Application of Internet of Things and Blockchain Technologies to Improve Accounting Information Quality

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ABSTRACT Following the rapid development and maturity of Blockchain (BC) and Internet of Things (IoT) technologies, this study proposes two applications of a BC-IoT transaction model in the accounting field. The BC-IoT transaction model is capable of automatically collecting, uploading and recording all relevant data in the enterprise transaction process under the premise of satisfying certain assumptions. This model does not require manual intervention at any point in the process; no data recorded on the distributed ledgers can be tampered with or revoked. The data collected using this model can be used as information on events, providing data support for the events approach to basic accounting theory. This practice responds to the important insight of Sorter, who proposes the provision of accounting information in real time and on demand to substantially improve the usefulness of accounting information. This study also identifies that BC technology can significantly improve the relevance, faithful representation, timeliness, comparability, and other aspects of accounting information quality.

INDEX TERMS accounting information quality, blockchain, events approach to basic accounting theory, internet of things, smart contract

I. TECHNICAL CHARACTERISTICS OF THE IoT AND BC AND THEIR APPLICATIONS IN THE BUSINESS WORLD

A. INTERNET OF THINGS (IoT)
The concept of the IoT was originally derived from the Radio Frequency Identification (RFID) system, proposed by the Automated Identification Center (AutoID Labs) established by the Massachusetts Institute of Technology (MIT) in 1999. Based on the linkage between RFID information from different items obtained via RFID sensing devices and the Internet, RFID is able to achieve intelligent identification and management.

At the 2005 World Summit on the Information Society (WSIS) held in Tunis, the International Telecommunication Union (ITU) published the “TTU Internet Reports 2005 – the Internet of Things”, which introduced the IoT’s features, relevant technologies, challenges and future opportunities [2]. The IoT is an integrated part of the future network; it is a global dynamic network facility with self-configuring capabilities that is based on standard and interoperable communication protocols. In this network, all substantial and virtual items have specific coding and physical features that can be seamlessly linked through smart interfaces to achieve the sharing of information [3].

In brief, the IoT is the interconnection between physical objects and the digital world [4]. From a vertical perspective, the IoT system can be divided into three layers: the sensing layer, the network (or transmission) layer and the application layer [5]. As illustrated in Figure 1, the IoT’s application layer has highly personalized features, in which the development of blockchain (BC) technology can provide a reliable platform for the IoT’s application layer.

The IoT, robo-advising, and BC are some of the most valuable innovation types [6]. In the recent development of the IoT, deep learning appears to be a valid approach to extracting accurate raw sensor data from IoT devices, as
deployed in complex environments. Using edge computing, Li et al. [7] designed a novel offloading strategy to optimize the performance of IoT deep learning applications. IoT technology can be used in different industry sectors, such as industrial IoT, smart energy, smart homes, smart cities, health care, social care, sports and well-being [8]. However, there are still obvious challenges for its further development: i) specific IoT solutions are likely to be only a small part of an overall solution, ii) it is not always clear how an IoT solution can contribute to overall services, iii) IoT solutions can be fragmented and difficult to scale, iv) actors experience distrust and hesitation around sharing data and platforms and finally, v) enterprises hesitate to change their business model.

The IoT acquires sensory data from the physical world through a sensing device, establishing a correspondence linkage. Before the appearance and application of BC, security and privacy concerns have stopped large-scale development and further applications for the IoT. Such concerns include how to ensure that data come from real and reliable sensing devices, are not tampered with when they are transferred between different application systems, and are not illegally accessed and stolen. BC technology can help solve the security and privacy issues around IoT data on the one hand, and intelligent contract scripts based on BC, on the other hand, can give the IoT socialization attributes. The integration of the two helps to achieve interaction between different subjects and establish a new business transaction model.

**B. BC TECHNOLOGY**

BC connects blocks of transaction records in the order of timestamps on a chain (including data), the hash value of the block, and the hash value of the previous block, which are arranged in chronological order to record all transaction activities that occur in a process. The header and the body of the block together form a block structure (Figure 2). The header of the newly formed block contains the hash value of the previous block as an important part of its label, and such process is iterated. Each block is marked with a timestamp that indicates the creation time while confirming the existence of the transaction data. From the genesis block to the most recent block, all blocks are linked in a long chain based on the timestamp order. All historical data are stored in the BC with timestamps as their labels.

The transaction data recorded in each block represent all the value exchange activities that occurred after the formation of the previous block and before the creation of the current block, and all the blocks aggregate to form a record set [9]. The recorded data include asset transaction records, asset issuance records, clearing records, smart contract records, and even IoT data records. For example, the bitcoin BC system records all loan transaction data in full based on ‘double-entry bookkeeping’, including the bitcoin deposit and withdrawal amounts, transaction amounts, and the addresses of payers and receivers. These data are encrypted to form the block’s hash value, and this block is further labelled with a timestamp. In general, recorded data are organized into a Merkle tree structure in the storage process. The hash value of a block is, in fact, the hash value of the root node of the data record tree, which is calculated in stepwise fashion using the hash algorithm following a bottom-to-top approach based on the data record tree. If stored data at the bottom-most level are tampered with or deleted, the hash values of the top layers will be altered, which then recursively results in the change of the block’s root hash value, which is also a component of the next block. Such characteristics of recorded data increase the likelihood of discovering the origin of any data tampering in a BC system. The first appearance of BC technology was bitcoin, a digital currency developed by Satoshi Nakamoto, who established the principles and construction of bitcoin [10]. Bitcoin establishes a globally distributed ledger system, termed ‘blockchain’ by Nakamoto, in which deception is impossible.

**FIGURE 1. Different layers of the Internet of things.**
Following the initial research into BC for digital currency such as bitcoin [11], other different applications for BC have been, such as cross-border remittances, smart contracts, automated bank books and digital assets, that can revolutionize the current banking system [12], as well as securities trading, supply chain management, voting and digital ticket trading platforms [13]. Swan [14] envisioned the application of BC in three phases: (1) BC 1.0 involves digital currency such as bitcoin; (2) BC 2.0 introduces the smart contract to BC to realize a programmable economy, which is represented by Ethereum; (3) BC 3.0 is represented as the decentralized autonomous organization (DAO), decentralized autonomous corporation (DAC) and decentralized autonomous society (DAS).

The concept of a smart contract, one application of BC, addresses the issue of recording contract events. It is a computer protocol with executable contract terms [15]. A smart contract is digitalised with the functions of contract reading, rule verification, and contract execution. This concept of a smart contract stagnated due to the lack of a corresponding platform to execute the contract. However, BC, the underlying technology of smart contracts, was developed and is able to protect the contract terms from leakage or tampering before the execution of the smart contract. Therefore, smart contracts can be truthfully and completely recorded in BC in real time.

Recently, the applications of smart contracts and corresponding improvements have developed significantly. For example, based on smart contract technology, a systematic framework to aggregate online identity and reputation information to achieve a holistic approach to personal online behavioural ratings has been developed [16]. To improve the performance/efficiency of smart contracts and IoT technologies, a formal language to specify interactions between offers and requests and a methodology for the autonomous negotiation of smart contracts were developed by Scoca et al. [17]. This methodology analyses the cost and the necessary changes to reach an agreement. In addition, Zhang et al. [18] propose a smart contract-based framework that consists of multiple access control contracts (ACCs), one judge contract (JC) and one register contract (RC). Better distributed and trustworthy access control for IoT systems can be achieved based on this framework. However, it is also important to recognize the challenges of smart contract application. Based on the experience of teaching an undergraduate course on smart contract programming at the University of Maryland, Delmolino et al. [19] identify a few mistakes in designing safe and secure smart contracts as practised by students; In addition, they also suggest ways to fix/avoid them, and some of the best practices for programming smart contracts [19].

II. ‘EVENTS’ APPROACH TO BASIC ACCOUNTING THEORY (EABAT)

In 1969, Sorter [1] proposed the ‘Events’ Approach to Basic Accounting Theory (EABAT) to address the defects of the traditional accounting model. He argued that this approach would provide more raw data (i.e., information about economic events) for information users and could thus meet the individual needs of various accounting information users. Following Sorter’s viewpoint, accounting scholars have advanced basic theoretical research on EABAT [20]–[24] and gradually established its theoretical foundation. Focusing on the information system of EABAT, the question of how to use information technology to improve financial reporting and its relevance has made some progress, e.g., the database reporting model [25], [26]; the resources, events, agents (REA) reporting model [27], [28]; the large-scale on-demand reporting model [29]; the extensible business reporting language (XBRL) [30]–[32] and the multi-layer interface financial reporting model [33].
However, limited by the slow pace of development of data-processing technology, EABAT has not been substantially studied and developed to the same extent as the value approach to the basic theory of accounting. Although information technology (including data-processing techniques) has experienced significant developments in the past decade, research on accounting information systems based on EABAT is still limited, especially that addressing the self-formation process of accounting information [34]. The recent development of BC technology has exposed some opportunities for EABAT research.

III. JUSTIFICATION OF BC AND IoT TECHNOLOGIES IN ACCOUNTING RESEARCH (EABAT)

Recent developments in BC research have appeared in the field of accounting study. For example, Dai and Vasarhelyi [35] investigated how to establish a real-time, reliable and transparent accounting system with BC technology. This accounting system is capable of providing to users the reliable storage of accounting information with real-time and low-cost operations and of using smart contracts to ensure the compliance of accounting information processing. Dai and Vasarhelyi [35] also constructed a ‘three-entry’ bookkeeping approach based on BC technology, using a distributed ledger based on BC technology as an independent and reliable third-party intermediary to verify and record all transactions. Such a journal recording approach can generate transparent, secure and self-verifying accounting information that can be shared with other nodes (organizations) in a timely manner.

Dai and Vasarhelyi [35] discuss the application of BC in the accounting field based on the theory of value accounting; this differs from the current study, which discusses this topic based on the EABAT. In addition, Dai and Vasarhelyi [35] focus on the reliability issue of chain data, following the adoption of BC as a third-party accounting approach that will not change the existing accounting process, while the current study explores the restructuring of the current business model and re-creates the accounting process. Finally, while Dai and Vasarhelyi’s [35] discussion solves the chain data reliability issue, this study introduces the IoT layering theory to address the reliability issue in transmitting off-chain data onto the chain.

Taking a broader business perspective, Yermack [9] argued that BC technology would have a profound impact on corporate governance, including the real-time updating and recording of shareholder status, improving the accuracy and reliability of company elections, increasing the liquidity of equity transactions, and effectively suppressing or mitigating agency problems, such as corporate earnings management, insider trading and related party transactions. Rozario and Vasarhelyi [36] believe that smart contracts based on BC can replace auditors by conducting audit procedures automatically and provide real-time and transparent audit reports that meet the requirements of various information users, thereby improving audit quality.

The above literature reveals how BC may influence professional accounting practices, such as through the improvement of corporate governance and audit quality, indicating that accounting information quality can be enhanced by BC technology. However, their discussions are only based on the existing frameworks of accounting models and theories in the spectrum of value accounting and overlook the context of the EABAT. In addition, while current BC technology is able to protect chain information security, few papers study how to make sure the external data sources of the BC are also reliable. IoT technology responds to the need for information source reliability in the EABAT approach.

This study discusses three key topics: 1) applications of BC and IoT technologies in the EABAT, 2) construction of a simple transaction model and its accounting and reporting mode in a BC and IoT environment supporting the EABAT, and 3) discussion of how BC technology may affect accounting information quality.

A. AN EXAMPLE OF A SIMPLE BC-IoT TRADING MODEL

The traditional transaction models and approaches of financial information gatherings lead to the ‘separation of business practice and financial information’ and ‘information isolation’, which inevitably reduces the relevance of accounting information. Based on BC technology, we established a simple ‘BC-IoT’ transaction model. This transaction model is capable of the automatic identification of as well as the transmission and recording of massive amounts of data. It requires no manual intervention. Because all data are recorded in distributed ledgers, tampering or revoking is not possible. Current traditional accounting practices are based on countless paper documents as information sources; manual processing is required to input data into the accounting information system. This manual processing practice is time consuming, costly, and, most importantly error prone. With the help of IoT technology (such as RFID), it is becoming possible to achieve the real-time transmission and updating of inventory information, thus improving the efficiency and quality of data acquisition.

As recorded in Figure 1, the proposed transaction model has three sub-systems: smart contracts (contract system), the IoT (logistic system), and tokens (monetary system). It adopts the following assumptions: smart contracts (contract system), the IoT (logistic system), and tokens (monetary system). It adopts the following assumptions: first, this model is limited to sales and procurement in the manufacturing industry; the inventory under discussion includes raw materials, work-in-process products, and finished products, all of which are physical commodities to which IoT technology is applicable; second, this trading model disregards/neglects transportation and taxation (costs); third, the commodity transaction uses tokens to realize the debit-credit system.
1) THE SMART CONTRACT (CONTRACT SYSTEM)
In this model (as shown in Figure 3), the contract is regarded as the starting point of a transaction and directly links logistic flow, capital flow, and information flow. If there is no contract, then there is no transaction. When there is a transaction, there is always a contract. A contract can provide a large amount of useful information. Therefore, the EABAT should be treating contracts, orders and similar entities as important events. In the proposed ‘BC-IoT’ transaction model, all transaction contracts are implemented through smart contracts, including those that are successfully (partially; failed to; and not yet) executed. This corresponds to three situations: first, when the contract fails to be executed due to reasons such as contract cancellation, the contract is invalidated, and the transaction is cancelled. However, the contract information is still recorded, stored in the block, and marked as ‘Smart Contract 1’. Second, if the contract is fully executed, the logistics and cash flow steps are also executed. For example, according to a smart contract term, Company A should transfer goods from the warehouse that belongs to Company A to the warehouse that belongs to Company B before December 31st. When the access control system and warehousing system in the warehouse of Company B confirm that they have received the batch of goods, the ownership of the goods is transferred from Company A to Company B. Ownership transfer is the criteria required for contract execution, token payment, and recognition of sales revenue. Third, the contract is partially executed. In this case, not all transactions are completed, which means that the old contract is invalidated, and a new contract (including all transactions that can be completed) is created and successfully executed. This new contract is denoted as ‘Smart Contract 2’ in this model.

2) THE IoT (LOGISTICS SYSTEM)
A logistics system based on IoT technology contributes to the key technical foundation of this trading model. A mature and stable IoT system assists in the smooth implementation of a smart contract system. The IoT serves as a data collector and recorder immune to mistakes and fraud, which ensures the faithful and prompt upload of inventory information to the BC. Under this logistics system setting, goods become smart items that can be located in real time with scene information. They are more than physical objects in the logistic process: they are also resources that can be utilized to form a smart automated execution system with real-time information acquisition and processing. In this model, the warehouse control systems, the access control systems, and the GPSs as implemented by Companies A and B will be able to monitor, record and upload the goods’ status in real time. By reading, analysing and judging the uploaded data, the smart contract can decide whether to execute the contract.

3) TOKEN (CAPITAL FLOW SYSTEM)
The token used in this system is similar to a proof-of-receiving entitlement (money) similar to a cheque. The token is used for transaction settlement and helps the regulatory authority perform fund monitoring for the entire cycle. First, the use of token settlement can solve the problems stemming from recognizing sales revenue based on sales invoices and the like. In this proposed ‘BC-IoT’ transaction model, sales invoices are no longer required. For example, when goods arrive at warehouse B, the sensing layer of the IoT can
instantly inform the smart contract, the token will be compulsorily transferred to Address A, and the sales revenue will be simultaneously recognized. Second, the token can be used to manage accounts receivable. When the credit transaction method is adopted, the smart contract can record all information of the credit transaction, such as the transaction time, goods quantity, pre-arranged time for paying the token, etc., onto the distributed ledgers and then form an account receivable item. The smart contract will automatically execute the program at the agreed-upon time and then transfer the token from the buyer to the seller. Third, the use of tokens allows users to monitor the flow of funds within the company during the entire process. Thus, financial fraud is minimized.

B. CONSTRUCTION OF AN ACCOUNTING INFORMATION SYSTEM BASED ON THE BC-IoT MODEL

The EABAT argues that events are economic activities related to an accounting entity; examples include but are not limited to leasing, promising, and placing. “Inventory, thus, does not report either value or costs but rather describes the acquisition and consumption activities that have occurred” [1]. Qi [37] argued that economic events are the smallest unit of accounting information and a boundary of the accounting information system. All economic activities that match such definitions should be faithfully recorded and collected when such business transactions occur. EABAT only records the original economic events and deletes the user-related accounting procedures, such as adjustment, estimation, amortization, and summarization, which allows users to retrieve needed information and substantially improves information relevance.

This study proposes an accounting information system (AIS) as presented in Figure 4. It follows the EABAT system design suggested by Qi [37]: economic event→accounting event→accounting report. In the previous example involving Companies A and B, as illustrated in Figure 3, for Company A, the economic event is ‘Smart Contract 1’, goods (inventory) decrease, tokens increase. ‘Smart Contract 1’ includes the content and execution result of a smart contract. Information related to the decrease in goods (inventory) as recorded in the block includes the name, quantity, cost, location and date the goods were shipped, and information about the token increase includes the address, date, and notifications (e.g., revenue from the sales of a certain item). These records correspond to accounting events in terms of asset items, which are the reduction in goods (raw materials, work-in-process products, finished products) and the increase in tokens. However, the valuation of goods, e.g., the lowering of historic cost or net realizable value method, belongs to the category of accounting policy choice, which is determined by the information user. Based on the above information, a financial report is ultimately generated.

C. CONSTRUCTION OF A FINANCIAL REPORTING SYSTEM BASED ON THE BC-IoT MODEL

Using the EABAT as the theoretical foundation and the distributed ledger as a platform, a restructuring of the current financial report produces a new type of distributed financial report that is interactive, real time, and demand driven. Regarding the contents it covers, its new format exceeds the scope of reporting items as reported in the current value-based financial report, as it further incorporates reporting items such as smart contracts and product sales details. Depending on the level of trade secrets, it can also set access restriction for the associated reporting items. This new format for the financial statement allows the report maker to add and/or delete items from the existing/old-style financial report and then release the old-style financial reports for reference. Such a financial reporting model design is presented in Table 1, embedded with the following characteristics.

<table>
<thead>
<tr>
<th>TABLE I NEW FORMAT FOR THE BALANCE SHEET</th>
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<tbody>
<tr>
<td><strong>Assets</strong></td>
</tr>
<tr>
<td>Token</td>
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<tr>
<td>Accounts Receivable</td>
</tr>
<tr>
<td>Inventory</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Others: Smart Contract 1; Smart Contract 2; Smart Contract 3</td>
</tr>
</tbody>
</table>

1) REAL TIME

The existing accounting mode relies on the manual entry of accounting information, which cannot satisfy the requirement for timely recorded information in the EABAT system. In contrast, IoT technology can sense event occurrence in real time and the real-time status of actual products (such as inventory). This allows IoT technology to transmit such information to data-processing systems, such as distributed ledgers, to achieve real-time information sharing. Therefore, the values of the reported items in the financial reports based on BC will be updated in real time. Although it is no longer a periodic financial report, it can still be used for the purpose of comparing corporate performance.

2) TRACEABLE AND IRREVERSIBLE DATA

Each figure in the financial report comes with a hyperlink, which can be used to trace the original source and evaluation (pricing) model in use. In addition, a key feature of a distributed ledger is irreversibility. In the case of the subsequent adjustment or revision of accounting information, such changes must be recorded on the chain and a new block is then generated. Such action stores the original accounting information and the newly modified accounting information together on the chain, which improves accounting information transparency.
3) DIVERSIFIED CALCULATION ATTRIBUTES
The new financial report provides not only the value data of monetary measurement but also data for other measurement attributes, such as the size, weight, and quantity of inventory. This is because the sensing layer of the IoT can sense the external world and collect various types of information, such as physical measurements (e.g., length, width, height, weight, and volume), identity, location, and audio and video data.

4) A PERSONALIZED DECISION-MAKING MODEL
This model is used to transfer the choice of accounting evaluation model to the users of financial reports so that users can insert relevant values and perform accounting estimations based on their own judgement. Corporate accounting professionals can still provide tradition financial reports for reference.

5) COMPREHENSIVE AND SAFE REPORTING
The financial report includes both accounting and economic matters that need to be recorded, such as smart contracts. As the underlying technology of smart contracts, BC is able to protect contract terms from leaking or being tampered with before the execution of the smart contract. Therefore, smart contracts can be truthfully and completely recorded in BC in real time.

IV. THE IMPACT OF THE IoT AND BC ON ACCOUNTING INFORMATION QUALITY
In 1980, the Financial Accounting Standards Board (FASB) [38] first stated that the primary quality characteristics of accounting information are ‘relevance’ and ‘reliability’. In 1989, the Inter-Agency Standing Committee (IASC) recognized ‘comprehensiveness’, ‘relevance’, ‘reliability’ and ‘comparability’ as the primary quality characteristics of accounting information [39]. In 2010, the FASB and the International Accounting Standard Board (IASB) together proposed new financial information quality characteristics, which newly included ‘relevance’, ‘importance’ and ‘faithful representation’ [40]. This discussion of accounting information characteristics indicates that ‘reliability’ and ‘relevance’ should be considered to be fundamental.

According to the Statement of Financial Accounting Concepts (SFAC) No. 2 Qualitative Characteristics of Accounting Information [38], the definition of ‘relevance’ should include three dimensions: predicted value, feedback value, and timeliness. According to ISAB/FASB’s Qualitative Characteristics of Useful Financial Information [40], ‘relevance’ requires that financial information enable users to make different decisions. It includes the connotations of ‘predicted value’, ‘confirmed value’, and ‘importance’. According to IASB/FASB [40], ‘faithful representation’ includes completeness, neutrality, and error-free statements. In this study, we use accounting information quality characteristics as criteria to discuss the impact of the IoT and BC technologies on the relevance, faithful representation, timeliness, comparability, verifiability, and the cost-benefit principle of accounting information (Table II).
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V. SUMMARY

IoT and BC technologies could significantly change the existing accounting information systems, through the provision of transparent, credible, real-time accounting information. They can improve accounting information quality and ultimately realize the EABAT vision. In this study, we first constructed a simplified BC-IoT transaction model that includes three sub-systems: a contract system, a logistics system, and a capital flow system. Based on this simplified BC-IoT transaction model, we further develop an accounting information system that is able to produce personalized financial reports based on the EABAT approach. This newly developed AIS model is capable of automatic identification, analysis, and judgement of a contract; automatic execution of a contract (i.e., the transaction); automatic transmission of data, recording and storing event information; and the creation of personalized financial reports.

This study demonstrates that both IoT and BC technologies can have significant effects in terms of improving the relevance of completeness, neutrality, timeliness, and the cost-benefit balance of accounting information. However, their impacts are limited in terms of information importance and the consideration of substance over form. We should also acknowledge the difficulties of employing IoT and BC technologies to improve accounting information quality: first, the applicability to non-manufacturing industries, i.e., those not involving material goods, such as the service industry, remains a challenge; second, because a token is a pass card instead of legal tender, the use and redemption of token systems in the setting of large-volume credit transactions remains a significant issue; third, the application of BC technology is limited to certain aspects, such as accounting information verification, and accounting procedures such as forecasting and valuation still require managerial judgement via credit and auditing assurances; and fourth, since BC requires and records extensive information that may contain trade secrets, the information safety of sensitive accounting information remains a substantial challenge. All these challenges are excellent directions for future research on BC/IoT applications in accounting practice.

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