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A CONCEPTUAL FRAMEWORK FOR USING VIDEOGRAMMETRY IN BLOCKCHAIN PLATFORMS FOR FOOD SUPPLY CHAIN TRACEABILITY

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Abstract:

With the modern age of using genetically engineered products and growing concerns about food recalls and outbreaks, businesses are looking for ways to secure their brand names and assuring consumers about food safety and quality. Recently, Blockchain has been introduced as a promising approach for increasing the visibility of the supply chain and reducing the sale of contaminated and counterfeit products. Along this line, this study discusses the capabilities of Blockchain for the collection and monitoring of product lifecycle information ranging from production, wholesale, and logistics to standards, business reputation, and certification. The particular focus of the study is to discuss the use of videogrammetry as a data collection mechanism for bringing the product lifecycle data on digital Blockchain platforms and solving the “last mile” problem and data verification issue on Blockchain platforms. A conceptual example of organic meat processing is discussed to describe the proposed procedure and show how videogrammetry in combination with RFID and fingerprints can be used to solve the data verification issue on Blockchain platforms.

Keywords: Blockchain, Food Traceability, Videogrammatry, Hash Tree, Consumer Behavior, Organic Products

1. INTRODUCTION

Food supply chains are among the most common local and global supply chains. As food products are becoming an important aspect of international commerce [1], food safety assurance will be a major focus of businesses in both developing and developed regions. The laws pretending to food safety are becoming more stringent and changes are implemented to both public (product liability and direct regulation) and private (self and third-party certification) quality control systems. The changes are often highly influenced by the implementation of the Sanitary and Phytosanitary (SPS) Agreement regulated by the World Trade Organization (WTO) [2]. Over the past few years, many food scandals have been under scanner. Examples are milk scandal in China (2008), horse meat scandal in the UK (2013), expired meat in KFC and McDonalds in the US (2014) and many others [3].

Food and Drug Administration (FDA) regulations govern most of the food items produced in the market. What is the best possibility that the organic label in the food is trustable? The National Organic Program (NOP) is the federal regulatory framework governing organically produced crops and livestock. The NOP has a certain set of standards and regulations that are separate from those of the FDA. Foods marked as “organic” coming under FDA should comply with both NOP and FDA regulations. The reliability of

these food items can be referred to using the National Organic Program website [4].

Consumers have started questioning the origin of the products they consume. They have become more environmentally-conscious and are willing to pay more for quality food. Several studies focused on understanding consumer behavior towards buying organic food [5]–[9]. Shepherd et. Al [10] worked on determining the factors responsible for customer behavior towards organic food. Vermeir and Verbeke conducted a survey to prove people started moving towards sustainable food products and try to avoid chemicals or processed food [11]. With individuals taking efforts, governments have also started promoting organic farming with environment consciousness [12]. They give allowances like tax exemptions and products at subsidized prices for these farmers.

With organic farming taking a toll in food commerce, methodologies are needed to help companies improve the business models of such supply chains. Consumers are becoming more conscious and they would like to know the origin of their food [13]. Looking at the current scenario, most of the existing food traceability projects fail [14], [15]. It may be due to a failure at any level in the supply chain [16]. This is the harsh reality in farms, slaughterhouses, or retail markets which forms the major part in the food supply chain.

With food trade taking place at the global scale, it has become very much essential to check the integrity of the food especially the origin and quality [17]. Users demand verified evidence about the traceability system, information on the origin, processing, the retailing and final destination of foodstuffs [18]. To improve the visibility, the traceability analysis needs to be done on the materials used as feed and the food origin combined with the use of information technology systems [19]. To assure quality among public and rebuild confidence in the food chain, it is essential to design and implement the whole chain traceability from farm to end-user [20].

An emerging technology which has received considerable attention in the supply chain recently and has the capabilities to solve the above-mentioned challenges is Blockchain technology. Blockchain could transform the entire food industry by increasing transparency, efficiency and promote collaboration [21], [22] within the food ecosystem. With such technology, customers can trace the origin of vegetables they consume in seconds, and storekeepers can see where the products are coming from (e.g. if the eggs they sell are cage free). There comes the need to scrutinize the evolution of this technology. This technology uses a huge number of computer systems

which is currently associated with considerable energy cost. This would determine the agriculture space, where farmers need to grow more and use less [23], [24].

Blockchain is often defined as a peer-to-peer distributed or decentralized digital ledger which is available to a group of users or nodes on the network. It may be available to a group of public users or can be distributed privately [25]. All transactions in a Blockchain are performed using cryptography as well as a consensus mechanism to verify the legitimacy of transactions, and allows for high-value transactions in a trustless environment. This makes all transactions transparent and does not require a third party administrator to verify any financial or operational transactions [26]. While the origin of Blockchain refers back to the financial industry and the born of Bitcoin as the first digital currency, Blockchain has many other applications. Product tracking and increasing the visibility of the value chain is one of those applications. This application can help users verify and track the origin of products and avoid trading of illegal and counterfeit products.

Blockchain works based on Consortiums, there are around 40 consortiums that have formed over the last 6 months [27]. Among executives knowledgeable about Blockchain technology, 18 percent already participate in a consortium, 45 percent are likely to join one, and 14 percent are considering forming one. They are either business focused or technology focused. Some of the most famous consortia currently in the market Deloitte, 2017; Hyperledger, 2018; R3, 2018 and others. Many central banks, regulators and policymakers have started investing in this technology [28]. Some of the big industry players like Walmart, Bank of America Merrill Lynch, Citigroup, Credit Suisse, Goldman Sachs, and JP Morgan have already invested in this promising technology. Members investing in this sectors are from finance, banking, logistics, and manufacturing with likes of IBM, Intel, SAP, Daimler and Fujitsu [29].

However, one of the current limitations of Blockchain technology is how to verify the data recorded/entered on the Blockchain. This problem is known as the “last mile problem” in which companies need to assure the accurate data are recorded on Blockchain platforms. This is particularly important for Blockchain compared to other traditional information systems since changing the transaction recorded on Blockchain is almost impossible and that is one of the main advantages of Blockchain compared to other information-sharing digital platforms. To solve the “last mile” problem, this study proposes a concept for integrating the hash tree algorithm [30] in Blockchain

with 3D videogrammetry technique [31] to form an effective business model for data collection and record on the platform. A case study of a slaughterhouse is used to show the effectiveness of the proposed concept for different levels of the supply chain.

To the best of our knowledge, the number of studies that have worked on solving the last mile problem in Blockchain is very limited. Mechanisms such as IoT technology, certified vendors, and certified inspectors can be used to verify and support the information uploaded on Blockchain platforms but the efficiency and accuracy of such methods have not been studied so far, since Blockchain is still at its infancy. The main contribution of this paper is to discuss the existing commonly-used RFID and videogrammetry technologies and describes how the combination of them can support information collection on Blockchain platforms to solve the “last mile” problem.

Bar code and Radio Frequency Identification (RFID) technologies are the most prominent data collection methods implemented in food chains that can help reduce manual errors making the system more feasible [32], [33]. More database and software systems are proposed in terms of increasing efficiency in collecting, transmitting, and analyzing larger volumes of safety and quality related data [34]. In addition, 3D videogrammetry is a proven technology that has been used in food traceability systems [35], [36].

While the previous studies have already described the application of Blockchain for food traceability and also the use of videogrammetry for object detection, the focus of this study is to describe the application of videogrammetry, fingerprint and RFID on Blockchain platforms as a data verification mechanism.

2. BACKGROUND

2.1. Statistics on the Organic Food Market in the United States

The section provides an overview of the organic food market in the US. Figure 1 shows the distribution of the organic market around the world. The graph shows that 24% of the market is in the US followed by Germany.

The organic food market has been growing tremendously over the past 15 years. Looking at the global scale shows that North America has the prominent growth among other countries. It is predicted that the market will increase by 10 to 20 percent per year during the next few years.

Table 1 shows the total food and organic food sales in different years. It also shows the percentage of growth and penetration into the market every year. The global organic market is expected to increase

twice the current value in terms of business in 10 years. It is predicted to be \$ 262.85 Billion by 2027 in contrast to the \$124.31 business it made in 2017.

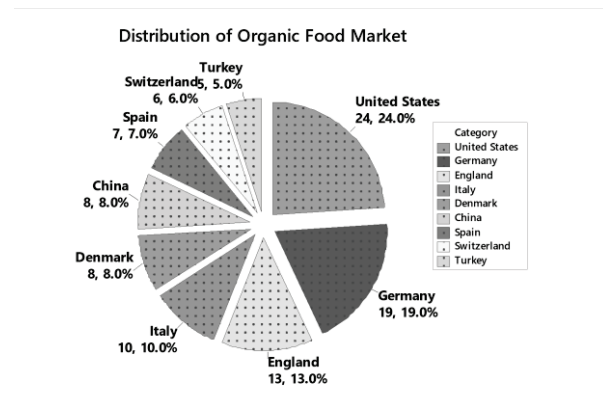


Figure 1 Organic market Analysis for major countries (Represented as %) [37]

Table 1 Organic food consumption (million dollars) in the US and its growth over the years [38]

Year	Organic Food	Growth (%)	Total Food
2008	20393	17.50%	659012
2009	21266	4.30%	669556
2010	22961	8%	677354
2011	25148	9.50%	713985
2012	27965	11.20%	740450
2013	31378	12.20%	760486
2014	35099	11.90%	787575
2015	39006	11.10%	807998
2016	42507	9%	812907
2017	45209	6.40%	822160

Customers started realizing the importance of protecting the environment and consuming healthier products. The willingness to pay for quality food and safety is increasing among US customers. US News conducted a survey for customer Willingness to pay for various categories of organic products (as shown in Figure 2). This is mainly attributed to the consumer’s attitude towards the environment and food quality. The customer’s attitude can be associated with their personal experiences of food poisoning, their attitude towards food poisoning, as a precautionary method or individual choice/ personal characteristics. Consumers’ willingness can be used as a predictor for organic food demand.

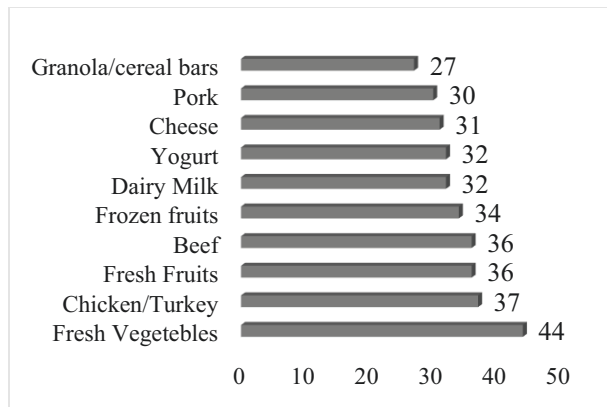


Figure 2 Customer willingness to pay for organic food categorized in terms of products [39]

2.2. Review of Blockchain and Its Application for Food Traceability

The term Blockchain was first coined in 2008 when an anonymous person or group of people named Satoshi Nakamoto released a white paper to introduce Bitcoin, a digital currency that allows users to transfer money from one person to another person without the need for any financial institution, intermediary or bank. The aim was to eliminate fraudulent transactions and provide a secure and transparent financial system. It slowly started attracting the global financial systems and has high scope for possible expansions. Blockchain has distributed database stored as public ledgers or encrypted blocks of events or transactions [40]. Generally, Blockchain has a series of computers/nodes/miners controlling and verifying every transaction based on some pre-defined protocols or consensus algorithms. The information or the transactions are shared and can be verified by all users in the chain/ peer-to-peer network. Every record needs to be verified by multiple users/miners before the action is complete. Once completed it gets stored in Blockchain permanently and cannot be deleted. The saved data in Blockchain are highly secured with mathematical problems requiring high computational power thereby preventing the public ledger to be hacked. The consensus within the network is done using different algorithms. For example, in the case of Bitcoin, it is “proof of work” [41] and in the case of Ethereum, it is “proof of stake”.

Miners are a group of users/nodes/computers in the network who are responsible for verifying the transactions recorded on Blockchains. They need to run computational algorithms to help with coding the data with the use of hash functions and verifying the information [42]. They are often rewarded for the amount of effort that they put in the network for verifying the transactions. Depending on the type of

Blockchain networks and consensus algorithms, miners follow different protocols. Currently, developers and startup companies are trying to reduce the redundancy in the network and increase the efficiency of the mining process for miners by developing new consensus algorithms beyond “proof-of-work” or “proof-of-stake” that are secure, have less redundancy and require less energy consumption.

The concept of Blockchain has already been suggested for the traceability of organic food in supply chains [43]–[46].

Planning, investment and commitment form the basics of Blockchain. Researchers have used the concept of Blockchain in food traceability and have found it to be successful. Ethereum agriculture has been a success in the supply chain. Kentaroh et al. [47] designed an item-level smart contract to manage the event information of product using Blockchain. IBM’s hyperledger was successful in its collaboration with Walmart meat processing [48]. Daniel et al. [44] are working on the aspects of information security, they have come up with a concrete algorithm which is in the stage of implementation. Another promising area of research is the AgriBlockIoT with advantages like data transparency, fault tolerance, immutability and auditability for Agri-food traceability system [49].

Using this technology, an end to end traceability can be provided, thereby enabling customers to access the story behind every food product they consume. Smart labels in the form of QR codes or RFID is printed on the food products that can help the consumers track the allergens information, type of meat, organic, farm details/slaughterhouse, info of batch numbers, nutritional value, manufacturing and expiry dates, temperature storage, and shipping information.

This is possible only if the whole process is coordinated properly. All personnel related to particular business need to sit and set standards and principles to be employed in the supply chain. This information needs to be fed into Blockchain and need to be approved by every user. This can help us in managing the products better and everyone can look it up as it gets permanently stored in the database. The advantage of using such a system is every transaction or action taken by any individual should go through everyone in the system and they need the action before it is being implemented. It is hard to alter or add a new action to Blockchain by an individual. This can help brands in protecting the food chain and prevents any fraudulent activities thereby maintaining the conscientious among every individual associated with the business.

Blockchain promotes transparency, where people involved in Blockchain can access the information. The retailer can know where their shipment progress is. The slaughterhouse can check the inventory of their buyers, and the customer can verify every information associated with the food they consume. Anything related to food safety or credibility of the products can be verified in every step which is very important in a business model in order to serve the customer better.

To track products in today complex supply chain, there needs to be a secure and trustworthy system in place. Blockchain process is traceable as the information is stored and accessible to all users linked in the chain. The information once stored is permanent and cannot be erased, moreover, a single user cannot change anything in the system. It always makes sure everything goes through the whole system thus making decisions more matured. The scope for this technology is immense and worth investing. All transactions going through Blockchain is secured and there is no third party involved to authenticate or verify every transaction made.

Different benefits are reported for the successful implementation of Blockchain including greater transparency, enhanced security, improved traceability, increased efficiency and speed of transactions, and reduced costs [50]. All personals of a business should be aware of the importance of implementing Blockchain. An idealistic approach of believing in the success of Blockchain is required to convince any company involved in the supply chain to accept and invest in this technology. Every individual starting from the farmer who cultivates the crops or who raises the cattle need to be trained to the standards and requirement.

Not just the training, there may be people with conflicting interests who are part of the supply chain. They might be used to certain fraudulent activities and they might oppose such technology as they may be exposed. For example, a farmer may use sedatives to pigs in their farms to enhance the color of meat or their storage temperature for meat may not be proper as per standards. The food habits may be different from what the farmer is advised to do. These things may not be properly monitored in the supply chain or there might be a lack of awareness in those levels.

The technology is relatively new and it has been implemented successfully by Walmart in collaboration with IBM. This proved to be very profitable for Walmart after being accused of an E.coli outbreak with the spinach problem in 2006 [51].

When making the decision about implementing Blockchain platforms, companies need to consider

every aspect of the business. Most of the time, companies do not consider the unbalanced cost, the cost spent by the primary participants of the food supply chain system. They need to focus more on the primary cycle to achieve better results.

3. METHODOLOGY

3.1. 3D videogrammetry in traceability system

As we mentioned before, businesses who would like to implement Blockchain technology, not only should think about the development of Blockchain platform but also about the “last mile” problem or how to facilitate data collection and verification of the data on Blockchain digital platforms, since the data recorded on the public ledger/Blockchain is not erasable and the quality of input data is very important to the success of the rest of the system.

To solve the data collection problem, this paper describes the use of 3D videogrammetry. 3D videogrammetry has revolutionized the art of monitoring, it has been widely used for monitoring worksite. Its application can be extended to monitoring any type of industry ranging from food, construction, manufacturing, and others. Clip [52] and his group proposed a Mobile 3D City Reconstruction system. It can be efficiently used to capture large scale urban scenes with efficiency in the reconstruction system and flexible capture. Further, a group of scientists developed a video surveillance system for food traceability which retrieves 3D trajectories from target objects [35]. We are using this successful methodology to our framework to solve this ‘last mile’ problem.

The system works based on the principle of photogrammetry. A still camera is used to record the camcorder or movie function. The images captured by the still cameras are used to produce a real-time video which can be used for obtaining real-world data. There are two parameters that control the working of this system, video speed and time between captures. The number of images is controlled by setting the video speed.

For Example, if the video speed is set to 30 fps, and the time between captures is 1 minute/60 seconds, then the total images per minute for the video is 1800 images.

A 3D model of the target is created. The cameras are mapped on to this target 3D model and we calculate the transform function for each camera.

Consider the transform function F ,

$$F(a, b) = (x, y, z) \quad (1)$$

Where (a,b), image coordinates of camera are given as input parameters and corresponding coordinate in 3D model (x, y, z) are returned as output. Depending on the orientation of the surface, the type of mapping is selected. Using the video surveillance data, the objects of interest can be extracted, such as products or people and obtain their trajectories based on the transfer function F. The information from multiple cameras are used to obtain the complete traceability track using different trajectories of the target object.

The first step is the creation of a 3D model which is done using CAD or satellite image. This can be a source of videogrammetry. The extracted frames of the target objects are difficult to process; a transformation function is proposed to convert object coordinates from 2D frame to 3D real world. The geometric parameters are defined by the inner orientation. The location in space and the view direction are defined by the exterior orientation of the camera.

The idea behind this approach is the proposed transform function maps the image coordinates with the real world coordinates. The target object is fixed to be in a plane and the triangulation method is used to simulate the on-plane.

Let us fix the real world coordinates as (V1, V2, V3) and the corresponding frame images as (v1, v2, v3). The transformation matrix is defined as M. The equation can be represented as follows:

$$\begin{bmatrix} v1.x & v1.y & 1 \\ v2.x & v2.y & 1 \\ v3.x & v3.y & 1 \end{bmatrix} M = \begin{bmatrix} V1.x & V1.y & V1.z \\ V2.x & V2.y & V2.z \\ V3.x & V3.y & V3.z \end{bmatrix} \quad (2)$$

To calculate v1, v2 and v3, the input parameters V1, V2 & V3 and the transformation matrix M are available,

$$M = inv \begin{bmatrix} v1.x & v1.y & 1 \\ v2.x & v2.y & 1 \\ v3.x & v3.y & 1 \end{bmatrix} \begin{bmatrix} V1.x & V1.y & V1.z \\ V2.x & V2.y & V2.z \\ V3.x & V3.y & V3.z \end{bmatrix} \quad (3)$$

Labels are assigned for every camera and assign their location based on orientation. These are termed as reference coordinates, their corresponding coordinates of the camera are manually recorded to generate the transformation matrix M.

In order to explain this, consider the following example of a slaughterhouse. For the 3D models find the coordinates on the ground for any of the corners. Based on this the corresponding coordinates in the camera is computed using the location of the corner on the monitoring frame. In case of a complex area, a multi-triangular mesh to represent n-plane surface is

defined. Thus, multiple transform functions are required for such a complex area. In this case, the input parameters can be defined by the user based on the requirement such as the plane of interest, object of interest and other factors to monitor the workplace. Overall, videogrammetry can be implemented in a 3D slaughterhouse.

3.2. Security level in Blockchain

There are different security layers associated with Blockchain technology. The technique of hash tree used with fingerprint identification. The data can be securely stored in a variety of levels using this technology. The different levels of security are associated with the sensitivity of the data and the need for accessibility of data. In this paper, a five-level security system is proposed which can be adapted for storing data. The basic level of data storage is through fingerprints, fingerprint data of every individual in the particular level is stored to identify any changes or manipulation of data within the organization. Next two levels are combining the fingerprint with hash tree or commonly known as the Merkel tree, which basically has a series of combined hashes that gives more security and difficult to break [53].

The hash tree can be either internal with someone within the organization controlling the system or it can be an external hash tree which basically has a third party authorizing any change to the existing system. Using this many small firms can be controlled by a common company [54]. Next level of security is an external hash tree in a distributed ledger, in which the information is distributed to various firms. It protects the system from failure since any action happening through the system is requiring multiple authorizations. Finally, the major thing is the external hash tree in the public consensus database, in this case, the information is accessible to public and they can make contributions to the system but the controls remain with the authorized users who can only implement changes on these databases.

3.3. Hash tree or the Merkel tree

Hash functions form the essential part of major cryptocurrency or cybersecurity protocols. It converts any form of data into a unique string of text. Hashing doesn't depend on the type or size of data, regardless it gives us data of the same length. The advantage of using a hash function is that it is irreversible. You cannot retrieve data using the hash strings, this is a major reason for using it in Blockchain. The same hash is produced for every unique piece of data, in our case when the fingerprints are used it should always give us the same hash function to make it work.

Figure 3 represents how a hash tree works. The block currently under action is represented as a leaf node. Every leaf node is associated with the data of particular action. Non-leaf nodes are from previous hashes. We always need even number of leaf nodes to perform an action, in other words, Merkle trees are binary and in terms of actions with an odd number of nodes it uses the duplicate of the previous hash to complete the action.

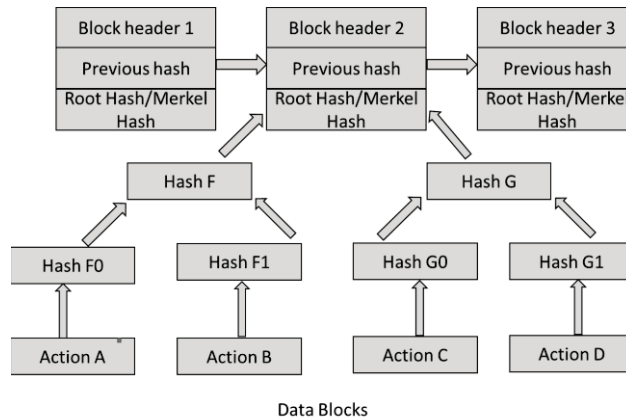


Figure 3 Working of a Hash tree/Merkel tree in Blockchain [55]

Hashing is often confused with encryption but the difference is encryption can be decrypted or reversed but hashing cannot be reversed easily. MD5, SHA1, and SHA-256 are the widely used hashing functions [56]. To add more security to hash tree cybersecurity uses a mechanism called as Salting [57], this prevents the hackers from accessing the platform password. This process involves adding a random data called the salt value with the hash. This makes it hard for hackers to crack the passwords using the hashed data they obtain.

Another advantage of using Merkle trees is that it enables SPV (simplified payment verification) which lets users download and verify a particular action of interest. Thus making the process faster and easier.

3.4. Implementation in Blockchain using RFID tags

RFID (radio frequency identification) is an identification technique that has stored information which can be communicated between a chip and reader. The stored information emits frequency as radio waves that can be read using the reader. This technology is used in payment cards, banknotes, vehicle identification, and other electronic documentation. This technology is very useful as all information can be contained inside the RFID tags and can be extracted easily [58].

Videogrammetry can be employed in Blockchain using RFID which can be employed by electronic traceability and condition monitoring. The RFID is linked with the transformation function using the hash tree function in Blockchain. Each transformation function is associated with the hash function. When the parameters of interest are selected the leaf nodes of each parameter are combined to form the transformation function. Thereby forming a root hash, we assign the program to calculate the inverse function to transform 2D coordinates into real time 3D data. In case, when one parameter is selected, it uses the hash from the previous function as we need even number of leaf nodes to form the root hash.

Figure 4 shows how the hash algorithm is used to combine videogrammetry technique using RFID. This represents how hash tree functions are stored as parameters inside the RFID. We choose the best hash tree function based on the requirement and include the program at the end of the hash function to calculate the inverse and obtain the real-time 3D data.

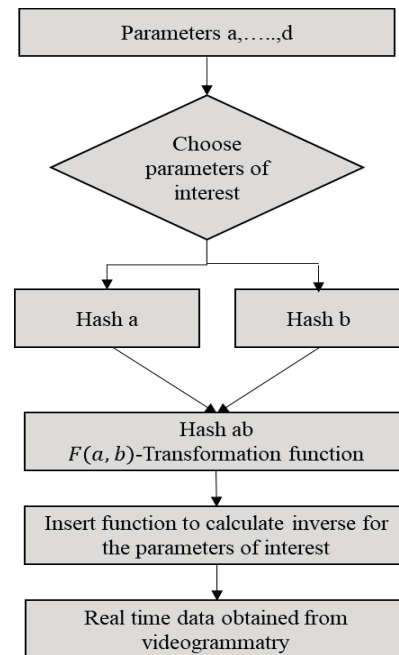


Figure 4 Videogrammetry using hash functions stored in an RFID

Figure 5 shows how data stored in an RFID tag. So any form of data can be electronically stored using RFID tag. Blockchain protects the data from being manipulated. Thereby making sure any piece of information in the RFID tag can be tracked at any point by the users involved in the supply chain.

```
// Structure of a logfile stored in RFID//
BATCH_ID/[SCAN_TIME]/ORIGIN/Employee_ID/

716431980805678/[02/Apr/2018:09:03]/PRV-07/12345678
716431980805678/[07/Jun/2018:10:26]/VA-16/564789458
716431980805678/[08/Jun/2017:08:18]/PK-VA/42567896
716431980805678/[09/Jun/2017:09:04]/PK-VC/47896542
716431980805678/[10/Jun/2017:18:44]/PK-VU/87426548
```

Figure 5 Illustration of information stored in RFID tag [59]

If we clearly look at Figure 6, let us take the first line we have a number starting with 716 which will be seen as a part of the RFID tag printed in the product commonly referred to as the batch ID. When it is scanned it gives out the SCAN_TIME i.e. the date and time the product was processed and packed, PRV-07 gives the location and the station. Finally the numbers 12345678 gives the employee ID working in the unit who packed it. So every sensitive information associated with the product is stored in the RFID tags. This information can be varied as per the product requirement and multiple lines can be stored in the same RFID number showing different stages of processing. When RFID combined with Merkel tree gives us an advantage of data stored being permanent in the system and any sort of data manipulation is not possible. Also, combining RFID with Merkel tree helps us in codifying the data and improving anonymity.

4. CONCEPTUAL EXAMPLE OF ORGANIC MEAT PROCESSING

This section discusses an example of using Blockchain for organic meat processing. For producing organic meat, it is essential to have all entities starting from the farmer to the retailers to be on the same page. They need to set agreements, define smart contracts and determine clauses and agree on the terms together for the business model to be successful.

Farmers are provided with the basic training on hygiene, food habits and other requirements for organic farming of livestock. Cameras are installed on the farms where these livestock are raised. Videogrammetry techniques are employed which gives users the option to analyze the parameters of interest. In this case, the parameters are set as people, temperature, food habits, and hygiene of the place. An authorized person from the farm is trained to feed in data, their fingerprint is used for authentication, this goes through the hash tree algorithm and verified before they can add or manipulate data. Their work is approved by other entities such as inspectors and verified users involved in Blockchain.

The livestock are transported to the slaughterhouses for processing. RFID tags are inserted into the livestock to track the information associated with it. This may include the category of meat, food habits, age in case of veal and the shipping information. This need to be verified and controlled by the slaughterhouse. The slaughterhouse needs to certify the origin and the processing date of the meat. All the information must be shared in Blockchain. The videogrammetry is implied in place. The slaughterhouse has still cameras installed for different parameters of interest and these images are converted into a 3D real-time data. This information is shared with the customers. The slaughterhouse needs to assign the batch numbers with the date of processing so that the customer can access that particular information. They need to add information associated with processing like the allergens information, batch number, expiry date and other information which are as per the standards set in the business model. Next is the transportation of these products to the retailers. The retailer should be able to track the progress of the shipping using the platform or other apps and software linked to the Blockchain platform. This need to be updated from the vendor's end. Then the retailers need to verify the food and certify its quality before selling it to the market and they are the ones who should decide on what information they need to share with the customers. All the information is controlled using hash tree function and fingerprints are used as security to authenticate any action. A group of computers/users called miners help with authenticating the actions using a voting system which lets every user verify and authenticate the process. Figure 6 shows an overview of the proposed procedure.

Development of such digital platforms based on the capabilities of Blockchain technology requires an extensive collaborative effort from different stakeholders (e.g. farmers, processors, retailers, grocers, users). The purpose of this paper was to just describe the last mile problem part of the platform and suggest tools and mechanisms for data collection and verification at the end of the chain. Quantitative analyses are needed to compare the effectiveness of the proposed data collection approach with other data collection mechanisms. However, since the development of the actual digital platform is beyond the scope of the paper and the field of Blockchain is emerging and the number of real-world case studies is limited, the unavailability of the field data limited our capabilities in running quantitative evaluation. Based on the above case study, let us demo a situation in which a customer wants to know the origin of the meat they consume.

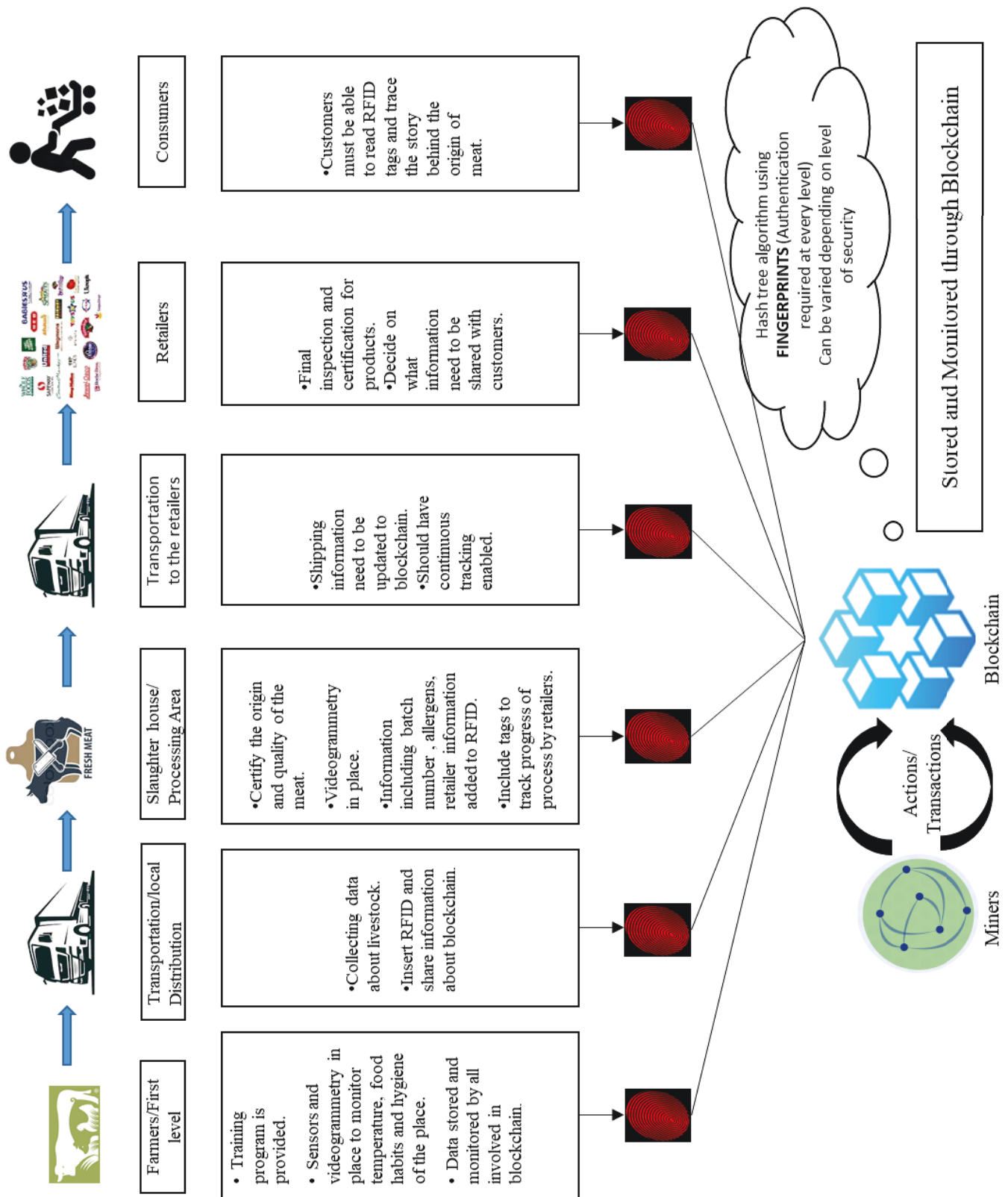


Figure 6 Food traceability system adopted for our case study using the proposed methodology

They would like to know the details from farm to fork. The information should include the food habits of the animals, the way they were raised, the hygiene and the processing of the meat in the slaughterhouse. Other information includes the temperature it was stored in the slaughterhouse through the transportation process till it reaches the retailer, weight and allergens information. This can happen only with a consortium in place. A group of organizations needs to be put together. They should all have a common motive towards serving the customer with quality. This consortium helps in achieving a more transparent fraud-free system in the food chain.

5. CONCLUSION

Organic farming is a growing market; as customers are becoming more conscious of the type of food they consume and the origin of their food. Blockchain is a promising technology that can help retailers and consumers track the origin of their food and avoid trading of contaminated and counterfeit products. In this paper, a general concept based on the use of videogrammetry, RFID and hash or Merkel tree algorithms are introduced to help businesses solve the “last mile” problem in Blockchain platforms with facilitating data collection and verification. This work is primarily focused on introducing the videogrammetry technique used in the traceability system in combination with fingerprints, RFID, and Merkle trees. The proposed procedure is illustrated as a case study for monitoring the progress of organic meat.

The proposed method can be extended to other traceability systems. Different data collection techniques based on IoT and Artificial Intelligence can be developed and connected to Blockchain platforms. New business models would emerge based on the capabilities of Blockchain and how the data should be collected and verified. In this work, RFID chips and smart labels are used for traceability. The study can be extended to consider the impact of damaged labels, sensitive sensors, and inaccurate data collection tools. In addition, the lack of existing Blockchain platforms and data collection mechanisms connected to such platforms limits the quantitative evaluation of the proposed concept. Future work requires close collaboration with Blockchain developers and industry partners who might be able to allow practical implementation of the proposed concept on the integration of Blockchain, videogrammetry, Merkle tree and RFID.

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References

- [1] B. Bordel, P. Lebigot, R. Alcarria, and T. Robles, “Digital Food Product Traceability: Using Blockchain in the International Commerce,” in *The 2018 International Conference on Digital Science*, 2018, pp. 224–231.
- [2] S. Henson and J. Caswell, “Food safety regulation: an overview of contemporary issues,” *Food Policy*, vol. 24, no. 6, pp. 589–603, 1999.
- [3] Jason, “25 Insane Food Scandals That Actually Happened.” [Online]. Available: <https://list25.com/25-insane-food-scandals-that-actually-happened/>.
- [4] U.S. Food and Drug Administration, “Organic on Food Labels,” *U.S. Department of Health and Human Services*, 2017. [Online]. Available: <https://www.fda.gov/food/labelingnutrition/ucm473870.htm>.
- [5] G. Roddy, C. A. Cowan, and G. Hutchinson, “Consumer attitudes and behaviour to organic foods in Ireland,” *J. Int. Consum. Mark.*, vol. 9, no. 2, pp. 41–63, 1996.
- [6] M. Wier and C. Calverley, “Market potential for organic foods in Europe,” *Br. Food J.*, vol. 104, no. 1, pp. 45–62, 2002.
- [7] A. Krystallis and G. Chrysosohoidis, “Consumers’ willingness to pay for organic food: Factors that affect it and variation per organic product type,” *Br. Food J.*, vol. 107, no. 5, pp. 320–343, 2005.
- [8] J. Paul and J. Rana, “Consumer behavior and purchase intention for organic food,” *J. Consum. Mark.*, vol. 29, no. 6, pp. 412–422, 2012.
- [9] H. Yeon Kim and J.-E. Chung, “Consumer purchase intention for organic personal care products,” *J. Consum. Mark.*, vol. 28, no. 1, pp. 40–47, 2011.
- [10] R. Shepherd, M. Magnusson, and P.-O. Sjöden, “Determinants of consumer behavior related to organic foods,” *AMBIO A J. Hum. Environ.*, vol. 34, no. 4, pp. 352–359, 2005.
- [11] I. Vermeir and W. Verbeke, “Sustainable food consumption: Exploring the consumer ‘attitude–behavioral intention’ gap,” *J. Agric.*

- Environ. ethics*, vol. 19, no. 2, pp. 169–194, 2006.
- [12] F. Worner and A. Meier-Ploeger, “What the consumer says,” *Ecol. Farming*, vol. 20, no. 2, pp. 14–15, 1999.
- [13] K. G. Grunert, “Food quality and safety: consumer perception and demand,” *Eur. Rev. Agric. Econ.*, vol. 32, no. 3, pp. 369–391, 2005.
- [14] R. Badia-Melis, P. Mishra, and L. Ruiz-García, “Food traceability: New trends and recent advances. A review,” *Food Control*, vol. 57, pp. 393–401, 2015.
- [15] A. Chua and W. Lam, “Why KM projects fail: a multi-case analysis,” *J. Knowl. Manag.*, vol. 9, no. 3, pp. 6–17, 2005.
- [16] T. Davis, “Effective supply chain management,” *Sloan Manage. Rev.*, vol. 34, p. 35, 1993.
- [17] M. Bertolini, M. Bevilacqua, and R. Massini, “FMECA approach to product traceability in the food industry,” *Food Control*, vol. 17, no. 2, pp. 137–145, 2006.
- [18] B. Peres, N. Barlet, G. Loiseau, and D. Montet, “Review of the current methods of analytical traceability allowing determination of the origin of foodstuffs,” *Food Control*, vol. 18, no. 3, pp. 228–235, 2007.
- [19] M. Thakur and C. R. Hurburgh, “Framework for implementing traceability system in the bulk grain supply chain,” *J. Food Eng.*, vol. 95, no. 4, pp. 617–626, 2009.
- [20] L. U. Opara, “Traceability in agriculture and food supply chain: a review of basic concepts, technological implications, and future prospects,” *J. Food Agric. Environ.*, vol. 1, pp. 101–106, 2003.
- [21] M. Crosby, P. Pattanayak, S. Verma, and V. Kalyanaraman, “Blockchain technology: Beyond bitcoin,” *Appl. Innov.*, vol. 2, pp. 6–10, 2016.
- [22] J. Yli-Huuma, D. Ko, S. Choi, S. Park, and K. Smolander, “Where is current research on blockchain technology?—a systematic review,” *PLoS One*, vol. 11, no. 10, p. e0163477, 2016.
- [23] J. Splitter, “What Can Blockchain Really Do For The Food Industry?,” *Forbes*, 2018. [Online]. Available: <https://www.forbes.com/sites/jennysplitter/2018/09/30/what-can-blockchain-really-do-for-the-food-industry/#755186ba488e>.
- [24] F. Tian, “An agri-food supply chain traceability system for China based on RFID & blockchain technology,” in *Service Systems and Service Management (ICSSSM), 2016 13th International Conference on*, 2016, pp. 1–6.
- [25] J. W. MICHAEL, A. COHN, and J. R. BUTCHER, “Blockchain technology,” *Journal*, 2018.
- [26] S. Apte and N. Petrovsky, “Will blockchain technology revolutionize excipient supply chain management?,” *J. Excipients Food Chem.*, vol. 7, no. 3, p. 910, 2016.
- [27] P. Gratzke, D. Schatsky, and E. Piscini, “Banding Together for Blockchain, Deloitte Insights.” 2017.
- [28] R. Post, K. Smit, and M. Zoet, “Identifying Factors Affecting Blockchain Technology Diffusion,” 2018.
- [29] Tom Groenfeldt, “Linux Foundat’s Hyperledger Fabric 1.0 ready for production,” *Forbes*. [Online]. Available: www.forbes.com/%0Asites/tomgroenfeldt/2017/07/13/linux-foundats-hyperledger-fabric-1-0-ready-for-production/.%0D.
- [30] A. Kiayias and G. Panagiotakos, “On Trees, Chains and Fast Transactions in the Blockchain,” *IACR Cryptol. ePrint Arch.*, vol. 2016, p. 545, 2016.
- [31] B. Mao, J. He, J. Cao, S. Bigger, and T. Vasiljevic, “3D model-based food traceability information extraction framework,” in *International Conference on Data Science*, 2015, pp. 112–119.
- [32] V. Salin, “Information technology in agri-food supply chains,” *Int. Food Agribus. Manag. Rev.*, vol. 1, no. 3, pp. 329–334, 1998.
- [33] M. Kärkkäinen, “Increasing efficiency in the supply chain for short shelf life goods using RFID tagging,” *Int. J. Retail Distrib. Manag.*, vol. 31, no. 10, pp. 529–536, 2003.
- [34] D. Folinas, I. Manikas, and B. Manos, “Traceability data management for food chains,” *Br. Food J.*, vol. 108, no. 8, pp. 622–633, 2006.
- [35] A. Van Den Hengel, A. Dick, T. Thormählen, B. Ward, and P. H. S. Torr, “VideoTrace: rapid interactive scene modelling from video,” in *ACM Transactions on Graphics (ToG)*, 2007, vol. 26, no. 3, p. 86.
- [36] S. P. Singh, P. K. Jain, and V. R. Mandla Dr,

- "Design and calibration of multi camera setup for virtual 3D city modeling," *Int. J. Eng. Res.*, vol. 2, no. 5, pp. 1373–1376, 2013.
- [37] V. da V. Dias, G. Schultz, M. da S. Schuster, E. Talamini, and J. P. Révillion, "The organic food market: a quantitative and qualitative overview of international publications," *Ambient. Soc.*, vol. 18, no. 1, pp. 155–174, 2015.
- [38] -The Hagstrom Report, "Organic food sales up, but growth slower," *The Fence post*. [Online]. Available: <https://www.thefencepost.com/news/organic-food-sales-up-but-growth-slower/>.
- [39] Zlati Meyer, "Organic food is pricier, but shoppers crave it," *USA Today*.
- [40] M. Swan, *Blockchain: Blueprint for a new economy*. "O'Reilly Media, Inc.," 2015.
- [41] M. Vukolić, "The quest for scalable blockchain fabric: Proof-of-work vs. BFT replication," in *International workshop on open problems in network security*, 2015, pp. 112–125.
- [42] M. Atzori, "Blockchain technology and decentralized governance: Is the state still necessary?," *Available SSRN 2709713*, 2015.
- [43] F. Tian, "A supply chain traceability system for food safety based on HACCP, blockchain & Internet of things," in *2017 International Conference on Service Systems and Service Management*, 2017, pp. 1–6.
- [44] D. Tse, B. Zhang, Y. Yang, C. Cheng, and H. Mu, "Blockchain application in food supply information security," in *2017 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 2017, pp. 1357–1361.
- [45] D. Galvin, "IBM and Walmart: Blockchain for Food Safety," *IBM Walmart*, 2017.
- [46] J. F. Galvez, J. C. Mejuto, and J. Simal-Gandara, "Future challenges on the use of blockchain for food traceability analysis," *TrAC Trends Anal. Chem.*, 2018.
- [47] K. Toyoda, P. T. Mathiopoulous, I. Sasase, and T. Ohtsuki, "A novel blockchain-based product ownership management system (POMS) for anti-counterfeits in the post supply chain," *IEEE Access*, vol. 5, pp. 17465–17477, 2017.
- [48] R. Aitken, "IBM & Walmart launching blockchain food safety alliance in China with Fortune 500's JD. com." *Forbes*, 2017.
- [49] M. P. Caro, M. S. Ali, M. Vecchio, and R. Giaffreda, "Blockchain-based traceability in Agri-Food supply chain management: A practical implementation," in *2018 IoT Vertical and Topical Summit on Agriculture-Tuscany (IOT Tuscany)*, 2018, pp. 1–4.
- [50] M. Hooper, "Top five blockchain benefits transforming your industry," *Blockchain Pulse: IBM Blockchain Blog*. [Online]. Available: <https://www.ibm.com/blogs/blockchain/2018/02/top-five-blockchain-benefits-transforming-your-industry/>.
- [51] B. Tan, J. Yan, S. Chen, and X. Liu, "The Impact of Blockchain on Food Supply Chain: The Case of Walmart," in *International Conference on Smart Blockchain*, 2018, pp. 167–177.
- [52] B. Clipp, R. Raguram, J.-M. Frahm, G. Welch, and M. Pollefeys, "A mobile 3d city reconstruction system," in *Workshop on Virtual Cityscapes, IEEE Virtual Reality*, 2008.
- [53] A. Buldas, M. Saarepera, and J. Pearce, "Blockchain-supported, hash tree-based digital signature infrastructure." Google Patents, 31-May-2018.
- [54] M. S. Niaz and G. Saake, "Merkle Hash Tree based Techniques for Data Integrity of Outsourced Data.," in *GvD*, 2015, pp. 66–71.
- [55] S. Ray, "Merkle Trees." [Online]. Available: <https://hackernoon.com/merkle-trees-181cb4bc30b4>.
- [56] S. Ray, "Blockchain Security Mechanisms," *Towards Data Science*. [Online]. Available: <https://towardsdatascience.com/mechanisms-securing-blockchain-data-9e762513ae28>.
- [57] M. Swan, "Blockchain for business: Next-generation enterprise artificial intelligence systems," in *Advances in Computers*, vol. 111, Elsevier, 2018, pp. 121–162.
- [58] J.-S. Cho, Y.-S. Jeong, and S. O. Park, "Consideration on the brute-force attack cost and retrieval cost: A hash-based radio-frequency identification (RFID) tag mutual authentication protocol," *Comput. Math. with Appl.*, vol. 69, no. 1, pp. 58–65, 2015.
- [59] T. S. R & D faizod, Dresden, "Supply Chain With Blockchain-Showcase RFID." [Online]. Available: <https://faizod.com/supply-chain-with-blockchain-showcase-rfid/>.