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Cloud-based Manufacturing Blockchain: Secure Knowledge Sharing for Injection Mould Redesign

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Abstract

This paper proposes a cloud-based manufacturing knowledge sharing system for injection mould redesign (IMR) based on blockchain technology. In our proposed system, private cloud is used to store the IMR knowledge, and blockchain provides standards and protocols for implementing the system as well as ensuring the security in a trustless environment. K-Nearest Neighbors is used for retrieving the blockchain-based document knowledge. The proposed system not only can facilitate injection mould redesign, but also provide a mechanism for knowledge owners to share their own assets securely.

Keywords: Manufacturing blockchain; Private cloud; Knowledge sharing; Injection mould redesign

1. Introduction

Mould design is a vital part of any injection mould project that influences the mould quality, delivery and cost [1]. It involves assessment of the part design, making modification based on the product usage and function, and performance of the mould trial etc. It is a process that is susceptible to errors during its iteration, resulting in the necessity of mould redesign (MR). As a matter of fact, it has been estimated that on average 49 out of 50 moulds require some redesign or modifications during the start-up process [2].

MR, as a typical stage of mould design, refers to modifying the previous design in terms of parameters, materials and processes, to resolve the problems assessed in mould trials, and to ensure that most suitable knowledge and technology are incorporated into the redesign [3]. In addition, MR project usually consists of several sections and tasks involved with high requirement of appropriateness. And each task is conducted within different groups i.e. even the enterprises. Moreover, it requires highly cooperative work among different departments. It is extremely knowledge intensive [4].

Traditionally, MR is conducted by a mould redesign engineer fulfilled with lots of professional knowledge. This process is time-consuming and complex, becoming very inefficient when the cross-enterprise cooperation is involved from other geographical regions. Ideally, MR should be conducted by sharing accumulated knowledge from previous cases [5]. On the one hand, previous research has utilized the knowledge-based expert system and/or ontology to solve the problems in mould redesign [6-7]. On the other hand, Cloud manufacturing is a paradigm that uses network, cloud computing, IoT etc. It can share computing, data and information resources for full connectivity, remote access and interoperability in the company-wide [8]. These studies have great merits to facilitate the mould redesign.

However, almost none efforts have been made on the secure and trusted knowledge sharing for the redesign problems in the mould manufacturing alliance. In view of the characteristics of mould redesign, challenges still exist. Firstly, security is always

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a concern in implementing knowledge sharing system [9]. When the number of participants of the system increases, questions regarding to ownership, access and control arise. Secondly, the current knowledge sharing method are designed based on centralized framework [10]. Knowledge is owned by a small group of parties. Knowledge sharing remains superficial and limited. Furthermore, although researchers have developed different cross-enterprise knowledge sharing systems to solve this problem in the last decade [11-12]. However, enterprises in the mould industry are lack of trust.

In order to achieve an effective knowledge sharing for injection mould redesign cross-enterprise, we propose a secure manufacturing knowledge sharing system based on private cloud and blockchain. In particular, private cloud can offer the benefits of greater control, tighter security and flexible management options. We use the feature extraction and latent semantic analysis (LSA) in the private cloud of each party to manage the content of mould redesign knowledge. Thus, it could provide a standardized knowledge format for sharing. However, it is still not enough for enterprises to build a trusted network with the parties in the manufacturing alliance. This is because private cloud service struggles with a lack of collaboration (i.e. knowledge sharing due to the adverse risks associated with exposing contents [13]. One of the advantages of blockchain is that it enables the exchange of information securely in the trustless environment [14]. Moreover, the realization of blockchain requires the knowledge format that can be provided by the private cloud. Therefore, both technologies are adopted in the proposed system. In the application stage, k-Nearest Neighbor (KNN) is used for achieving a blockchain-based retrieval. This method is effective, non-parametric and easy to implement for the document knowledge retrieval by calculating similarity between the existed cases and sample case [15], which will be discussed in details in Section 4.

The rest of the paper is organized as follows: Section 2 provides a review on knowledge sharing in the mould industry. The architecture of the CKshare system is proposed in Section 3. Section 4 describes the mechanism of the CKshare system for knowledge sharing. Finally, conclusion and further research are summarized in Section 5.

2. Literature review

Varied definitions of knowledge sharing existed in the academia. Due to features of interoperability of mould industry, in this paper, we consider knowledge sharing refers to the mutual exchange or transaction of knowledge amongst teams and organizations. It has been shown, through the literature available, that knowledge sharing provides individuals, teams and enterprises with the opportunity to improve their work performance as well as creating new ideas and innovations [16].

After the awareness of the advantages of knowledge sharing, researchers have conducted a lot of studies on achieving effective information sharing in the mould industry. For instance, Guo et al. integrated ontology technology into a CBR system by constructing domain ontology as case-base in order to meet the need of design support for injection mould design [11]. Based on core and specialized domain ontologies, Chungoora et al. proposed interoperable manufacturing knowledge systems in order to understand the content of manufacturing interoperability. It provided the previous manufacturing knowledge to support the new design decision [17]. Aiming to support lesson-learned knowledge sharing, Huang et al. proposes a novel approach using a semantic-based visualized wiki system (SVWkS), which helps engineers to find needed lesson-learned knowledge and reuse-related knowledge [18].

More recently, Li et al. coined the term “cloud manufacturing” in 2010 and they defined CM to be a service-oriented, knowledge-based smart manufacturing system [19]. CM is a manufacturing paradigm that uses network, cloud computing, IoT etc. It can share computing, data and information resources for full connectivity, remote access and interoperability in the company-wide. Ren et al. illustrated a private cloud manufacturing system for a conglomerate. It provides a centralised management and operation for utilizing internal dispersed resources and capabilities to quickly respond to markets [20].

However, there are very few secure and trustless systems to achieve an effective knowledge sharing across-enterprises in the mould industry. As intangible assets, the knowledge is owned by a small group of parties. The sharing of knowledge stuck in a limited range. To address this problem, a combined solution of blockchain and private cloud is proposed to realize the knowledge sharing for mould redesign in the injection mould enterprises.

3. The proposed system architecture

In order to achieve formatted knowledge storage, retrieval and effective sharing in the injection mould alliance, we propose a cloud-based manufacturing knowledge sharing system. As shown in Figure 1, it consists of 4 layers, including Enterprise layer, Knowledge resource layer, Blockchain network, and Application layer.

The enterprise layer consists of different kinds of stakeholders related to the mould industry. It includes the designer of the injection mould part (IMP), designer of mould, finite element analyst, mould manufacturer, mould redesigner, etc. Each party has their own data format, and hence it should be standardized for sharing.

Knowledge resource layer is the foundation of the proposed knowledge sharing system, and requires a large amount of knowledge in order to optimally execute the sharing of knowledge across the parties concerned. Therefore, the data and information provided from the enterprise layer will be collected and processed in this layer. To achieve the standardised knowledge format, the knowledge resource can be built by the three steps: data source, data preprocess and standardized knowledge.

- Data source: Different parties have their own applications, including the data sources, representation format, and storage structure. The design phase has the CAD and CAE; while the manufacturer phase has the MES and CAPP etc. These applications contain different kinds of knowledge in the manufacturing alliance. Furthermore, we use Cloud-API to connect these applications with private cloud.

- Data pre-process: In this paper, the text document is the main source of knowledge for the mould redesign. Therefore, we use TF-IDF (term frequency-inverse document frequency) to extract the features in the texts. As a typical feature of the extraction method, it has both the characteristic of high speed and effectiveness in the recognition process. LSA has been used to simplify the computational complexity of the algorithms for document retrieval purposes. This is shown in Section 4 in detail.
- Knowledge source: The standardized knowledge format can be achieved after the data preprocess. The private cloud has been used to store the knowledge. Unlike the public cloud, the private cloud provides a more convenient infrastructure service for the knowledge resource layer, that is, cloud database storage [21]. Alliance members usually store acquired knowledge in a cloud database, this not only increases the data security but also reduces the operational cost. At the same time, in order to ensure the security of the knowledge, each party has their own private cloud, this means that every knowledge cannot be connected directly with others.

After the standardised format is built, the blockchain network provides an open and trusted knowledge sharing network in the injection mould alliance. In this blockchain network, there are two types of networks, namely knowledge blockchain and transaction blockchain, which have the function of storing the knowledge and recording the transactions amongst the parties in the alliance respectively. In this paper, the updated manufacturing knowledge from the private cloud layer can be updated to the blockchain network once the volume of the knowledge is over a certain threshold, which can be set by owner of the private cloud. The parties can share the knowledge in the injection mould alliance by blockchain network. Therefore, they can leverage each other's strengths and focus on their core competence [22].

In the application layer, the KNN is used for searching the most relevant knowledge case that the users desire to guide their mould redesign. The searched results will be output and sent to the users according to the blockchain transaction network. This can be applied in the knowledge inquiry, mould redesign guidance and redesign assessment procedures.

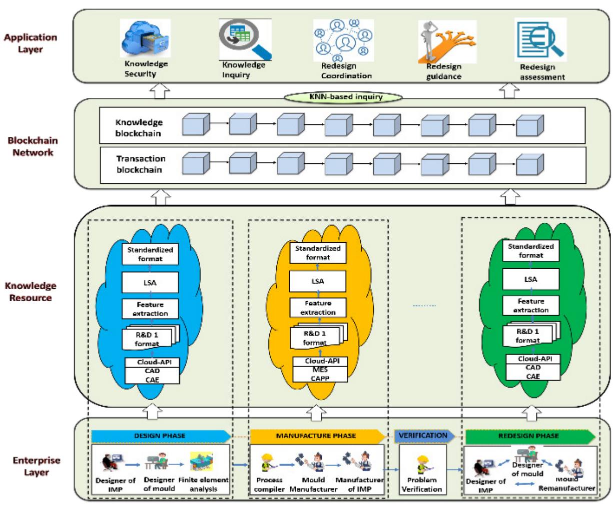

Fig. 1. The architecture of the proposed system based on private cloud and blockchain

4. The mechanism of the proposed system for knowledge sharing

In this section, we present the mechanism of proposed system for knowledge sharing in the injection mould alliance.

4.1. Private cloud

To construct the proposed system, it is necessary to standardise the knowledge sharing. Private cloud is adopted to store the updated data of each party in the manufacturing alliance and unifying the knowledge format.

The feature extraction is utilized to extract the important features in the collected data in order to build the standardized data format. In this paper, as a typical keywords extraction method, TF-IDF has been used to extract the key words in the text data. It has a characteristic of high speed and effectiveness in the recognition process and has been widely used in as a representation for real-valued feature vectors. Furthermore, the key words to be retrieved in this system are often large granularity text, like product name. Therefore, the terms of the features are quantified based on the term frequency-inverse document frequency (TF-IDF), which has been proved to be an effective method to cope with large-scale real corpus.

A template-based feature extraction method is used for extracting the important features in the existing redesign cases. Term frequency (TF) refers to the number of times of the given word in a document, which is shown in as Equation 1:

$$tf_{ij} = {n_{ij}}\Big/{\sum_k n_{kj}} \quad (1)$$

tf_{ij} is the term frequency; n_{ij} is number of times of the given word in the document d_j; $\sum_k n_{kj}$ is the sum of all the words appearing in the document d_j.

Inverse Document Frequency (IDF) refers to the parameters of weight adjustment to measure whether if a word is a common word or not, which can be calculated as Equation 2:

$$idf_i = log \frac{|D|}{|\{j|t_i \in d_j\}|} \quad (2)$$

$|D|$ is the total number of the documents in a corpus; $|\{j|t_i \in d_j\}|$ represents the number of documents containing the word t_i.

In order to divide the cases into smaller groups for easing computations for further processing to take place, LSA is used in this paper. The LSA utilizes a term document matrix. Latent semantic analysis (LSA) is a text mining method that is used in the informational retrieval of documents and it is improvement over the traditional vector space model of the documents. It contains a sparse matrix whose rows and columns correspond to terms and documents, respectively.

Let X be matrix where element (i, j) describes the occurrence of term i (t_i^T) in the document j (d_j). X will look like the following matrix:

$$\begin{bmatrix} x_{1,1} & \cdots & x_{1,n} \\ \vdots & \ddots & \vdots \\ x_{m,1} & \cdots & x_{m,n} \end{bmatrix}$$

Thus, a row (shown in Equation 3) in this matrix will be a vector corresponding to a term, giving its relation to each document.

$$t_i^T = [x_{i,1} \; \dots \; x_{i,n}] \quad (3)$$

Similarly, a column (shown in Equation 4) in this matrix will be a vector corresponding to a document, giving its relation to each term:

$$d_j^T = [x_{1,j} \; \dots \; x_{m,j}] \quad (4)$$

Now, from the theory of linear algebra, there exists a decomposition of *X,* such as *U* and *V,* which are orthogonal matrices and Σ a diagonal matrix. This is called a singular value decomposition shown in Equation 5. It is used for reducing the dimension of the large mould redesign document corpus.

$$\mathrm{X} = \mathrm{U}\Sigma V^T = [U_1 \; U_2]\begin{bmatrix} \Sigma_r & 0 \\ 0 & 0 \end{bmatrix}[V_1 \; V_2]^T \quad (5)$$

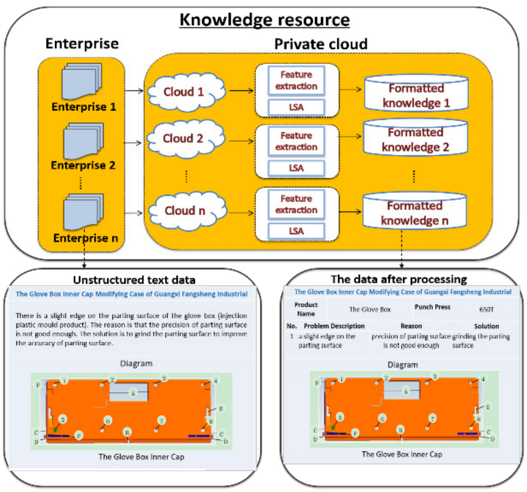

Fig. 2. The creation of formatted knowledge in the private cloud layer

Take plastic injection mould as an example, we assume that the optimal selection criteria for mould redesign are the {product name, existing problems, reason, structure and precision of mould}. More precisely, there is a redesign case with the following information: "*There is a slight edge on the parting surface of the glove box (injection plastic mould product). The reason is that the precision of parting surface is not good enough. The solution is to grind the parting surface to improve the accuracy of parting surface.*" After the features extraction and LSA, the information stored in database is that product name is "glove box", the existing problem is "a slight edge on the parting surface", the reason is "the precision of parting surface is not good enough", the solution is "grinding the parting surface", and there is no auxiliary information. Thus, we can unify the represented format of the updated knowledge from each company to facilitate the further retrieval process.

4.2. Knowledge blockchain creation

In this paper, the knowledge block is shown in Figure 3. The Smart contract defines the transaction of knowledge using the predefined programming language. It is a simple code which is deployed on the block as a contact between the different parties e.g. "*A starts a request for knowledge from B. If A transfers $5 to B, then B sends the knowledge block to A…",* in which contains "the predefined trigger condition", "predefined response condition" and "response". The state records the change of the block compared with the former one. Still, it can show some part of this knowledge content to make the potential buyers understood that the knowledge is helpful to their manufacturing activities. The value is the file of core manufacturing knowledge which has been stored using the InterPlanetary File System [23]. Each file is given a unique fingerprint called a cryptographic hash. The knowledge in this file is separately stored in the different blocks and some indexing information that helps figure out who is storing what. When looking up the files, it just needs to find out the nodes storing the content behind a unique hash.

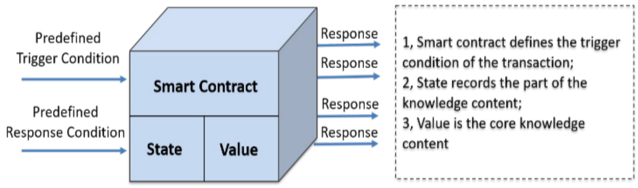

Fig. 3. The sample of a knowledge block

The encrypted knowledge, as described above, will be used to create a new knowledge block in the knowledge blockchain. Here we show a sample code of the creation of knowledge block in Figure 4. In particular, the "State" contains "furtherBlockAddress", "currentBlockAddress", and "time"; the "Value" contains the "knowledge", which has been encrypted and shown as the "knowledgeHash" before the decryption. "merkle" is used to check if the knowledge is in block. Moreover, the "Nounce" is used for creating a random number, which can be regarded as the private key of the knowledge. The new knowledge block will be broadcast to the nodes of the distributed network for approval and validation. Each node can be provided by different enterprises or parties within the ecosystem. So that no single institution is required as a third party to control and store the knowledge. When the knowledge block is approved, the new block will be added to the chain of each distributed node, which is shown in Figure 4.

```
{"furtherBlockAddress": None,        //The address of the last block
"currentBlockAddress": 0,            // The address of the current block
"merkleTree":                        //merkle  is used to check if the knowledge is in block
{"dadf2b7f54d7e23aa928f6be1
5afc798dccd3d06946d2d1514e
2f718891782b0": {}},
"time": 1513605020.4423366,
"Nounce": 1911,                      //Random number
"knowledgeHash":                     //The value of hash of knowledge
 ["dadf2b7f54d7e23aa928f6be15
Afc798dccd3d06946d2d1514e2f7
18891782b0"],
"knowledge":                         //The content of knowledge
["There is a slight edge on the parting surface of the glove box (injection plastic mould
product).The reason is that the precision of parting surface is not good enough. The solution
is to grind the parting surface to improve the accuracy of parting surface."]
}
```

Fig. 4. The code sample of knowledge block

The creation of the knowledge blockchain has been shown in Figure 5. Firstly, the owner of the mould manufacturing knowledge can achieve the formatted knowledge representation after the processing in the private cloud layer. Secondly, the knowledge block was created which was discussed in the Figure 4. Thirdly, the creation of the block will be encrypted by the private key of the knowledge owner before the encrypted block broadcast to nodes of the distributed network provided by the different enterprises or parties in the blockchain-based mould enterprise. Thus, a third party will be unnecessary to control and store the knowledge, which could increase the securities. Fourthly, the public key of the owner will be utilized by the parties in the alliance to approve and validate the knowledge creation. Finally, the knowledge block can be added to the blockchain once it's been approved by more than half parties.

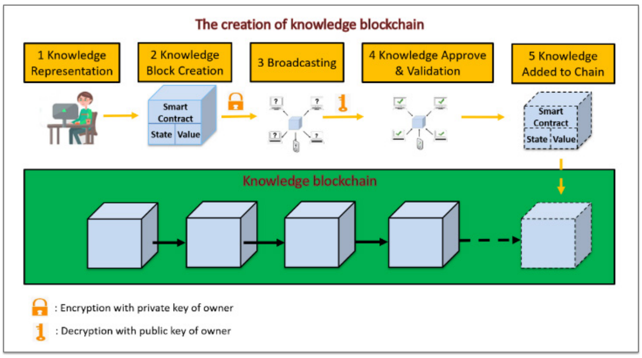

Fig. 5. The creation of knowledge blockchain in the mould alliance

4.3. KNN-based inquiry

In the knowledge application, an inquiry is conducted when a designer would like to search for a knowledge of mould redesign. It will then look up the knowledge chain of the distributed knowledge (the content of "State" in each block) to find the most related knowledge. A matching will be performed based on the query and the information provided in the meta-data of each knowledge block. Considering that the knowledge repository contains many cases of the mould modification along with enormous mould terminology, it is inevitable that some relevant words will be repeated. Therefore, we use KNN to achieve the retrieval. Since the KNN method mainly relies on the limited neighbouring samples, rather than by identifying the class, the KNN method is more suitable for the overlapping samples in the knowledge repository. The detailed KNN method steps are illustrated follows:

Step 1: Initializing parameter K;

Step 2: Calculating the distance between the problem and the existed case in the knowledge repository. In this case, we calculate the similarity between them, shown as follows: the similarity can be calculated as shown in Equation 9:

$$Sim(P_a, P_b) = \sum_k \omega_k \cdot Sim(P_{ak}, P_{bk}) \quad (9)$$

where P_{ak} is the n-dimensional vector of the k-th selection criteria of the case a in the knowledge repository, and P_{bk} is that of the input design problem b;

Step 3: Comparing the values of the similarity;

Step 4: Looping through the samples in the corpus. (Repeat the Step 2, Step 3);

Step 5: Calculating the error rate after testing the tuple set and outputting the K results;

After the designer reviews the search results, s/he can retrieve a particular knowledge block from the owner of the knowledge. Moreover, a request of the retrieval will be made and hence a new transaction block can be created, broadcast, validated, and finally added to the transaction blockchain for record, which will be discussed in the Section 4.4. The entire knowledge sharing process can also be finished by implementing an automatic search and retrieval process through the KNN-based inquiry layer.

The designer can use the attained blockchain-based knowledge, which could be a beneficial guide from all the experienced experts and help s/he avoids mistakes that existed previously. According to the results of finite element analysis, the designer could decide if there is any knowledge adaptation in the mould redesign. S/he can update the adaptation into the proposed system if there exist a new design knowledge. And the process of creation of the blockchain knowledge has been discussed in the Figure 5.

4.4. Transaction blockchain creation

In this section, we elaborate on the creation of transaction blockchain of the knowledge block. Similar with the bitcoin transaction [24], the knowledge transaction is a distributed network that is open and public. However, there are still three distinguished differences between the bitcoin and knowledge transaction. These differences can be categorized as the ownership, content and double-spending problem. Briefly explained as follow:

- **Ownership**. In Bitcoin, the ownership of the digital currency flows with the transfer. However, the ownership cannot be changed in the sharing or transaction behaviours. Thus, it is vital that a record of every knowledge transaction in the blockchain network is done.
- **Content**. Bitcoin transaction would hide the personal information between the two parties rather than the content of the transaction. However, the content of the knowledge in the sharing process needs to be encrypted and the information of receivers and senders need to be verified by each node.
- **The Double-spending Problem.** The blockchain in Bitcoin has solved the "Double-spending" problem perfectly. However, there is no double spending problem in the knowledge transaction process. In particular, the block in the knowledge blockchain network has to show some part of the knowledge in the "State", and then hide the core knowledge in the "Value".

Therefore, the existing Bitcoin platform cannot fully be supported the operation of the proposed system. The modification mechanism in the proposed system is illustrated in Figure 7, which fills the gap of knowledge sharing based on blockchain in the mould industry. The transaction process of knowledge can be described as follows.

Firstly, an inquiry can be operated by the receiver when the knowledge blockchain is created. Secondly, the receiver will send a request to the owner of the knowledge when s/he finds there is potential knowledge available. In particular, for a receiver who wants to have access to sets of mould knowledge, s/he can generate a key pair (Receiver private and public keys), stores the private key for creating and signing the request and shares the public key with the knowledge owner. Thirdly, the knowledge owner and other parties can confirm the request by verifying the signature with the Receiver's public key. And the receiver can get the desired knowledge once s/he pays a certain amount of money that is defined in the smart contract. Finally, the transaction block will be created and encrypted by the private key of the knowledge owner (sender).

To guarantee the ownership of knowledge, we use the transaction blockchain to record the transaction process between the two parties. To be precise, the “transaction block” will be created firstly. This contains a statement: *“Receiver have received the knowledge from sender”* from the receiver. Secondly, the created block will be broadcast into the mould alliance after it is encrypted with the private keys of the sender and the receiver. Thirdly, “Transaction approval and validation” will be operated by the parties in the alliance using the public keys of the sender and receiver. Fourthly, the transaction will be added into the transaction blockchain successfully. After those processes, the mould redesign knowledge can be shared securely and beneficially among the parties in the mould alliance.

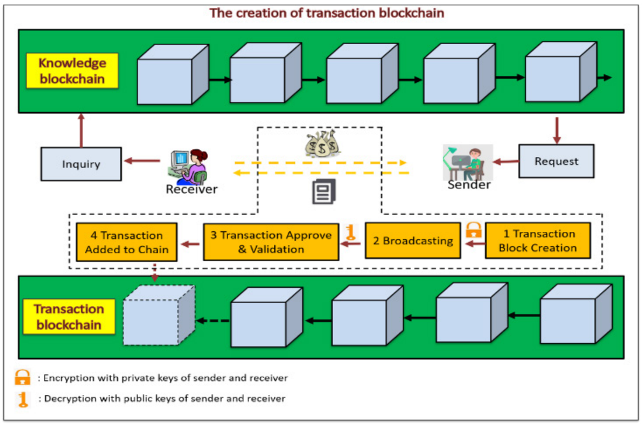

Fig. 7. The creation of transaction blockchain in the mould alliance

5. Conclusion

In this paper, a cloud-based manufacturing knowledge sharing system for mould redesign was proposed for building a secure and trusted network in the mould alliance. The contributions of this paper can be shown as follows: 1) it proposeds a distributed and secure system to realize the knowledge sharing of injection mould redesign based on blockchain and private cloud. 2) it illustrateds the mechanism of knowledge sharing in the injection mould enterprises. 3) k-Nearest Neighbor retrieval method of document knowledge has been applied in the proposed system to improve the efficiency of the knowledge searching process.

In the future, the work can be further extended in the following aspects. Firstly, the proposed system be fully implemented and key technology of the implementation will be explained based on the practical Byzantine Fault Tolerance. Secondly，the developed system will be adopted into different application scenarios of knowledge sharing to validate the effectiveness of the proposed system. Finally, more applications with blockchain in many other manufacturing fields will be explored in the further research.

Acknowledgements

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