], and decentralized governance [46]. Nofer et al. [47] elaborated on the characteristics and core technologies of blockchain technology. Zheng et al. [48] analyzed the challenges and opportunities of blockchain technology. The architecture, consensus and future trends of blockchain technology were discussed by Zheng et al. [49]. Regarding production industries, the potential benefit of blockchain technology in the manufacturing supply chain was discussed [50], Hardjono and Smith [51] investigated the cloud-based commissioning of constrained devices using a permissioned blockchain. A framework based on blockchain technology was proposed to enhance digital infrastructures [39]. Korpela et al. [52] applied blockchain technology to digital supply chain transformation. Kim and Laskowski [40] considered the province of the supply chain, which integrated ontology technology and blockchain technology to achieve this purpose. Overall, it is feasible to apply blockchain technology to solve data management problems of digital twin of product.

3. Data management method for digital twin of product based on blockchain technology

Data management is very important for the successful implementation of digital twin of product for product lifecycle management. However, the data management process is complex and difficult, particularly considering data security and management efficiency.

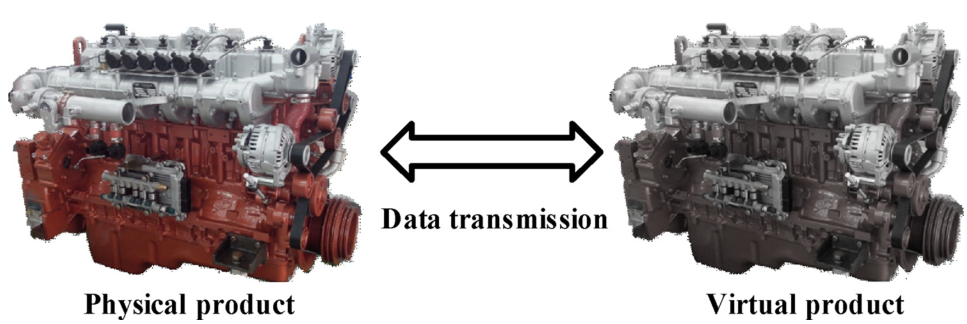


Fig. 1. Digital twin of product.

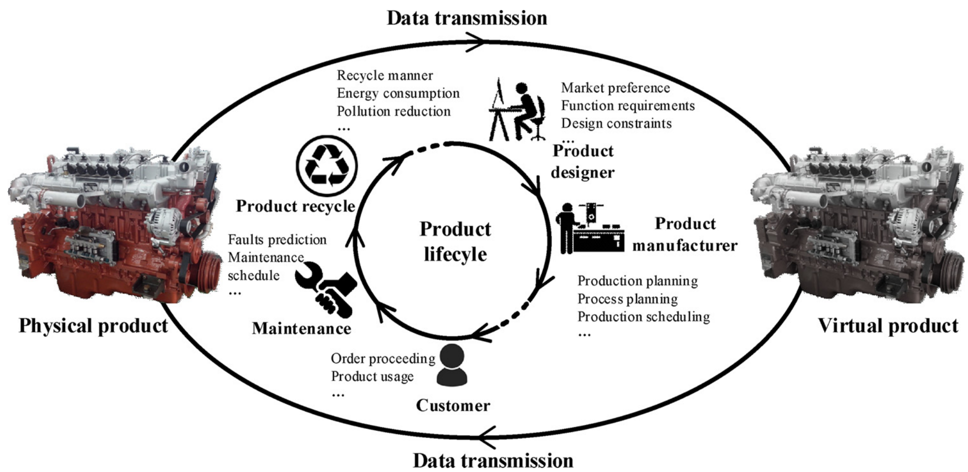


Fig. 2. Digital twin-driven product lifecycle management.

Therefore, a data management method for digital twin of product based on blockchain technology is introduced in this section to solve this problem.

3.1. Peer-to-peer network for data management

There are many participators in the lifecycle of a product, which can be classified as product designer, manufacturer, etc. Each participant type (e.g. designer) consists of one or more participators. The relationships among participant types and participators can be expressed as Eq. (1).

$$PL = \{PT_i | PT_i \in \mathbb{N}^*, i = 1, 2, ..., n\} \tag{1}$$

where PL denotes the set of participators; PT_i denotes the participators of i^{th} participant type; $\mathbb{N}^*$ denotes natural number, $PT_i \in \mathbb{N}^*$ means the participators of i^{th} participant type equal to one or more; n denotes the total numbers of participant types.

Communication activities are required not only by the participators from the same participant type, but also by the participators from different participant types. There are one or more participators of each participant type resulting in a complicated communication network. To increase the communication efficiency among the participators within the product lifecycle, it would be better to create a peer-to-peer network that is required by blockchain technology as well, as shown in Fig. 3.

Participator can join the network after validation to eliminate bad nodes that may destroy the network. Also, participator can quit the network freely. The product lifecycle data is recorded as a transaction and stored in a specific block. All verified blocks are chained together to constitute a blockchain. Eligible participators can have a copy of the blockchain to prevent data fraud and maintain data authenticity. Due to the complete product lifecycle data are recorded on the blockchain, it is convenient to obtain the data of the digital twin in a specific time by directly querying the blockchain. Moreover, as a benefit of the peer-to-peer network, each participator can share data conveniently by directly sending the data to the requester through the network as well. For example, if a product designer wants to know the manufacturing situation of the product for improving the new design, he can request specific data from the manufacturer. In addition, the product lifecycle data shared through the peer-to-peer network is secured by encryption technology that ensures data security. The encrypted data only can be accessed by the eligible participators. Therefore, the product lifecycle data can be shared through the network securely.

3.2. Block and blockchain of blockchain technology

The base of the blockchain technology is the block. A block is composed of the block header and block body, as shown in Fig. 4. The block header consists of “Prev Hash”, “Timestamp”, “Root Hash” and “Nonce”. The “Prev Hash” is the hash value of the previous block. The “Timestamp” is a sequence of characters or encoded information identifying when a block created. The “Root Hash” is the identity of the current block. The “Nonce” is a random number used to solve a mathematical puzzle that is associated with “Prev Hash”, “Timestamp” and “Root Hash” to connect the previous and current block. The block body holds batches of valid transactions that are hashed and encoded into a Merkle tree resulting in “Root Hash”. The “Root Hash” represents all the transactions within the same block. The transaction is a standard template to record product lifecycle data of digital twin.

A group of verified blocks constitutes a blockchain in chronological order according to the adopted consensus algorithm (proof of work, proof of stake, etc.), where the longest blockchain is seen as the main chain in the same network and others will be removed. The first block of the blockchain is called the genesis block. It is a special block without “Prev Hash”. The “Root Hash” of the genesis block is the “Prev Hash” of the second block. The second block is chained with the genesis block through the “Nonce” that is a solution of “Prev Hash” and “Root hash” of the second block based on the consensus algorithm. In the same fashion, the third block, fourth block, and the subsequent blocks are added to the chain successively, as shown in Fig. 5. The introduction of the timestamp embeds the time property into the blockchain for tracing the exact time of the block creation. Every participator has the right to add a new block to the chain. The “proof of Work” is adopted as the consensus algorithm, which is a widely adopted mechanism in the application of blockchain technology.

3.3. Transaction for recording product lifecycle data of digital twin

Transaction is the basic component for data recording and sharing, including public key, private key, timestamp, and product lifecycle data, as shown in Fig. 6. Each participator owns a pair of keys that consists of a private key and a public key. The public key is broadcasted to every participator through the network while the private key is only known by the owner. The key pair can be used to encrypt and decrypt product lifecycle data to ensure the safety of data sharing, which only the match key can decrypt the encrypted data. The public key in the top of the transaction denotes the current owner of the product. The private key in the bottom of the transaction denotes the previous owner of the product, which signs to change the ownership of the product. The timestamp is used to mark the creation time of the transaction. The

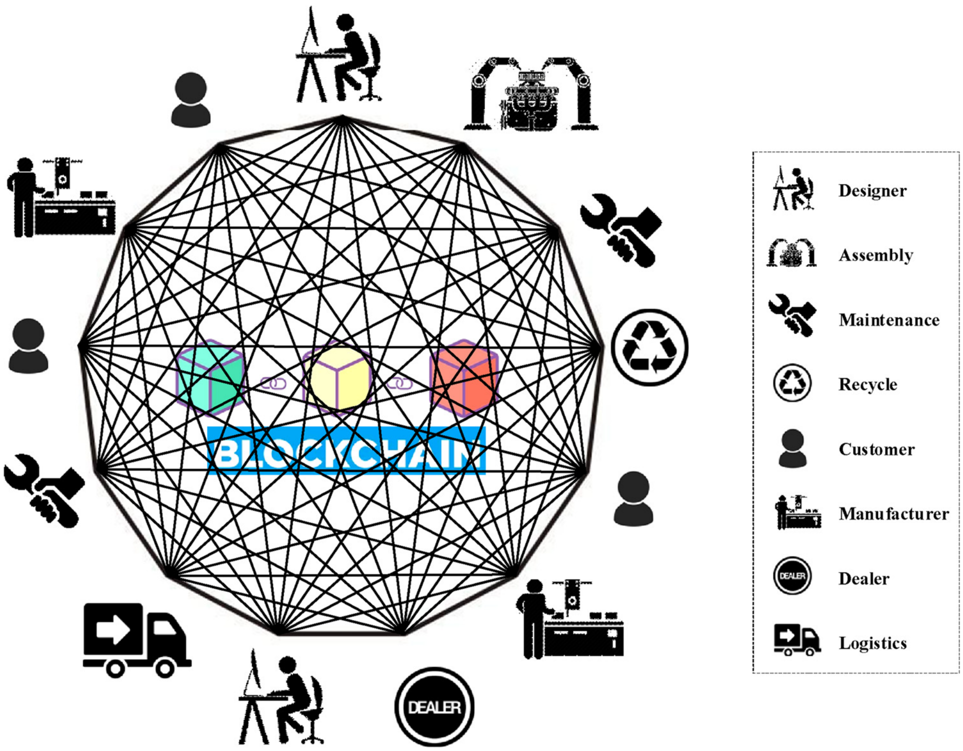


Fig. 3. Peer-to-peer network for data management.

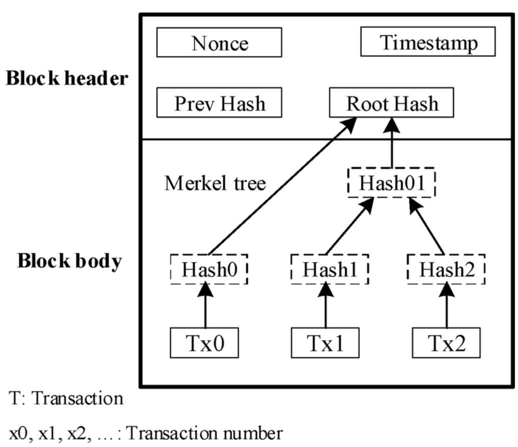


Fig. 4. Block structure.

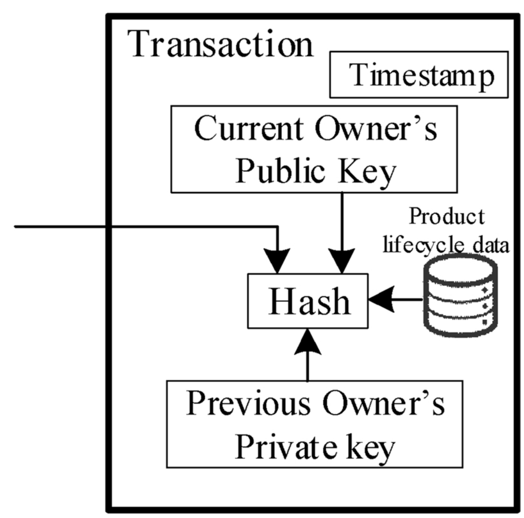


Fig. 6. Transaction structure.

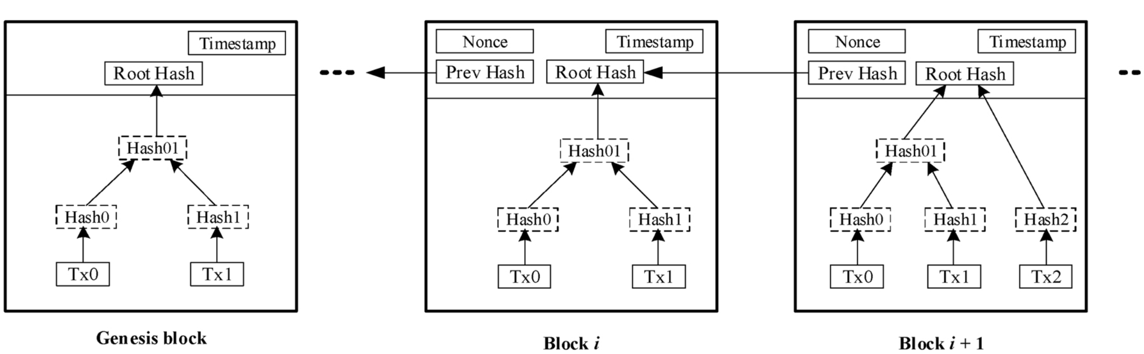


Fig. 5. Blockchain structure.

```
Smart contract: 0xCB8***77EF1        Contract Creator: 0xf2f9##
if   designer 1 signature & designer 2 signature → True
       → sent design files to manufacturer for manufacturing
       → create a new transaction
else
       return
end if
```

Fig. 7. Pseudocode of an example smart contract.

product lifecycle data is the core part of a transaction describing the key information of the product in a specific period of product lifecycle. The product lifecycle data belongs to the owner of the product. In other words, the ownership of the product lifecycle data is changed along with the ownership changes of the product. Every participator will possess the product for a while. Any change of the product lifecycle data will be recorded using the same public key and private key, which only the product lifecycle data and timestamp are different. This operation is similar to someone sends digital currency to himself.

Any change of the product lifecycle data can start a transaction if necessary. For example, when the ownership of the product is changed (e.g. a product is sold from a dealer to a customer), the current owner (dealer) can start a new transaction by hashing the current transaction with the new owner's public key and signing by using his private key to transfer the ownership to the next owner (customer). The new owner can decrypt the transaction to obtain the data of the previous period of the product by his private key. Here, only the private key's owner can decrypt the data, which can avoid data leakage and maintains data security during data sharing. In addition, the public key and private key in a transaction can come from the same participator. This type of transaction happens when the product lifecycle data is changed without changing the ownership of the product. It is helpful for data management of digital twin of product, which the product lifecycle data change often during usage.

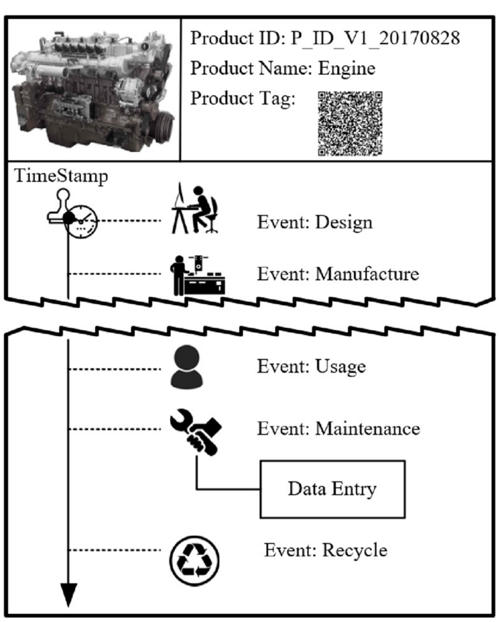
Fig. 7. Pseudocode of an example smart contract

Once the data recorded on a transaction is verified, the transaction cannot be changed anymore. Any change to the data will result in a new transaction and be broadcasted to all the participators within the network. To increase the flexibility of the blockchain, a smart contract [53] can be embedded with a transaction to execute some actions automatically. The introduction of the smart contract affords significant convenience among departments/companies for corporations. For example, the feasibility of product design should be validated by different departments that sign the smart contract if the validation passes. When the smart contract is signed by all the relative departments (e.g. designer 1 and designer 2), the product design will be sent to the manufacturer for manufacturing automatically. The pseudocode of the corresponding smart contract is shown in Fig. 7.

3.4. Product lifecycle data of digital twin

The physical product is going through all the processes of the product lifecycle, including design, manufacturing, assembly, sale, usage, etc. The development processes of the physical product should be recorded according to the requirement of data management. Therefore, a profile of physical product is generated to track the development processes, as shown in Fig. 8(a). The basic information of the physical product is included in the profile, such as product ID, product name, etc. The development processes including design, manufacture, and other events are recorded along with the timestamp. So, the profile of physical product is a dynamic profile that is recorded using the transaction. In other words, a new transaction is created when the profile is updated. A brief description of the corresponding event will add to the new transaction. The update procedure of product profile is shown in Fig. 8(b).In addition, the documents obtaining from the event can be added to the new transaction if necessary.

The virtual product is updated to the latest state of the physical product through the sensors embedded into the key position of the physical product. The digital twin of product aims at monitoring the real-time states of the physical product. As mentioned in the problem statement, the updating processes of the virtual product is always overwritten by the new sensor data transforming from the physical product. To monitor the overwritten process, a new transaction is created when new sensor data is generated. Considering that the sensor number and installation position remain unchanged during once the sensor system is constructed on the physical, the types of data used to update the virtual product is fixed. In other words, a variable set with fixed numbers of variables $D_{sensor} = \{d_i | i = 1, 2, ..., n\}$ is used to capture the data changes, where d_i is the value of each variable and n denotes the numbers of sensors installed in the physical product. The variable



(a)

Product profile update procedure

New event happens?

If yes

update product profile

create a new transaction

attach the updated product profile to the new transaction

End if

(b)

Fig. 8. An example of product profile.

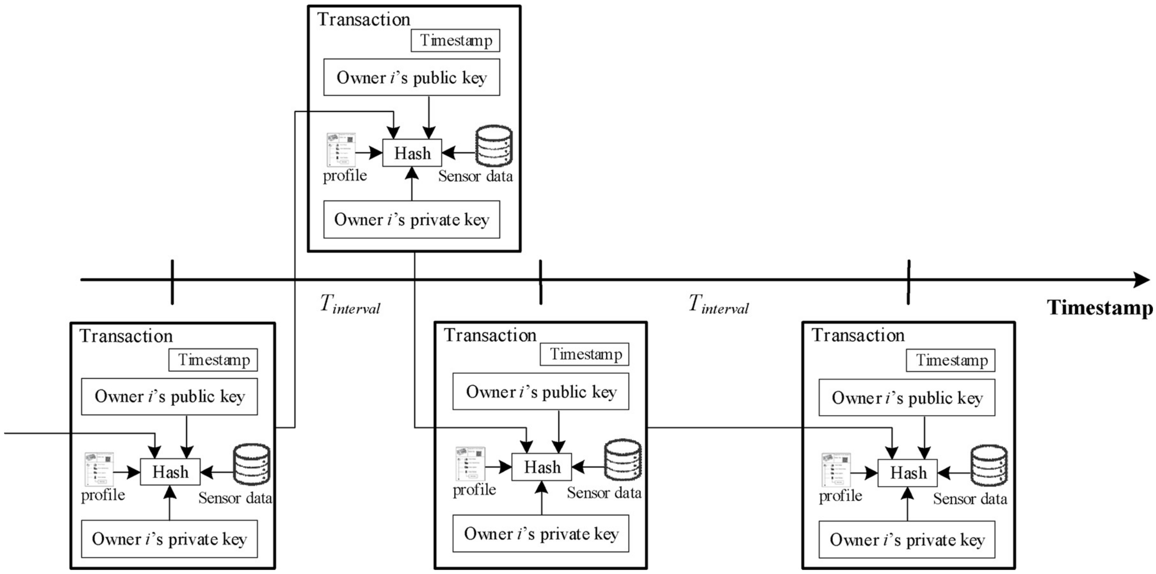


Fig. 9. The processes of recording sensor data.

Sensor data update procedure

Preset D_{sensor}^{upper} D_{sensor}^{lower} $T_{interval}$

If $t \geq T_{interval}$

Update sensor data

Else

If $d_i - d_i^{lower} < 0$ Or $d_i - d_i^{upper} > 0$

Update sensor data

End if

End if

Fig. 10. Sensor data update procedure.

Table 1
Required performances of turbine.

Electrical power	34,300 kW
Fuel input	75,100 kW
Efficiency	40.3 %
Exhaust gas mass flow	87.2 kg/s
Exhaust gas temperature	470 °C
Generator Voltage	10.5 kV
Steam mass flow 8 bar (g) saturated	46.2 t/h
Fuel type	Natural Gas
Emissions	NO × 15ppm (9ppm)/CO 25ppm
Performance at ISO-condition w/o duct losses at Generator Terminal	

set D_{sensor} is dynamic according to the sensor data.

However, it is impossible to store real-time sensor data, where a tremendous amount of data is generated from the physical product entailing a very expensive data storage cost. Generally, the physical product is in stable status. To reduce the data storage cost, a time interval $T_{interval}$ (per minute, per hour, per day, etc.) is preset, according to the practical situation, to create the new transaction for capturing the development trend of the physical product. In addition, abnormal sensors should be captured for performance analysis. The upper boundary and lower boundary of sensor data is preset, that is, $D_{sensor}^{upper} = \{d_i^{upper} | i = 1, 2, ..., n\}$ and $D_{sensor}^{lower} = \{d_i^{lower} | i = 1, 2, ..., n\}$. If the sensor data d_i exceeds its upper/lower boundary ($d_i - d_i^{upper} > 0$ or $d_i - d_i^{lower} < 0$), a new transaction is created immediately without needing to consider the preset time interval. The processes of recording the sensor data are shown in Fig. 9. The corresponding update procedure is given in Fig. 10.

4. Case study

To demonstrate the effectiveness of the proposed data management method for digital twin of product, a case about data management of the digital twin of turbine is presented in this section. Turbine is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work, which can be used for generating electrical power. Turbine is a complex product consisting of inlet, compressor, combustor, rotor, etc. It is too expensive to construct another turbine to monitor its operation states. Therefore, a digital twin of turbine is constructed to monitor and optimize the operations of the corresponding turbine. Moreover, tremendous data is generated during the development of the digital twin of turbine. It is urgent to manage the tremendous data in a suitable way to maintain the advantages of digital twin.

First, a turbine is designed by two product design departments (designer) according to the performance requirements of turbine (Table 1), including electrical power, fuel input, efficiency, etc. The performance requirements are converted into different parts including the inlet, compressor, exhaust casing, and exhaust manifold, as shown in Fig. 11(a). The turbine is designed on *Solidworks* according to the realization of these performance requirements, as shown in Fig. 11(b). In addition, the performances should be verified through simulation as well. The entire set of design contents of the turbine are entered into the product profile of the turbine once the design scheme is confirmed, as shown in Fig. 11(c).

Then, the digital design files of the turbine are sent to the manufacturer and assembly to convert the design scheme into the physical turbine. In the manufacturing of turbine, the parts of turbine should be manufactured first, including impeller blade and combustion chamber. The operations of impeller blade are given in Fig. 12(a), including raw

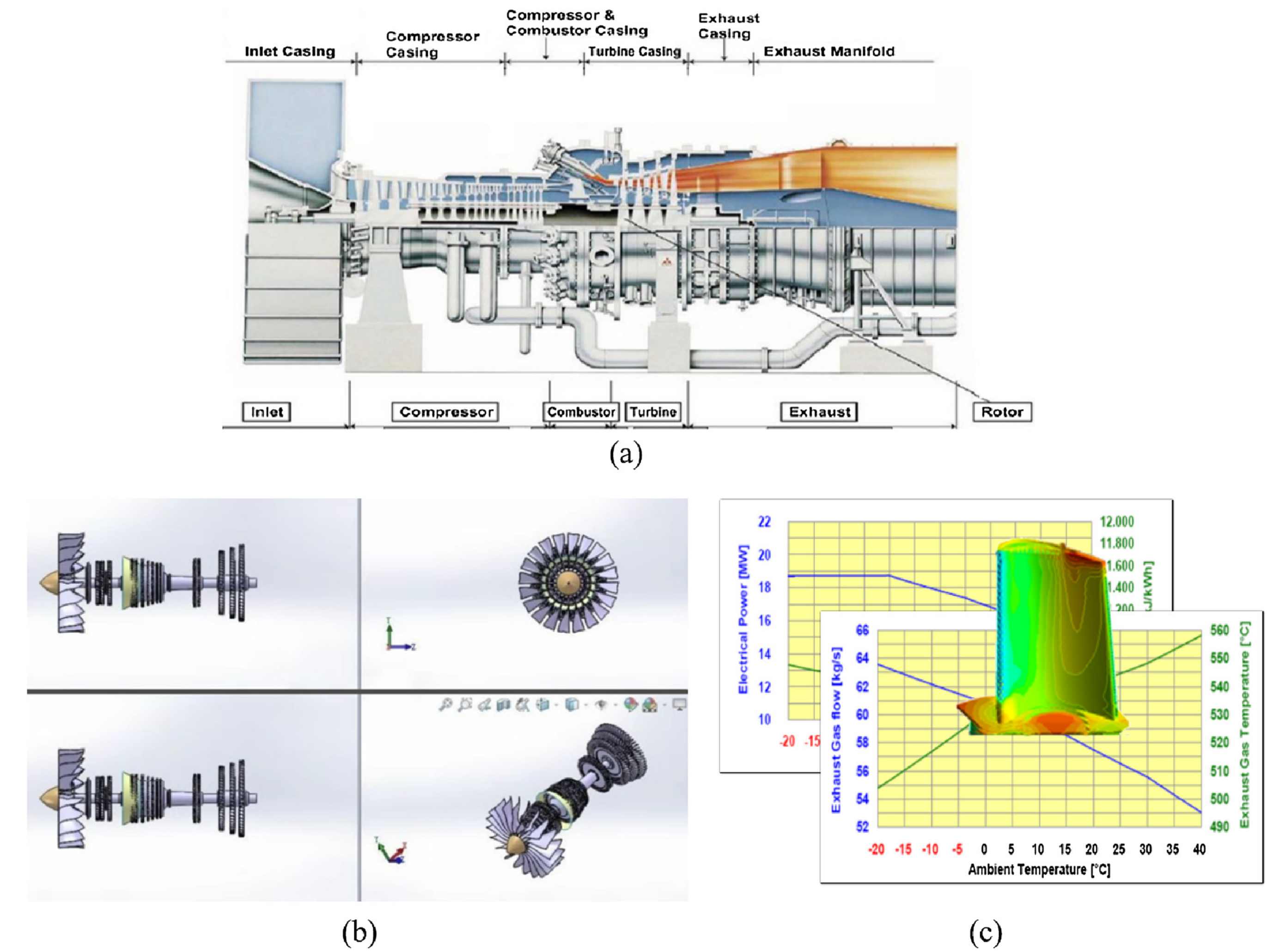


Fig. 11. (a) Functional decomposition based on performance requirements; (b) Design model on *Solidworks*; (c) Performance simulation instance.

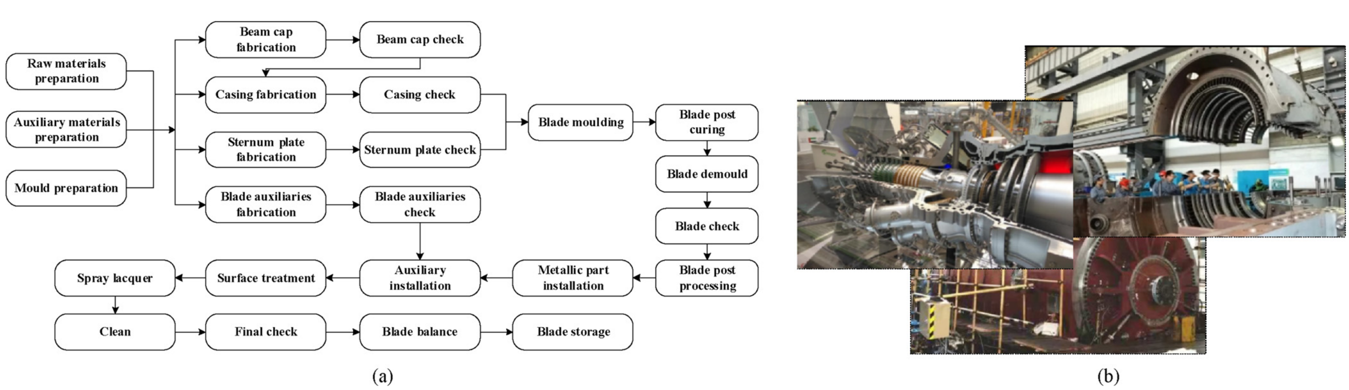


Fig. 12. (a) Operations of the impeller blade; (b) Assembly of the turbine.

materials preparation, casing fabrication, blade moulding, blade post processing, etc. Then, the parts and purchased components are assembled together to constitute a turbine in the assembly plant, as shown in Fig. 12(b). The manufacturing of turbine is the starting point of the digital twin of turbine. The data transmission between the virtual turbine and the physical turbine begins as well. Once the entire set of manufacturing processes of turbine are finished, the product profile of turbine is updated according to the manufacturing results. Similarly, the other processes in the development of digital twin of turbine, including logistics, usage, maintenance, and recycle, are recorded into transactions and stored in the blockchain.

Afterward, the physical turbine is delivered to the customer by a delivery procedure. The customer possesses the turbine until the end of its service life, during which the maintenance personnel will engage with the maintenance activities of the physical turbine. The general maintenance contents of turbine are shown in Table 2, which are the core contents of the maintenance report. The previous maintenance report can be referred as well in the new around maintenance, which should be granted by the owner of the maintenance report.

The virtual turbine keeps updating according to the wear and tear of

Table 2
Maintenance Contents.

Maintenance interval	maintenance types	maintenance details
1 st maintenance (8000 equivalent running hours or 300 times start-up, whichever comes first shall prevail)	Combustion chamber maintenance (disassembly combustion chamber only)	● Appearance, NDT*1 combustor chamber flame tube, transition section and fuel injection nozzle inspection; ● Visual inspection, ignition test, flame detector experiment;
2nd maintenance (16000 equivalent running hours or 600 times start-up, whichever comes first shall prevail)	Turbine maintenance (disassembly turbine cylinder head only)	● Appearance inspection of turbine rotor blades, stator blades, seal and NDT*1; ● Appearance inspection of gas compressor inlet guide vane, 1 st blade, last partition and exit guide vane; ● Combustion chamber maintenance.
…	…	…
6th maintenance (48000 equivalent running hours or 1800 start-up times, whichever comes first shall prevail)	Overhaul and inspection (disassembly cylinder head of turbine and all gas compressor, and disassembly generator rotor)	● Visual inspection of all components and NDT*2 ● Additionally, inspection of accessory equipment, control system and instrumentation.

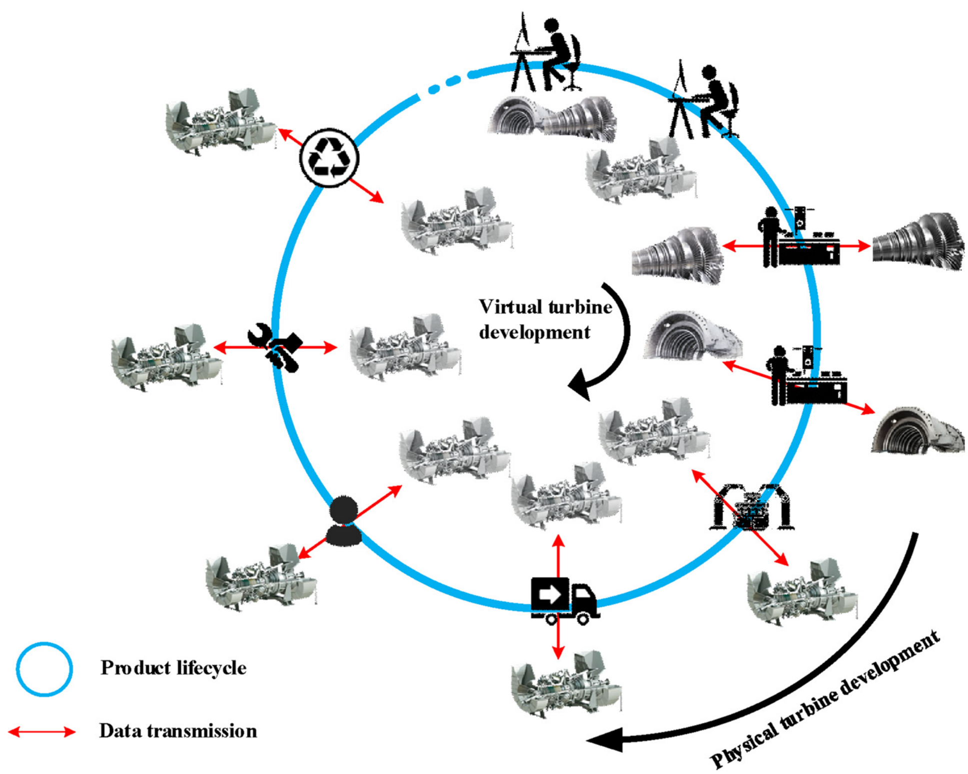
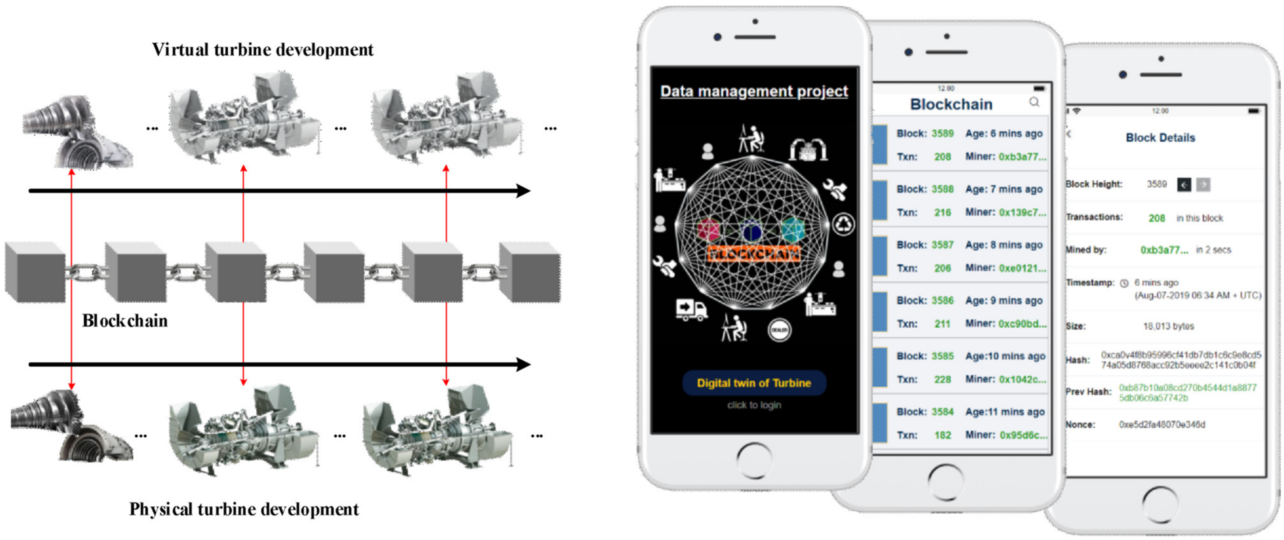


Fig. 13. The development processes of the digital twin of turbine.

the physical turbine. The test results of the virtual turbine will help to predict faults, schedule maintenance, etc. of the physical turbine. Finally, the physical turbine goes through scrap or recycle process. The development processes of the digital twin of turbine are shown in Fig. 13.

The evolution processes of the digital twin of turbine are recorded on blocks through bunches of transactions, which are chained together to constitute a blockchain in chronological order according to timestamp, as shown in Fig. 14(a). Considering that all the participators within product lifecycle can constitute a consortium, the most suitable framework to implement the blockchain for data management of digital twin is consortium blockchain. Therefore, a data management platform is constructed for managing the data of the digital twin of turbine, as shown in Fig. 14(b). The data management platform can be accessed through mobile device. It is convenient for monitoring the states of the digital twin of turbine. The entire blockchain can be presented on the platform, where a specific block can be explored through the search function. The block details are shown after clicking a block number on the blockchain screen, including block height (block number), transactions stored in this block, the miner of this block, etc.

Additionally, bunches of transactions recording the product lifecycle data of the digital twin of turbine are stored in a specific block, as shown in Fig. 15. There are two types of transactions. Type 0 means the ownership changes of the turbine. For example, the transaction "ox401b8…" records the ownership changing from "0 × 2bd5…" to "0xb67b…". Type 1 means the sensor data, which records the data transmission details between the virtual turbine and the physical turbine. Seen from the transaction details, the transaction hash, status, product ID, and other necessary information are provided. The input data content of the transaction details records the details of ownership changes or the update of the sensor data. The input data can be encrypted for data security. For example, the input data of the left part of Fig. 14 is the ownership change details of turbine. Only the eligible participator knowing the passcode and right encryption algorithm can decrypt the data. The actual information of the above example is shown in Fig. 16. The documents (e.g. maintenance report) can be attached on the transaction as well. The product ID is a unique ID of a specific turbine. It is easy to obtain all transactions associating with a specific turbine through product ID search. The development trends of variables can be obtained by plotting the values of the variables recorded on



(a) (b)

Fig. 14. (a)The blockchain used to record the data of digital twin of turbine; (b) Data management platform for digital twin of turbine.

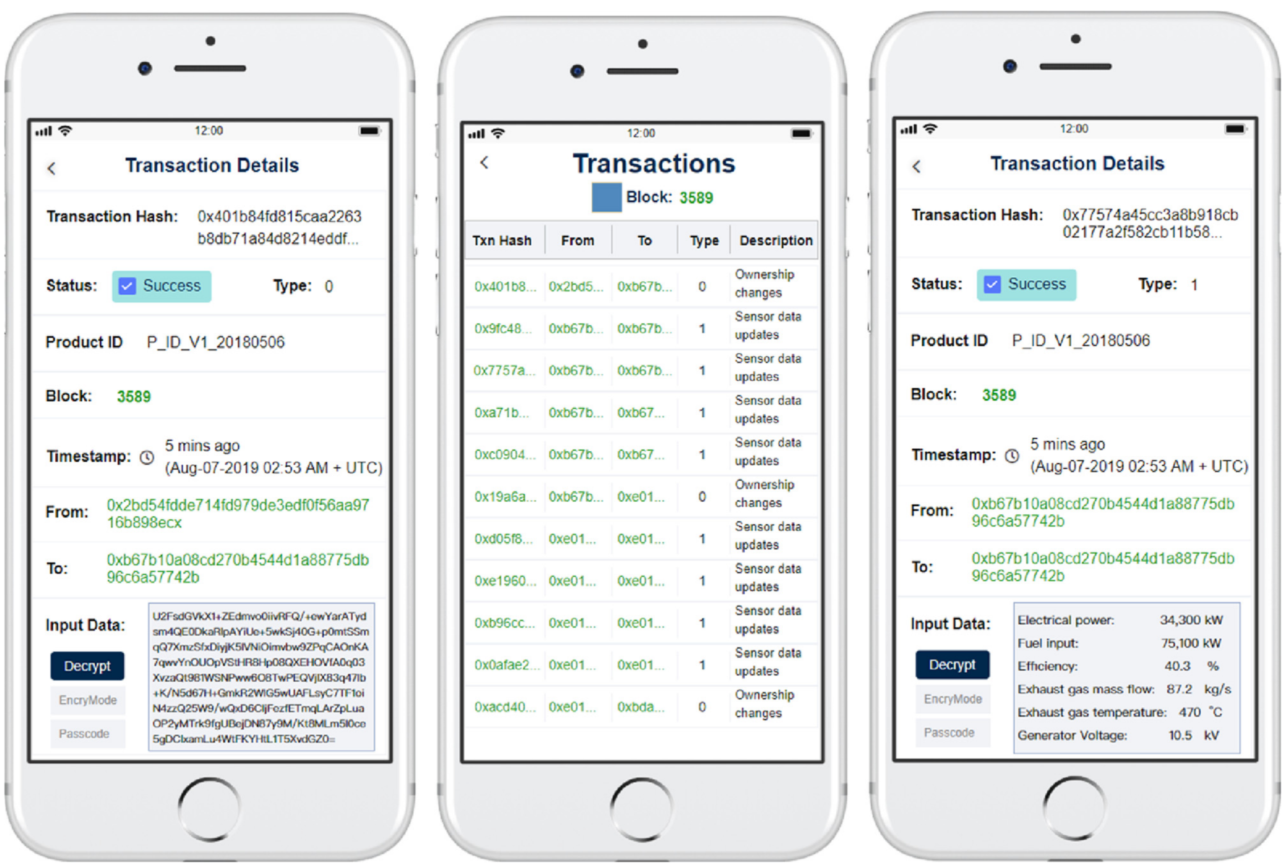


Fig. 15. Transaction list and details.

these transactions, which cannot be tampered ensuring the data authenticity. It is convenient for maintenance personnel to diagnose the potential problem based on the development trend. Moreover, these data also are valuable for performance optimization and design improvements of the new turbine.

In conclusion, the proposed data management method based on blockchain technology is implemented on the digital twin of turbine, including turbine design, manufacturing, usage, maintenance, etc. A data management platform is developed using blockchain technology as well. Obviously, it is a secure and convenient way to manage the product lifecycle data of turbine.

5. Conclusion

To solve the data management problems of digital twin within product lifecycle, including data storage, data access, data sharing, data authenticity, and data overwritten (virtual product), a data management method based on blockchain technology is proposed in this paper.

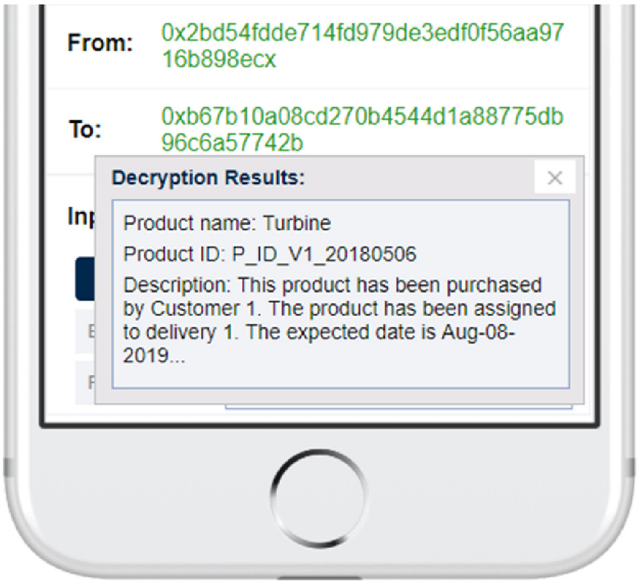


Fig. 16. Decryption information.

A peer-to-peer network is constructed to connect every participator within the product lifecycle. All actions of digital twin of product among participators are recorded by the transaction. The sensor data between the physical product and the virtual product is recorded by transaction as well. All transactions are stored in the blocks that are linked using cryptography to constitute a blockchain. The timestamp involves the entire processes to mark the time of occurrence. A case study associating with digital twin of turbine is presented to demonstrate the effectiveness of the proposed data management method. The results show that the proposed method can solve the abovementioned data management problems simultaneously, that is, the data can store in the blocks, the data accessed should be verified, the data sharing is efficiency through peer-to-peer network, the data authenticity can be guaranteed through traceability that can avoid data overwritten. However, the documents stored in the blockchain will decrease the query efficient of the blockchain, which does no good for data management of digital twin and will be investigated deeply in future work. In addition, only the data management problems of the digital twin of product are addressed in this paper, more attentions can be paid to digital twin of floor shop, manufacturing system, and supply chain in future work.

Declaration of Competing Interest

I declare that no conflict of interest exits in the submission of this manuscript, and manuscript is approved by all authors for publication. I would like to declare on behalf of my co-authors that the work described is original research that has not been published previously, and not under consideration for publication elsewhere, in whole or in part. All the authors listed have approved the manuscript that is enclosed.

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