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Internet of Things and Blockchain Technology in Apparel Manufacturing Supply Chain Data Management

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Abstract

The rapid changes in textile and clothing industry's operational environment in which apparel businesses are collaborating with their suppliers and customers have recognized interoperability of information systems as an important factor. The need to address this challenge becomes vital in the context of new paradigms such as the Internet of Things (IoT), and its ability to capture real-time information from different parts of textile and cloth manufacturing value chain by using Radio Frequency Identification (RFID) tags and sensors-based data communication networks. In this process, enterprise information system architecture plays an important role in storing, processing, and distributing data. Despite contributing to the rapid development of IoT applications, the current IoT-centric architecture has led to a myriad of isolated data silos. This paper presents a blockchain-based architecture for the IoT applications, which brings distributed data management to support transactions services within a multi-party apparel business supply chain network.

Keywords: Internet of Things; Blockchain Technology; Global Apparel Manufacturing; Supply Chain Management; Radio Frequency Identification; Sensor Network

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1. Introduction

Textile and clothing industries are an integral part of the world economy and society. In a global economy privileged access to natural resources, capital, trained human resources, and even access to markets are not enough to gain competitive advantage for any apparel enterprise [8]. Moreover, the future of world textile manufacturing, in a vision of 'Gandhian Engineering' based economy [2] needs cost effective production methods to cater the constantly evolving demands of its customers. In this way, a profound globalization effect is currently shaping the future of global apparel manufacturing industry. As with any transformation effect, the opportunities for growth are enormous – but so are the challenges. This environment of globalization and competition directs the flow of business activities through the supply chain networks or more recently, collaborative networks of business partners, since apparel manufacturing companies are not individually self-sufficient. Therefore, it is necessary that apparel manufacturing companies that make up these operational chains or networks are integrated and that they coordinate their business processes to become more efficient, thus enabling the fulfilment of the overall objectives of the business partners and its own strategic objectives. In all this, research and operational process automation provides a great boost in apparel manufacturing supply chain network design and its performance improvement.

In a typical apparel manufacturing chain, raw materials are purchased from suppliers and products are manufactured at one or more production plants [9]. Then they are transported to intermediated storage facilities (e.g. warehouse, distribution centres) for packing, loading and shipping to retailers or customers. In this way, an apparel manufacturing supply chain consists of business entities in the chain and these are suppliers, manufacturers, distributors, retailers, and customers [10]. In many industries (e.g. textile and clothing), manufacturing and logistics supply chains are challenged by their increasing complexity and the need for higher flexibility to meeting individual customer requirements [8].

In this way, product and service provision is getting importance in apparel industry. Flexibility and adaptability are the crucial characteristics of today's short-lived fashion clothing, where fashion trends and customer demands change in the blink of an eye. Moreover, there exists another layer of complexity in current apparel manufacturing network, which is attributed to geographical separation of the contributing suppliers and manufactures; and efficient information sharing mechanism within the business partners along global supply chain operations. In this way, sharing, storing and processing of apparel supply chain data requires secure information systems architecture. Apparel manufacturing supply network data could be analysed for locating the areas with problems, so that proper operational instructions could be provided by the logistics controlling management teams.

Modern information and communication technologies (ICTs) often regarded as the catalyst of improve supply chain information sharing ability. Information sharing across textile manufacturing networks is based on linking unique identifications of objects – tagged by means of RFID transponders or barcodes – with records in supply chain database management systems. In this process, Electronic Product Code Information services (EPCIS) is the most relevant industry standard. Internet of Things (IoT) is one of the most promising technological innovations, is used now-a-days in apparel manufacturing. In simple, RFID tags, sensor technology, and relevant data communication networking provision form the concept of IoT. The IoT is a concept in which the digital world of information technology integrates seamlessly with the real world of things. This real world becomes easily accessible through modern computers and data communication networked devices in apparel manufacturing business. In recent decades, IoT technology is used heavily in apparel manufacturing business processes - inventory management, warehousing, and transportation of products, automatic object tracking and supply chain management. With access to precise information, apparel supply chain operational managers can perform their analysis on nearly real-time basis and can take appropriate strategic decisions.

Despite contributing to the rapid development of IoT applications, the current IoT-centric architecture has led into a myriad of isolated data silos that hinders the full potential of holistic data-driven business applications with the IoT. Moreover, standalone IoT application systems face security and privacy related problems. The blockchain technology has introduced an effective solution to the IoT based information systems security. A blockchain enhance IoT devices to send data for inclusion in a shared transaction repository with tamper-resistant record and enables business partners to access and supply IoT data without the intervention of central control and management. This paper presents a blockchain-based design for the IoT applications that brings a secure distributed data management to support transactions services within a multi-party global apparel business network, as shown in Fig

1.

Fig. 1 RFID tagging level at different stages in the apparel manufacturing network

The rest of this paper is organized as follows. Section 2 describes the background knowledge about global textile industry. It also explains different paradigms of ICT world, which are used for business processes automation. Section 3 presents the proposed three-layer framework for information system. Section 4 explains the emerging issue in blockchain based information system's deployment. Section 5 reviews related research works. Finally, Section 6 concludes the paper by discussing relevant research issues.

2. Background Information

In recent decades, it has become a significant tendency for apparel industry to adopt decentralization as a new manufacturing paradigm. At the same time, advantages in data analysis give more insights into apparel production lines, thus improving its overall productivity. This enables more efficient operations and facilitates the shift from mass to customized production. This section presents a brief review of important aspects of the service-oriented computing, the IoT based information system, and provide an introduction on the blockchain technology.

2.1 Service oriented computing

Service oriented computing platforms are mainly hosted in large-scale data centre environments that are empowered by the data communication networks. The consolidation and centralization of data centres, however, yield an increased distance between clients and services. This arrangement creates different outcomes in a high variability in latency and bandwidth. To address this issue, particularly with regards to resource-intensive and interactive applications, decentralized service-oriented computing architectures, namely cloudlets, have emerged. Cloudlets are small-scale data centres that are situated nearer to users and can mitigate low latency and high bandwidth guarantees. This research embraces this locality-aware data storage and processing trend and brings it to its full potential with decentralized access control layer which ensure ownership and secure sharing of data.

2.2 IoT based information system

The Internet of Things (IoT) is a smart worldwide network of interconnected objects, which through unique address schemes can interact with each other and cooperate with their neighbours to reach common goals. The primary purpose of the IoT is to share information acquired by objects, which reflects the manufacture, transportation, consumption and other details of textile and clothing industries detail. The gathered information can be used for effective operational decision making.

Prompt and effective decision not only depend on reasoning techniques, but also on the quality and quantity of data. Every major apparel manufacturing paradigm has been supported by the advancement of Information Technology (IT) and its applications. For example, the widely adoption of enterprise resource planning (ERP) and industrial business processes automation made flexible apparel manufacturing systems feasible. It includes the technologies for computer aided textile design, computer-aided garment development, and computer-aided process planning made computer integrated apparel manufacturing practical. In developing enterprise systems (ESs), more and more enterprises rely on the professional providers of IT software service to replace or advance their conventional systems. Therefore, it makes sense to examine the evolution of the IT infrastructure and evaluate its impact on the evolution of apparel business process automation paradigms, when a new IT (e.g. blockchain technology) becomes influential.

2.3 Blockchain technology

Blockchains have attracted wide attention as the basis of the cryptocurrencies, e.g., bitcoin [8]. Cryptocurrencies may or may not be the future of money, but blockchain-oriented technologies are very attractive for other types of business applications. Blockchains are considered a new form of information technology that could revolutionize technology, industry, and commerce. In simple, blockchain is a distributed data structure comprising a chain of blocks. Blockchain acts as a distributed database or a global ledger that maintains records of all transactions on a blockchain network. The transactions are time stamped and bundled into blocks where each block is identified by its cryptographic hash. The blocks form a linear sequence where each block references the hash of the previous block, forming a chain of blocks called the '*blockchain*'. A blockchain is maintained by a network of nodes and every node executes and records the same transactions. The blockchain is replicated among the nodes in the blockchain network. Any node in the network can read the transactions. Fig. 2 shows the structure of a blockchain.

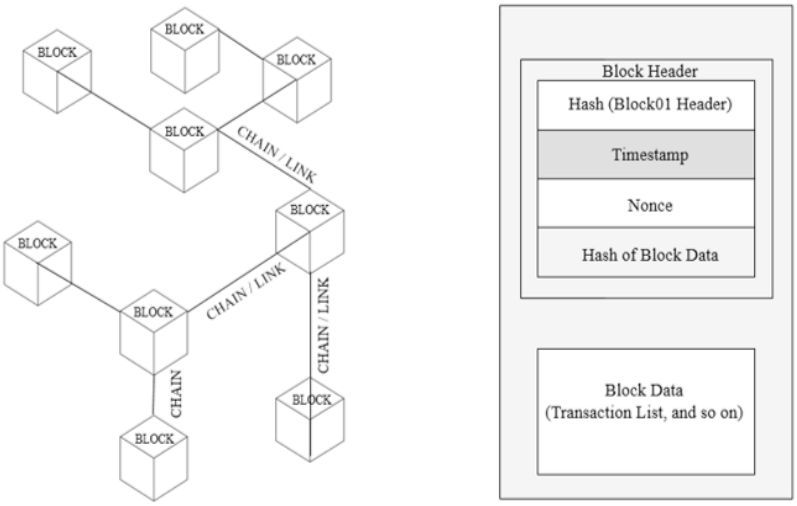

Fig. 2 Structural parts of a blockchain

Blockchain technology, at its core, features an immutable distributed ledger, a decentralized network that is cryptographically secured. Blockchain architecture gives participants the ability to share a ledger, through peer-to-peer replication, which is updated every time a block of transaction(s) is agreed to be committed. In this way, the blockchain technology can reduce operational costs and friction, create transformation records that are immutable, and enable transparent ledgers where updates are nearly instantaneous. It may also dramatically change the way workflow and business procedures are designed inside an enterprise and open-up new opportunities for innovation and growth.

3. Proposed enterprise information system architecture

Service oriented computing (SOC), and IoT applications are key technologies that will have a huge impact in the next decades for apparel manufacturing supply chain management. This section describes that how SOC technology

will improve efficiencies, providing new business opportunities, address regulatory requirements, and improve transparency and visibility of global apparel manufacturing activities. The IoT systems allow capturing real-time manufacturing business processes data from plant-level operational environment. The enterprise architecture for distributed apparel manufacturing supply network used for current research is shown in Fig. 3. This architecture mainly consists of three layers: (i) IoT-based service, (ii) blockchain-based data controlling, and (iii) data storage and processing part.

3.1 IoT-based service layer

The development of the IoT has created many devices, such as sensors, interconnected and interoperable devices for data collection and exchange. The data obtained from the IoT can make apparel manufacturing more convenient through numerous types of decision-making at all its levels and areas of apparel business activities.

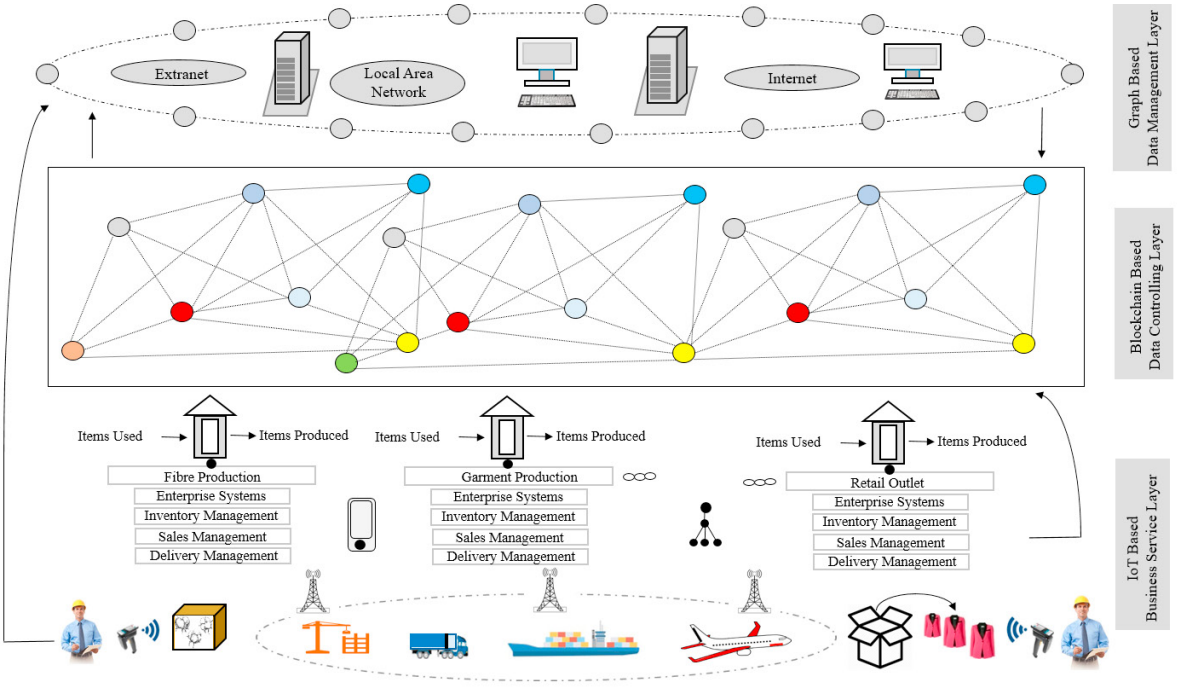

Fig. 3 Enterprise information system architecture for apparel business

3.2 Blockchain-based data controlling

The blockchain-based controlling part is a distributed database, which record transactions occurred in each time span in blocks, chained by means of cryptographic hashes. The reliability of such a structure comes from the fact that every transaction is approved by consensus of majority of nodes acting in the system. This prevents any single node or small group of nodes from tampering with data and ensures all and only valid transactions are recorded.

3.3 Data storage and processing

Apparel manufacturing and distribution chain nodes register as semantic-enabled agents in the blockchain. Tagged objects are registered as assets in the blockchain supported graph-based data storage and processing facility.

4. Emerging issues in blockchain based application deployment

The acceptance of IoT-based technological solution, the use of Electronic Product Code (EPC) for individual products identification purpose, as well as of EPC global network for nearly real-time data gathering, object tracking and different types of business services providing a greatly improve accuracy for supply chain operation management [9].

Blockchain-based technologies allow for the decentralized aggregation of vast amounts of data generated from IoT devices and ensures that benefits are shared more equitably across supply chain exchange partners. Some of the research issues (e.g. scalability, security, and IoT data management) are highlighted in Table 1.

Blockchain facilitates machine-to-machine interaction where sensors and IoT devices attached to machinery will be synchronized, resulting in high flexibility and collaboration with exchange partners. The importance of this new capability lies in the secure communication, confidentiality, and integrity of the exchange transactions. Users can transact with the machine directly and engage in on-demand manufacturing services by sending transactions to a registered machine. Blockchain-based distributed legers that harness smart contracts enable the embedding of business logic covering a wide range of purpose such as payment conditions, product acceptance, smart inventory replacement, predictive maintenance, and repairs.

Table 1. The research issues of combing IoT with blockchain technology

Internet of Things (IoT)	Blockchain Technology
Scalability	• There continues to be the quest for scalable transaction throughput in blockchain. Some of the blockchain-based information systems implementation use consensus method that is computationally expensive (by design) for requiring to solve a cryptographic puzzle in the process. Instead, the permissioned blockchains where participants are identified use consensus methods based on variant of Byzantine fault-tolerant state machines, which have been chosen to provide higher transaction throughput and lower consensus latency. • In order to assess effectiveness and scalability of IoT-based blockchain technology, early implementation and performance evaluation are important research challenge.
Security	• With the proliferation of global apparel business exchange partner relationships, textile and clothing industries are driven to protect their data and information as well as the integrity of their physical objects to protect against theft and different types of illicit trade including diversion and counterfeiting. In addition, blockchain-based information systems can transform the potential advantages of IoT and bridging the difference of device-data interoperability while keeping security and privacy intact.
IoT data management	• There are research issues regarding design decisions of IoT data streams, storage and processing applications. Hence, one important problem is interpreting the data with respect to reference data and business glossary. Technical problems include identification of reference data entities, automatic interpretation, and managing the reference data as they are provided by external sources.

By combining blockchain technology and IoT, business information exchange partners gain new and timely insights into their supply chain in real-time with more precise and reliable information about key processes, events, and product attributes – such as quality, performance and availability. This fusion of IoT and blockchain technology can help to enhance end-to-end traceability and enable rapid recall capabilities of unsafe goods. As a result,

exchange partners will be informed about the products, potential risks, and the preventative and corrective actions needed for sustaining the enough flow of safe products to the final consumers.

5. Related research works

Academics and practitioners identified industrial business processes, particularly supply chain and logistics management, are important areas for deploying IoT based information system applications [11] [7]. IoT based industrial information systems can enhance competitiveness of enterprise through more effective tracking of flow of raw materials, leading to improve the effectiveness and efficiencies of business processes [4]. In the context of globalized business practice, with multiple collaborating-partners based supply chains, IoT-based applications enhance to facilitate the sharing of more precise and timely information relevant to production, quality control, distribution and logistics [6]. However, researchers expressed their concern regarding standalone IoT-based applications along global supply chain management [8]. The main concerns were raised on the issues of standalone IoT systems security and privacy.

Different hybrid information system architectures (e.g. IoT with blockchain, cloud based IoT and blockchain technology) have been proposed by the research community. A blockchain enhances IoT-based applications tamper-resistant characteristics. In recent years, different blockchain-based information management systems have been reported by researchers. For example, IBM has developed a new blockchain-based service that is designed to track high-value items through complex supply chains in a secure cloud-based application system [12]. Another exemplary industrial application is a fine-wine Provence-tracking service, known as the Chai Wine vault, developed by London-based Company Ever ledger [5] in business-partnership with fine-wine expert Maureen Downey. Blockchain-based digital identification tools for physical property and packaging have been reported for enhance high-value parts for supply chain management [1]. An innovative anti-counterfeit application, called Block Verify, is designed and deployed for tracking anti-counterfeit products [3] to create a sustainable business world. A start-up company from Finland (i.e. Kouvola) in partnership with IBM, developed a smart tendering application for supply chain management. The reported application is built on an automatic blockchain-based smart contract [14]. Another blockchain-based smart contract, called SmartLog, application was launched by Kouvola in recent years [13].

In recent decades, due to globalization manufacturing supply chain networks are going through an evolutionary change through continued digitization of its business practices. These global manufacturing chains are evolving into value-creating networks where the value chain itself turns into an important source of competitive advantage. At the same time, developments are in progress to integrate blockchain technology with other innovation technological solutions (e.g. IoT-based applications, cloud-based solutions, and fog computing-based automation), leading to novel structures of modern apparel manufacturing supply chains, new types partnerships, holistic mechanisms of collaboration and value enhancing applications for global apparel business. The reported research in this paper is one of these value creating applications, which explains the adoption of IoT-based item description and use in a blockchain infrastructure, in order to reap the combined advantages for future-generation apparel business supply chain management.

6. Conclusion

Today's textile and clothing manufacturing businesses face significant volatility, uncertainty and complexity imposed by a dynamic operating environment. Changes in consumer buying pattern – the demand for lower price, better service levels, mobile commerce and so on – necessitate customer intelligence and varying fulfilment models. These have introduced significant stress on apparel manufacturing supply chain networks, compelling clothing businesses to revisit their supply chain design strategies. It includes deployment of appropriate information systems that improve supply chain execution. In such scenarios, enterprise information systems architecture plays a very important role.

This paper presents a hybrid enterprise information systems architecture, which consists of IoT applications and a blockchain-based distributed ledger to support transaction services within-in a multi-party global apparel business network. The IoT is a smart global network of interconnected objects, which through unique address schemes can interact with each other and cooperate with their business-partners to achieve common objectives. The data obtained from the IoT applications along apparel business processes can make operational decision-making much easier. However, standalone IoT application systems faces *security* and *privacy* related problems.

Security and business organizational issues tend to enhance the need to build an apparel manufacturing supply chain management system leveraging blockchain ledger technology. Regardless of the particularities of the specific textile manufacturing supply chain related application, blockchain can offer a wide range of advantages. By registering and documenting a product's (e.g. cotton, fibre, textile cloths) lifecycle across the manufacturing supply chain nodes increases the transparency and the trust of the participating business-partners. Finally, the paper presents research proposition outlining how blockchain technology can impact important aspects of the IoT system and thus provide the foundation for future research challenges.

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